GEOHYDROLOGY AND WATER QUALITY OF STRATIFIED-DRIFT AQUIFERS IN THE BELLAMY, COCHECO, AND SALMON FALLS RIVER BASINS, SOUTHEASTERN NEW HAMPSHIRE

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Multiply	By	To Obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
	Flow	
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
cubic foot per second per per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
gallon per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Transmissivity	
cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)/ft^2$] / ft	0.3408	cubic meter per day per square meter times meter of aquifer thickness
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day

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

Geohydrology and Water Quality of Stratified-Drift Aquifers in the Bellamy, Cocheco, and Salmon Falls River Basins, Southeastern New Hampshire

By Thomas J. Mack and Sean M. Lawlor

ABSTRACT

A study was done by the U.S. Geological Survey, in cooperation with the New Hampshire Department of Environmental Services, Water Resources Division, to describe the geohydrology and water quality of stratified-drift aquifers in Bellamy, Cocheco, and Salmon Falls River basins in southeastern New Hampshire.

Discontinuous stratified-drift aquifers underlie 50 of the 330 square miles of the three river basins. Saturated thickness of stratified drift exceeds 100 feet in some areas but is generally less than 50 feet. Transmissivity exceeds 8,000 feet squared per day in some aquifers but is commonly less than 2,000 feet squared per day.

A two-dimensional ground-water-flow model was used to evaluate aquifer yield of two aquifers and the effects of pumping, one in New Durham and the other in Farmington. On the basis of the simulation of steady-state conditions, the authors concluded that pumping from the New Durham aquifer at a rate of 0.50 million gallons per day and nearly 0.25 million gallons per day from the Farmington aquifer could be sustained. Simulations involving different placement or number of wells would likely predict different sustained pumping rates; however, model calibrations are based on limited data, and results of simulations are to be used with caution.

Water samples from 21 test wells and 3 public-supply wells were analyzed to assess background-water quality within the stratified-drift aquifers. All wells were in areas not known to have water-quality problems. On the basis of the analyses, water in the stratified-drift aquifers generally meets drinking-water standards with some exceptions. Median concentrations of iron and manganese of the samples were 0.2 milligrams per liter and 0.08 milligrams per liter. Median concentrations of sodium and chloride (11 and 18 milligrams per liter, respectively) were well below Federal drinking-water regulations. Concentrations of other constituents were generally less than a few micrograms per liter. Volatile organic compounds were detected in samples from three sites; at one of these sites six volatile organic compounds were detected. Trace amounts of chloroform were detected at the other sites.

INTRODUCTION

Increases in population within the Bellamy, Cocheco, and Salmon Falls River basins in southeastern New Hampshire have been accompanied by increases in the demand for water. Projected continued population growth will understandably result in additional water demands. The population of most of the study area, within Strafford County, increased by 26 percent during 1970-85, and will probably increase by another 25 percent during 1985-90 (Strafford Regional Planning Commission, written commun., 1988). The remainder of the population in the study area, in the towns of Brookfield and Waterfield, Carroll County, increased by 83 and 66 percent during 1970-84 (Carroll County Commissioners Office, written commun., 1988). This growth has resulted in increasing demands on the water resources of the region (fig. 1), and demands will probably increase in the future.

Of all the communities in the Bellamy, Cocheco, and Salmon Falls River basins, Dover, Farmington, Milton, and Rollinsford rely completely on **ground water** as their source of public-water supply. Somersworth relies on a combination of surface water and ground water for its supply. The remaining communities rely primarily on individual wells or small public-supply systems. The towns of Dover, Rollinsford, and Somersworth need additional water supplies immediately, whereas the other communities will need additional resources in the near future (Strafford Regional Planning Commission, 1985).

Quality of ground water is a problem in the three river basins. The U.S. Environmental Agency (USEPA) (1986b) has placed three sites within those basins on the National Priority List (NPL) of hazardous-waste sites to be evaluated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. Five additional sites require monitoring of ground-water quality for hazardous wastes under the Federal Resource Conservation and Recovery Act (RCRA) of 1976. An additional 17 sites, including landfills and septic lagoons, are sites of potential degradation of ground-water quality and are being monitored (New Hampshire Water Supply and Pollution Control Commission, 1982). Consequently, many communities want to identify aquifer areas in need of protection.

The U.S. Geological Survey, in cooperation with the State of New Hampshire, has studied ground water in sand and gravel aquifers in several basins in New Hampshire. Detailed geohydrologic information is provided in reports for use by regional and local officials/agencies in planning for optimum use of ground-water resources and in the location of potential new sources of water. Reports have been provided for the Nashua Regional Planning Commission area (Toppin, 1987), the Exeter, Lamprey, and Oyster River basins (Moore, 1990), and the Saco River basin (Tepper and others, 1990). This report is a continuation of the series and is modeled after the reports by Toppin (1987), Moore (1990), and Tepper and others (1990).

Purpose and Scope

The purpose of this report is to (1) describe the hydrologic and the geologic characteristics of local stratified-drift aquifers--areal extent, saturated thickness, **transmissivity** of the aquifers; ground-water levels; and general directions of ground-water flow; (2) evaluate the yield of stratified-drift aquifers; and (3) assess background quality of water in those aquifers.

This study was generally limited to the collecting, compilation, and evaluation of data from the stratified-drift aquifers in the study area. Major emphasis was on potentially productive, slightly developed aquifers. Minor emphasis was on thin, slightly permeable, or discontinuous aquifers. A numerical ground-water-flow model was used to simulate the effects of pumpage on water-table configuration and sources of water to supply wells to estimate yield of aquifers in New Durham and Farmington.

Previous Investigations

The ground-water resources in southeastern New Hampshire have been the subject of several regional and local investigations. Regional investigations include a basic-data report by Bradley and Petersen (1962) and an interpretive report by Bradley (1964) on geology and ground-water resources for southeastern New Hampshire. Favorable areas of ground-water resources (including the entire study area) are delineated on a map by Cotton (1977). A ground-water appraisal of this area by Anderson-Nichols and Co., Inc. (1980) was based on Bradley and Petersen's (1962) data. A detailed hydrogeologic and ground-water-quality report for the Cocheco River basin has been written by Cotton (1989).

Surficial geologic maps for parts of the study area are available through the Cooperative Geologic Mapping Program (COGEOMAP), a cooperative program between the New Hampshire Office of the State Geologist and the Geologic Division of the U.S. Geological Survey (USGS). The 7.5-minute quadrangles being mapped are Barrington, Dover East, Dover West, Northwood, and Rochester (Eugene Boudette, New Hampshire Department of Environmental Services,

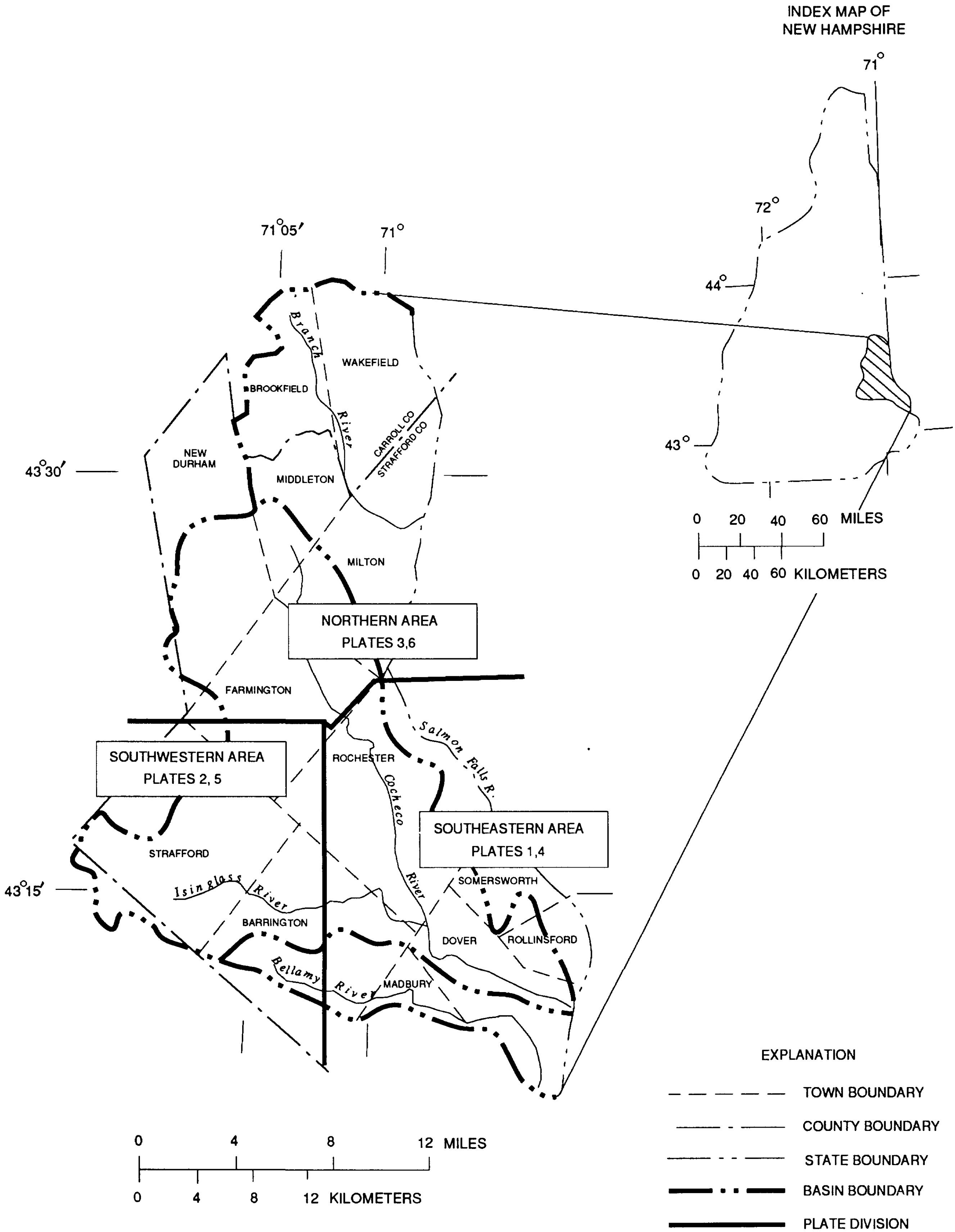

Figure 1.--Location of study area (Bellamy, Cocheco, and Salmon Falls River basins) southeastern New Hampshire.

Office of the State Geologist, written commun., 1988). These quadrangles constitute most of the southeastern section and a small part of the southwestern section of this study area (fig. 1). **Surficial geology** of the Wolfeboro 15-minute quadrangle, which includes part of the northern section of the study area, was published by Goldthwait (1968).

Site-specific investigations for several towns have been done by private consultants. Camp, Dresser, and McKee (1979) investigated aquifers within the city of Dover for development of additional water supplies. Other studies also have been completed for Dover by BCI Geonetics, Inc. (1987), and Caswell, Eichler, and Hill, Inc. (1987). Stratified-drift aquifers within the city of Somersworth and test borings, seismic profiles, and aquifer tests have been mapped by Hoyle, Tanner, and Associates, (1982); BCI Geonetics, Inc. (1984); and Hydro Group, (1985). Investigations of USEPA at Superfund landfills in Dover and Somersworth resulted in much data on the Hoppers aquifer in Dover and the Tates Brook aquifer in Somersworth. Thomson (1987) completed a detailed map of soil types for the town of Madbury. A test-well-drilling program by Farmington resulted in the development of its municipal well (Layne-New England Company, 1974 and 1982).

Graduate students and professors have done seismic-refraction and geophysical surveys (Birch, 1980 and 1984) and hydrologic studies (Hall and others, 1976) within the study area. The Hoppers area of western Dover and eastern Barrington was studied by Lemire (1981), Skipp (1983), and Shope (1986) as part of their master's theses. Other studies under the direction of researchers at the University of New Hampshire include those by Hensley (1978) and Moore (1978).

Acknowledgments

Appreciation is expressed to officials of all the towns and to private citizens who allowed the authors to install and to sample observation wells and to do seismic investigations on their property. Appreciation is also extended to the private consultants and well drillers who made reports and drilling logs available.

APPROACH AND METHODS

The geohydrologic characteristics of stratified-drift aquifers within the study area were described using a number of methods. Those methods include an inventory of data, aquifer mapping, seismic reflection and refraction, test-well drilling, streamflow measurement, ground-water-flow simulation, and water-quality sampling. This section describes the approach of the study and the methods involved, which are listed below.

(1) An inventory of subsurface data was compiled from well logs of the New Hampshire Department of Environmental Services, Water Resources Division; the New Hampshire Department of Transportation; domestic well records; consultant reports for private firms and municipalities; and data from published and unpublished USGS studies.

Local identifiers assigned to wells and test borings consist of a two-character town code (table 1), a supplemental-letter designation ("A" for borings related to hydrology, "B" for borings related primarily to construction, and "W" for all wells in which a casing was set), and a sequential number with each town. For example, the first well in the town of Barrington is BBW-1 (BB, W, and 1).

Table 1.--*Two-character town codes used as prefixes in the numbering system for wells and borings*

Town	Two-character code	Town	Two-character code
Barrington	BB	New Durham	NF
Brookfield	B3	Rochester	RH
Dover	DJ	Rollinsford	RL
Farmington	FA	Somersworth	SK
Madbury	MA	Strafford	SQ
Middleton	ML	Wakefield	WA
Milton	MT		

Data from more than 1,500 sites in the inventory have been entered into the USGS's national data base (Ground Water Site Inventory (GWSI)) by Mercer and Morgan (1981). Each site is referenced by site identifier, latitude, longitude, and a two-digit identification number for data from the same location. Identifiers are consistent for data derived from previous USGS reports, but the location may be reported differently because of a new, more accurate location. Lawlor and Mack (U.S. Geological Survey, written commun., 1990) have summarized data collected for this study.

(2) Aquifer boundaries were mapped in the field where possible. Soils maps and preliminary surficial-geologic maps from the COGEOMAP program were used in mapping the till-stratified-drift **contact**. Aquifer boundaries were delineated where possible from surficial geologic maps. Preliminary surficial geology maps were available from the COGEOMAP program for Dover East, Maine-N.H., and Dover West, N.H., 7.5-minute quadrangles (Eugene Boudette, New Hampshire Office of the State Geologist, written commun., 1989). Maps compiled for the Barrington, N.H. and Northwood, N.H. quadrangles, by Richard Moore (U.S. Geological Survey, written commun., 1990) were also used to delineate aquifer boundaries. The preliminary source of data for mapping the remaining areas were soils maps for Strafford (Vieira and Bond, 1973) and Carroll Counties (Diers and Vieira, 1977). Soils with parent materials consisting of sand or gravel were included in aquifer areas. Boundaries estimated with soils maps were then refined by examining well logs adjacent to an **aquifer boundary** and by field checking the stratified-drift and till contact.

(3) Continuous seismic-reflection profiling was run on selected lakes and reaches of rivers using methods described by Haeni (1986). The reflection equipment consisted of a boat outfitted with a graphic recorder, high-voltage power supply, sparker sound source, hydrophone-streamer array, filter-amplifier unit, and generators. Sound energy travels through the water and is reflected back to the surface from subsurface layers of contrasting acoustic properties (fig. 2). This interface is commonly at the contacts among lithologic units (Haeni, 1986). Sound-energy travel time and acoustic-interface data are displayed graphically on a strip-chart that is interpreted to represent lithologic units. The depth to these lithologic units, primarily **bedrock**, was calculated from the graphic record and known seismic velocities of several materials (Haeni, 1986). Depth to bedrock, where known, was used as a guide in interpreting the reflection record. Locations of seismic-reflection profiles are shown on plates 1-3.

At some locations, the nature of the lake-bottom **sediments** resulted in poor records. These bottom sediments were (1) cobbles or a compacted bottom that reflects sound energy without penetration, and (2) thick organic bottom sediments containing entrapped gases, such as those in a shallow, eutrophic marsh or pond. Those sediments scatter sound energy and prevent penetration to deeper layers. Because sound penetration was excellent in fine-grained **sediments, the**

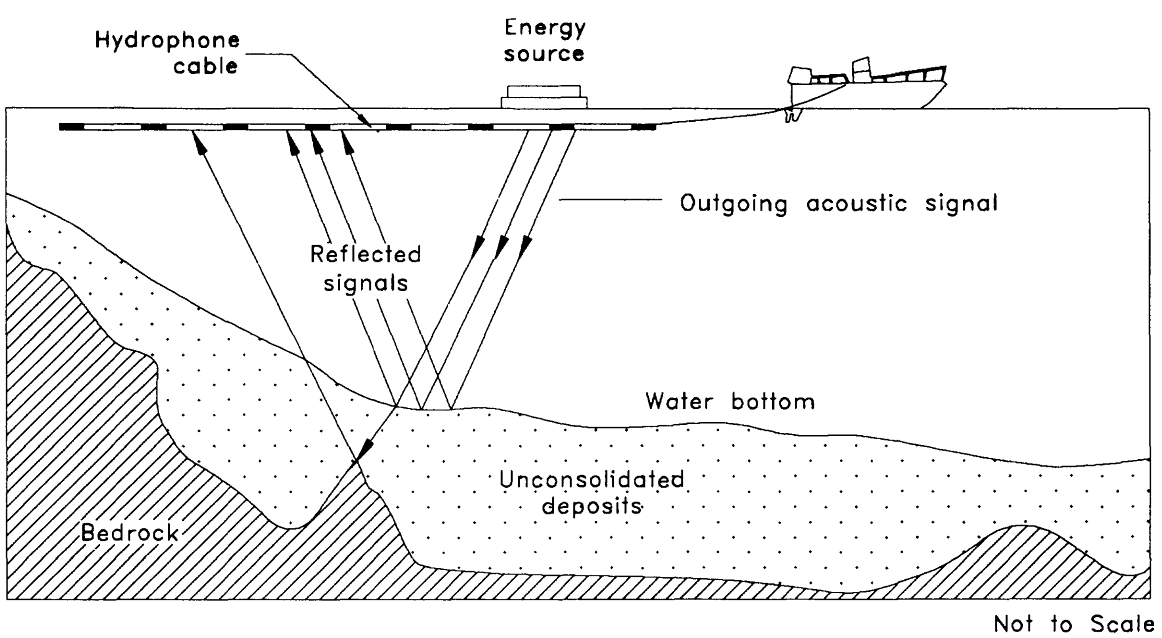

Figure 2.--Seismic-reflection operation and ray paths.

authors were able to collect detailed subsurface stratigraphic data in areas containing these sediments. Interpreted seismic-reflection profiles, completed at five locations, are shown in figures 3a-e.

(4) Seismic-refraction profiling was done with a 12-channel signal-enhancement seismograph (Haeni, 1988). The method consists of a sound-energy wave generated by a small explosive charge placed beneath the ground surface. After traveling through unconsolidated sediments, the energy is refracted back to the land surface by the **water table** and by the bedrock surface. The arrival of the first sound wave at each geophone is recorded on a seismograph (fig. 4). A computer program developed by Scott and others (1972) was used to convert the data to depth to the water-table and bedrock surfaces.

Seismic-refraction profiles were completed at 71 locations (pls. 1-3) to determine depths to the water table and the bedrock. Seismic velocities estimated for the materials under investigation range from 900 to 1,500 ft/s for unsaturated **stratified drift**, 5,000 ft/s for saturated stratified drift, and from 10,000 to 15,000 ft/s for bedrock. Depths to bedrock and water table estimated by use of seismic refraction were generally in agreement with depths determined by well logs and ground-water-level measurements.

Interpreted profiles are shown in figures A1-A24 (appendix). The top of the profile represents land surface in feet above **mean** sea level. The line below land surface (figs. A1-A24, appendix) is an estimate of altitude of the water table within **unconsolidated deposits** at the time the seismic data were collected. The line below the water table is an estimate of altitude of the bedrock surface. The relative altitudes of each geophone and shot were determined by leveling. The actual altitudes, relative to mean sea level, were determined either by leveling to locations of known altitudes or were estimated from topographic maps. Altitudes estimated from topographic maps are assumed to be accurate to within half of the contour interval.

Actual depths to the bedrock surface are probably within 10 percent of the estimates from seismic-refraction profiles. Till is not identified in these interpretations because it is generally thin and cannot be distinguished from stratified-drift with seismic-refraction methods. Where till is present, and is not identified in the interpretation of seismic data, the computed depth to bedrock is slightly less than the actual depth.

At two locations, in Dover at well DJW-164 and in Rochester at well RHW-152, seismic-refraction data could not be interpreted because a saturated clay unit was found above unsaturated unconsolidated deposits. This clay unit was confirmed by observation-well logs at both sites. When seismic-refraction profiling was applied at the site, a seismic-velocity depth inversion resulted. The inversion violates the principles and the assumptions needed to do seismic-refraction profiling (Haeni, 1988).

(5) Test-boring data were used to determine hydrologic and geologic properties of aquifers. Split-spoon samples were collected to determine grain-size distribution and variability. Observation wells were constructed in borings where the stratified drift was sufficiently permeable for measuring water levels and collecting ground-water samples for water-quality analysis. Wells (locations shown on plates 1-3) were constructed of 2-in.-diameter-polyvinyl chloride (PVC) pipe with 2- to 5-ft-long slotted screens. Connections were made without the use of glue to avoid possible contamination by glue-based organic compounds. To be developed, wells were surged with compressed air to displace water and sediment from the well screen and to improve the hydraulic connection with aquifer materials. Ground-water levels were measured periodically at 45 observation wells installed in 1986 and 1987. Ground-water-level measurements collected before 1985 include those compiled by Bradley and Petersen (1962) and Cotton (1989). Other sources of data for water levels were the New Hampshire Department of Environmental Services, Water Resource Division (NHDES-WRD), consultant reports, USGS siesmic-refraction data, and altitudes of rivers, streams, and other water bodies shown on USGS topographic maps.

(6) Maps showing the water-table configuration, direction of ground-water flow, and saturated thickness of aquifers were constructed from data collected by use of the preceding methods. Several steps were required to estimate saturated thickness at wells where data on water-table altitude and till or bedrock-surface altitude were not available. The water table was extrapolated for use in estimating the saturated thickness of the aquifer at wells where depth to bedrock was available but water levels were not. Because the depth to the base of an aquifer was needed to determine saturated thickness, depths were collected from a variety of sources. A list of these sources follows in order of priority:

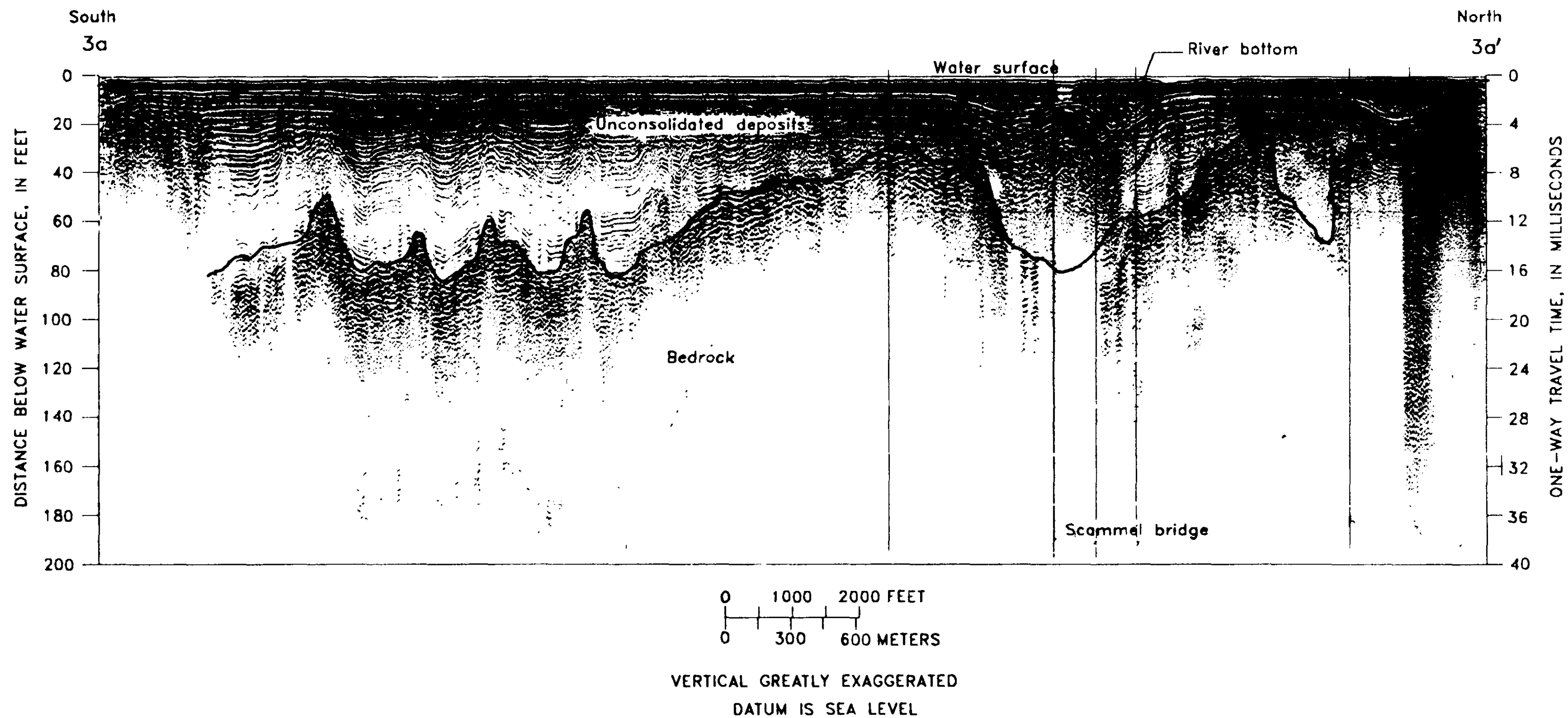

Figure 3a.--Geologic sections interpreted from seismic-reflection data for Dover Point and Bellamy River, Dover, a-a'.

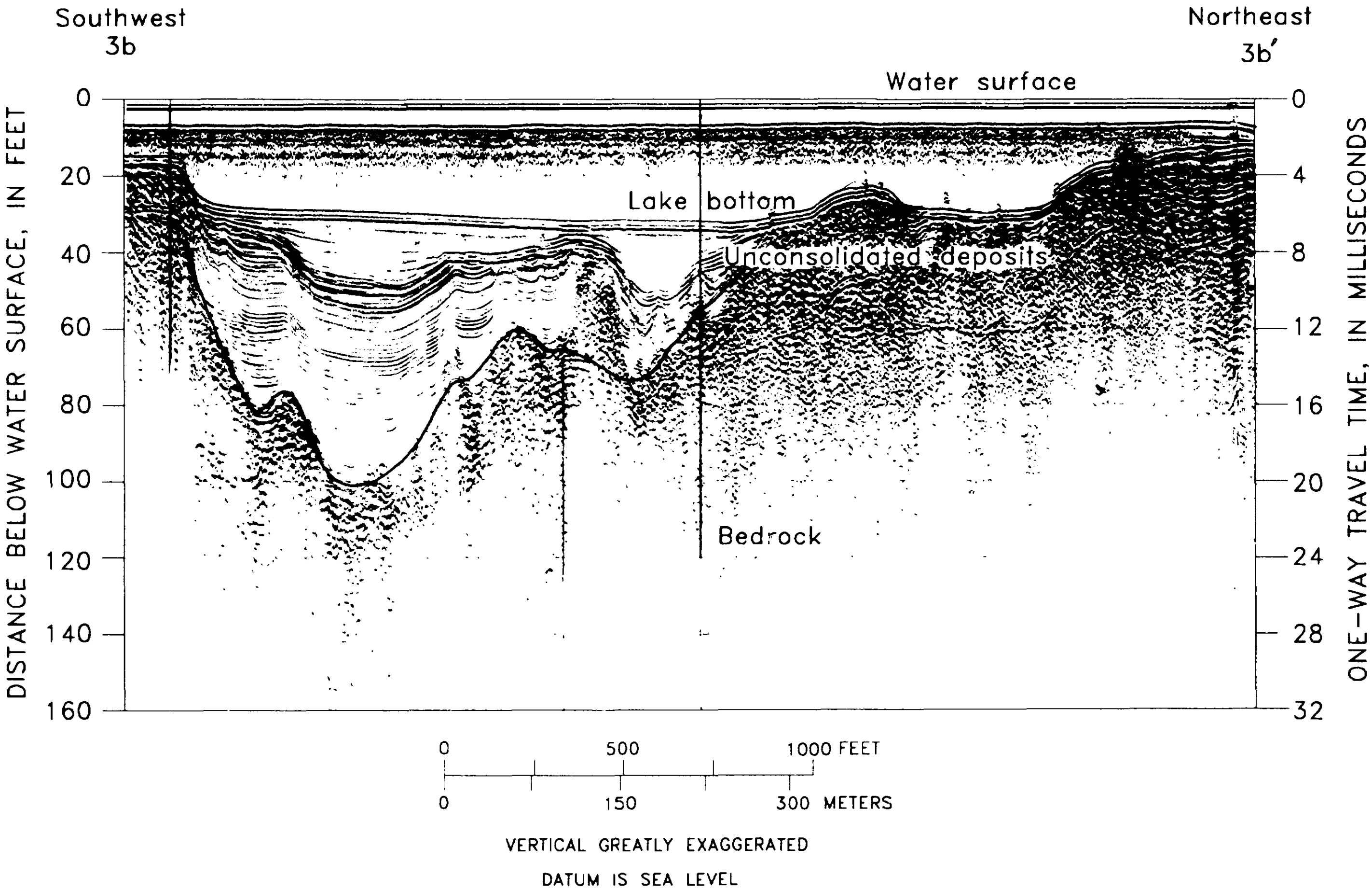

Figure 3b.--Geologic sections interpreted from seismic-reflection data for Bow Lake, Strafford, b-b'.

a) Till surface determined from drilling logs (if till is present, its top represents the stratified-drift aquifer bottom);

b) Bedrock surface determined from drilling logs;

c) Bedrock surface determined from seismic refraction or reflection;

d) Bedrock surface assumed to be 10 ft above the casing bottom where no stratigraphic logs were available (a common drilling procedure used in the area for domestic wells is to drive casing 10 ft into bedrock);

e) Auger refusal assumed to be at or above the bedrock surface depending on whether refusal is assumed to be in boulders; and

f) Bedrock surface is assumed to be at a depth greater than the bottom of the well in wells that did not reach bedrock or refusal. Unless the thickness of a till is known, it is assumed to be insignificant (less than 15 ft). This assumption generally holds true because thickness of most till in southeastern New Hampshire and nearby areas (Bradley, 1964) is less than 15 ft.

(7) Low-flow measurements of rivers and streams were compiled for use in determining **ground-water recharge** and discharge and in estimating potential for ground-water development.

(8) Hydraulic conductivities of aquifer material were estimated from grain-size distribution and by use of an empirical relation developed by Olney (1983). A **hydraulic conductivity** for each material type in a lithologic unit was multiplied by the saturated thickness of that unit and the sum of the products was the transmissivity for all the units in a well log. These data were then used to construct transmissivity contour maps.

(9) **Aquifer yield** was estimated and the effects of pumping were simulated for two aquifers with a numerical ground-water-flow model, developed by McDonald and Harbaugh (1988).

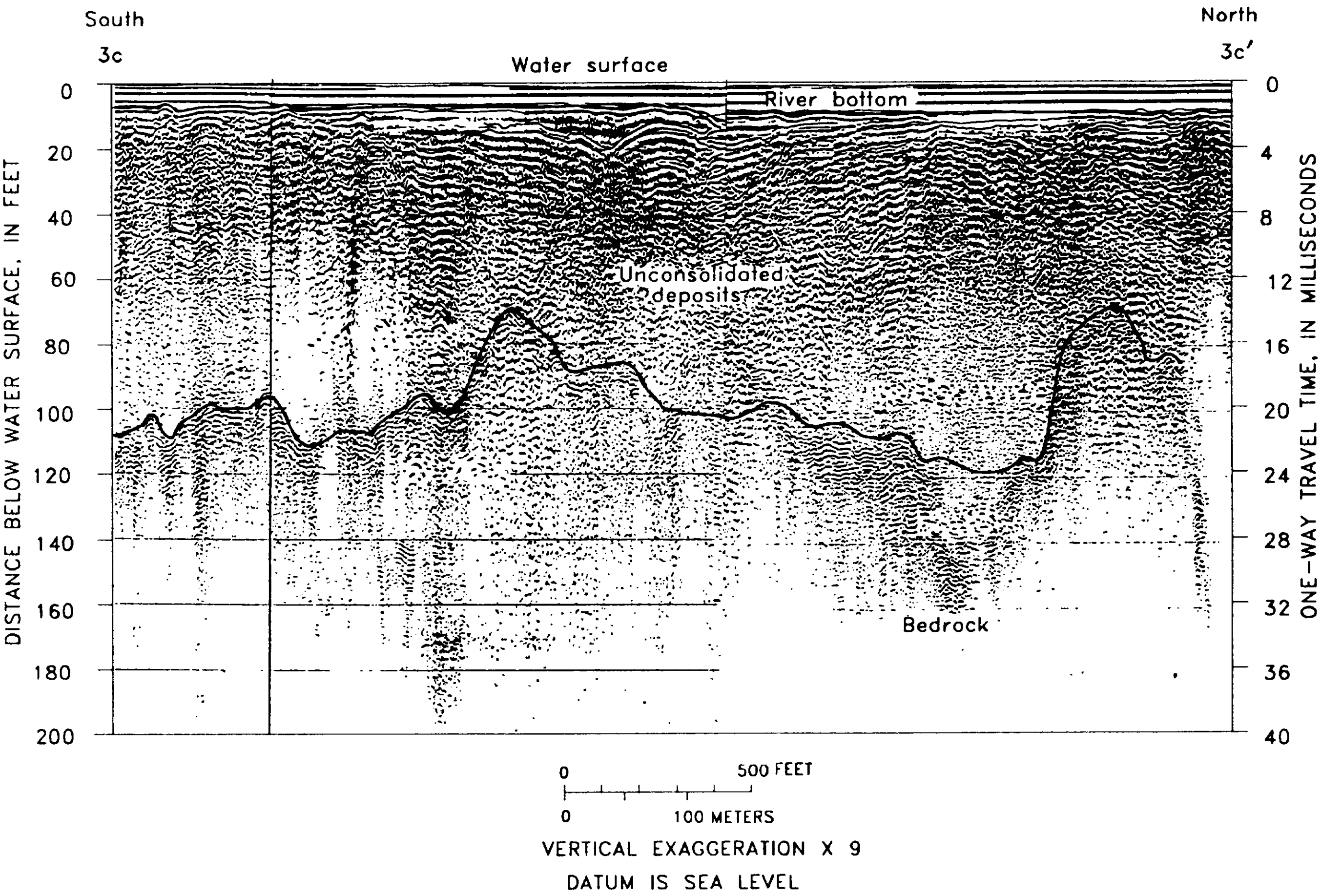

Figure 3c.--Geologic sections interpreted from seismic-reflection data for Salmon Falls River at Town House Road, Milton, c-c'.

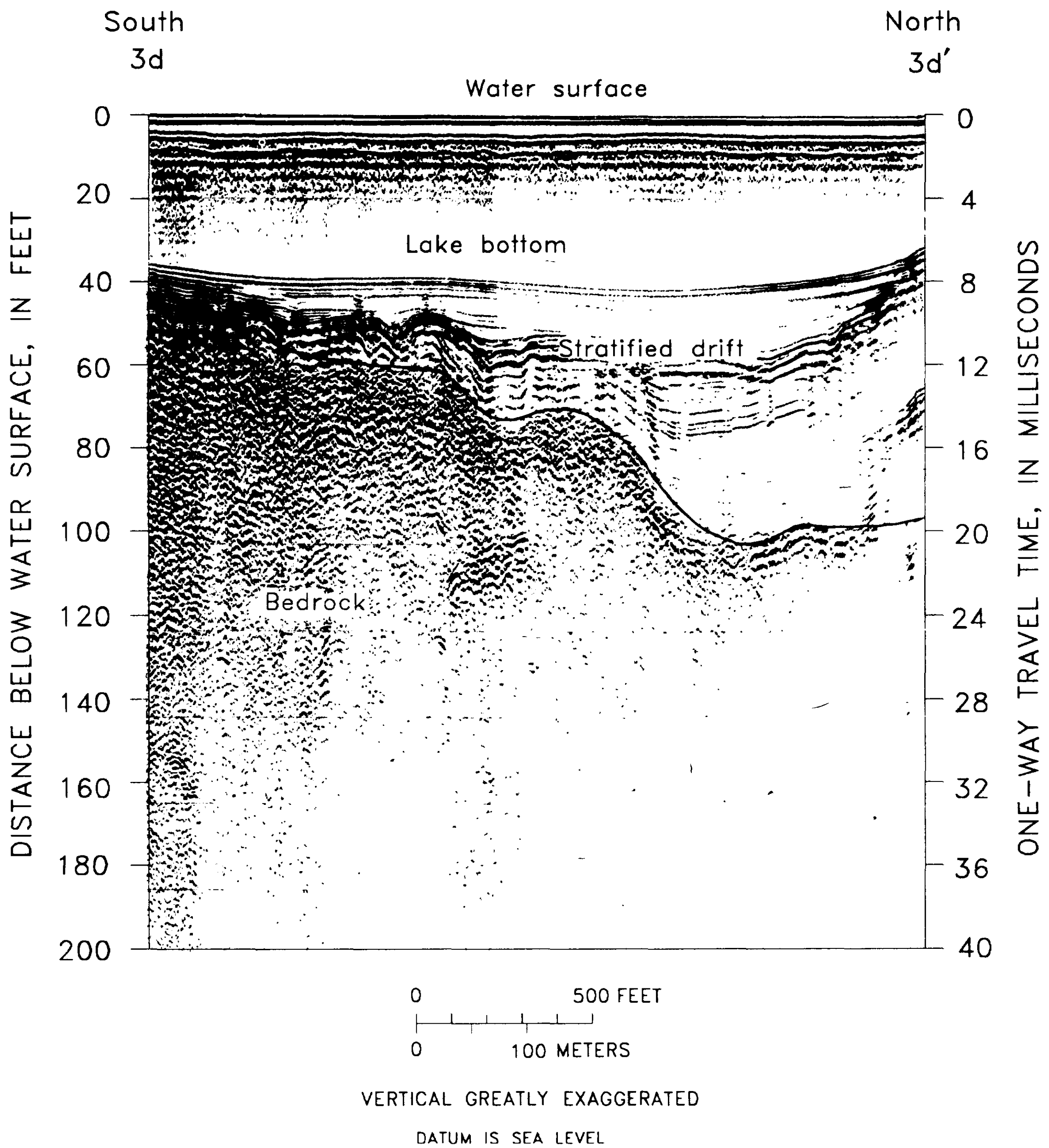

Figure 3d.--Geologic sections interpreted from seismic-reflection data for Great East Lake, Wakefield, d-d'.

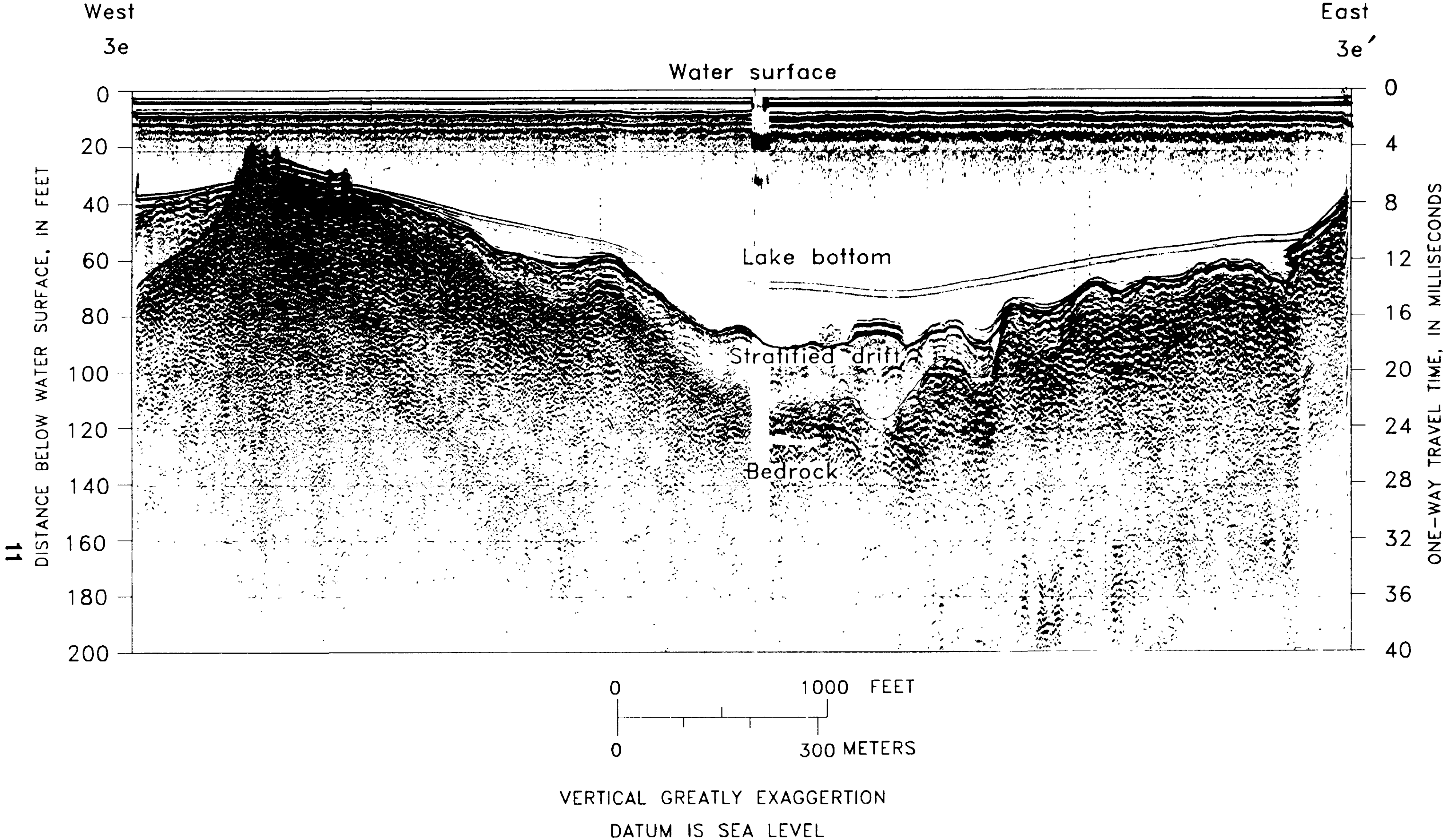

Figure 3e.--Geologic sections interpreted from seismic-reflection data for Great East Lake, Wakefield, e-e'.

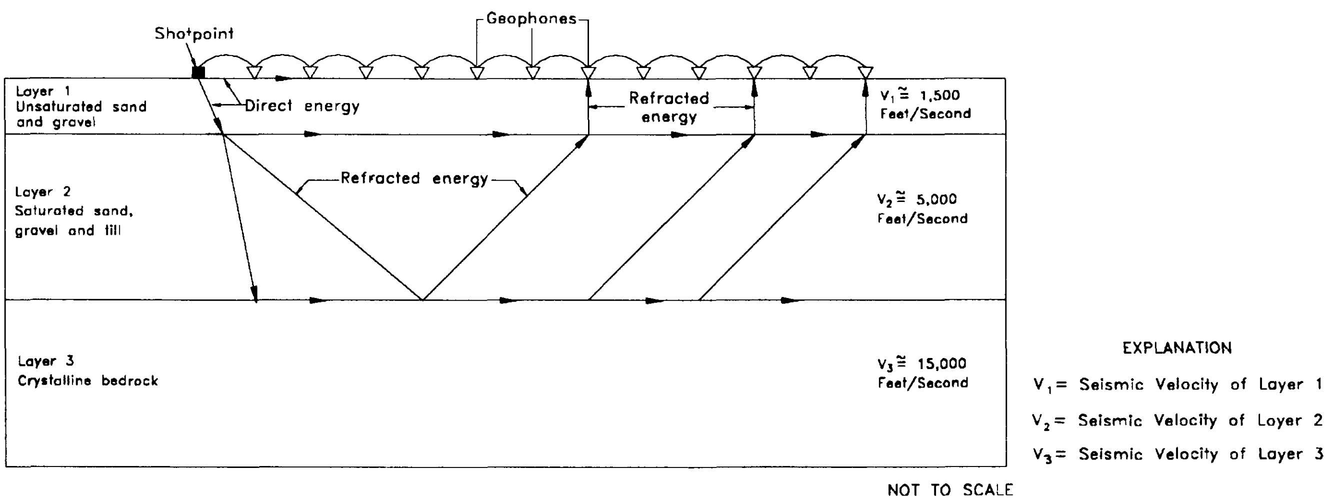

Figure 4.--Seismic-refraction operation and ray paths.

(10) Samples of ground water from 24 wells were analyzed for specific conductance, **pH**, water temperature, and concentrations of trace elements, volatile organic compounds (VOCs), dissolved oxygen, and alkalinity. These data were used to assess the ambient ground-water quality in the stratified-drift aquifers.

GEOHYDROLOGIC UNITS

Ground water is present in variable quantities in all the geologic units in the study area. Three general geohydrologic units are (1) stratified drift (unconsolidated, predominantly coarse-grained sediment), the most productive aquifer in the study area; (2) till, which locally can supply sufficient amounts of water to wells for domestic use; and (3) bedrock, which supplies sufficient amounts of water for many households, but is generally not a major source of water. The three units are discussed briefly with respect to their water-bearing characteristics in the following paragraphs, and the stratified-drift aquifers of this study area are discussed in detail in the section, "Aquifer Characteristics by River Basin." Further discussions of the geologic and the geohydrologic units of the region are given in Goldthwait and others (1951), Tuttle (1952), Bradley (1964), Moore (1978, 1982), and Koteff and Pessl (1981).

Stratified Drift

Stratified-drift **deposits** consist of sand and gravel transported by Pleistocene glaciers and deposited in layers by meltwater streams. The texture and the sorting of these deposits are indications of the depositional environment and the proximity of the deposits to the melting-ice margins. Two basic categories of deposits, ice contact and **outwash**, occur in depositional environments.

Ice-contact deposits are generally poorly sorted, coarse-grained sand and gravel deposited near or at the melting-ice margin in a high-energy environment, such as a fast-moving meltwater river or stream. Ice-contact deposits include **kame terraces**, formed by materials deposited between a glacier and a valley side; **eskers**, formed by meltwater streams beneath or on glacial ice; and deltas, formed where meltwater streams enter standing bodies of water. Ice-contact deposits have large pore spaces associated with their coarse-grained texture, which permits water to be transmitted easily. Deposits that have sufficient saturated thickness are high-yield aquifers.

Outwash deposits form when slow-moving, meltwater streams or glacial lakes, deposit well sorted sand and gravel farther from the ice front than the ice-contact deposits. When sediments carried in meltwater streams are deposited, heavier, coarse-grained materials are deposited first. These deposits can range in size from coarse-grained or gravelly sand, near the stream source, to fine-grained sands in out-

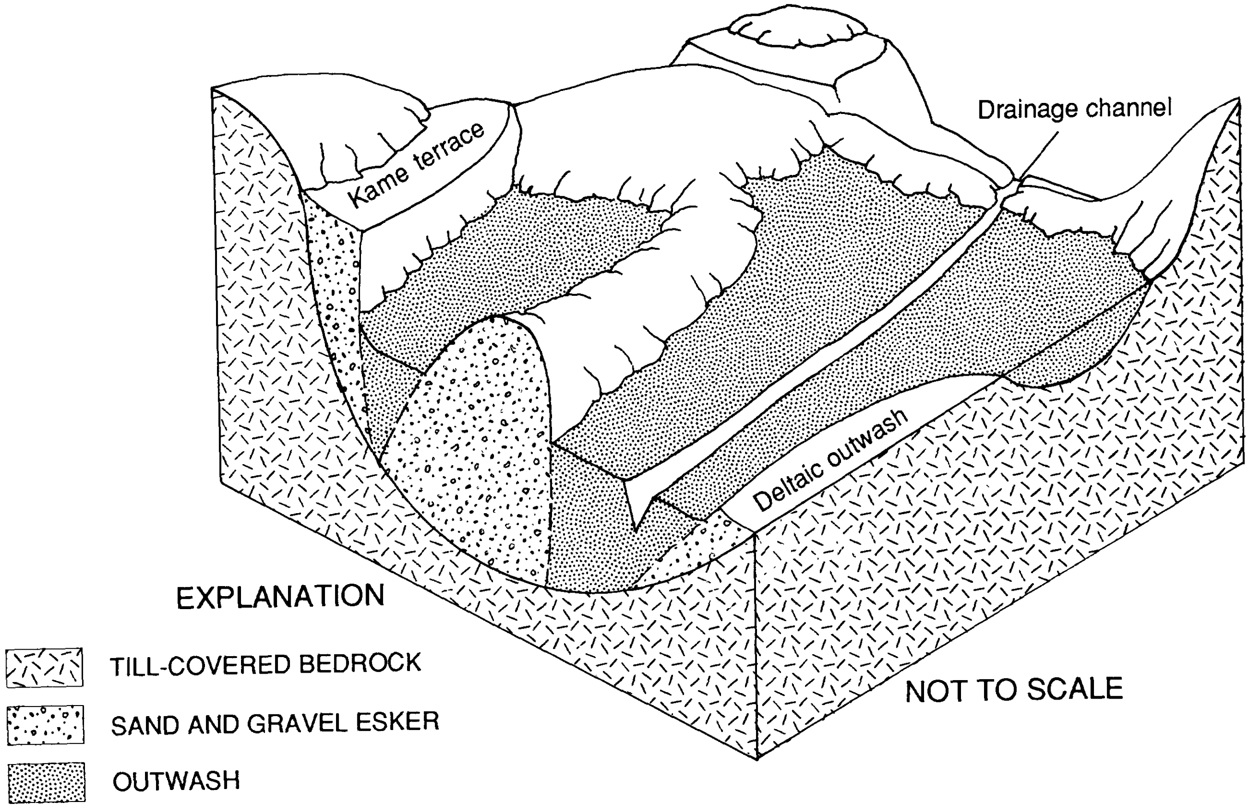

Figure 5.--Diagram of a valley-fill aquifer.

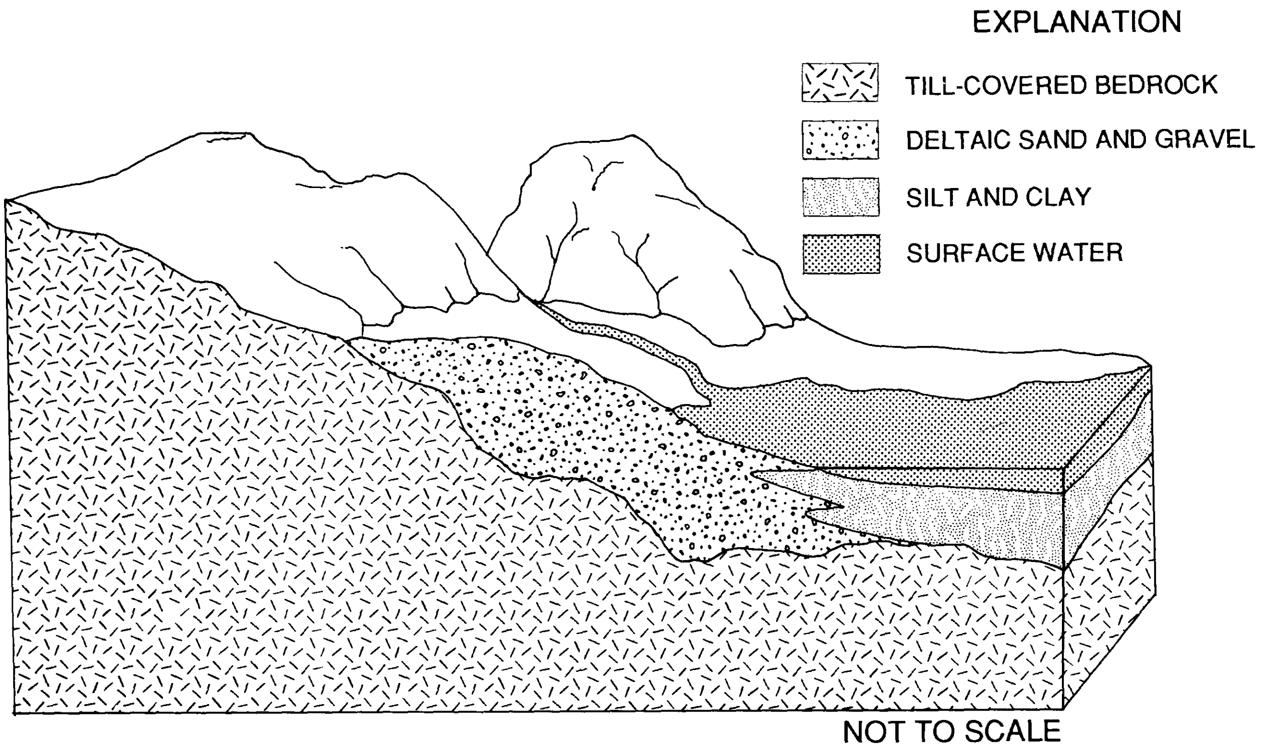

Figure 6.--Diagram of a glacioestuarine deltaic aquifer.

wash plains, and to silt and clay in lakes, estuaries, and marine embayments. The fine-grained outwash sands do not transmit water as easily as coarse-grained sand or gravel. Silt transmits water poorly and clay can act as a barrier to ground-water flow.

Two types of high-yield aquifers, valley-fill and glacioestuarine deltaic aquifers resulted from deglaciation. Valley-fill aquifers are in the northern part of the study area in Cocheco, Ela, Branch, and Salmon Falls River valleys. Glacioestuarine deltaic aquifers, which were formed contemporaneously with periods of marine inundation, occur in the southern part of the study area in Bellamy, lower Cocheco, Isinglass, and Salmon Falls River basins.

An example of a valley-fill aquifer is shown in figure 5. This type of aquifer formed as the active ice margin retreated from the valley and left stagnant ice behind. Deposits here include eskers, kame terraces, outwash, and **outwash deltas**.

A glacioestuarine deltaic aquifer is shown in figure 6. In places, these deltaic deposits have been reworked by beach processes and are in contact with glacioesturarine silts and clays. These deltaic deposits can be classified as shoreline deltas that formed at the ocean interface away from the glacial-ice margin or as grounding-line deltas that formed at the glacial-ice/ocean interface. Moore (1990) discusses the origin of these types of deltas.

Till

Till is an unsorted mixture of clay, silt, sand, gravel, and rock fragments deposited directly beneath the ice sheets (Bradley, 1964). In the study area, till covers most of the bedrock surface as a compact layer and, in low-lying areas, it is overlain by more recent surficial deposits. Thickness of till is commonly less than 15 ft but can be tens-of-feet thick (Bradley, 1964). In the **drumlins**, exposed at Long Hill in Dover and Gonic Hill in Rochester (pl. 1), thickness of till is more than 100 ft. In southeast New Hampshire, till can be divided into an upper and lower unit (Goldthwait, 1948, and Tuttle, 1952). Both tills contain angular to subangular materials; the upper till is brown or olive and the lower till is a blue grey. The lower till is more compact than the upper till and its silt and clay content is greater than that of the upper till (Goldthwait, 1948).

Till is generally not considered to be a major source of ground water because of its low hydraulic conductivity. Large-diameter dug wells completed in till can provide modest amounts of water for household needs, but water-level fluctuations within till can be large enough to make these wells unreliable during dry seasons.

Bedrock

Bedrock consists primarily of metamorphic rocks of pre-Silurian and Precambrian age; gneiss, slate, schist, quartzite, and metavolcanic rocks. These rocks were intruded by granite and granodiorite of Devonian age (Billings, 1956; Novotny, 1969; Lyons and others, 1986). The rocks occur in northeasterly trending belts that parallel the region's structural grain (Lyons and others, 1982). Major fault zones trend northeasterly and are parallel to the regional structure. Secondary **fractures** transverse the primary fractures (Bradley, 1964).

Ground water from wells completed in bedrock originates from water in the fractures that are intersected by the well. The yields of these wells depends on the interconnection and degree of fracturing. Yields vary from well to well. In an inventory of 100 wells, in southeastern New Hampshire, Bradley (1964) found yields that ranged from 1.5 to 100 gal/min, with a **median** of 9.5 gal/min. Bedrock wells commonly supply sufficient amounts of high-quality water for domestic use but generally not enough for municipal or industrial use (Stewart, 1968).

GEOHYDROLOGY OF STRATIFIED-DRIFT AQUIFERS

Geohydrology of stratified-drift aquifers was described by mapping (1) aquifer boundaries, thickness, and transmissivity; and (2) generalized direction of ground-water flow. Sources of data used in the investigation include soils maps, surficial geologic maps, records of wells and test borings, seismic-reflection and -refraction profiles, and streamflow records. Aquifer boundaries, data-collection locations, and water-table contours are shown on plates 1-3. Saturated thickness and transmissivity are shown on plates 4-6.

The study area is subdivided into three regions on plates at a scale of 1:24,000. Boundaries of the plates were chosen to avoid the dissecting of aquifers.

The three regions are: (1) southeastern area (pls. 1 and 4); (2) southwestern area (pls. 2 and 5); and (3) northeastern area (pls. 3 and 6).

Aquifer Boundaries

Locations of the lateral boundaries of an aquifer were defined as the contact between stratified-drift and till or bedrock valley walls. Location of the contact was determined by use of surficial geologic maps, well logs, information on soils maps, and field mapping. The bases of stratified-drift aquifers correspond to the upper surface of till or bedrock as determined from surface geophysics or test borings.

Areal extent of the stratified-drift aquifers is shown on plates 1, 2, and 3. Because of the regional scale of the investigation, these aquifer boundaries are approximate. Site-specific investigations may require more accurate delineation of aquifer boundaries than those presented on plates 1, 2, and 3. Also shown on plate 1 is the approximate western limit of a marine clay unit equivalent to the Presumpscott Formation of Bloom (1960) in Maine as determined by surficial geologic mapping, and well logs. Coarse-grained stratified-drift deposits may occur beneath the marine clays at some locations, but no distinction is made among these deposits because of the complexity of the stratigraphy and the lack of data to map them adequately.

Recharge, Discharge, and Direction of Ground-Water Flow

Recharge to stratified-drift aquifers is the difference between **precipitation** and water loss due to evapotranspiration and **runoff**. Precipitation directly on exposed sand or gravel may infiltrate to the water table with little surface-water runoff or evapotranspiration (Mazzaferro and others, 1979). Estimated ground-water recharge is approximately half the annual precipitation (about 20 in.) in the glaciated areas of upstate New York (MacNish and Randall, 1982); Long Island, New York (Pluhowski and Kantrowitz, 1964); in eastern Massachusetts (Olimpio and de Lima, 1984; de Lima and Olimpio, 1989); and in southern Maine (Morrissey, 1983) for an aquifer similar to those found in the Cocheco River basin. Average annual precipitation, from 35 years of data at a weather station in New Durham, N.H., is 43 in/yr (National Oceanic and Atmospheric Administration, 1986); therefore, annual recharge is approximately 21.5 in/yr in New Durham, N.H.

Annual water loss by evapotranspiration ranges from 18 to 24 in. over most of the Northeast (Knox and Nordenson, 1955) and is fairly constant from year to year. Lyford and Cohen (1988) estimate that recharge is equal to surface-water runoff (20 to 22 in. in southeastern New Hampshire) and ranges from 12 to 30 in. in glaciated areas of the Northeast.

The volume of water available annually for recharge is generally equal to annual runoff (Lyford and Cohen, 1988). This is accurately measured in a narrow valley incised in till or rock where runoff passes a gaging station as surface flow with little ground-water underflow. The average annual discharge at streamflow-gaging station 72850 on Mohawk Brook (pl. 2), which drains till and bedrock uplands, is 1.45 $(ft^3/s)/mi^2$ from 1966-77. This rate of surface-water runoff is 19.7 in/yr or nearly half the average annual precipitation in New Durham, 10 mi to the north. This rate is consistent with the estimates of recharge by Lyford and Cohen (1988) for southeastern New Hampshire, and supports the use of estimating recharge as one half the annual precipitation as determined in other studies in the Northeast.

Stratified-drift aquifers also receive recharge by lateral inflow of ground water from adjacent till and bedrock uplands. Lateral inflow from upland areas not drained by perennial streams recharges the stratified-drift aquifer at the contact with till or bedrock. Potential recharge to sand and gravel aquifers from upland areas not drained by streams may be about 1.45 $(ft^3/s)/mi^2$, if runoff to Mohawk Brook can be assumed to represent runoff from till and bedrock uplands of the region.

Streams that originate in uplands can lose water through seepage as they flow from the uplands on to permeable stratified-drift deposits in the valley. Recharge to sand and gravel aquifers from streams that lose water to the aquifer through permeable streambeds was documented by Randall (1978) in New York and by Morrissey and others (1989) in New Hampshire and Pennsylvania. At several tributary streams in the study area, streamflow decreased as the stream flowed from the till-covered uplands across the adjacent aquifer. Lily Pond Brook in Somersworth (pl. 1), was observed to dry up after crossing from the till upland to the stratified-drift aquifer.

Ground-water discharge from the aquifer includes seepage into streams, lakes, and wetlands;

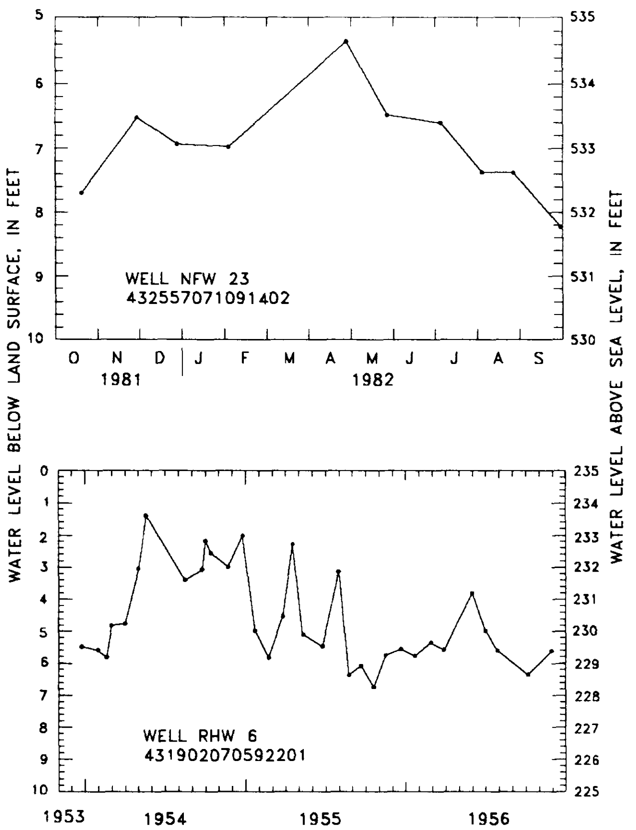

Figure 7.--Hydrograph of water level in well NFW-23 in New Durham and in well RHW-6 in Rochester.

evapotranspiration; and the pumping of wells. During periods of low streamflow, generally in late summer and early fall, after several days without rainfall, streamflow consists almost entirely of ground-water discharge. Streamflow measurements were taken during a low-flow period throughout the study area (pls. 1, 2, and 3) (Blackey and others, 1989) in September 1987, and by Cotton (1989) in September 1982. These measurements were used to estimate recharge to the aquifer.

Fluctuations in ground-water levels in the stratified-drift aquifers were less than 10 ft and were generally less than 5 ft annually (S.M. Lawlor and T.J. Mack, U.S. Geological Survey, written commun., 1990). Water-table altitude in the stratified-drift aquifers, therefore, changes little annually. For example, annual fluctuations in the ground-water-level **hydrographs** (fig. 7) for well NFW-23 in New Durham are about 3 ft from 1981-82, and for well RHW-6 in Rochester are 2 to 4 ft from 1953-56. These fluctuations are similar to those observed by Toppin (1987), Cotton (1989), and Moore (1990).

Generalized water-table altitudes and directions of ground-water flow for selected aquifers are shown on plates 1-3. The maps were constructed from water levels measured, during October 20-22, 1987, in wells drilled for the investigation and from water levels measured at various times in other wells (from files of State of New Hampshire; previously published USGS reports; Bradley and Peterson, 1969; Cotton, 1989; and other miscellaneous measurements). The water-table contours are considered to be generalized because a 20-ft contour interval was used and the data for constructing the maps were collected at several times.

Ground-water levels in areas containing marine-clay deposits represent the water table in sand overlying the clay. Saturated material may occur as a veneer perched above the clay unit, or only in the clay itself. This accounts for the steep water-table gradients seen in deeply dissected clay areas. Water-table gradients varied with topography and stratified-drift material. Gradients exceeded 6 percent in fine-grained material where the topographic relief is steep. Low gradients, less than 0.1 percent, were observed in areas of low relief and coarse-grained materials. Potentiometric surfaces within confined stratified-drift aquifers were not contoured because of a lack of data in these types of aquifers.

Saturated Thickness and Storage

Saturated thickness of stratified-drift aquifers is the vertical distance between the water table and the base of the aquifer (top of bedrock or till). Saturated thickness shown on plates 4-6 includes silts and clays in addition to sands and gravels. Because of a lack of data, the authors did not attempt to differentiate between saturated thicknesses of fine-grained and coarse-grained stratified drift. Saturated-thickness contours (pls. 4-6) were drawn from well-log data and seismic-survey profiles.

The **storage coefficient** of an aquifer is an estimate of the amount of water released from or taken into storage per unit surface area of aquifer per unit change in head (Heath, 1983). In **unconfined aquifers**, storage coefficient is equal to **specific yield**. Specific yield is the amount of water released by gravity drainage from a unit volume of aquifer per unit decrease in hydraulic head. A value of 0.2 is commonly used for specific yield for stratified-drift aquifers in New England (Moore, 1990) and for **unconsolidated deposits** in other areas (Freeze and Cherry, 1979). Specific yields ranging from 0.14 to 0.34 and averaging 0.26 have been reported by Weigle and Kranes (1966) in laboratory analysis of 13 samples from southern New Hampshire.

Water released from storage in **confined aquifers** results from expansion of water and from compression of the aquifer as hydraulic head declines. Storage coefficients for confined aquifers, which are significantly smaller than specific yields, range from 0.00005 to 0.005 because water derived from expansion and aquifer compression is much less than that from gravity drainage. Most references on aquifer tests in the study area do not contain sufficient data for calculation of storage coefficients and, therefore, storage coefficients are not listed in this report.

Hydraulic Conductivity and Transmissivity

Aquifer transmissivity is defined as the rate at which water can be transmitted through a unit width of aquifer under a unit **hydraulic gradient** (Heath, 1983). Transmissivity is equal to saturated thickness multiplied by horizontal hydraulic conductivity and is expressed in feet squared per day (ft^2/d). Aquifer transmissivity at a specific site was derived from estimates of hydraulic conductivity of lithologic units in the aquifers as described below.

Horizontal hydraulic conductivity was estimated from grain-size distributions of sand samples determined by use of an empirical relation developed by Olney (1983). In this relation, an effective grain size (D_{10} in phi units) is used to estimate horizontal hydraulic conductivity (K, in ft per day) with the following equation:

$$K = 2{,}100 \times 10^{-0.655(D_{10})} \quad (1)$$

The effective grain size is a controlling factor in the hydraulic conductivity of stratified drift and is defined as that grain size where 10 percent of the sample is finer than the effective grain size and the remaining 90 percent is coarser than the effective grain size. Olney (1983) developed this relation on the basis of permeameter tests of stratified-drift samples from Cape Cod, Mass. Moore (1990) found this relation to give results comparable to the methods of Krumbein and Monk (1942), Bedinger (1961), and Masch and Denney (1966). Equation 1 is not suitable for very coarse sand or gravel grain sizes; therefore, estimates of horizontal hydraulic conductivity for these materials were from values reported for aquifer tests in the study area.

Horizontal hydraulic conductivity was estimated for 175 samples of stratified-drift from southern New Hampshire. The samples were collected by Moore (1990) in the Exeter and the Lamprey River basins, by Flanagan and Stekl (1990) in the Lower Merrimack and the Seacoast River basins, and in the Bellamy, Cocheco, and Salmon Falls River basins as part of this investigation. The grain-size distribution and the effective grain size (D_{10}) were determined by sieve analysis for 122 samples collected by Moore (1990). Samples collected by Flanagan and Stekl (1990) and those collected for this investigation were analyzed by use of a settling-tube apparatus.

Mean horizontal hydraulic conductivity of samples of stratified drift from southern New Hampshire, grouped by mean grain size, is shown in table 2. Horizontal hydraulic conductivities were calculated for each group and were averaged to determine a mean hydraulic conductivity per group. For example, mean horizontal hydraulic conductivity of sediment samples whose mean grain size was defined as fine was 10 ft/d (table 2).

Horizontal hydraulic conductivities of silt and clay samples from the Rochester Neck area (pl. 4) were generally less than 0.01 ft/d (Goldberg-Zoino, 1982). Silts and clays are estimated to have a low horizontal hydraulic conductivity and were assumed to be zero in calculation of transmissivity. Estimates of hydraulic conductivity for gravel was determined from aquifer tests on municipal wells completed in gravel.

The hydraulic conductivities in table 2 were used to estimate horizontal hydraulic conductivity for materials listed in well logs. For example, in a well where 10 ft of coarse sand and 20 ft of fine sand overlie bedrock the coarse and the fine sand would be assigned horizontal hydraulic conductivities of 130 ft/d and 10 ft/d, and the estimate of transmissivity, based on that log, would be (10 ft x 130 ft/d) + (20 ft x 10 ft/d) or 1,500 ft^2/d.

Transmissivities estimated from aquifer tests (table 3) were also used to construct the transmissivity maps shown on plates 4 and 6. No aquifer-test data and minimal lithologic data were available for use in estimating transmissivity values shown on plate 5. Estimates of transmissivity calculated from grain size and from aquifer tests were found to compare favor-

Table 2.--*Relation of mean horizontal hydraulic conductivity to mean grain size*

[mm, millimeter; ft/d, foot per day; <, less than; >, greater than; phi, a dimensionless unit to measure grain size]

Lithology	Grain size, mean or range (mm)			Grain size, mean or range (phi)			Estimate of mean horizontal hydraulic conductivity (ft/d)
Sand							
Very fine	<0.125					>3	3 or less
Fine	.25	to	0.125	2	to	3	10
Medium	.50	to	.25	1	to	2	30
Coarse	1.00	to	.50	0	to	1	130
Very coarse	2.00	to	1.00	-1	to	0	190
Gravel							
Fine	4.00	to	2.00	-1	to	-2	250
Coarse	>4.00					<-2	300 or greater

ably. Transmissivity can differ significantly over short distances (pls. 4 and 6) because of the heterogeneous nature of stratified-drift aquifers.

Aquifer Characteristics by River Basin

Areas of thick, saturated, stratified-drift deposits were mapped (pls. 4-6). Characteristics of stratified-drift aquifers are described below by major river basin.

Bellamy and Lower Cocheco

A prominent buried valley crosses the Bellamy and Cocheco River basins in the southern part of the study area (pl. 4), which was the focus of a study by Hensley (1978). This valley is shown in a geologic section (fig. 8a) and extends from the Pudding Hill aquifer (pl. 4) northward through the Barbadoes Pond and Hoppers areas in western Dover and eastern Barrington, and through Rochester Neck. The buried valley, was mapped during this investigation, and is indicated by the saturated thickness contours on plate 4. The valley extends northward through the Gonic area of Rochester at the Cocheco River and to the western side of the city of Rochester at the Rochester Fairgrounds. The buried valley does not extend beyond the Cocheco River valley south of Farmington.

The Pudding Hill aquifer in Dover occupies the southern part of a long buried valley (pl. 4). The maximum saturated thickness of the Pudding Hill aquifer exceeds 100 ft, and transmissivity exceeds 3,000 ft^2/d (Moore, 1990). A river-basin drainage divide bisects this aquifer. Approximately half of the aquifer is in the Oyster River basin, and the remainder is in the Bellamy River basin. This aquifer was mapped by Moore (1990) and is not discussed in this report.

The city of Dover withdraws approximately 1.8 Mgal/d of water from 3 wells in the Hoppers aquifer (fig. 8a). This aquifer seems to be in hydraulic connection with the Cocheco River (Cotton, 1989). In most of the aquifers on plate 4, ground-water withdrawals are limited by marine silts and clays.

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Table 3.--*Average saturated thickness and estimated transmissivity and horizontal hydraulic conductivity according to published reports*

[ft^2/d, feet squared per day; ft, foot; ft/d, foot per day]

Aquifer and location	Transmis-sivity (or range of) (ft^2/d)	Average saturated thickness (or range of) (ft)	Horizontal hydraulic conductivity (ft/d)	Source of information
Willand Pond, Dover	6,700 to 5,300	37	162	(1)
Willand Pond, Dover	4,700	40	117	(2)
Pudding Hill, Dover	6,600 to 14,700	36	182 to 408	(1)
Barbadoes Pond, Dover	13,300	85	157	(1)
The Hoppers, Dover	13,300 to 26,700	54	245 to 490	(1)
West side, Farmington	12,600	40	315	(3)
East side, Farmington	[4]9,900	46	[4]215	(4)
Chestnut Hill Rd, Rochester	5,800 to [4]13,800	90	65 to 153	(5)
Willand Pond, Somersworth	2,400	44	54	(6)
Lily Pond, Somersworth	4,900 to 6,300	55	89 to 114	(7)

[1] Camp, Dresser and McKee, Inc. (1979).
[2] Caswell, Eichler, and Hill (1987).
[3] Layne-New England (1982).
[4] Layne-New England (1974).
[5] Ranney Water Collection Corporation (1947).
[6] Layne-New England, 1969.
[7] BCI Geonetics (1987).

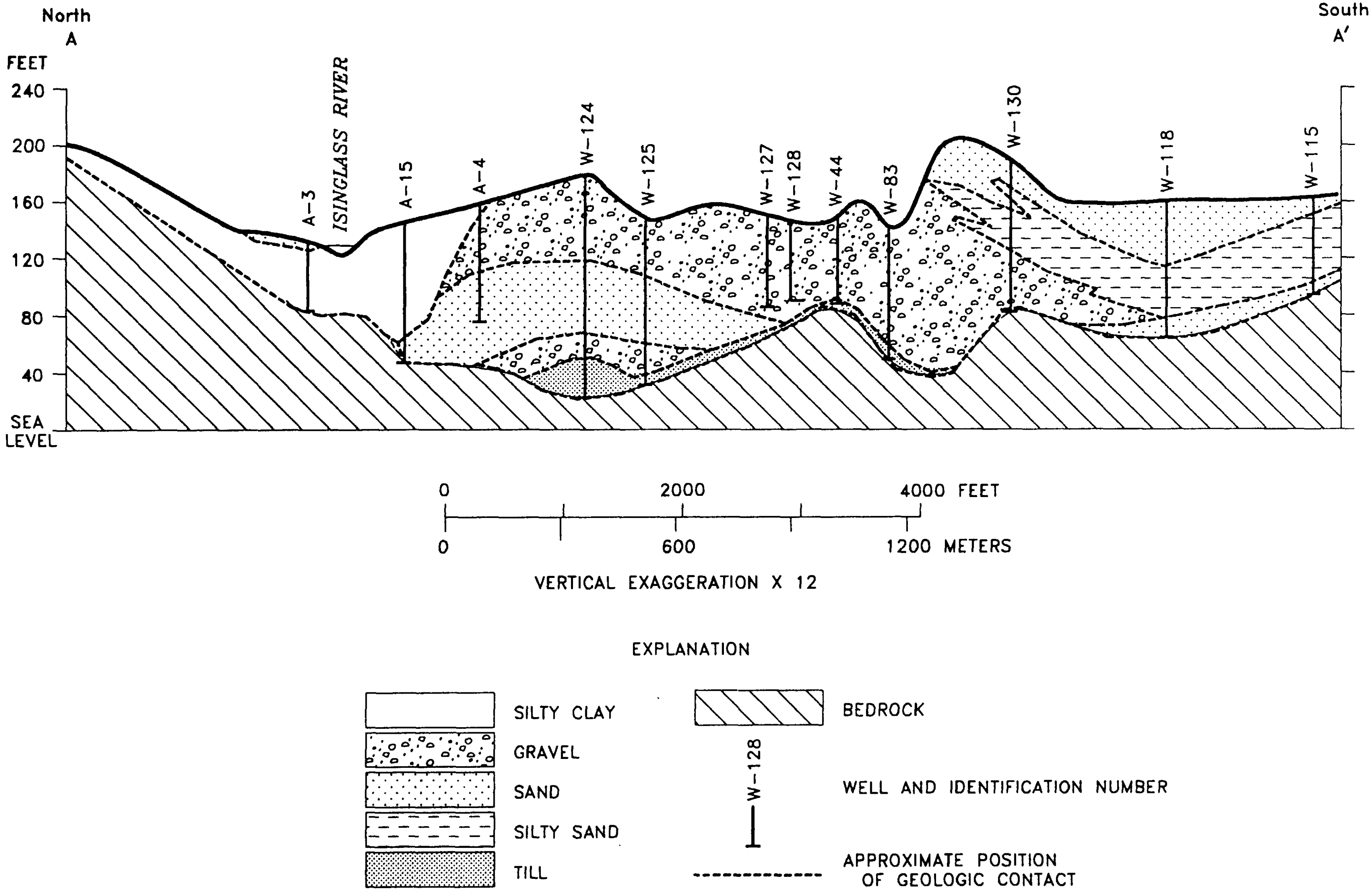


Figure 8a.--Geologic section through the Hoppers aquifer in Dover and Rochester, A-A', plate 1.

Middle Cocheco

The northern side of Rochester Neck, in southern Rochester, is composed of ice-contact sand and gravel. The saturated thickness of the aquifer here is nearly 100 ft (pl. 4), and the maximum transmissivity is estimated to be 2,100 ft^2/d. A landfill here may affect ground-water quality and thus limit the aquifer's potential for development. Thick saturated deposits (100 ft) were discovered where the buried valley passes through the Gonic area (pl. 4). These deposits consist of fine-grained sand, silt, and clay that have little potential for water-supply development. A shallow-collector-well system in coarse-grained sands and gravels along the Cocheco River was proposed for the the northern end of the buried valley, near the intersection of Route 11 and Spaulding Turnpike (pl. 4). Estimates of yield from this aquifer, termed aquifer yield, range from 3.7 Mgal/d (Whitman and Howard, 1982) to 6 Mgal/d (Ranney Water Collection Corporation, 1947). **Induced infiltration** at this site would reduce flow in the Cocheco River proportionally.

Upper Cocheco

The Farmington aquifer, delineated on plate 3, is a few miles north of the Rochester town line along the Cocheco River. A geologic section of this area is presented in figure 8b. The northeastern part of the aquifer is the source of water for Farmington municipal well FAW-73. A second municipal well, FAW-71, is in the south-central part of the aquifer. Use of the second well had been discontinued because of contamination by organic compounds from undetermined sources. Aquifer yields, with respect to these two wells, are discussed in the section, "Simulation of Ground-Water Flow and Effects of Pumping."

Saturated thickness of the Farmington aquifer is 30 to 40 ft throughout most of its extent and as much as 78 ft in the southern part (pl. 6). Along the western side of the aquifer, estimated transmissivities exceed 8,000 ft^2/d where coarse-grained sand and gravel are present. Approximately half of the aquifer's area extent has transmissivities estimated to be less than 2,000 ft^2/d.

Ela

Saturated thickness of the New Durham aquifer (pl. 6) in the Ela River valley is more than 100 ft near the drainage divide that separates the Ela River and the Merrymeeting River valleys. The aquifer, therefore, occurs within these two separate drainage basins. A geologic section of this area is presented in figure 8c. The saturated thickness of this aquifer is large; however, fine-grained deposits cause the low estimates of transmissivities for much of the aquifer. Where coarse-grained, ice-contact deposits are present on the southwestern side of the valley, transmissivities are estimated to be 8,000 ft^2/d and a potential exists for future ground-water development. Currently, there are no municipal wells. Estimates of the aquifer's yield are given in the section, "Simulation of Ground-Water Flow and Effects of Pumping." Aquifer properties were not determined in the southwestern end of this aquifer where a wetland overlies the area and prevents access.

Lower Salmon Falls

Isolated stratified-drift deposits form small but high-yield aquifers near the Salmon Falls River (pls. 1 and 4). Most of the isolated deposits of stratified drift in Rollinsford and eastern Dover are fine-grained sediments. A small area of coarse-grained, ice-contact deposits exists on the southern tip of Dover Point (pl. 1) that was formerly the site of a municipal well (DJW-16). Somersworth (pl. 1) has developed three municipal-supply wells in sand and gravel aquifers along the Salmon Falls River. Two municipal wells (SKW-49 and SKW-50) are located in the Lily Pond aquifer where all available streamflow was lost to induced infiltration during low flow in September 1987. A third municipal well (SKW-43) near Peters Marsh Brook (pl. 1), downstream from Willand Pond, is not used because of high iron concentrations. A municipal well (SKW-94) near Tates Brook in Somersworth (pl. 1) also was abandoned because of its proximity to a landfill and the potential for water-quality problems.

A broad outwash plain is adjacent to the Salmon Falls River in the Melrose Corner area of Rochester (pls. 1 and 4), between North and East Rochester. Low-flow measurements along this section of the river showed a gain of 4.8 ft^3/s, or 3 Mgal/d of ground water. that discharged to the river; this quantity of water is

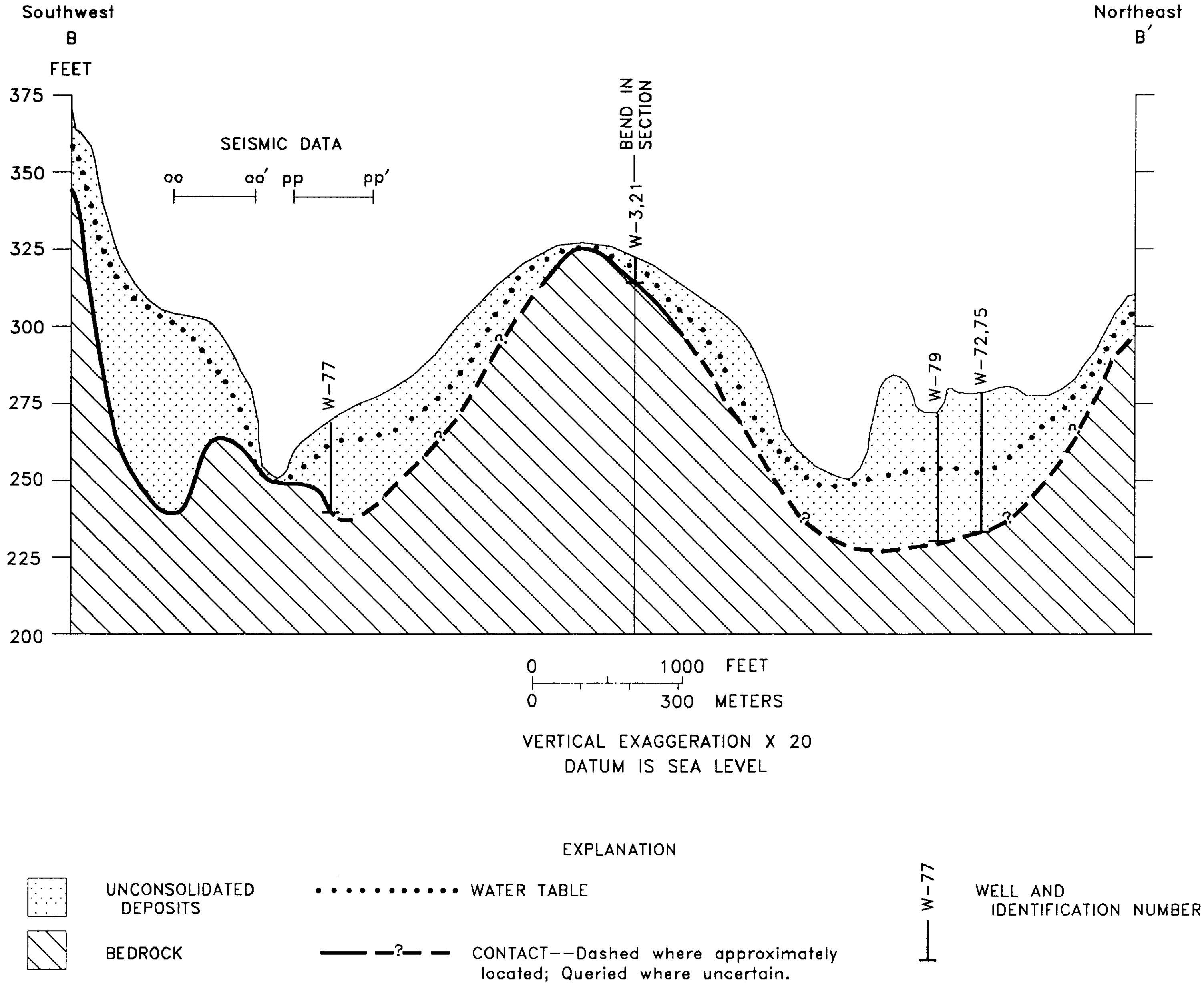


Figure 8b.--Geologic section through the Farmington aquifer, B-B', plate 3.

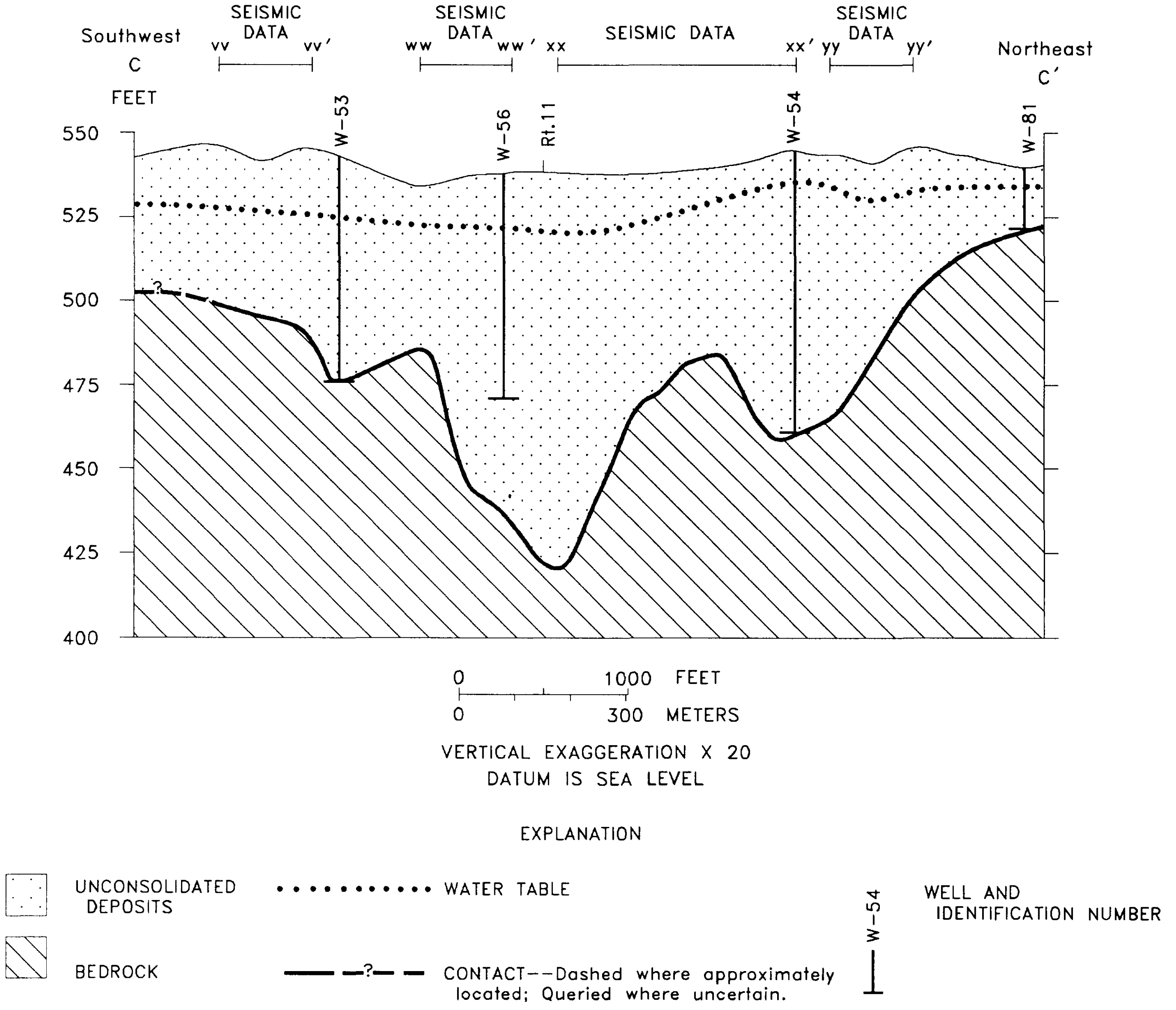


Figure 8c.--Geologic section through the New Durham aquifer, C-C', plate 3.

potentially recoverable by wells. This aquifer yield may be difficult to obtain because the locations of fine-grained deposits could restrict the siting of high-yield wells.

Middle Salmon Falls

An area of thick stratified-drift was delineated in the Salmon Falls River valley near Milton (pl. 6). Deposits 140 ft thick were found in an area locally known as Milton Three Ponds (figs. A19-A20, appendix), an area between Milton Pond, Town House Pond, and Northeast Pond. This area is depicted in the geologic section in figure 8d. A buried channel probably continues beneath the Salmon Falls River at Northeast Pond and trends northward towards Laskey Corner, Milton. In this area, thick deposits (90 ft) were found between the confluence of the Branch and the Salmon Falls Rivers (figs. A20 and A21, appendix). Stratified-drift deposits generally are

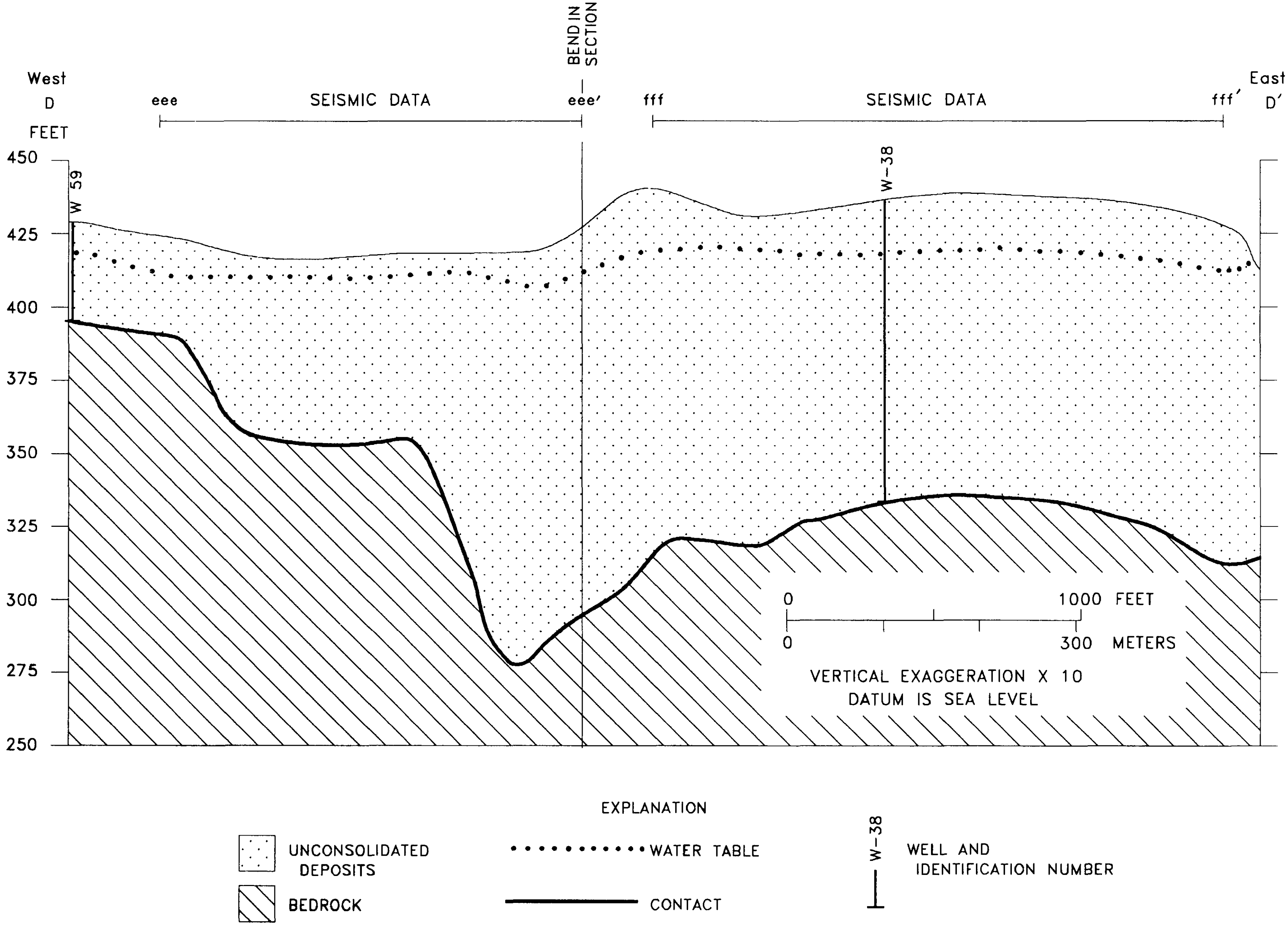


Figure 8d.--Geologic section through the Milton Three Ponds aquifer, D-D', plate 3.

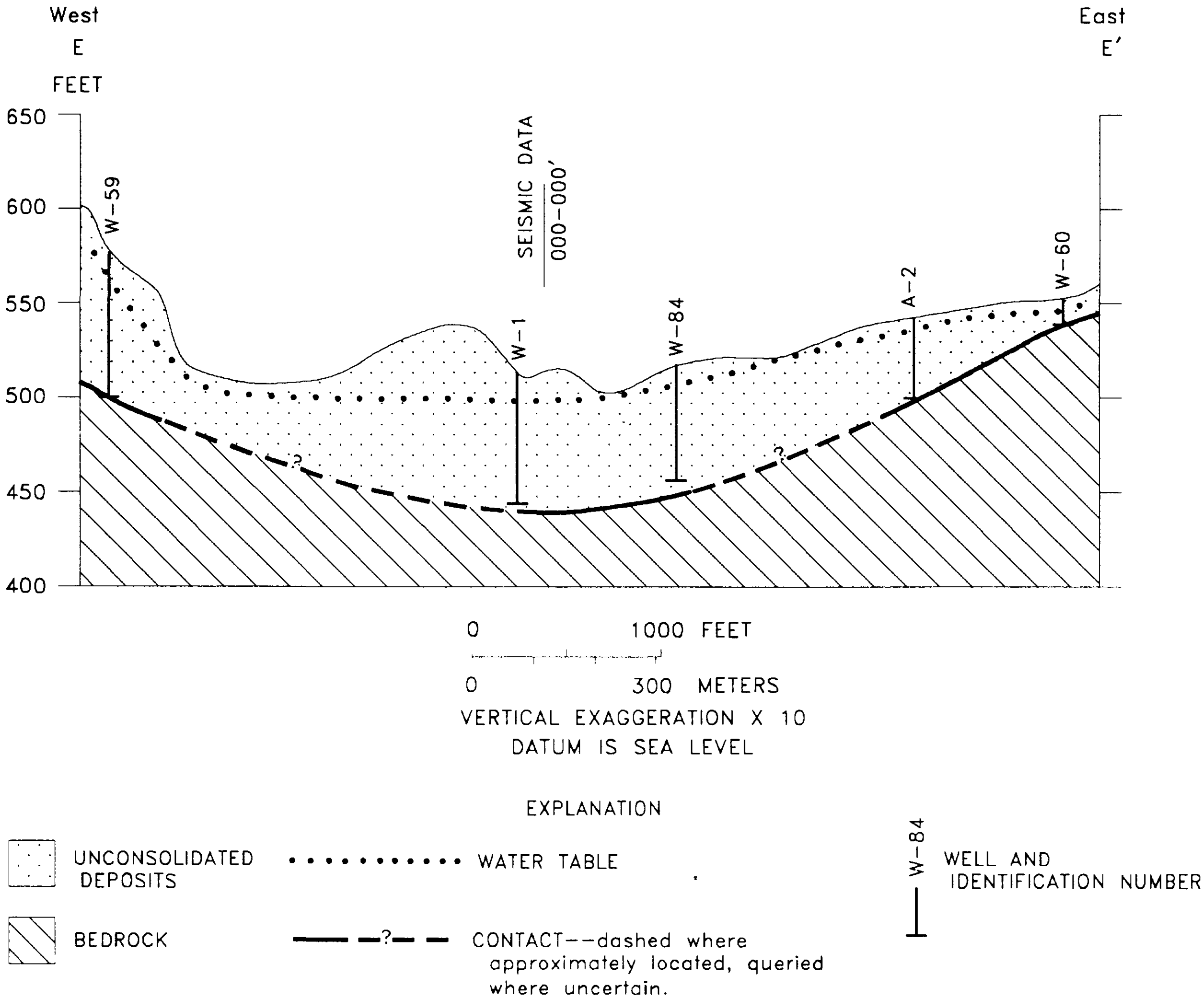


Figure 8e.--Geologic section through the Branch River valley in Wakefield, E-E', plate 3.

medium- to fine-grained sand in the Milton area. Where deposits are coarse grained, the potential is good for development of additional water-supply wells. Saturated thickness is large in the Milton Three Ponds area, and the ponds there would provide a source of induced infiltration.

Currently, the town of Milton (pl. 3) withdraws water from a well (MTW-61) adjacent to Milton and Town House Ponds near the valley wall. The source of water pumped from this site is most likely induced infiltration from the ponds because the aquifer is limited in extent and thickness (pl. 6).

Upper Salmon Falls and Branch

South of the town of Union, at the Carroll and the Strafford County boundary, a small stratified-drift aquifer on the Branch River has some potential for ground-water development (pls. 3 and 6). Saturated thickness of the aquifer is estimated to be 30 ft, and coarse-grained deposits based on the log of observation well MTW-43. Low-flow measurements on the Branch River, between the dam in the town of Union and at the Spaulding Turnpike downstream, show a gain in streamflow of 2.29 ft^3/s, or roughly 1.5 Mgal/d. This gain in ground-water discharge is potentially available for capture by properly constructed and located wells.

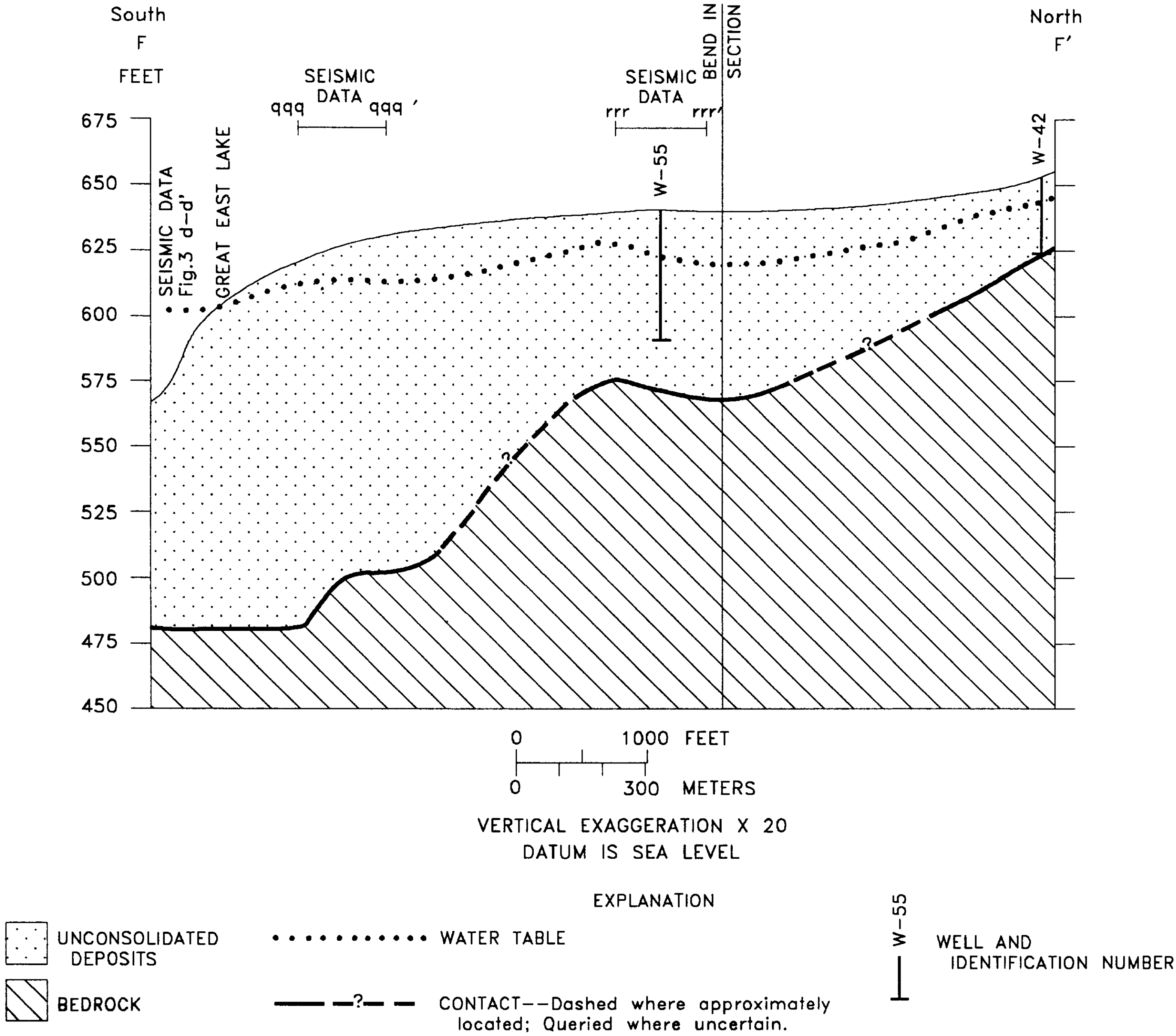


Figure 8f.--Geologic section through Great East Lake to Lake Ivanhoe, Wakefield, F-F', plate 3.

Stratified-drift thicknesses of up to 90 ft were found in the Branch River valley near Brookfield and Wakefield (pl. 6). These deposits trend in a northwest direction along Branch River and thin in Brookfield. A geologic section through the Branch River valley in Wakefield is shown in figure 8e. The town of Wakefield operates a well (B3W-11) that supplies Sanbornville and parts of Brookfield at the northern end of the aquifer. There is potential for ground-water development in this valley. Low-flow measurements on the Branch River show a gain in streamflow of 1.48 ft^3/s (1.0 Mgal/d) from ground-water discharge. Degradation of ground-water quality is possible because of a sewage-treatment infiltration plant on the west side of the valley and a landfill on the eastern side of the valley may preclude or severely limit development of the southern part of the aquifer.

Saturated thickness of stratified-drift deposits between Great East Lake and Lake Ivanhoe, at the headwaters of the Salmon Falls River in Wakefield, is more than 100 ft (pl. 6, fig. 8f). This thick sequence of stratified drift was identified by use of seismic reflection (figs. 3d and 3e) and seismic refraction (fig. A23-

A24, appendix). Cobbles and boulders in the bottom of Lake Ivanhoe prevented successful collection of seismic-reflection data in that area. Potential for ground-water development here is high because of the thick stratified drift and the potential for induced infiltration to wells from surface water. Additional stratigraphic data would be needed, however, to quantify aquifer yields.

Isinglass

Elsewhere in the study area, stratified-drift deposits are thin, widely scattered, and discontinuous. This is particularly true in the western areas of West Barrington, Strafford, and southern Farmington (pls. 2 and 5). An exception to this is the 35 ft of saturated deposits at well SQW-9, in eastern Strafford. Thick stratified-drift deposits in the northwestern area of Bow Lake in the town of Strafford were identified by seismic-reflection profiling (fig. 3c). Bedrock outcrops on shore, however, are an indication that the shoreline deposits are thin. Other areas where stratified-drift deposits with high ground-water potential may occur are shown on plate 5. In some areas, shown by dashed contour lines on plate 5, saturated thicknesses greater than 20 ft are inferred on the basis of their topographic setting. Assessment of these areas is difficult because of the discontinuity of deposits and the inaccessability of sites.

Simulation of Ground-Water Flow and Effects of Pumping

A block-centered, finite-difference, ground-water-flow model (McDonald and Harbaugh, 1988) was used to simulate flow in two stratified-drift aquifers. This model (computer program) includes independent subroutines that simulate ground-water flow, ground water and surface water interaction, recharge, evapotranspiration, several types of boundary conditions, and pumping stress. Algebraic approximations of the equations that describe ground-water flow can be solved by the strongly implicit procedure or slice-successive overrelaxation method (McDonald and Harbaugh, 1988).

Two stratified-drift aquifers, New Durham and Farmington (pls. 3 and 6), were selected for **steady-state** model simulation of ground-water flow. These aquifers were selected because the hydrologic boundaries are well understood and sufficient data were available to describe the parameters that control ground-water flow. The simulations are described with respect to model calibration, sensitivity, and prediction of aquifer yield.

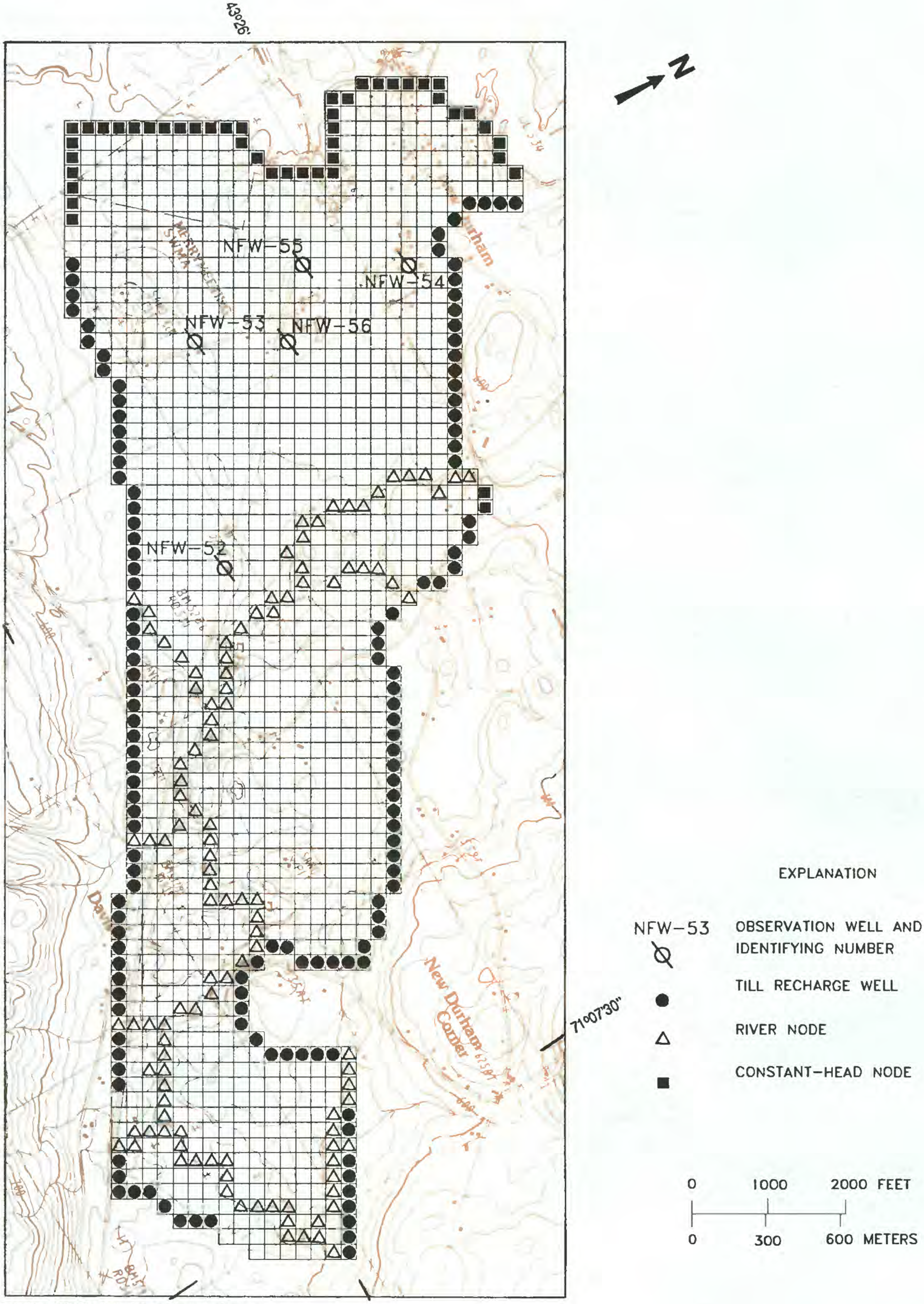
Flow Model of New Durham Aquifer

Model Grid and boundaries

The finite-difference grid used to discretize the New Durham stratified-drift aquifer (pl. 3 and 6) is shown in figure 9. The grid represents an area 15,600 ft long and 6,000 ft wide with 200-ft by 200-ft cells. The model consists of 78 rows and 30 columns or 2,340 cells. Only those cells that overlie the aquifer are assumed to be "active" and are involved in numerical calculations.

The aquifer is represented in the model as a single unconfined layer. The bottom boundary of the aquifer is the contact between the highly permeable stratified drift and the relatively impermeable till and bedrock. This contact is simulated as a no-flow boundary because the fluxes between the drift and the bedrock are assumed to be negligible relative to fluxes in the overlying aquifer. The top boundary of the aquifer, the water table, is simulated in the model as a constant-flux boundary that receives recharge from precipitation.

The aquifer is bounded by valley walls on its northeastern and southwestern sides. Edges of the grid that coincide with these natural boundaries are simulated as a constant-flux boundary. This constant flux represents lateral ground-water inflow from upland till and bedrock areas adjacent to the aquifer. The southeastern side of the valley also is modeled as a constant-flux boundary and represents ground-water inflow to the aquifer from a small upland area. The northern side of the model coincides with the Merrymeeting River and with a large marsh, the Merrymeeting State Wildlife Management Area (the area designated "SWMA" on figure 9). The stages of the river and the marsh are held at constant levels by dams, so they were simulated in the model by a constant-head-boundary set equal to the water-surface altitudes. A surface-water divide between the Ela River and the Merrymeeting River **drainage areas** also is the location of a **ground-water divide** in the modeled area.



Base from U.S. Geological Survey topographic maps; Alton, N.H., 1987. 1:24,000.

Figure 9.--Model grid and cell types for the New Durham aquifer.

Aquifer hydraulic properties

The aquifer hydraulic properties used in model construction include initial water-table altitude (till or bedrock-surface) altitude of base of aquifer, and hydraulic conductivity. A matrix consisting of data for each cell in the grid was constructed for these properties. Known values for each property were assigned to the appropriate cells of the grid; unknown values among known points were determined by interpolation.

An initial water-table altitude is needed in the model as a starting point for model simulations. Because of the nature of the simulation, an approximate water-table surface is all that is necessary for this step. For some cells in the matrix, initial ground-water levels were the field-measured levels. Data used for other cells were interpolated from known values and from seismic-refraction profiles.

The aquifer base used in the modeled area was determined from seismic-refraction profiles, test-borings completed for this study, and data from existing well logs. Saturated valley fill is more than 100 ft deep in the northwestern side of the valley (pl. 6). At the southeastern side of the valley, a bedrock outcrop reduces the width of the aquifer before it enters a broad marsh. Depths to bedrock below the marsh were estimated.

Horizontal hydraulic conductivities used as inital input for the model were estimated from transmissivity and saturated-thickness values (pl. 6). The southeastern side of the valley is composed of coarse-grained, ice-contact deposits whose hydraulic conductivities range from 100 to 200 ft/d. The northeastern side of the valley is overlain by low permeability, fine-grained, outwash sands and silts, whose horizontal hydraulic conductivities range from 10 to 50 ft/d.

Recharge and discharge

Lateral ground-water inflow from till and bedrock uplands recharges the sand and gravel aquifer at the contact between stratified-drift and the valley wall. This recharge is simulated in the model by use of recharge wells along this boundary (fig. 9). Lateral inflow to the aquifer is estimated to be 1.45 $(ft^3/s)/mi^2$ of upland, on the basis of discharge from Mohawk Brook, a small till-covered watershed (8.87 mi^2) in Strafford, N.H. The actual recharge applied at each boundary cell was proportional to the upland area contributing to the cell.

Streams were simulated in the model as head-dependant flux boundaries (fig. 9). This type of boundary allows simulation of flow between the aquifer and river as a function of head gradient and streambed permeability. The streams in New Durham ranged in width from 5 ft in channeled sections to 200 ft in the marshes. The average depth of the Ela River was assumed to be 2 ft; 1 ft in tributaries. The vertical hydraulic conductivity of the streambed of the Ela River was estimated to be 1.5 ft/d on the basis of values estimated by Olimpio and de Lima (1984) for a similar stream, and by estimates from a mass-balance isotope analysis (Dysart, 1988). In the tributaries, where the streambed consists of coarse sediments, a streambed vertical hydraulic conductivity of 3 ft/d was used. Stream elevation at each stream cell was estimated from topographic maps and from altimeter measurements.

On the basis of the discussion of recharge earlier in this report, recharge from precipitation directly on the aquifer was assumed to be equal to half of the average annual precipitation. Mean annual precipitation for 36 years in New Durham is 43 in. (National Oceanic and Atmospheric Administration, 1986). Half of this amount, 21.5 in., was applied uniformly over the modeled area.

Currently (1988), no municipal well is pumping water from the New Durham aquifer. Several domestic wells pump water from the aquifer; but because ground water discharged by pumped wells recharges the aquifer through septic systems, it is not necessary to simulate these fluxes.

Calibration

Calibration of ground-water-flow models allowed for an adjustment in model-input data to improve the match between model-calculated and field-measured hydraulic heads and discharge from the aquifer. Average water-table altitudes measured in the aquifer were used to calibrate heads in the New Durham model. Low-flow measurements of the Ela River were compared to simulated aquifer discharges.

Water levels measured in December 1986, at the five observation wells in the New Durham aquifer, were used to calibrate the steady-state flow model

(S.M. Lawlor and T.J. Mack, U.S. Geological Survey, written commun., 1990). December 1986 water levels at these five wells were at median values.

Because most of the southern half of the aquifer is overlain by marsh with the water table at or near ground surface throughout that area, the surface-water altitude in the marsh was used to calibrate head in the southern half of the aquifer. The surface-water altitude in this marsh is essentially flat and its altitude is regulated by bedrock control in the Ela River at the southeastern model boundary.

Water levels measured in 10 domestic wells in December 1980 and 1982 (Cotton, 1989; S.M. Lawlor, and T.J. Mack, U.S. Geological Survey, written commun., 1990) also were used to aid calibration. Measuring-point altitudes of the 10 domestic wells, which are mostly dug wells, are less precisely known than the 5 observation wells; therefore, the domestic wells were not formally included in the calibration process. Water levels in these 10 wells are considered to be accurate within ±5 ft. All wells used for calibration are located in the northern part of the aquifer.

The water level at the nearest long-term observation well 430721071005001 (K.W. Toppin, U.S. Geological Survey, written commun., 1990), in Lee, N.H., 20 mi south of New Durham, was 0.06 ft below the long-term average level in late November 1986. The difference between the maximum and minimum measured water level at this well was 5 ft. If the hydrologic conditions at this station are representative of conditions throughout the study area, water levels in the New Durham aquifer also were at their long-term average annual level during late November 1986 and December 1980 and 1982.

The calibration process involved a series of steady-state simulations, in which aquifer recharge was specified at average values (infiltration of precipitation was 21.5 in/yr and ground-water inflow from till and bedrock uplands was 1.45 ft^3/mi^2). Values of aquifer hydraulic conductivity and streambed conductance were adjusted to improve the match between model-calculated and measured heads. The final average of absolute difference between model-calculated and measured heads at five locations in the model area was 0.6 ft. Individual absolute difference ranged from 0.2 to 1.1 ft (table 4a).

Table 4a.--*Relation of model-calculated and measured heads in the final calibrated steady-state model for the New Durham aquifer*

[All values in feet]

Well	Head		Absolute difference
	Measured	Model-calculated	
W-52	521.9	522.3	0.4
W-53	525.2	526.1	.9
W-54	534.0	535.1	1.1
W-55	527.6	527.8	.2
W-56	527.5	527.9	.4

The steady-state, total water budget for the area derived from the model (6.04 ft^3/s, table 4b) is based on best-fit simulation. A water budget (Cotton, 1989) for the part of the New Durham aquifer that is drained by the Ela River, includes an estimate of the total balance of 2.2 Mgal/d or 3.4 ft^3/s. Cotton's estimate is low because it is based on the streamflow available during low flow in about two thirds of the New Durham aquifer area.

Table 4b.--*Model-calculated steady-state water budget for average conditions in the New Durham aquifer*

[ft^3/s, cubic foot per second]

Inflow		Outflow	
Source	Rate (ft^3/s)	Source	Rate (ft^3/s)
Recharge from precipitation	3.25		
Lateral inflow from till and bedrock uplands	2.03		
Constant-head leakage	.49	Seepage to constant-head nodes	1.46
Surface-water leakage	.27	Seepage to streams	4.58
Total	6.04		6.04

Simulated water levels in the New Durham aquifer (fig. 10) compare favorably with measured water

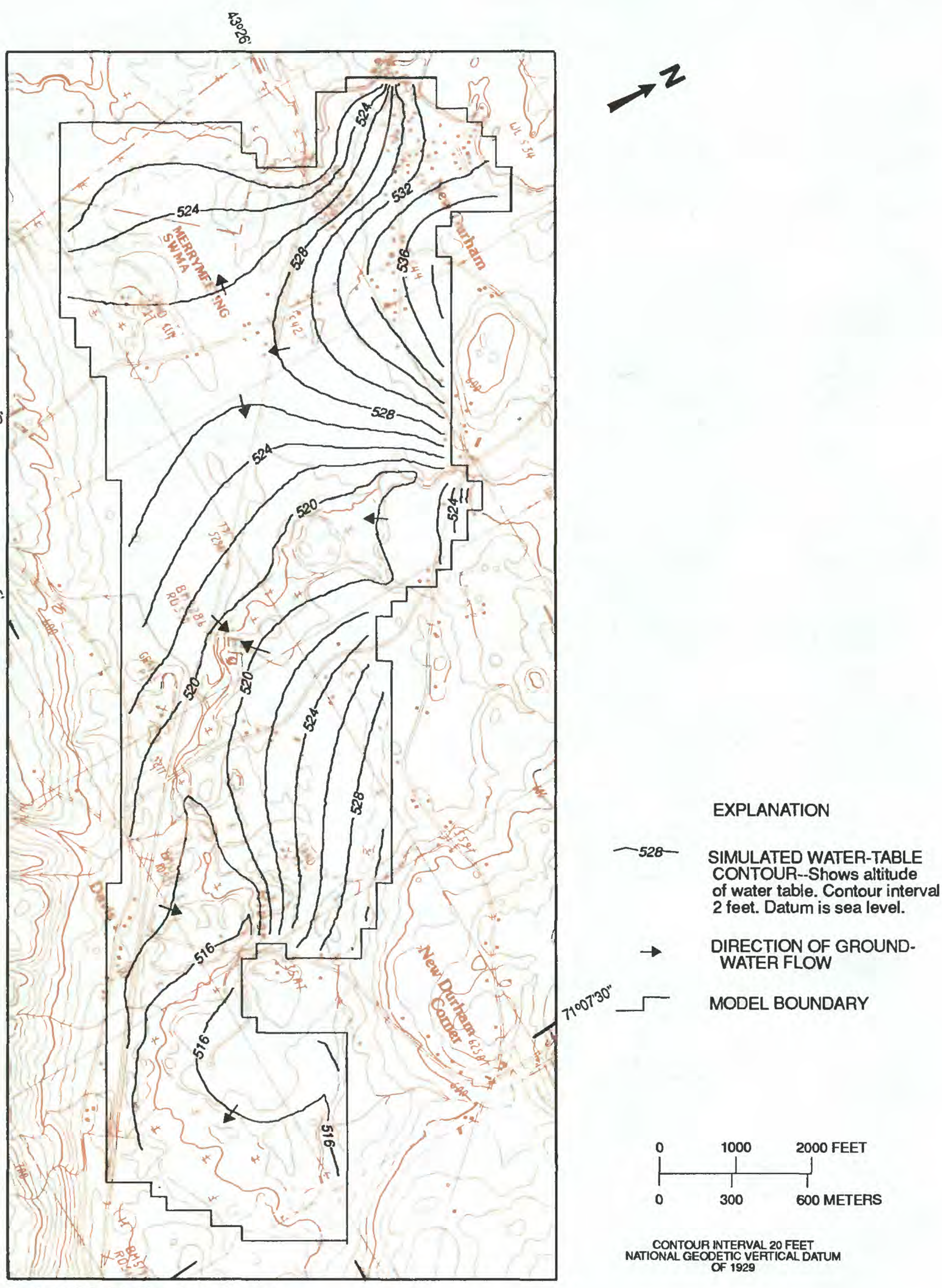


Figure 10.--Simulated water-table configuration in the New Durham stratified-drift aquifer.

levels (table 4a) and surface-water altitudes determined from topographic maps. A ground-water divide is evident in the northwestern part of the valley where ground water flows in a northwesterly direction to the Merrymeeting State Wildlife Management Area marsh and in a southeasterly direction to the Ela River.

Ideally, for detailed model calibration, the following data would be needed:

1) Discharge data from a large number of streamflow measurement stations within and outside the modeled area to determine seepages across all streams and to match simulated measured seepage;

2) Ground-water levels from a large set of observation wells in the modeled aquifer to match simulated and measured water levels; and

3) Long-term hydrographs of water levels to provide long-term water-level fluctuations and average conditions in the aquifer.

Extensive drilling for the ground-water data and collection of the streamflow measurements required for detailed model calibration was beyond the scope of this basin-wide study. Sufficient water-level and seepage data were collected, however, so that a simplified ground-water-flow model could be constructed, and estimated yield of the New Durham aquifer was determined. Because of the limited data that were collected, the results of model simulations are to be used with caution.

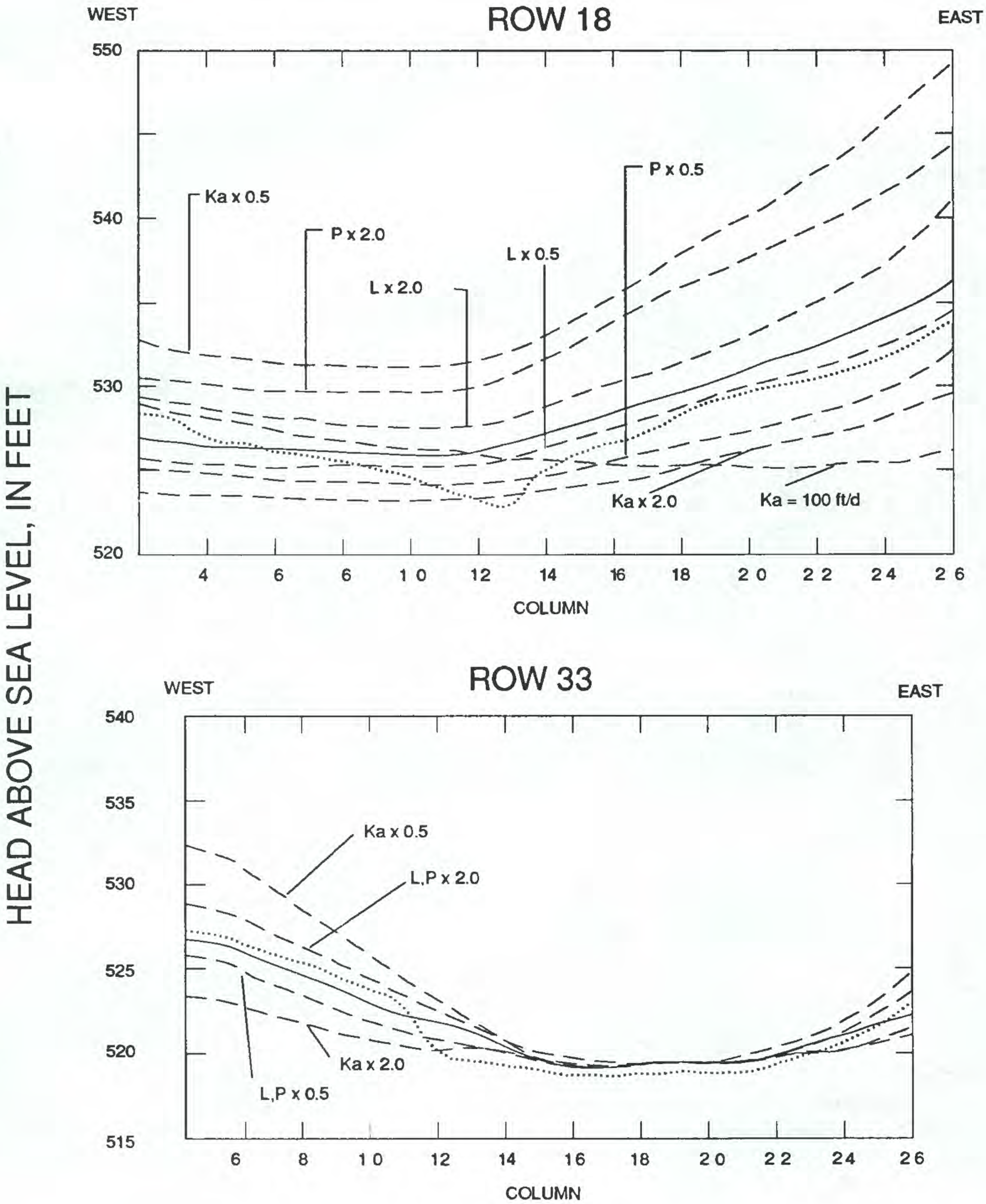
Sensitivity analysis

A series of steady-state simulations were done to assess the sensitivity of the model to variations in input data. Values used in the calibrated model for aquifer horizontal hydraulic conductivity, streambed hydraulic conductivity, and recharge were first doubled and then halved during sensitivity testing. Use of a uniform aquifer horizontal hydraulic conductivity (150 ft/d) throughout the model also was tested. Heads computed during the sensitivity runs are compared with those measured in the field at five check locations (table 5). The effects of varying the model input data is shown graphically in figure 11 where calibrated steady-state heads are compared with heads calculated during sensitivity runs along model rows 18 and 33.

Table 5.--*Changes in model-calculated heads during sensitivity testing of the New Durham aquifer model*

[all values in feet]

Well	Measured head	Changes in model-calculated hydraulic head in aquifer with changes in:						
		Horizontal hydraulic conductivity			Recharge by precipitation		Lateral inflow	
		x2	x 1/2	uniform K of 150	x2	x 1/2	x2	x 1/2
W-52	522.3	-1.4	2.5	0.0	0.5	-0.7	1.0	-0.5
W-53	526.1	-2.8	5.2	.2	3.7	-1.9	1.6	-.8
W-54	535.1	-5.9	11.0	-8.1	7.5	-4.2	2.9	-1.5
W-55	527.8	-3.4	6.2	-2.1	4.9	-2.7	1.2	-.7
W-56	527.9	-3.6	6.8	-2.4	5.1	-2.7	1.6	-.8
Average absolute difference		3.4	6.3	2.6	4.3	2.4	1.7	.9



EXPLANATION

Ka=AQUIFER HORIZONTAL HYDRAULIC CONDUCTIVITY
P=DIRECT PRECIPITATION RECHARGE
T=LATERAL INFLOW FROM UPLANDS

——— CALIBRATED MODEL
·········· APPROXIMATE WATER TABLE
— — HEADS

Figure 11.--Effects of varying the model input on computed heads for the New Durham aquifer.

Model-calculated heads are most sensitive to changes in aquifer horizontal hydraulic conductivity. When calibrated horizontal hydraulic-conductivities were doubled, the model-calculated water-table altitudes decreased throughout the entire model area. At the five measurement locations, the decreases ranged from 1.4 to 5.9 ft and averaged 3.4 ft. When hydraulic conductivity in the model was halved, simulated water levels increased throughout the modeled area. This increase ranged from 2.5 to 11.0 ft at the five measurement locations and averaged 6.3 ft. A uniform hydraulic conductivity (150 ft/d) tended to decrease water levels at the measurement locations, particularly on the eastern side of the aquifer, but had less effect than the increase or decrease that was tested.

Variations in simulated recharge also affected the model-calculated heads. Doubling the average recharge rate from precipitation caused water levels to increase by 7.5 ft at well W-54 and from 0.5 ft to 5.1 ft at the other wells, whereas lowering the recharge rate caused the water table to decrease by 0.7 ft to 4.2 ft below average values.

Doubling or halving the amount of recharge by lateral inflow from till had an effect similar to but less pronounced than varying recharge rate from precipitation. The changes in upland recharge had more effect in areas of low hydraulic conductivity and near model boundaries than in areas of high hydraulic conductivity on the northeastern side of the valley.

Changes in streambed vertical hydraulic conductivity did not produce significant water-level changes (less than 0.1 ft) at the five measurement locations (wells) because the areas containing stream cells were distant from the wells. In general, for stream reaches gaining water, large streambed hydraulic conductivities (3 ft/d) caused ground-water levels near the stream to decrease and small values (0.75 ft/d) caused water levels near the stream to increase. The opposite relation is true for stream reaches that lose water. The amount of water that flows through the streambed with a large streambed hydraulic conductivity, for the same head gradient, is greater than a stream with a small streambed hydraulic conductivity.

Model results were sensitive to variations in the assumed width of the Ela River. With the Ela River simulated as a 20- to 30-ft wide stream channel, computed water levels were too high near the river in adjacent marsh areas. Streambed width was then increased to include the full width of the wetlands along the river. This change improved agreement between model results and measured heads by allowing the entire wetland area to act as a discharge zone for ground-water flow.

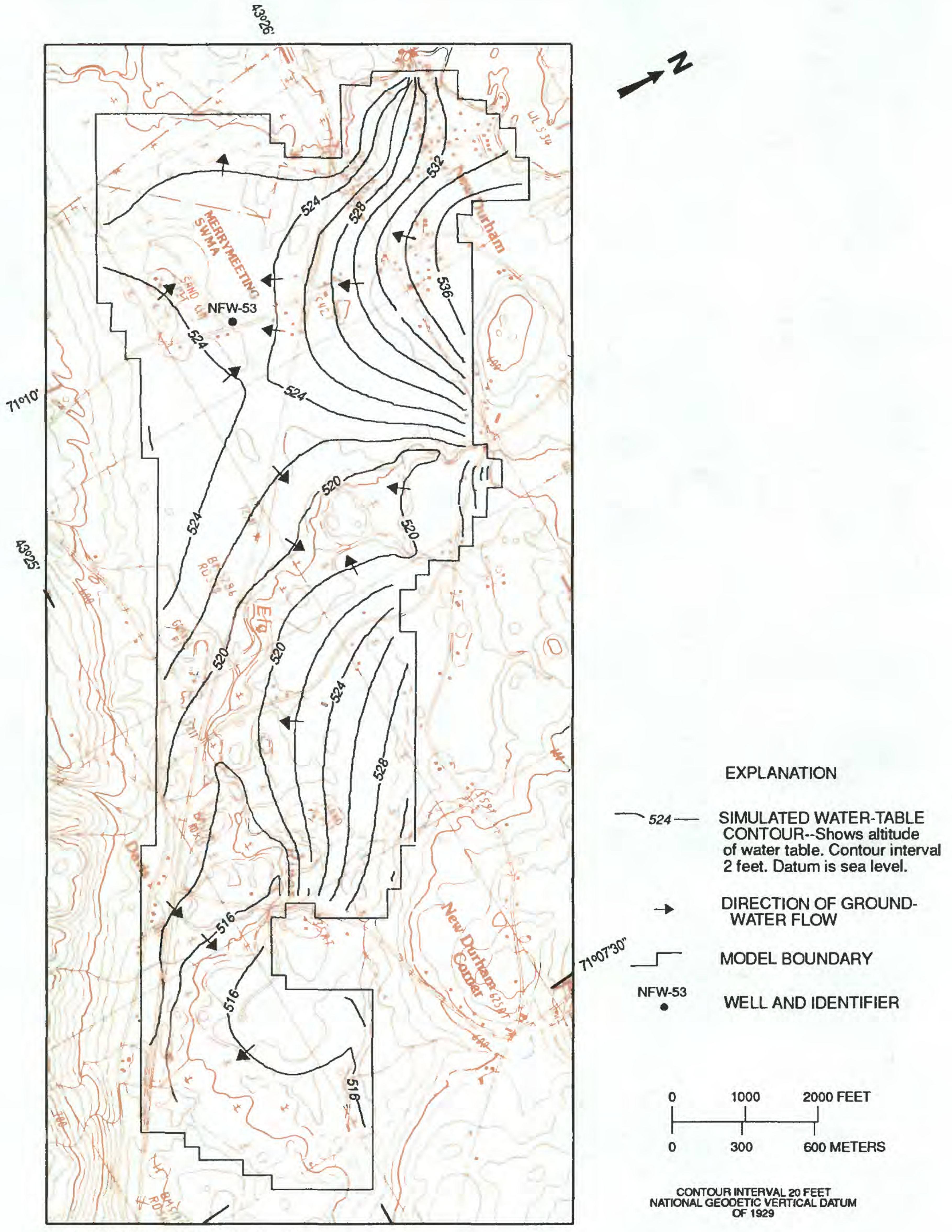
Simulation of pumping at hypothetical wells

The calibrated ground-water-flow model was used to simulate the effects of pumping at hypothetical production wells on ground-water levels in the aquifer, to determine effects on flow in the Ela and Merrymeeting Rivers, and to assess potential aquifer yield. Two locations (W-52 and W-53), were identified by test drilling where thickness of saturated permeable deposits was suitable for intallation of high-yield production wells. Steady-state simulations were run in which wells W-52 and W-53 were pumped at rates of 0.25, 0.50, and 0.75 Mgal/d (million gallons per day), individually and in various combinations. Simulated water-table configurations in the New Durham aquifer are presented in figures 12-16.

Drawdowns in the aquifer and reduction of flow in the Ela and Merrymeeting Rivers for each simulation are summarized in table 6. Drawdowns at wells W-52 and W-53, predicted on the basis of model results (table 6), are the difference in head between the final calibration run and the head in the pumped well during each simulation. The drawdown calculated by the model for a cell simulating a production well is an average for the entire cell. Actual drawdowns at the pumped cells (table 6) were determined by a formula presented by Trescott, Pinder, and Larson (1976). Diameters of hypothetical supply wells were assumed to be 18 in. for these calculations.

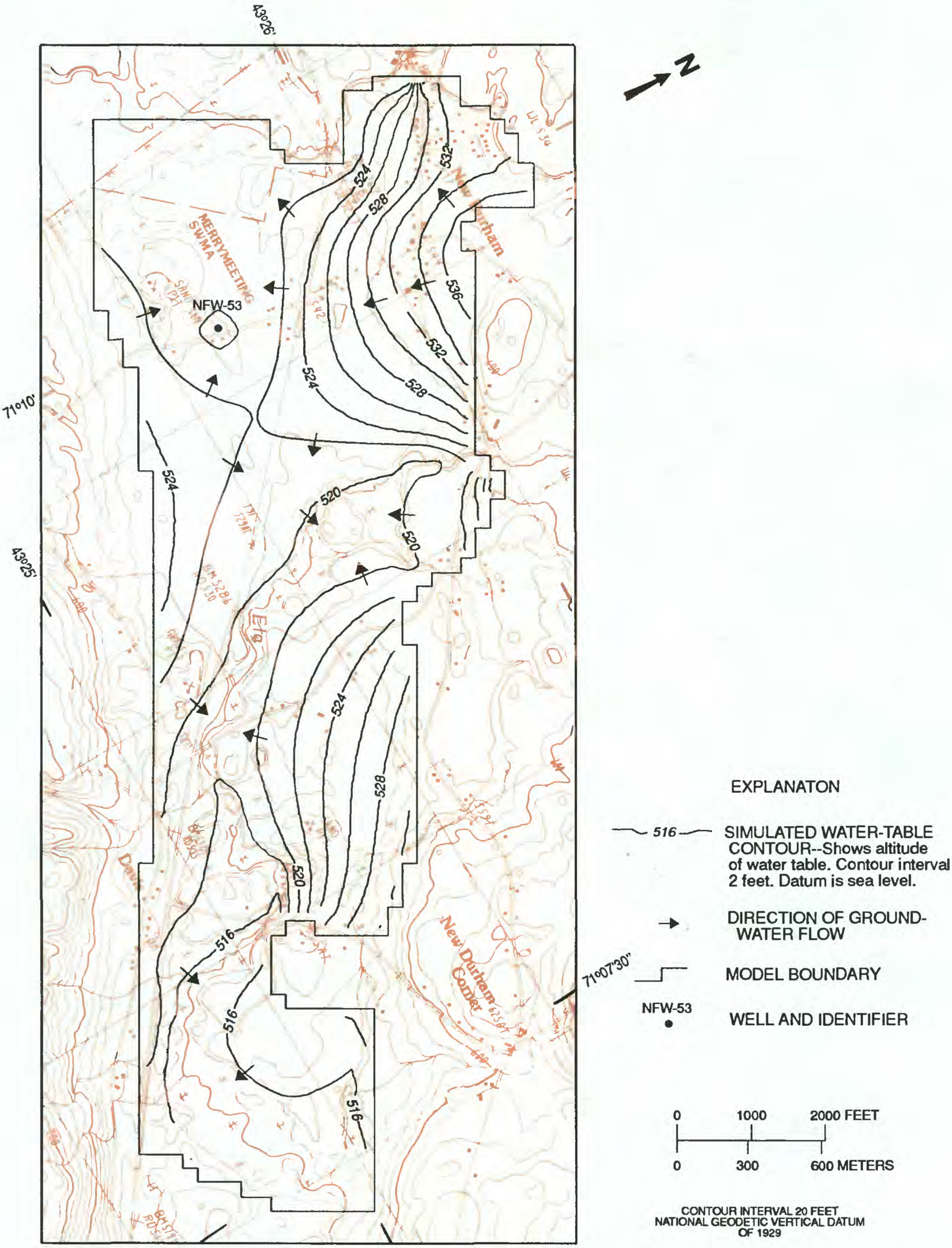
For the pumping rates listed in table 6, simulated drawdowns at cells containing the unpumped wells W-54, W-55, and W-56 ranged from 0.1 to 4.8 ft, less than 10 percent of aquifer thickness. Maximum drawdowns of 37.6 and 36.9 ft were observed at wells W-52 and W-53 when they were pumped simultaneously at 0.5 Mgal/d. When either well was pumped at 0.75 Mgal/d individual drawdowns were so large that the wells went dry. For this analysis, it was assumed a pumping rate that caused drawdowns to exceed 75 percent of total saturated thickness would be unacceptable.

Reduction in flow in the Ela and Merrymeeting Rivers that results from pumping is caused by some combination of induced infiltration plus capture of natural ground-water discharge before it reaches the rivers. Reduction of flow in the Merrymeeting River is caused entirely by capture of ground water before it



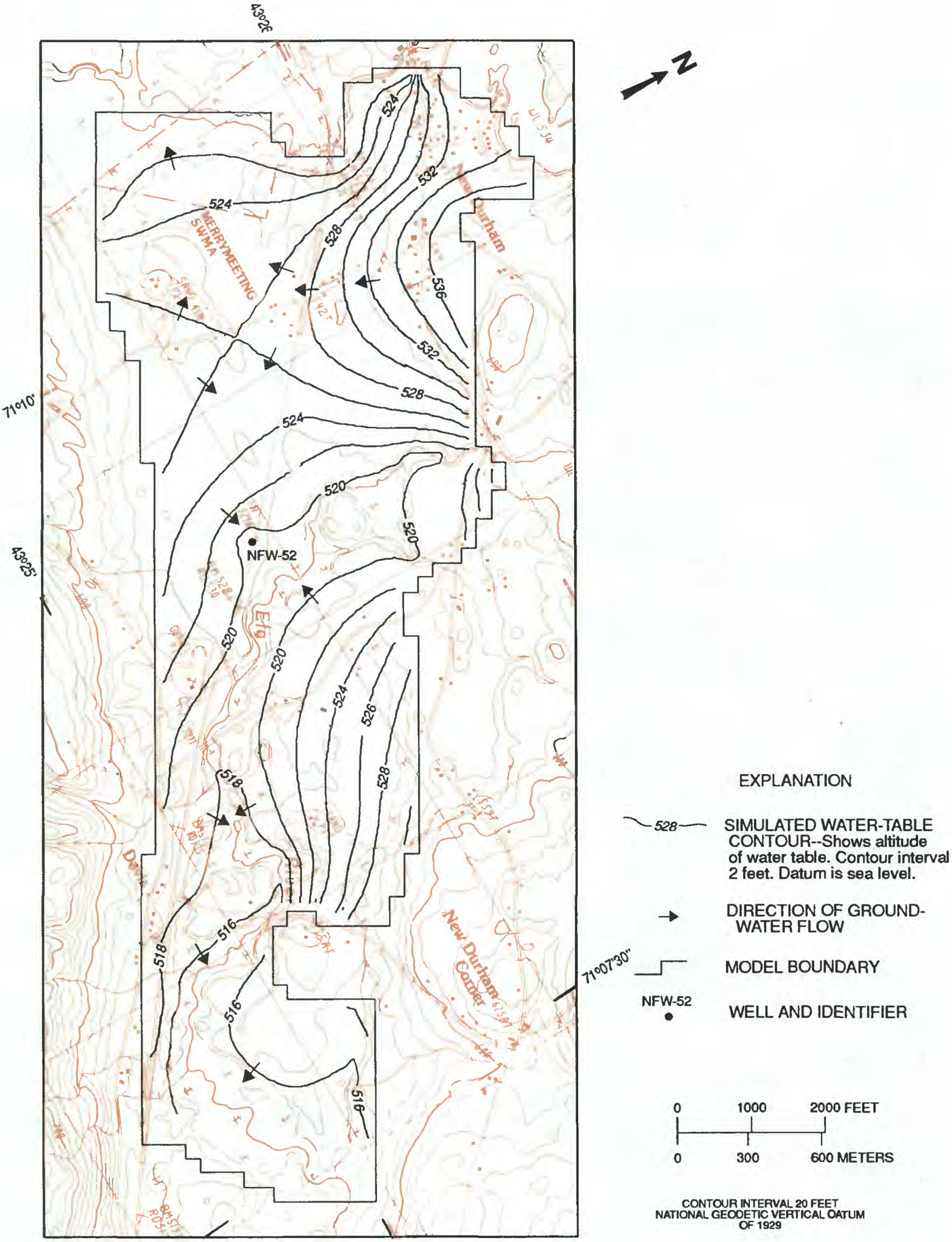
Base from U.S. Geological Survey topographic maps;
Alton, N.H., 1987. 1:24,000.

Figure 12.--Simulated water-table configuration in New Durham aquifer when well NFW-53 is pumped at 0.25 million gallons per day.



Base from U.S. Geological Survey topographic maps;
Alton, N.H., 1987. 1:24,000.

Figure 13.--Simulated water-table configuration in New Durham aquifer when well NFW-53 is pumped at 0.50 million gallons per day.



Base from U.S. Geological Survey topographic maps; Alton, N.H., 1987. 1:24,000.

Figure 14.--Simulated water-table configuration in New Durham aquifer when well NFW-52 is pumped at 0.25 million gallons per day.

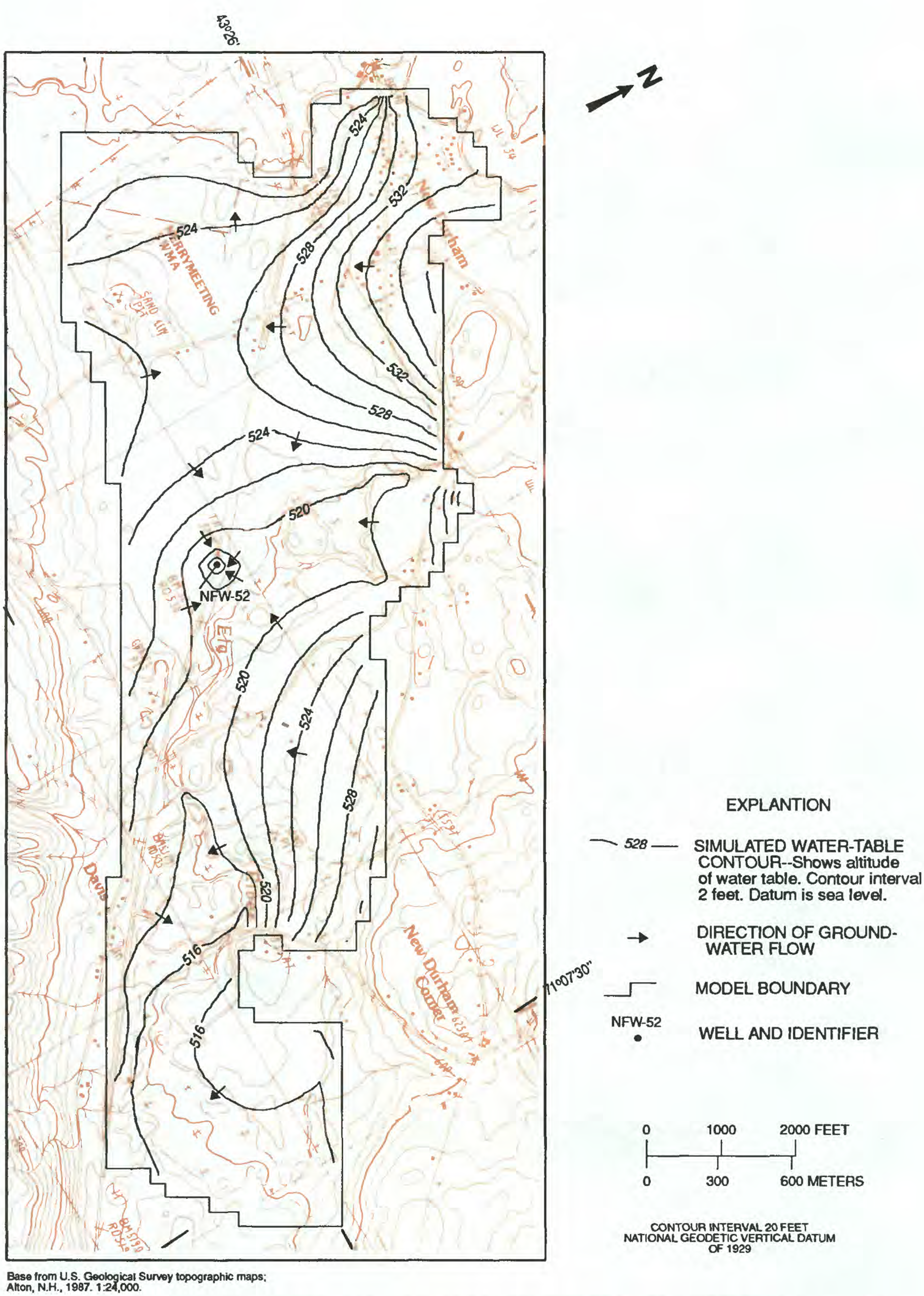


Figure 15.--Simulated water-table configuration in New Durham aquifer when well NFW-52 is pumped at 0.50 million gallons per day.

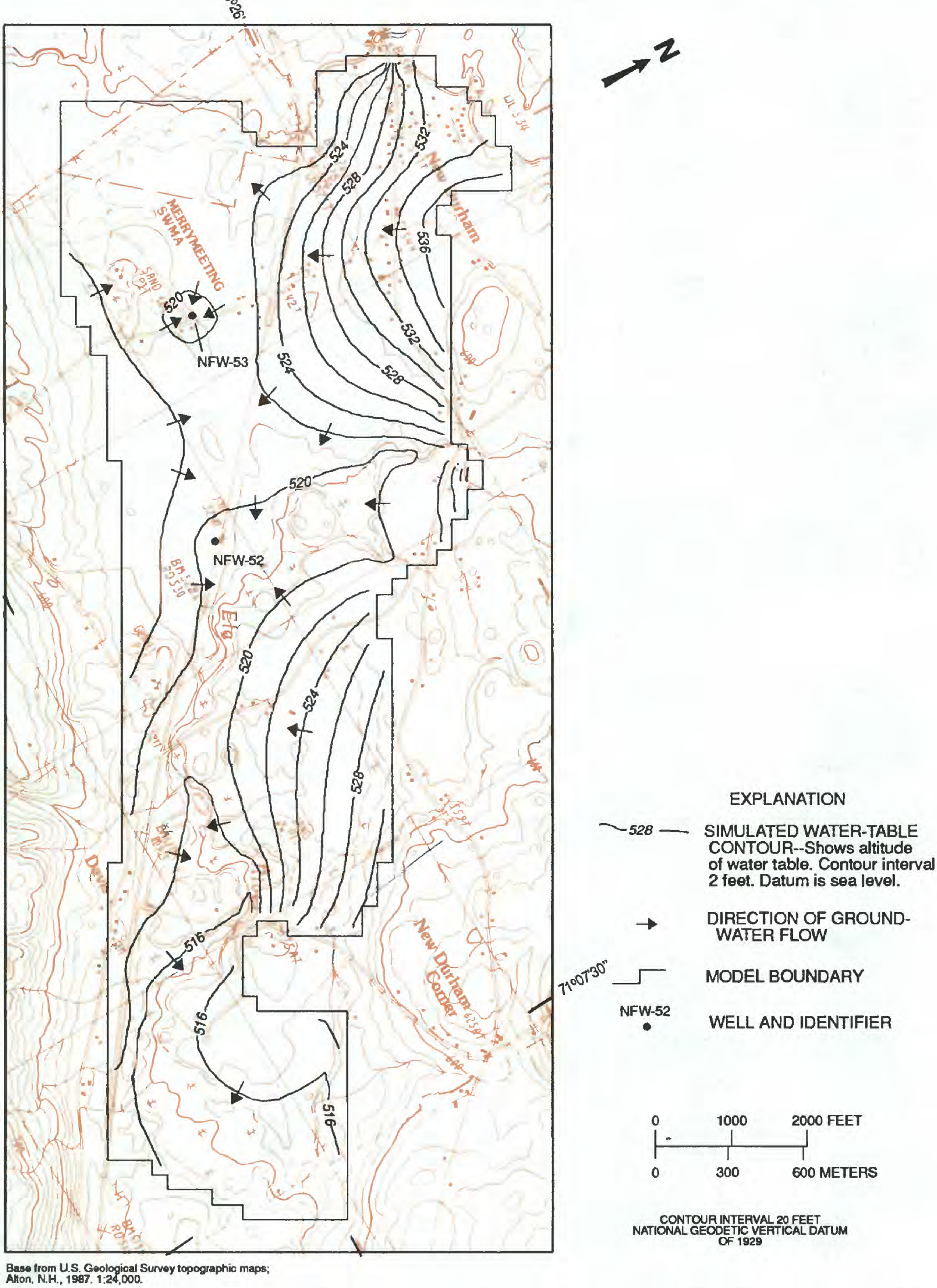


Figure 16.--Simulated water-table configuration in New Durham aquifer when wells NFW-52 and NFW-53 are pumped at 0.25 and 0.50 million gallons per day.

discharges to the river. For the Ela River, reduction in flow is caused by capture of ground water and induced infiltration. For this report, no distinction is made between captured ground-water flow and induced infiltration because only the total streamflow reduction is of importance.

Pumping at well W-52 has a much greater effect on flow in the Ela River than it does in the Merrymeeting River (table 6). When pumped alone at 0.25 or 0.50 Mgal/d, approximately 90 percent of the water from well W-52 comes from a reduction in flow of the Ela River. When well W-53 is pumped alone at 0.25 or 0.5 Mgal/d, approximately 60 percent of the water comes from reduction in flow of the Merrymeeting River and 40 percent comes from reduced flow in the Ela River (table 6).

When the wells are pumped simultaneously at 0.25 or 0.5 Mgal/d each, approximately two-thirds of the pumped water comes from the Ela River basin and one-third comes from the Merrymeeting River basin. The greatest effect on flow in either river occurs when both wells are pumped at 0.5 Mgal/d.

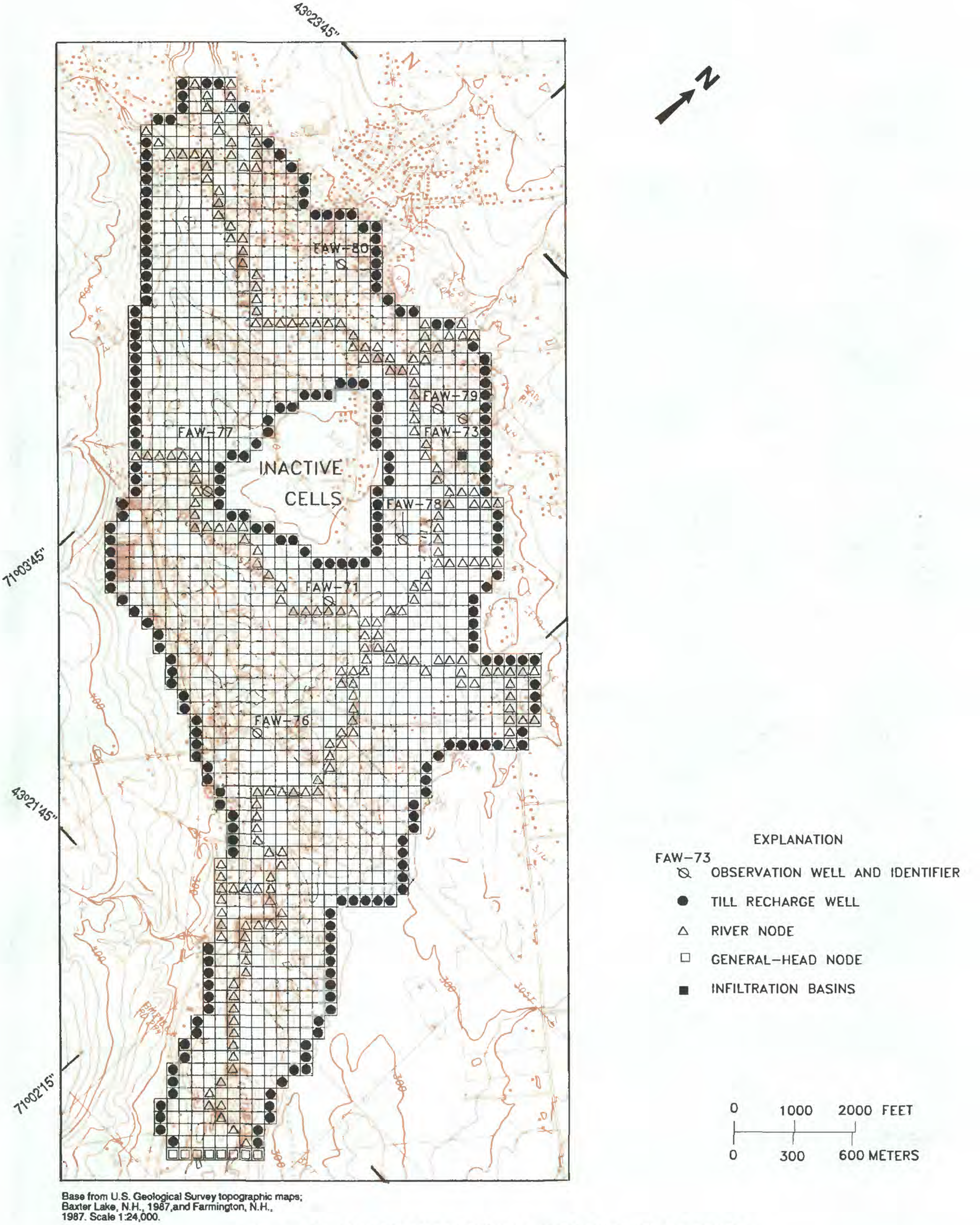
Flow in the Ela River downstream from the New Durham stratified-drift aquifer averaged 0.81 ft^3/s during September 1982 (Blackey and others, 1983). During this time, **flow duration** of the Oyster River, the nearest gaging station on an unregulated stream, was 86 percent. When wells W-52 and W-53 are pumped simultaneously at 0.5 Mgal/d each, flow in the Ela River would be reduced by 1.04 ft^3/s, which would exceed available streamflow during low flow periods. Furthermore, any time well W-52 is pumped at 0.5 Mgal/d, alone or with well W-53, model results indicate that streamflow will be reduced in the Ela River to the point where it may dry up at low flow. To minimize flow depletion on the Ela River and maintain a total withdrawal of 1.0 Mgal/d, it might be possible to increase pumping at W-53 and reduce pumping at W-52. Simulations involving different

Table 6.--*Effects of simulated steady-state pumping on water levels in the New Durham aquifer and on flow in the Ela and Merrymeeting Rivers*

[Mgal/d, million gallons per day; ft^3/s, cubic foot per second]

Total pumping (Mgal/d)	Drawdown at wells: (feet)					Reduction in flow in:	
	W-52	W-53	W-54	W-55	W-56	Ela River (ft^3/s)	Merrymeeting River (ft^3/s)
at W-52							
0.25	18.5	0.3	0.1	0.2	0.3	0.35	0.03
.50	37.2	.7	.3	.4	.6	.71	.06
at W-53							
.25	.3	17.8	.8	1.5	2.0	.17	.21
.50	.7	36.1	1.6	3.0	4.1	.34	.42
at W-52 and W-53 simultaneously							
[a].50	18.8	18.1	.9	1.7	2.3	.52	.24
[b]1.00	37.6	36.9	1.9	3.4	4.8	1.05	.48
[c].75	37.6	18.6	1.1	1.9	2.7	.88	.27
[d].75	19.2	36.5	1.8	3.2	4.4	.69	.45

[a] Both wells pumping 0.25 Mgal/d.
[b] Both wells pumping 0.50 Mgal/d.
[c] Pumpage of 0.50 Mgal/d at W-52, and 0.25 Mgal/d at W-53.
[d] Pumpage of 0.25 Mgal/d at W-52, and 0.50 Mgal/d at W-53.



Base from U.S. Geological Survey topographic maps; Baxter Lake, N.H., 1987, and Farmington, N.H., 1987. Scale 1:24,000.

Figure 17.--Model grid and cell types for the Farmington aquifer.

placement of wells would likely predict different sustained pumpage rates.

Flow Model Of The Farmington Aquifer

Model grid and boundaries

The finite-difference grid used to discretize the Farmington stratified-drift aquifer is shown in figure 17. The grid represents an area 18,000 ft long and 7,200 ft wide with 200-ft by 200-ft cells uniformly spaced. The model consists of 90 rows and 36 columns or 3,240 cells. Only cells that overlie the aquifer area are assumed to be "active" and are included in numerical calculations.

The aquifer is represented in the model by a single unconfined layer. The bottom boundary of the aquifer is the contact between the highly permeable stratified drift and the less permeable till and bedrock. This contact is simulated as a no-flow boundary because ground-water flow between the stratified drift and the till and bedrock is assumed to be negligible. The top boundary of the aquifer is the water table. This boundary is simulated as a constant-flux boundary which receives direct recharge from precipitation.

The aquifer is bounded by valley walls on its northeastern and southwestern sides and a valley headwall to the northwest. Edges of the grid that coincide with these natural boundaries are simulated as a constant-flux boundary. This constant flux represents lateral ground-water inflow from upland till and bedrock areas adjacent to the aquifer.

The southeastern side of the model is simulated as a general-head boundary. This type of boundary allows water to flow between the stratified-drift modeled aquifer within the simulated area and the stratified-drift aquifer outside the simulated area. The flow rate in or out of the modeled area is dependent on head differences between the aquifer within and outside the modeled area and on the hydraulic conductivity of the aquifer.

Aquifer hydraulic properties

The aquifer properties used in model construction include an initial water-table altitude, altitude of base of aquifer (till or bedrock surface), and hydraulic conductivity of the stratified-drift aquifer. A matrix consisting of data for each cell in the grid was constructed for these parameters. Known values for each parameter were assigned to the appropriate cells of the grid; unknown values among known points were determined by interpolation.

Water-table altitudes are required as a starting point for simulations. Measured ground-water-levels were used to provide values for corresponding cells in the model grid. Data for other cells were interpolated from known values and from seismic-refraction profiles.

The aquifer base used in the modeled area was determined from seismic-refraction profiles, test-borings completed for this study, and from existing well logs. A prominent bedrock outcrop is located in the center of the valley (pl. 6), and the greatest depth to bedrock is in the southeastern part of the valley.

Horizontal hydraulic conductivities used as initial input for the model were estimated from transmissivities and saturated thicknesses (pl. 6) and aquifer tests. The western side of the valley is composed of coarse-grained, ice-contact deposits with hydraulic conductivities that range from 200 to 400 ft/d. Continuous layers of boulders and cobbles are common in this area. The eastern side of the valley is composed of medium-grained, ice-contact deposits with hydraulic conductivities that range from 100 to 200 ft/d. Also on the eastern side of the valley are some areas of fine-grained outwash sands and silts, with horizontal hydraulic conductivities that range from 10 to 50 ft/d.

Recharge and discharge

Recharge includes lateral ground-water inflow from till and bedrock uplands, infiltrating precipitation, streamflow losses, and recharge of treated waste water. Discharges include ground-water flow to streams and pumped wells. Lateral inflow from till and bedrock uplands recharges the aquifer at the contact between the valley wall and the stratified drift. This recharge was simulated by placement of recharge wells at locations along the contact between till and stratified drift (fig. 17). Mean annual recharge from lateral inflow to the aquifer is assumed to be 1.45 $(ft^3/s)/mi^2$ of upland. This estimate for the model of the Farmington aquifer is based on the same rationale used for the New Durham aquifer. The actual amount of recharge applied at each boundary cell depends on the amount of upland area adjacent to the cell.

Recharge from precipitation directly on the aquifer was assumed to be half the average annual precipitation. For example, mean annual precipitation measured for 36 years in New Durham was 43 in. (National Oceanic and Atmospheric Administration, 1986). Half of this amount (21.5 in.) was then applied uniformly over the modeled area.

As in the model of the New Durham aquifer, streams were simulated as head-dependent-flux boundaries at cells overlying the stream channels (fig. 17). Width of the streams in the model of the Farmington aquifer ranged from 5 ft in small tributaries to 25 ft for parts of the Cocheco River. The average depth of water in the Cocheco River was assumed to be 2 ft and, in the tributaries, 1 ft. Estimated vertical hydraulic conductivity of the Cocheco River streambed was 1.5 ft/d and, in the tributaries, with cobbled streambeds, 3 ft/d. Surface-water stage at each of the stream cells was estimated from topographic contours.

Aquifer discharges include pumpage at the town of Farmington's primary production well (FAW-73) at the average rate of 0.25 Mgal/d. Treated wastewater (approximately 0.18 Mgal/d) artificially recharges the aquifer at infiltration basins 700 ft south of well FAW-73. The 0.07 Mgal/d difference between average pumpage and infiltration rates is assumed to be a consumptive loss. The production well (FAW-73) and the infiltration basins were simulated in the model.

Calibration

The calibration procedure for the Farmington model was essentially the same as that for the New Durham model discussed previously. Model-input data were adjusted to improve the match between model-calculated and field-measured values of hydraulic head and discharge from the aquifer. In October 1987, water levels at the five observations wells in the Farmington aquifer were at median values.

The water level at the nearest long-term observation well 430721071005001 (K.W. Toppin, U.S. Geological Survey, written commun., 1990), 15 mi south of Farmington, was 0.23 ft above the long-term average level in October 1987. The difference between the maximum and minimum measured water level at this well was 5 ft. Thus, water levels measured in October 1987 were assumed to represent long-term average conditions in the aquifer and were used to calibrate the Farmington model. Water levels reported for 35 wells, primarily dug wells inventoried in the early 1980s (Cotton, 1989; S.M. Lawlor and T.J. Mack, U.S. Geological Survey, written commun., 1990), were used to guide calibration at other locations. Measurement-point altitudes of these wells are less precisely known than the measurement-point altitudes of the observation wells in the Farmington aquifer, therefore, less

Table 7a.--*Relation of model-calculated and measured heads in the final calibrated steady-state model for the Farmington aquifer*

[All values in feet]

Well	Head: Measured	Head: Model-calculated	Absolute difference
FAW-76	250.1	250.8	0.7
FAW-77	263.6	264.7	1.1
FAW-78	253.2	255.7	2.5
FAW-79	259.3	260.7	1.4
FAW-80	267.2	269.2	2.0

Table 7b.--*Model-calculated water budget for steady-state conditions in the Farmington aquifer*

[ft^3/s, cubic foot per second]

Inflow: Source	Inflow: Rate (ft^3/s)	Outflow: Source	Outflow: Rate (ft^3/s)
Recharge from precipitation	3.85		
Lateral inflow from streams draining till and bedrock uplands	4.45		
Surface water leakage	.33	Seepage to streams	8.52
Infiltration of waste water	.28	Pumpage	.39
Total	8.91	Total	8.91

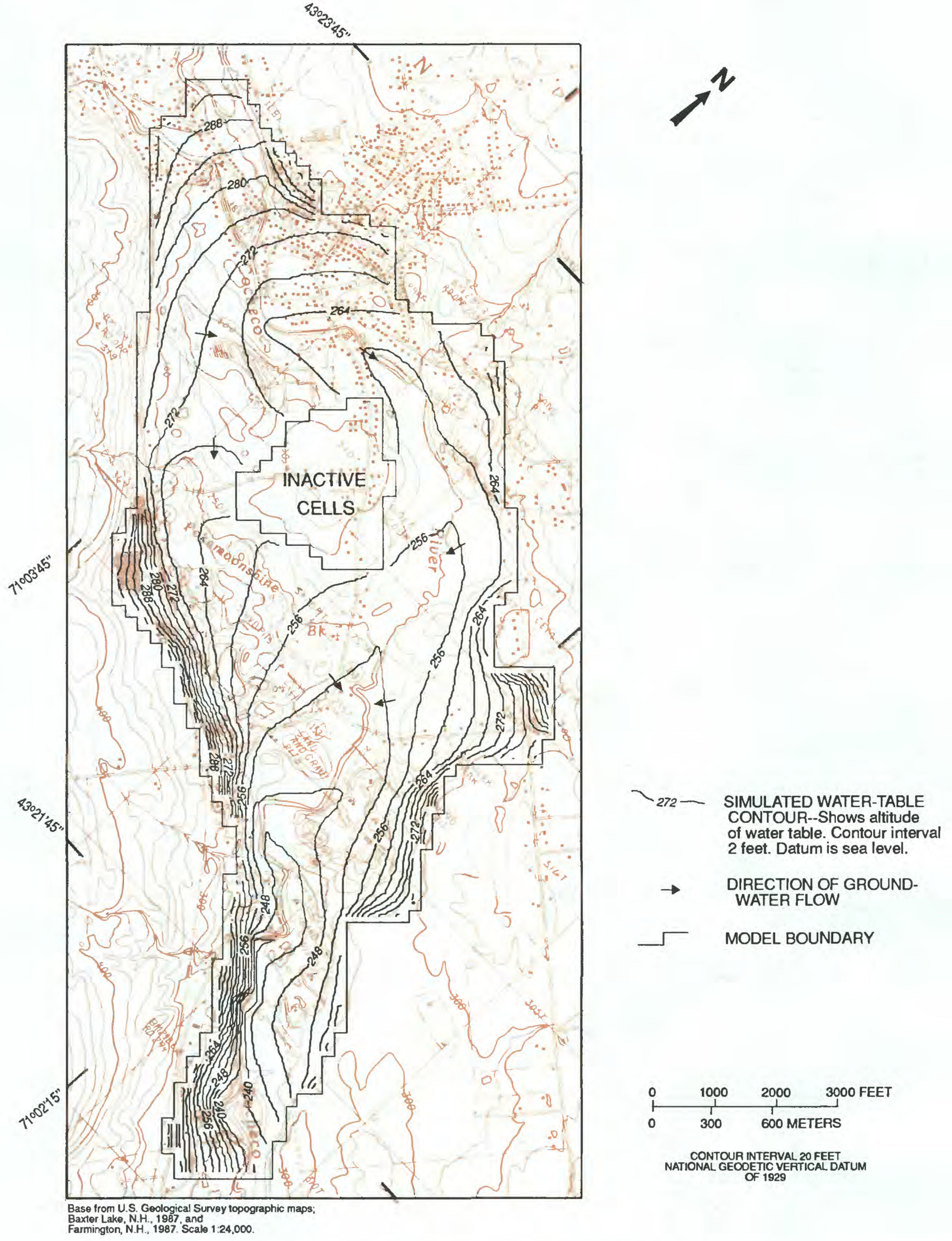


Figure 18.--Simulated water-table configuration in the Farmington statified-drift aquifer.

emphasis was placed on matching calculated heads to measured water levels in the 35 wells.

During steady-state calibration, aquifer recharge from infiltration of precipitation and lateral inflow from till and bedrock uplands were set at average rates (infiltration of precipitation was 21.5 in/yr and lateral inflow from uplands was 1.45 ft^3/mi^2). Aquifer and streambed hydraulic conductivities were varied to improve the match between model-calculated and measured heads and discharge. Pumpage of 0.25 Mgal/d at well FAW-73 and recharge of 0.18 Mgal/d at the infiltration basin were simulated in the model to represent average rates. The final average absolute difference between model-calculated and measured heads at five locations in the model area was 1.5 ft and individual absolute differences ranged from 0.7 to 2.5 ft (table 7a). The final steady-state water budget for the simulated area is presented in table 7b. The model-calculated water budget (8.9 ft^3/s) compares well with the annual recharge (9.1 ft^3/s) estimated by Cotton (1989). The simulated water table of the Farmington aquifer (fig. 18) compares favorably with measured ground-water altitudes (table 7a) and topographic surface-water altitudes determined from topographic maps.

The same considerations discussed for the New Durham model calibration apply to the Farmington model. Ideally, model calibration should consist of matching simulated to observed water levels from a large set of observation wells and matching simulated to observed ground- and surface-water interactions throughout the aquifer. Additionally, it is important to have long-term hydrographs of water levels in the model area. Hydrographs provide information on long-term water-level fluctuations and average conditions in the aquifer for calibration. Additional water level and seepage data would be needed throughout the aquifer to fully calibrate the model. The extensive drilling necessary for a large set of observation wells in the aquifer was beyond the scope of this basin-wide study; however, sufficient water-level information was collected with which to construct a simplified ground-water-flow model that can be used to estimate yield of the Farmington aquifer. For these reasons, the results of model simulations are to be used with caution.

Sensitivity analysis

A series of steady-state simulations were done to assess the sensitivity of the model to variations in

Table 8.--*Changes in model-calculated heads during sensitivity testing of the Farmington aquifer model*

[All values in feet]

Well	Changes in model-calculated hydraulic head with changes in: Hydraulic conductivity x2	Hydraulic conductivity x 1/2	Recharge by precipitation x2	Recharge by precipitation x 1/2	Lateral inflow x2	Lateral inflow x 3/4	Streambed hydraulic conductivity x2	Streambed hydraulic conductivity x 1/2
W-76	-0.9	1.7	2.1	-1.1	1.3	-0.3	-0.6	1.3
W-77	-.9	1.1	3.0	-1.7	2.7	-.9	-2.4	3.3
W-78	-.2	.5	.9	-.4	.6	-.2	-.5	.9
W-79	-.4	5.2	.7	-.5	3.3	-.9	-.3	.8
W-80	-1.2	3.4	1.9	-.9	3.2	-.8	-.7	1.6
Absolute average difference	.7	2.4	1.7	.9	2.2	.6	.9	1.6

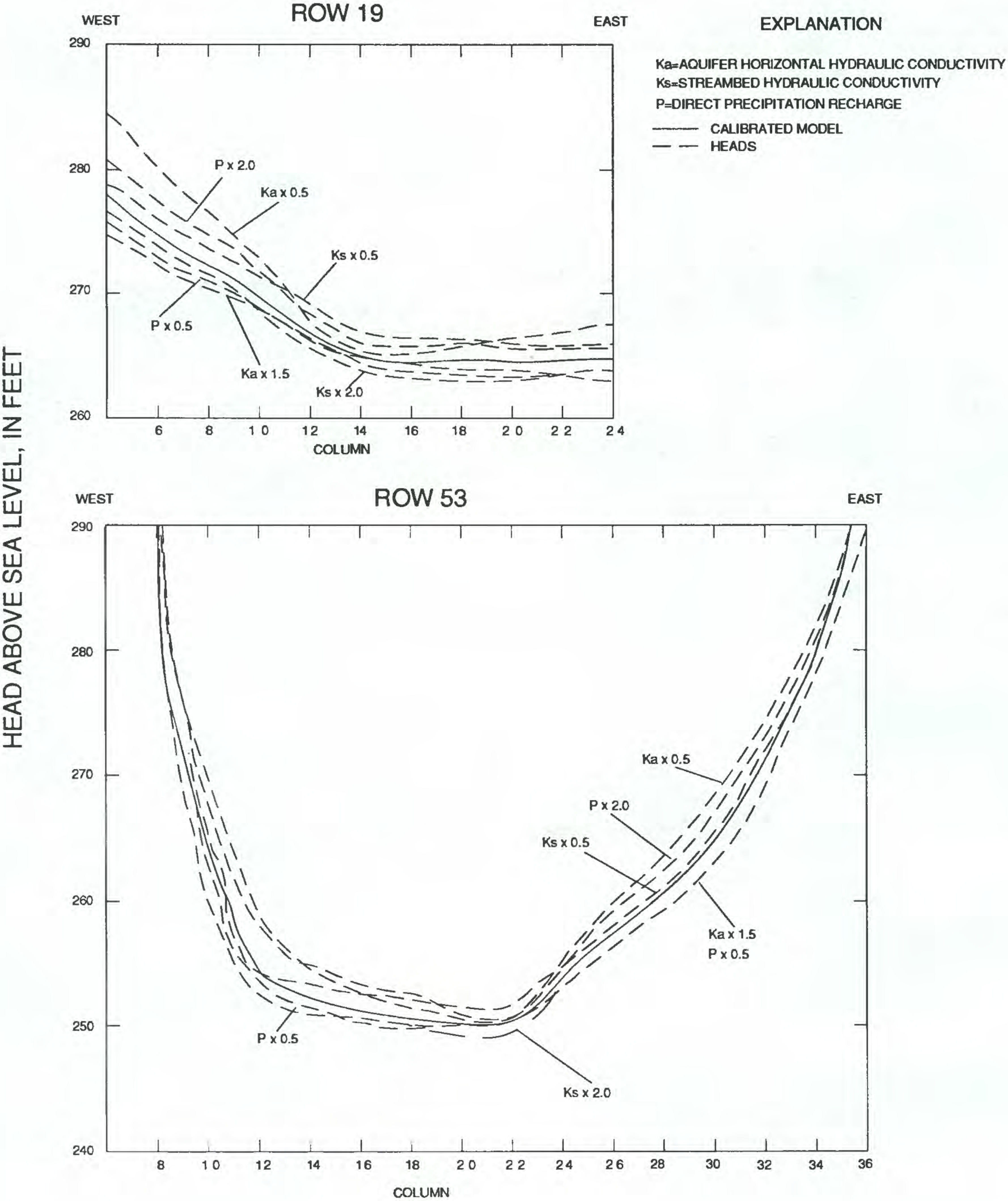


Figure 19.--Effects of varying model input on computed heads for the Farmington aquifer.

input data. Values used in the calibrated model for aquifer hydraulic conductivity, streambed hydraulic conductivity, and for recharge were first doubled and then halved during sensitivity testing. Use of a uniform horizontal hydraulic conductivity (150 ft/d) throughout the model also was tested. The difference between heads calculated by the model for steady-state conditions and for each sensitivity run, at five observation-well locations, are shown in table 8. The effect of varying model input data on computed heads is shown graphically for model rows 19 and 53 in figure 19.

Model-calculated heads are most sensitive to changes in aquifer horizontal hydraulic conductivity. When calibrated horizontal hydraulic conductivity was doubled, the model-calculated water-table altitudes decreased throughout the entire model area. At the observation-well locations, the decreases ranged from 0.2 to 1.2 ft and averaged 0.7 ft. When horizontal hydraulic conductivities in the model are halved, calculated water levels increase throughout the modeled area. At the well locations, the increase ranges from 0.5 to 5.2 ft and averages 2.4 ft. The use of a uniform 150 ft/d horizontal hydraulic conductivity resulted in slight decreases in water levels at the observation wells and caused some valley-wall boundary cells to go dry.

Variations in the model-simulated recharge also had significant effects on model-calculated heads. When the average recharge from precipitation was doubled, the water levels increased 3.0 ft at FAW-77 and from 0.7 to 2.1 ft at the other well locations. When the recharge rate was halved, the water table decreased from 0.4 to 1.7 ft below the steady-state altitude.

The sensitivity of the model to simulated variations in lateral ground-water inflow from uplands was similar to that of variations in precipitation recharge. The changes in recharge from lateral inflow affected the high and the low conductivity areas. When lateral inflow was doubled, water levels throughout the model area increased by an average of 2.2 ft and ranged from 0.6 to 3.3 ft at the five measurement locations. When lateral inflow was halved, many boundary cells on the western side of the model went dry. A 25-percent decrease in this recharge resulted in water levels dropping by an average of 0.6 ft.

Changes in vertical hydraulic conductivity of the streambed generally resulted in changes in water levels at the observation-well cells smaller than those

Table 9.--*Effects of simulated, steady-state pumping on water levels and streamflow in the Farmington aquifer*

[Mgal/d, million gallons per day; ft^3/s, cubic foot per second; --, no data]

Pumping rate (Mgal/d)	Drawdown at wells FAW-: (in feet) 71	73	76	77	78	79	80	Reduction in flow in the Cocheco River (ft^3/s)
FAW-73								
0.25	--	20.4	0.0	0.0	0.1	2.5	0.0	0.39
.50	--	(a)	.0	.0	.2	5.2	.0	.78
FAW-71								
.25	18.6	--	.4	.1	.0	.0	.0	.39
.50	37.5	--	.7	.1	.1	.0	.0	.78
.75	(a)	--	1.1	.2	.2	.0	.0	1.16
FAW-71 and FAW-73 pumped simultaneously, each at								
.25	18.6	20.4	.4	.1	.2	2.5	.0	.78

[a] Drawdown exceeds 75 percent of the aquifer saturated thickness.

caused by variations in other model parameters. When the vertical hydraulic conductivity was halved, water levels increased by an average of 1.6 ft. When streambed hydraulic conductivity was doubled, water levels decreased by an average of 0.9 ft at the five measurement locations. Changes were greatest at well FAW-77, approximately 50 ft from Pokamoonshine Brook.

Simulation of pumping at hypothetical wells

The calibrated ground-water-flow model was used to simulate the effects of two existing production wells (FAW-71 and FAW-73) on the aquifer and to assess potential aquifer yields (figs. 20-23). Well FAW-73 is the primary production well for the town of Farmington and FAW-71 is a production well that is no longer in use. Pumping rates of 0.25, 0.50, and 0.75 Mgal/d were simulated in steady-state runs at each well individually and in combination. Results of these analyses are summarized in table 9. As in the model of the New Durham aquifer drawdown at cells where pumping was simulated was adjusted to show actual drawdown in the well using the method of Trescott and others (1976).

Simulated drawdowns at observation wells FAW-76, FAW-77, FAW-78, and FAW-80 were less than 1.1 ft for all pumping simulations because they are distant from the pumped wells. Drawdowns in well FAW-79 ranged from 2.5 to 5.2 ft when well FAW-73 was pumped at 0.25 and 0.50 Mgal/d. Drawdowns in wells FAW-71 and FAW-73 were 18.6 and 20.4 ft when pumped individually, or simultaneously, at 0.25 Mgal/d. When well FAW-73 was pumped at 0.5 Mgal/d, drawdowns at the well exceeded 75 percent of the aquifer saturated thickness. A similar drawdown resulted when well FAW-71 was pumped at 0.75 Mgal/d (table 9). A pumpage rate of 0.5 Mgal/d produced 37.5 ft of drawdown at well FAW-71. Flow in Pokamoonshine Brook (pl. 3), adjacent to FAW-71, has been as low as 0.03 ft^3/s (Blackey and others, 1983); therefore, any significant pumpage at FAW-71 would probably capture all available streamflow during low flow periods.

In general, the simulated drawdowns due to pumping wells FAW-71 and FAW-73 are localized (figs. 20-23). When these wells are pumped simultaneously there is little interference between the two wells. Furthermore, the reduction in flow of the Cocheco River at a pumping rate of 0.5 Mgal/d is 0.78 ft^3/s. Low flow in the Cocheco River, was measured at 6.4 ft^3/s (Blackey and others, 1983). The streamflow reductions predicted with model simulations (table 9) would reduce the low flow by a maximum of 12 percent. Additional water could be pumped from the aquifer depending on the minimum flow requirement in the Cocheco River.

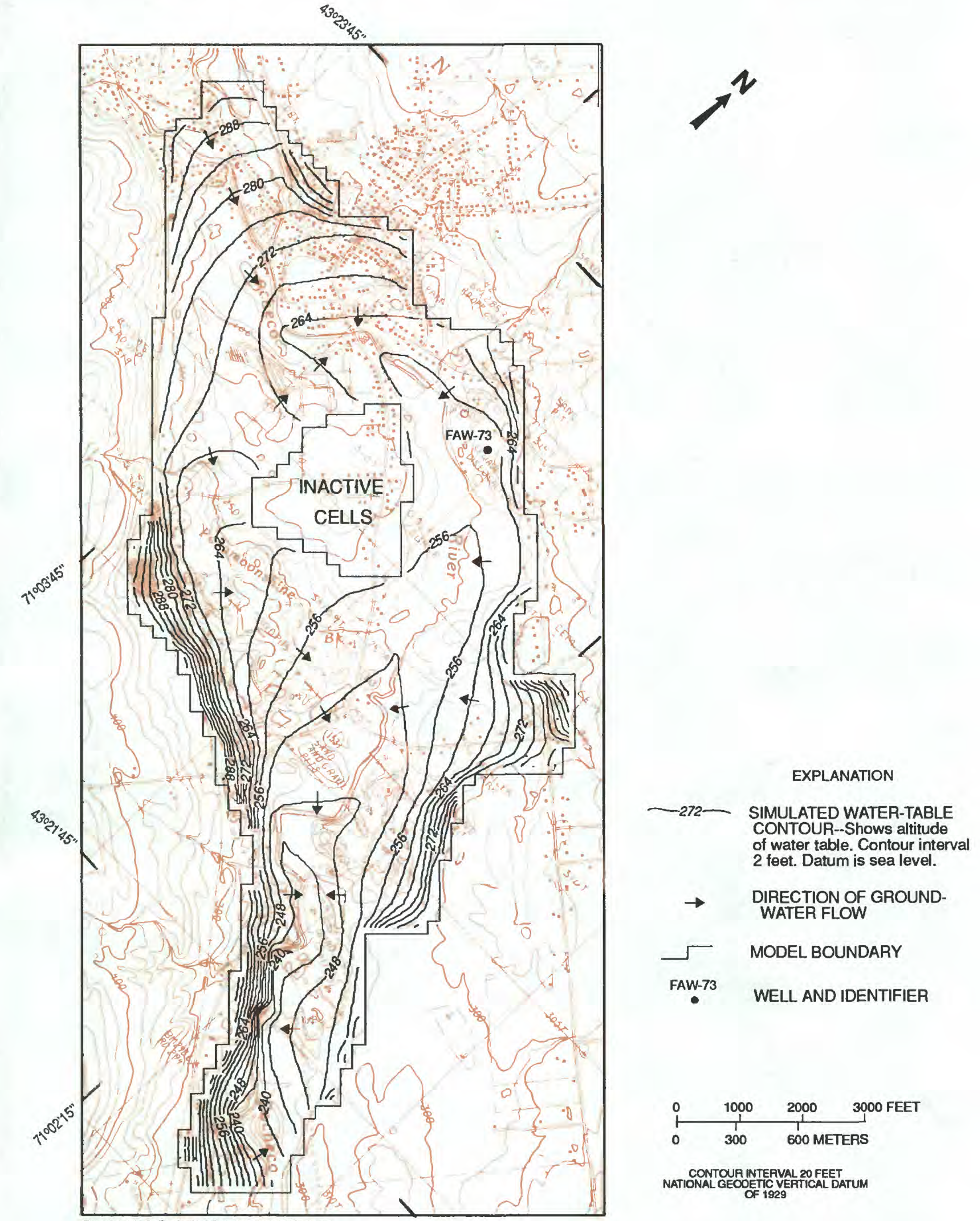
WATER QUALITY

The quality of ground water in stratified-drift aquifers was determined by analysis of samples collected from 24 wells. Sites of known ground-water contamination were avoided during sampling to ensure that water of background quality was sampled.

Areas where ground-water contamination was identified include three CERCLA "superfund" sites at the Somersworth Municipal Landfill in Somersworth (pl. 1), the Tibbets Road site in Barrington (pl. 2), and the Dover Municipal Landfill (pl. 1) in Dover (New Hampshire Water Supply and Pollution Control Commission, 1982). These sites are being studied by the USEPA. The Tibbets Road site (New Hampshire Water Supply and Pollution Control Division, 1985) is not in an area of stratified drift.

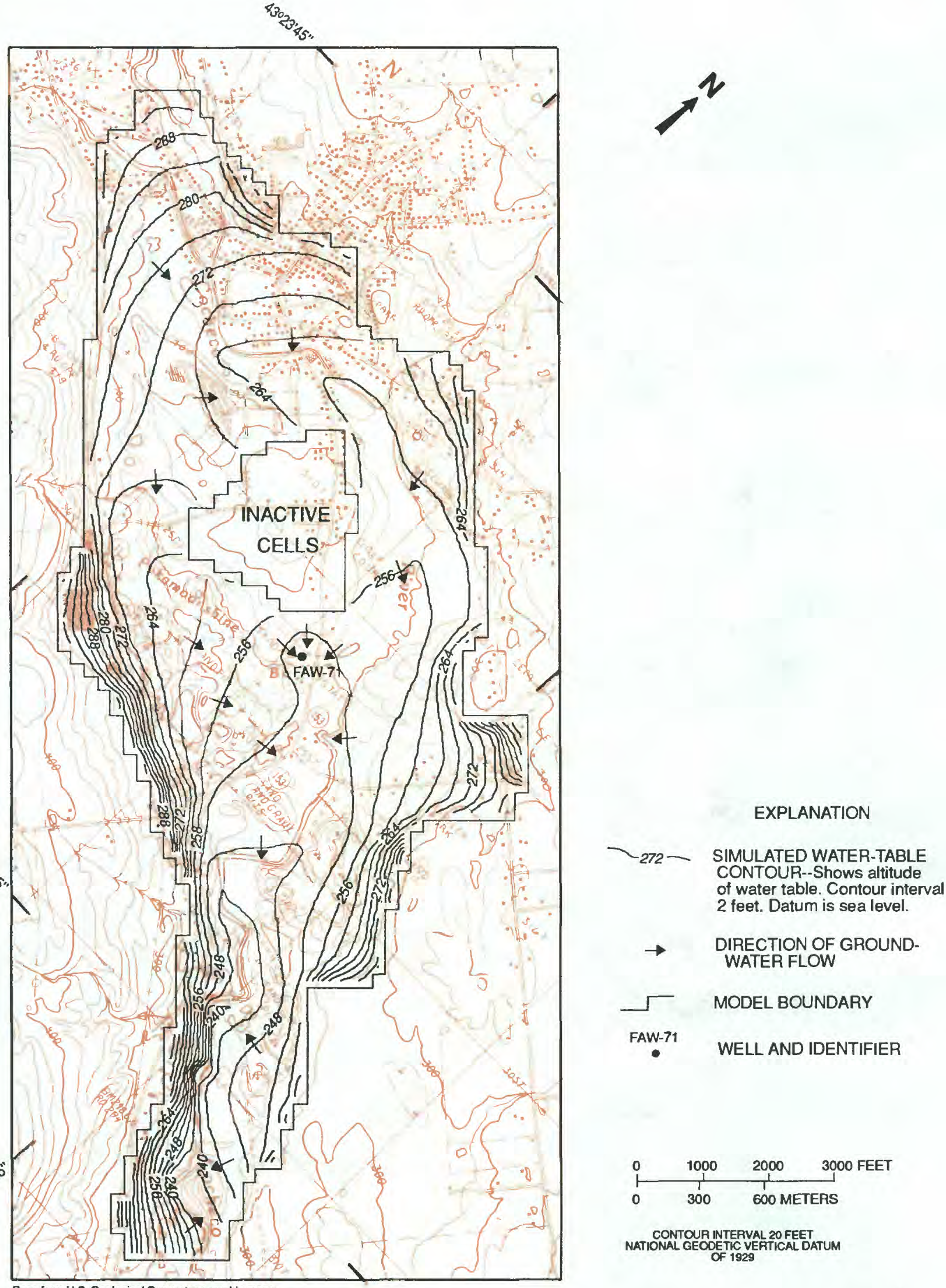
The methods outlined by Fishman and Friedman (1985) were used in the collection and the analysis of ground-water samples. Analyses were done at the USGS Central Laboratories in Arvada, Colo. All wells were developed with compressed air to remove drilling water, foreign materials or sediments, and to improve the hydraulic connection with the aquifer. Wells were allowed to stabilize for at least 1 month. Before sampling, each well was pumped to remove at least three casing volumes of water to ensure that the sample represented water from the aquifer. Municipal wells sampled (DJW-31, SKW-50, and SQW-8) are pumped almost continuously.

Chemical analyses are presented by Lawlor and Mack (U.S. Geological Survey, written commun., 1990). A statistical summary of the analyses is provided in table 10. In addition to the analyses, USEPA (1979) drinking-water regulations and recommended limits and New Hampshire Water Supply Engineering Bureau's (written commun., 1988) drinking-water recommendations are presented for comparison with the analyses. Table 10 also includes naturally occurring elements that have no recommended limits but whose concentrations are generally less than a few micro-



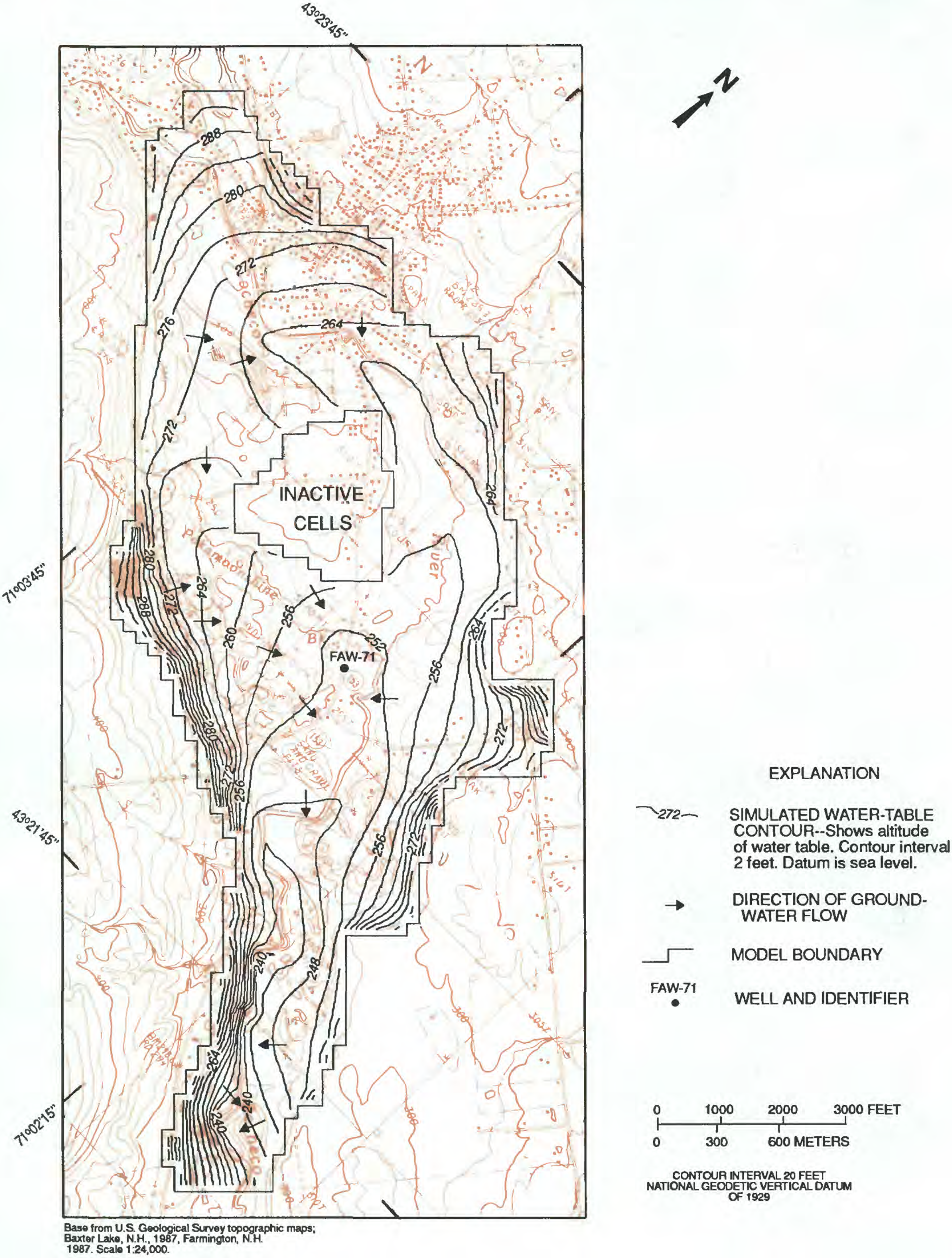
Base from U.S. Geological Survey topographic maps; Baxter Lake, N.H., 1987, and Farmington, N.H., 1987. Scale 1:24,000.

Figure 20.--Simulated water-table configuration in Farmington aquifer when well FAW-73 is pumped at 0.25 million gallons per day.



Base from U.S. Geological Survey topographic maps;
Baxter Lake, N.H., 1987, and Farmington, N.H.,
1987. Scale 1:24,000.

Figure 21.--Simulated water-table configuration in Farmington aquifer when well FAW-71 is pumped at 0.25 million gallons per day.



Base from U.S. Geological Survey topographic maps; Baxter Lake, N.H., 1987, Farmington, N.H. 1987. Scale 1:24,000.

Figure 22.--Simulated water-table configuration in Farmington aquifer when well FAW-71 is pumped at 0.50 million gallons per day.

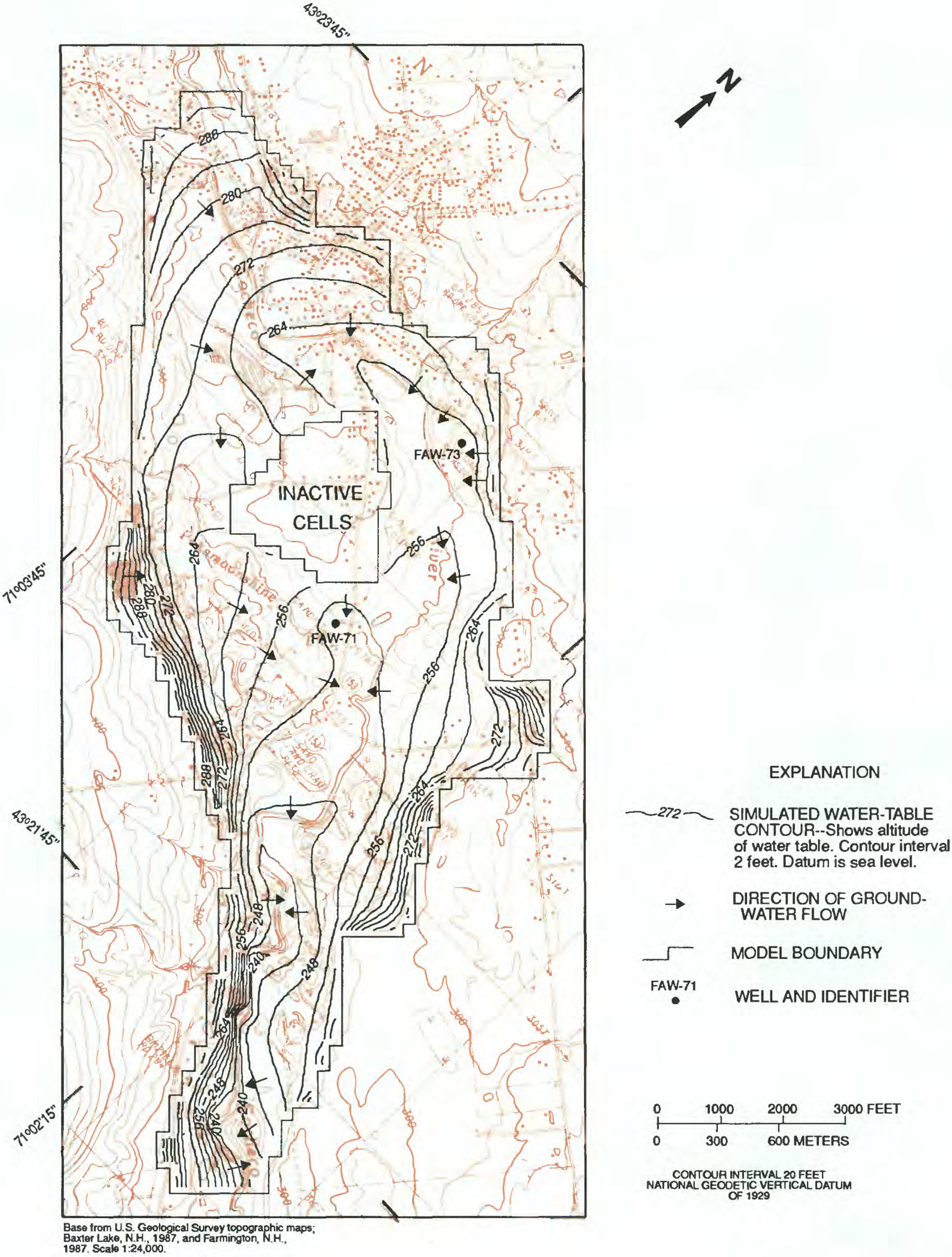


Figure 23.--Simulated water-table configuration in Farmington aquifer when wells FAW-73 and FAW-71 are pumped at 0.25 million gallons per day.

ERRATA SHEET

Table 10.--*Summary of results of water-quality-sample analyses*

[A "less than symbol" proceeds values below a detection limit. The routines of Helsel and Gilliom (1986) were used to compute statistics on data containing "less thans"; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degree Celsius; mg/L, milligram per liter; µg/L, microgram per liter; --, no standard (or statistics cannot be calculated because sample populations are too small)]

(Detection Limit) Constituent or property (or accuracy)	[1]SMCL	[2]MCL	Number of samples	Number below detection limit	Mean	Median	Standard deviation	Minimum	Maximum	First quartile	Third quartile
Specific conductance, field (1 µS/cm at 25 °C)	--	--	23	0	138	140	96	20	330	40	220
Temperature (0.1 degrees Celsius)	--	--	23	0	10.2	10.0	2.4	7.0	17.5	8.0	11.5
Dissolved Oxygen (0.00 mg/L as O_2)	--	--	23	0	5.6	5.2	4.0	.0	13.1	2.1	9.1
pH, field (0.01 standard units)	6.5-8.5	--	23	--	--	6.18	.47	5.26	7.14	5.84	6.53
Color (1 platinum-cobalt units)	15	--	23	0	9	2	21	1	98	1	3
Alkalinity, field (1 mg/L as $CaCO_3$)	--	--	23	0	20	11	23	3	106	8	29
Hardness, total (mg/L as $CaCO_3$)	--	--	23	0	32	22	30	6	120	11	45
Solids, sum of constituents, dissolved, residue on evaporation at 180 °C (mg/L)	500	--	23	0	90	80	58	25	235	34	125
Calcium, dissolved (0.1 mg/L as Ca)	--	--	23	0	9.1	6.0	7.9	1.7	31.0	3.3	11.0
Magnesium, dissolved (0.1 mg/L as Mg)	--	--	23	0	2.34	1.70	2.58	.38	11.00	.60	3.00
Chloride, dissolved (0.1 mg/L as Cl)	250	--	23	0	22.5	18.0	21.6	1.6	83	2.6	35.0
Sodium, dissolved (0.1 mg/L as Na)	--	--	23	0	13.0	11.0	11.6	1.8	41	3.0	18.0
Nitrogen, ammonia, dissolved (0.01 mg/L)	--	--	23	16	.02	--	.03	< .01	.13	--	--
Potassium, dissolved (0.1 mg/L as K)	--	--	23	0	1.7	1.3	1.1	.3	4.1	1.0	2.7
Sulfate, dissolved (0.1 mg/L as SO_4)	250	--	23	0	11.6	8.8	10.4	.3	38	4.9	14
Fluoride, dissolved (0.1 mg/L as F)	2	4	23	5	.1	.1	.1	<.1	.2	.10	.15
Carbon, organic, dissolved (0.1 mg/L as C)	--	--	23	0	1.1	.8	1.0	.4	5.6	.7	1.1
Silica, dissolved (0.1 mg/L as SiO_2)	--	--	23	0	14.3	12.0	5.8	7.1	26	9.2	20.0
Arsenic, dissolved (1 mg/L as As)	--	50	23	15	3	--	5	<1	20	--	--
Barium, dissolved (2 µg/L as Ba)	--	1,000 ([3]500)	23	3	7	7	4	<2	16	4	10
Beryllium, dissolved (0.5 µg/L as Be)	--	--	23	18	--	--	--	< .5	.9	--	--
Boron, dissolved (10 µg/L as B)	--	--	23	16	7	--	9	<10	40	--	--
Cadmium, dissolved (1 µg/L as Cd)	--	10 ([3]5)	23	21	--	--	--	<1	3	--	--
Chromium, dissolved (10 µg/L as Cr)	--	50 ([3]100)	23	20	--	--	--	<10	20	--	--

ERRATA SHEET

Table 10.--*Summary of results of water-quality-sample analyses*--Continued

(Detection Limit) Constituent or property (or accuracy)	[1]SMCL	[2]MCL	Number of samples	Number below detection limit	Mean	Median	Standard deviation	Minimum	Maximum	First quartile	Third quartile
Cobalt, dissolved (1 µg/L as Co)	--	--	23	13	1	1	2	<1	10	0.4	1.0
Copper, dissolved (1 mg/L as Cu)	1,000	--	23	11	4	1	10	<1	44	.3	1.5
Iron, dissolved (3 µg/L as Fe)	300	--	23	2	2,109	20	4,771	<3	19,000	6	2,050
Lead, dissolved (5 mg/L as Pb)	--	50 ([3]5)	23	22	--	--	--	<5	110	--	--
Manganese, dissolved (1 µg/L as Mn)	50	--	23	0	300	84	645	3	3,100	23	420
Molybdenum, dissolved (1 mg/L as Mo)	--	--	22	16	--	--	--	<1.0	3	--	--
Mercury, dissolved (0.1 µg/L as Hg)	--	2	23	22	--	--	--	< .1	.1	--	--
Nickel, dissolved (1 mg/L as Ni)	--	--	23	12	2	1	4	<1.0	15	--	--
Silver, dissolved (1 µg/L as Ag)	--	50	23	23	--	--	--	<1	<1	--	--
Strontium, dissolved (3 µg/L as Sr)	--	--	13	1	69	59	41	<3	1,140	34	100
Zinc, dissolved (3 µg/L as Zn)	5,000	--	23	8	4	3	3	<3	12	--	--
Antimony, dissolved (1 mg/L as Sb)	--	--	23	21	--	--	--	<1	2	<1.0	<1.0
Aluminum, dissolved (10 µg/L as Al)	50	--	23	14	38	5	134	<10	650	2	20
Selenium, dissolved (1 µg/L as Se)	--	10 ([3]5)	23	21	--	--	--	<1	<3	--	--

[1] Secondary maximum contaminant level, set by the U.S. Environmental Protection Agency (1988d). Equivalent to USEPA secondary drinking-water regulation.
[2] Maximum contaminant level, set by the U.S. Environmental Protection Agency (1988a).
[3] Proposed maximum contaminant level set by the U.S. Environmental Protection Agency (1989b).

grams per liter. Many of the constituents listed in table 10 were not detectable in samples at the limits shown. Where data sets contained values less than the detection limits, statistical measures were estimated by use of the methods developed by Helsel and Gilliom (1986) and are described as estimated mean or estimated median. With few exceptions, the quality of water is generally acceptable for most uses. At observation well RHW-63 volatile organic compounds (VOCs) were detected and a number of common and trace constituents were exceptionally high. This sample was not included in the statistical summary (table 10) because it does not represent background water quality.

Common and Trace Constituents

Specific conductance is a measure of water's electrical conductivity and is an indication of the concentration of ions in solution or of **dissolved solids**. High specific conductance is an indicator that the concentration of one or more ions in solution is high. For example, water in well RHW-63 had a chloride concentration of 790 mg/L and a specific conductance of 400 μS/cm. The range of specific conductance was from 20 to 330 μS/cm and the mean was 138 μS/cm. Dissolved solids ranged from 25 to 235 mg/L, and the mean was 90 mg/L, the maximum recommended limit for drinking water is 500 mg/L (U.S. Environmental Protection Agency, 1988a). The greatest concentrations for specific conductance and dissolved solids were at RHW-63, but were not included in the summary statistics.

The pH of water is a measure of the water's hydrogen-ion activity. Water having a pH of 7.0 is considered to be neutral. Water having a pH less than 7.0 is acidic and water having a pH greater than 7.0 is basic. The range of the pH of natural water is generally from 6.5 to 8.5 (Hem, 1985), the range recommended by the USEPA (1976). The range of pH of the samples collected for analysis was from 5.3 to 7.1, and the median was 6.2. Water having a pH in this range is weakly acidic, which is considered to be typical for ground water in southeastern New Hampshire (Cotton, 1989).

Alkalinity is defined by Hem (1970, p. 152) as "the capacity of a solution to neutralize acid". Practically all the alkalinity in most natural water can be attributed to carbonate and bicarbonate ions. The range of alkalinity was 3 to 106 mg/L (as calcium carbonate), and the median was 11 mg/L. Water with an alkalinity of 60 mg/L or less (as calcium carbonate) is considered to be soft; an alkalinity of 61 to 120 mg/L, moderately hard; and with an alkalinity of 121 and greater, hard. In terms of this hardness scale, one sample of water from well DJW-163 was moderately hard, and all the remaining samples were soft. Hard water makes washing with soap difficult but studies imply that hardness of drinking water may be beneficial (Hem, 1985) because of calcium and magnesium concentrations.

The predominate form of inorganic nitrogen in natural water is nitrate, from the oxidation of nitrogenous compounds. Excess nitrate in ground water can originate from fertilizer applications, leachate from sewage systems, or wastes from farm animals. Nitrate is weakly absorbed by transport through soils. Nitrogen also appears in ionic form in ammonia (NH_4^+). Nitrogen concentrations (in ammonia) ranged from 0.01 to 0.13 mg/L, and the estimated mean was 0.02 mg/L.

The secondary maximum contaminant level (SMCL) for sulfate (SO_4^{-2}) in drinking water is 250 mg/L (U.S. Environmental Protection Agency, 1988d). Oxidation of sulfide ores, gypsum, and anhydrite are natural sources of sulfate, but the minerals generally do not occur in stratified-drift aquifers. Sulfate is reduced by anaerobic bacteria to hydrogen sulfide (H_2S) gas, which can be detected by smell at concentrations of only a few tenths of a milligram per liter. The range of sulfate concentrations was 0.30 to 38.00 mg/L, and the median was 8.80 mg/L.

Iron and manganese concentrations above USEPA SMCLs for drinking water are common in ground water from the stratified-drift aquifers in New Hampshire. The SMCL for iron in drinking water is 300 mg/L and for manganese is 50 mg/L. The SMCLs for these constituents are based on aesthetic considerations because iron and manganese can impart an undesirable taste to drinking water and can stain plumbing fixtures. Iron concentrations greater than or equal to the SMCL were measured in 11 of the 23 samples, and manganese concentrations above the SMCL were measured in 14 of the samples. The maximum concentrations for iron and manganese were 19,000 and 3,100 mg/L; median concentrations were 20 and 84 mg/L.

Concentrations of sodium and chloride in ground water averaged 11 mg/L and 18 mg/L. In one sample, concentrations of chloride were above the SMCL of 250 mg/L and sodium concentrations in six samples were above the SMCL of 20 mg/L. Concentrations greater than this limit may be detrimental to people with heart, liver, or kidney ailments (Terry, 1974). Salt used to deice roads can be a source of elevated concentrations of sodium and chloride in ground water. Hall (1975) documented the effects of road-deicing salt on ground water in New Hampshire. Concentrations of sodium (510 mg/L) and chloride (790 mg/L) in only one sample (from RHW-63) exceeded the SMCLs for these two constituents.

The concentration of fluoride in ground water ranged from less than 0.1 to 0.2 mg/L, and the median concentration was 0.1 mg/L. Moderate concentrations of fluoride in drinking water may be beneficial to teeth. The USEPA maximum contaminant level (MCL) (U.S. Environmental Protection Agency, 1988a) for fluoride in drinking water is 4.0 mg/L.

Concentrations of other elements and trace elements (table 10) determined in analysis of ground-water samples were less than a few micrograms per liter, well below USEPA drinking-water regulations. Except for the water sample from well RHW-63, concentrations of barium (800 mg/L), zinc (110 mg/L), and aluminum (840 mg/L) exceeded USEPA drinking-water regulations.

Organic Constituents

Samples of water from wells drilled in 1987 were analyzed for the 36 VOCs listed in table 11. Three wells (DJW-31, SKW-50, and SQW-9) were not sampled for these organic compounds because they are municipal wells routinely sampled by the New Hampshire Water Supply and Pollution Control Division. Only six VOCs were detected in water from three of the wells that were sampled: RHW-63, RHW-64, and RHW-169. Water from well RHW-63, in Rochester, contained six VOCs: 1,1-dichloroethane (0.70 mg/L), 1,1-dichloroethylene (0.80 mg/L), 1,1,1-trichloroethane (2.8 mg/L), 1,2-dichlorobenzene (1.8 mg/L), 1,4 dichlorobenze (0.80 mg/L), and trichloroethylene (2.1 mg/L). The source of these compounds is unknown. Chloroform was the only organic constituent detected in water from wells RHW-64 (2.5 mg/L) and RHW-169 (2.6 mg/L).

SUMMARY AND CONCLUSION

Stratified-drift aquifers in the Bellamy, Cocheco, and Salmon Falls River basins of New Hampshire consist of sand and gravel deposited by glacial meltwater during deglaciation. Aquifers generally consist of valley fill, to the north and glacioestuarine deltas to the south.

Maximum saturated thickness of stratified-drift deposits in the northeastern and southeastern areas exceeds 100 ft. Saturated thickness of stratified-drift deposits in the western area is generally less than 20 ft. Annual water-level fluctuations, measured at 45 wells during 1986-88, were generally less than 5 ft.

Transmissivities of the stratified-drift aquifers range from less than 2,000 to greater than 10,000 ft^2/d. Transmissivities in the southern area are usually less than 2,000 ft^2/d because of a predominance of fine-grained marine silts and clays. Locally, transmissivities exceed 10,000 ft^2/d in glacioestuarine deltas. In many aquifers in the northern area, transmissivity exceeds 2,000 ft^2/d because of the coarse-grained texture of the valley-fill, ice-contact deposits and outwash.

Aquifer yields and the simulated response to pumping from hypothetical wells for the valley-fill, stratified-drift aquifers at New Durham and Farmington were estimated by use of a finite-difference ground-water-flow model. The New Durham aquifer is as great as 100 ft thick, whereas the Farmington aquifer is more areally extensive but thinner. Yield of the New Durham aquifer was estimated by ground-water-flow simulation to be approximately 0.50 Mgal/d from a combination of two hypothetical production wells. Simulations involving different placement or number of wells would likely predict different maximum sustained pumping rates. Available data allow for calibration of only a simple ground-water-flow model of the New Durham aquifer; therefore, model results should be used with caution. Flow in the Ela River, a tributary to the Cocheco River, and the Merrymeeting River in the Winnipesaukee River drainage basin would be affected by pumping in the New Durham aquifer.

Yield of the Farmington aquifer was estimated by ground-water-flow simulation to be less than 0.5 Mgal/d on the basis of simulated pumpage of two existing wells. Simulations involving different placement or number of wells would likely predict different maximum sustained pumping rates. Available data allow for calibration of only a simple ground-water-flow model of the Farmington aquifer; therefore, results of model simulations are to be used with caution. A simulated pumping rate of slightly more than 0.25 Mgal/d at the location of a municipal well (FAW-

Table 11.-- *Volatile organic compounds in water samples from 21 wells in southeastern New Hampshire, 1987*
[All measurments in microgram per liter (µg/L); --, no standard (or statistics cannot be calculated because sample populations are too small)]

Constituent	[1]SMCL	[2]MCL	Number of samples	Detection limit	Number of detections	Maximum
Dichlorobromomethane, total	--	--	21	0.2	0	--
Carbon Tetrachloride, total	--	[4]5	21	.2	0	--
1,2-Dichloroethane, total	--	--	21	.2	0	--
Bromoform, total	--	--	21	.2	0	--
Chlorodibromomethane, total	--	--	21	.2	0	--
Chloroform, total	--	--	21	.2	2	2.6
Toluene	[3]40	[4]2,000	21	.2	0	--
Benzene, total	--	[4]5	21	.2	0	--
Chlorobenzene, total	--	--	21	.2	0	--
Chloroethane, total	--	--	21	.2	0	--
Ethylbenzene, total	[3]30	[4]700	21	.2	0	--
Methylbromide, total	--	--	21	.2	0	--
Methylchloride, total	--	--	21	.2	0	--
Methylene chloride, total	--	--	21	.2	0	--
Tetrachloroethylene, total	--	[4]5	21	.2	0	--
Trichloroflouromethane, total	--	--	21	.2	0	--
1,1-Dichloroethane, total	--	--	21	.2	1	.70
1,1-Dichloroethylene, total	--	[4]7	21	.2	1	.80
1,1,1-Trichloroethane, total	--	[4]200	21	.2	1	2.8
1,1,2-Trichloroethane, total	--	--	21	.2	0	--
1,1,2,2 Tetrachloroethane, total	--	--	21	.2	0	--
1,2-Dichlorobenzene, total	--	--	21	.2	1	1.8
1,2-Dichloropropane, total	--	[4]5	21	.2	0	--
1,2-Transdichloroethene, total	--	--	21	.2	0	--
1,3-Dichloropropene, total	--	--	21	.2	0	--
1,3-Dichlorobenzene, total	--	--	21	.2	0	--
1,4-Dichlorobenzene, total	--	--	21	.2	0	.80
2-Chloroethylvinylether, total	--	--	21	.2	0	--
Dichlorodifluoromethane, total	--	--	21	.2	0	--
Trans-1,3-dichloropropene, total	--	--	21	.2	0	--
Cis-1,3-dichloropropene, total	--	--	21	.2	0	--
1,2-Dibromoethylene, total	--	--	21	.2	0	--
Vinylchloride, total	--	[4]2	21	.2	0	--
Trichloroethylene, total	--	[4]5	21	.2	1	2.1
Styrene, total	--	[4]5	21	.2	0	--
Xylene, total	[3]20	[4]10,000	21	.2	0	--

[1] Secondary maximum contaminant level, set by the U.S. Environmental Protection Agency (1988d). Equivalent to USEPA secondary drinking-water regulation.

[2] Maximum contaminant level, set by the U.S. Environmental Protection Agency (1988a).

[3] Proposed secondary concentrations set by the U.S. Environmental Protection Agency (1989b).

[4] Proposed maximum contaminant level set by the U.S. Environmental Protection Agency (1989b).

73) was estimated to be the maximum sustained yield at that location. A simulated pumping rate of 0.25 Mgal/d at the location of a discontinued municipal well (FAW-71) may dry up Pokamoonshine Brook during low flow. Additional water could possibly be obtained from the aquifer depending upon minimum streamflow requirements in the Cocheco River and Pokamoonshine Brook.

With three exceptions, water from 21 observation wells and 3 municipal wells in the stratified-drift aquifers in the Bellamy, Cocheco, and Salmon Falls River basins is generally suitable for drinking use. At one well (RHW-63), six VOCs were detected, and concentrations of sodium, chloride, zinc, beryllium, and aluminum exceeded USEPA drinking-water regulations. At two other sites, the VOC chloroform was detected.

Alkalinity, pH, nitrate, and sulfate were less than USEPA drinking-water regulations. Concentrations of iron in 11 of the 24 samples collected were equal to or greater than the USEPA SMCL, and concentrations of manganese exceeded the SMCL (U.S. Environmental Protection Agency, 1988d) in 14 samples. Concentrations of chloride in one sample exceeded the SMCL of 250 mg/L, and concentrations of sodium in six samples exceeded the SMCL of 20 mg/L. The median fluoride concentration of 0.1 mg/L was less than the MCL. Concentrations of other trace elements included in the analysis were generally below USEPA drinking-water regulations.

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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. Where water only partly fills an aquifer, the upper surface of the saturated zone is free to rise and decline (Heath, 1983).

Aquifer boundary.--A feature that defines the extent of an aquifer.

Aquifer yield.--The maximum rate of withdrawal that can be sustained without causing an unacceptable decline in the hydraulic head in the aquifer or depletion of streamflow.

Bedrock.--Solid rock, locally called "ledge," that forms the earth's crust. The rock may be exposed at the surface but more commonly is buried beneath a few inches to more than 100 feet of unconsolidated deposits.

Confined Aquifer.--An aquifer saturated with water and bounded above and below by material having a distinctly lower hydraulic conductivity than the aquifer itself.

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

Cubic foot per second (ft^3/s).--A unit expressing rate of discharge. One cubic ft per second is equal to the discharge of a stream 1 foot wide and 1 ft deep flowing at an average velocity of 1 foot per second.

Cubic foot per second per square mile [$(ft^3/s)/mi^2$].--A unit expressing average number of cubic feet of water flowing per second from each square mile of area drained.

Deposit.--Earth material that has accumulated by some natural process.

Dissolved solids.--The residue from a clear sample of water after evaporation and drying for 1 hour at 180 degrees Celsius; 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, where water accumulates and ultimately flows to some point on a stream channel, lake, reservoir, or other body of water.

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 water level during pumping.

Drumlin.--A low, smoothly rounded, elongated oval shaped hill of glacial till, built under the margin of glacial ice and shaped by its flow; its long axis is parallel to the direction of movement of the ice.

Esker.--A long ridge of sand and gravel that was deposited by water flowing in tunnels within or beneath glacial ice.

First quartile.--For a set of measurements arranged in order of magnitude, the value where 25 percent of the measurements are lower in magnitude than that value and 75 percent are higher.

Flow duration, of a stream.--The percentage of time during which specified daily discharges are equaled or exceeded within a given time period.

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

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

Ground water.--Water beneath the water table in soils or geologic formations that are fully saturated.

Ground-water discharge.--The discharge of water from the saturated zone by (1) natural processes such as ground-water seepage into stream channels 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 there is no ground-water flow.

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

Ground-water recharge.--Water that is added to the saturated zone of an aquifer.

Ground Water Site Inventory (GWSI).--A computerized file maintained by the Geological Survey that contains information about wells and springs collected throughout the United States.

Hydraulic conductivity (K).--A measure of the ability of a porous medium to transmit a fluid that can be expressed in unit length per unit time. A material has a hydraulic conductivity of 1 foot/day if it will transmit in 1 day, 1 cubic foot of water at the prevailing kinematic viscosity through a 1-foot-square cross section of aquifer, measured at right angles to the direction of flow, under a hydraulic gradient, of 1-foot change in head over 1-foot 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.--Stratified drift deposited in contact with melting glacial ice. Landforms include eskers, kames, kame terraces, and grounding-line deltas.

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

Kame.--A low mound, knob, hummock or short irregular ridge composed of stratified sand and gravel deposited by glacial meltwater; the precise mode of formation is uncertain.

Kame terrace.--A terrace-like ridge consisting of stratified sand and gravel formed as a glaciofluvial deposit between a melting glacier or stagnant ice lobe and a higher valley wall, and left standing after the disappearance of the ice.

Marine limit.--The former limit of the sea. The highest shoreline during a period of late-glacial submergence.

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

Median.--The middle value of a set of measurements, that are ordered from lowest to highest, 50 percent of the measurements are lower than the median and 50 percent are higher.

Micrograms per liter (mg/L).--A unit expressing the concentration of chemical constituents in solution as the mass (microgram) of a constituent per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter.

Milligrams per liter (mg/L).--A unit for expressing the concentration of chemical constituents in solution as the mass (in milligrams) of a constituent per unit volume (in liters) of water.

Outwash.--Stratified deposits chiefly of sand and gravel removed or "washed out" from a glacier by meltwater streams and deposited beyond the margin of a glacier, usually occurring in flat or gently sloping outwash plains.

Outwash deltas.--Deltas formed beyond the margin of the glacier where glacial meltwater entered a water body.

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.

Phi grade scale.--A logarithmic transformation of the Wentworth grade scale based on the negative logarithm to the base 2 of the particle diameter, in millimeters.

Porosity.--The property of a rock or unconsolidated deposit that is a measure of the size and number of internal 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 that is intrinsic to the sediment or rock matrix. See secondary porosity.

Runoff.--That part of the precipitation that appears in streams. It is the same as streamflow unaffected by artificial diversions, storage, or other human activites in or on the stream channels.

Saturated thickness (of stratified drift).--Thickness of stratified drift extending down from the water table to the till or bedrock surface.

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

Specific yield.--The ratio of the volume of water that a rock or soil will yield, by gravity drainage after being saturated, to the total volume of the rock or soil.

Steady-state.--When at any point in a flow field the magnitude and the direction of the flow velocity is constant with time.

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.--Sorted and layered unconsolidated material deposited in meltwater streams flowing from glaciers or settled from suspension in quiet-water bodies fed by meltwater streams.

Surficial geology.--The study of or distribution of unconsolidated deposits at or near the land surface.

Third quartile.--For a set of measurements arranged in order of magnitude, the value where 75 percent of the measurements are lower in magnitude than that value and 25 percent are higher.

Till.--A predominantly nonsorted, nonstratified sediment deposited directly by a glacier and comprised 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).--An aquifer only partly filled with water. In such aquifers the water is unconfined in that the water table or upper surface of the saturated zone is at atmospheric pressure and is free to rise and fall.

Unconsolidated deposit.--A sediment in which the particles are not firmly cemented together, such as sand in contrast to sandstone.

Unsaturated zone.--The zone between the water table and the land surface in which the open spaces are not completely filled with water.

Water table.--The upper surface of the saturated zone. Water at the water table is at atmospheric pressure.

APPENDIX

Figure A1-A24. Geologic sections interpreted from seismic-refraction data for:

1. Dover a-a', b-b', and c-c'.
2. Dover d-d', e-e', and Madbury f-f'.
3. Barrington g-g', h-h', and i-i'.
4. Barrington j-j', k-k', and l-l'.
5. Barrington m-m', n-n', and Rochester o-o'.
6. Rochester p-p', q-q', and r-r'.
7. Rochester s-s', t-t', and u-u'.
8. Rochester v-v', w-w', and x-x'.
9. Rochester y-y', z-z', and aa-aa'.
10. Rochester bb-bb', cc-cc', and dd-dd'.
11. Rochester ee-ee', ff-ff', and gg-gg'.
12. Rochester hh-hh', Farmington ii-ii', and Strafford jj-jj'.
13. Strafford kk-kk', Rochester ll-ll', and mm-mm'.
14. Farmington nn-nn', oo-oo', and pp-pp'.
15. Farmington qq-qq', rr-rr', and New Durham ss-ss'.
16. New Durham tt-tt', uu-uu', and vv-vv'.
17. New Durham ww-ww', xx-xx', and yy-yy'.
18. New Durham zz-zz', aaa-aaa', and bbb-bbb'.
19. New Durham ccc-ccc', Middleton ddd-ddd', and Milton eee-eee'.
20. Milton fff-fff', ggg-ggg', and hhh-hhh'.
21. Milton iii-iii', jjj-jjj', and kkk-kkk'.
22. Milton lll-lll', Brookfield mmm-mmm', and Wakefield nnn-nnn'.
23. Wakefield ooo-ooo', ppp-ppp', and qqq-qqq'.
24. Wakefield rrr-rrr' and sss-sss'.

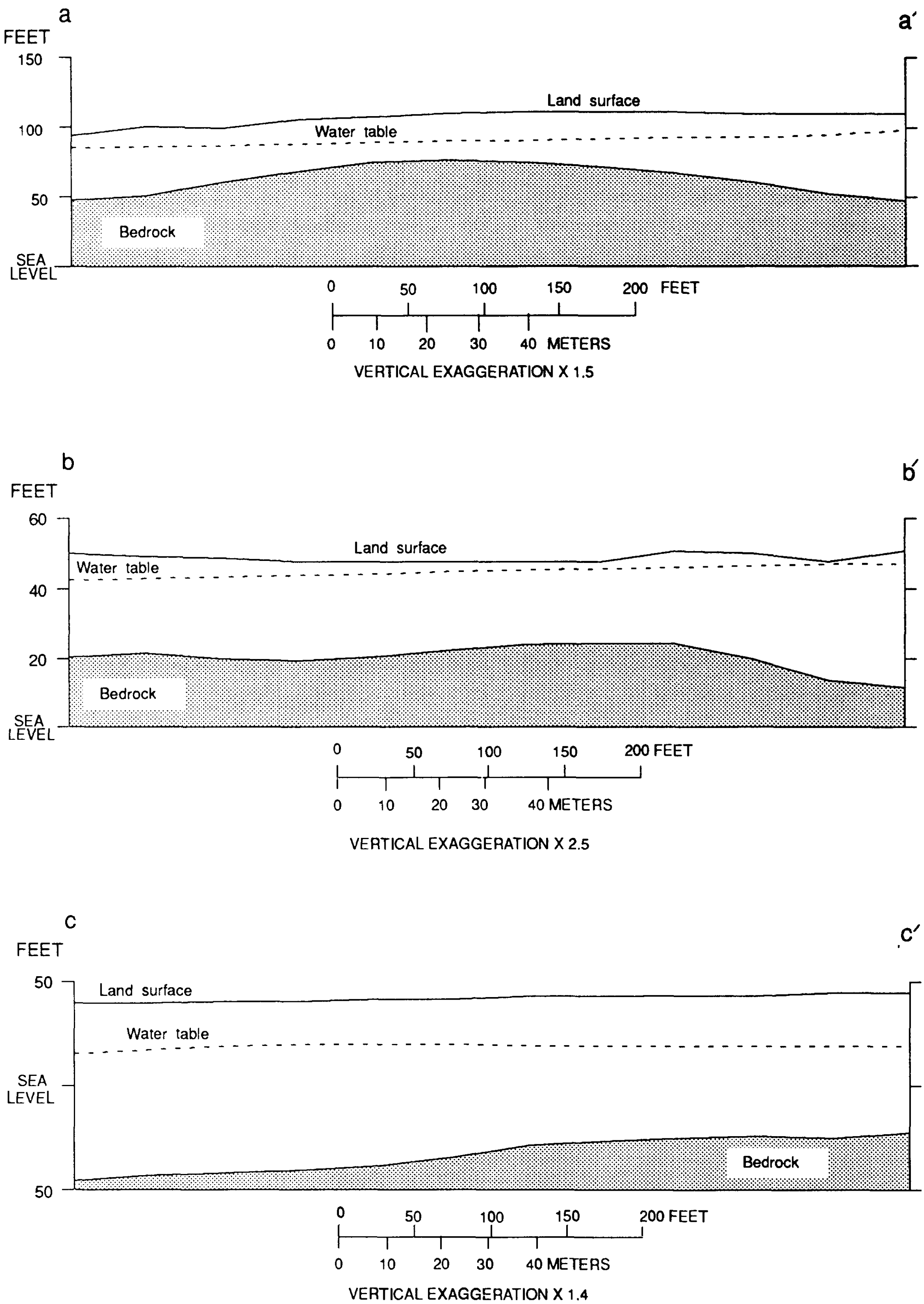


Figure 1.--Geologic sections interpreted from seismic-refraction data for Dover a-a', b-b', and c-c'.

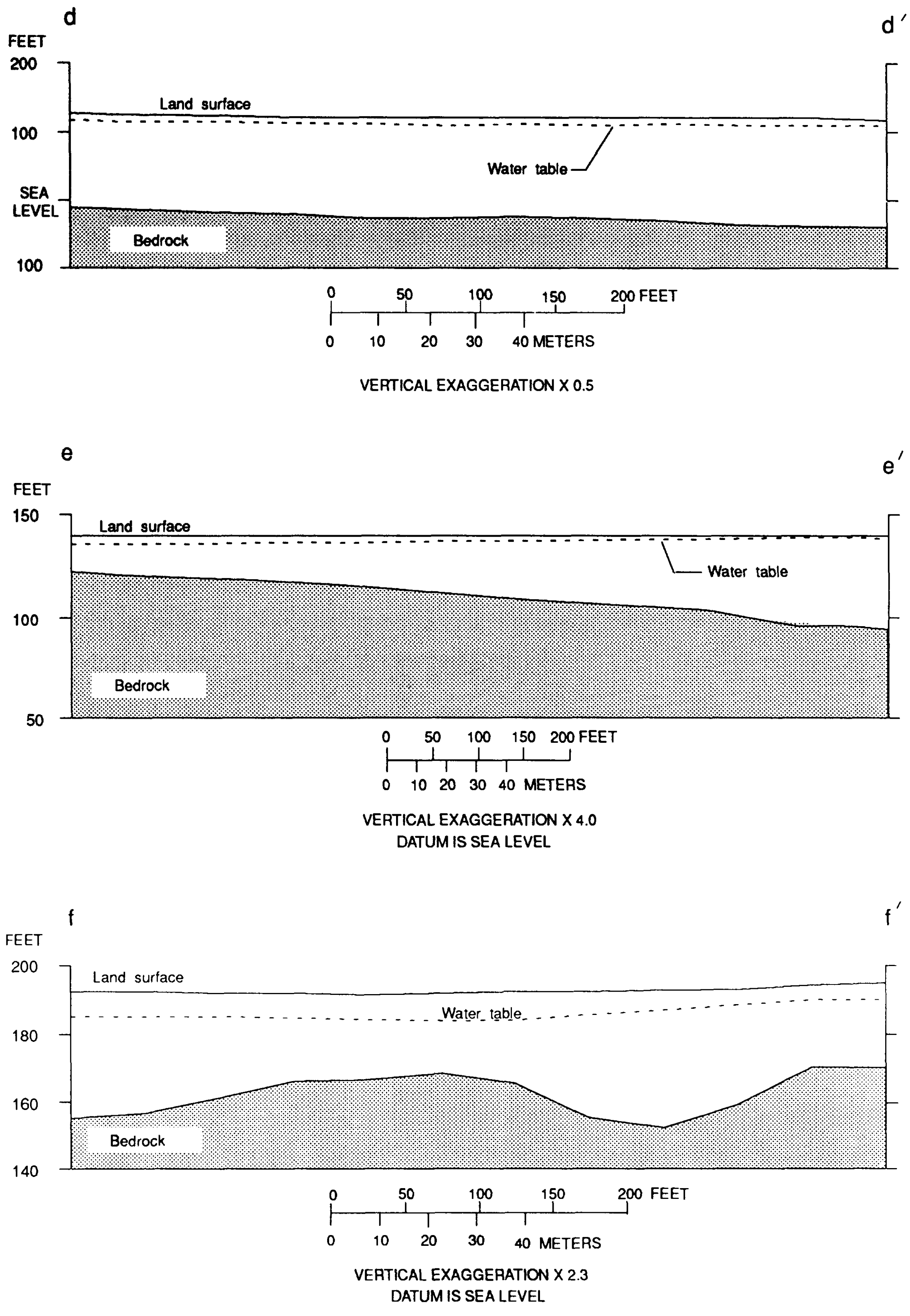


Figure 2.--Geologic sections interpreted from seismic-refraction data for Dover d-d', e-e', and Madbury f-f'.

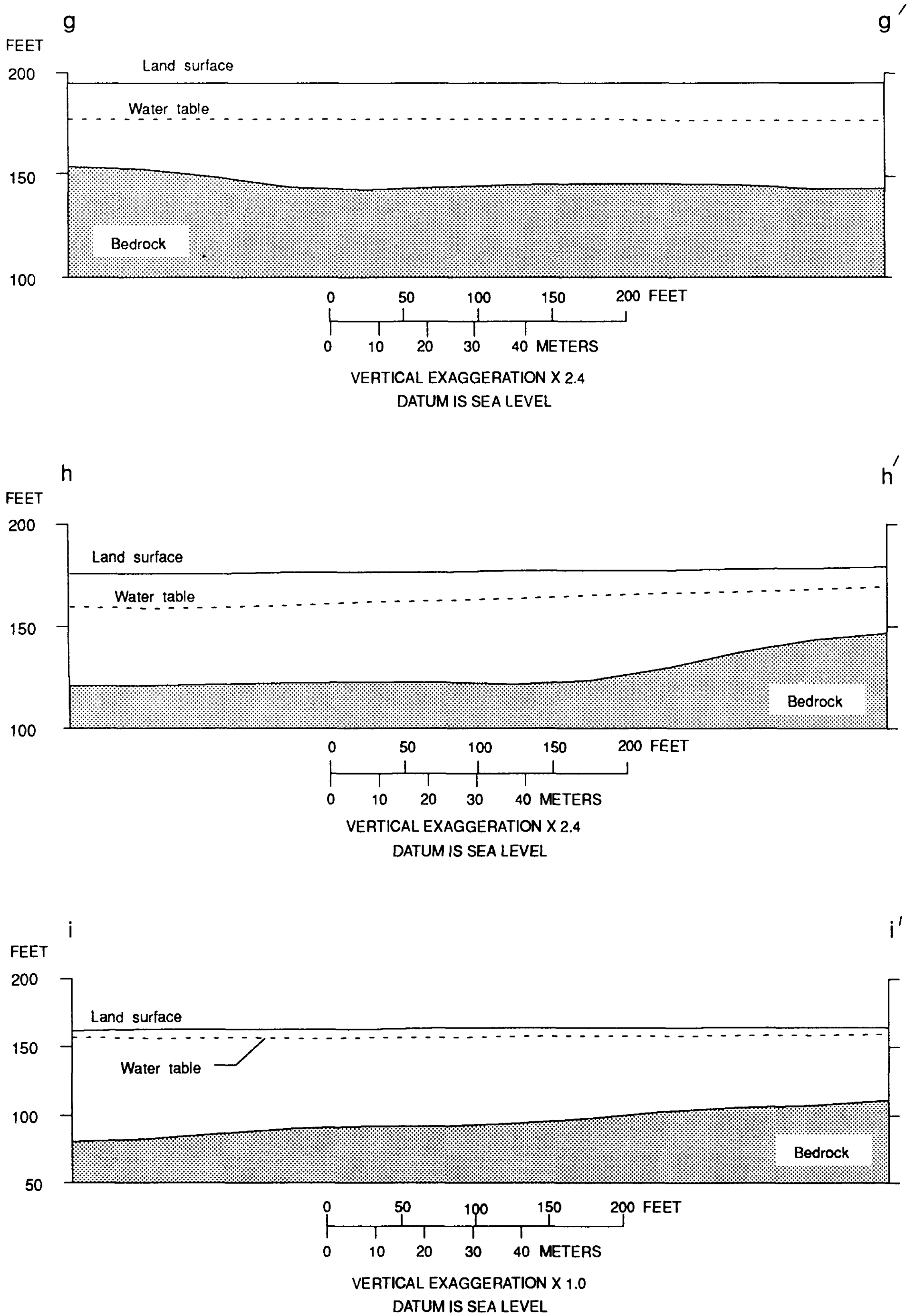


Figure 3.--Geologic sections interpreted from seismic-refraction data for Barrington g-g', h-h', and i-i'.

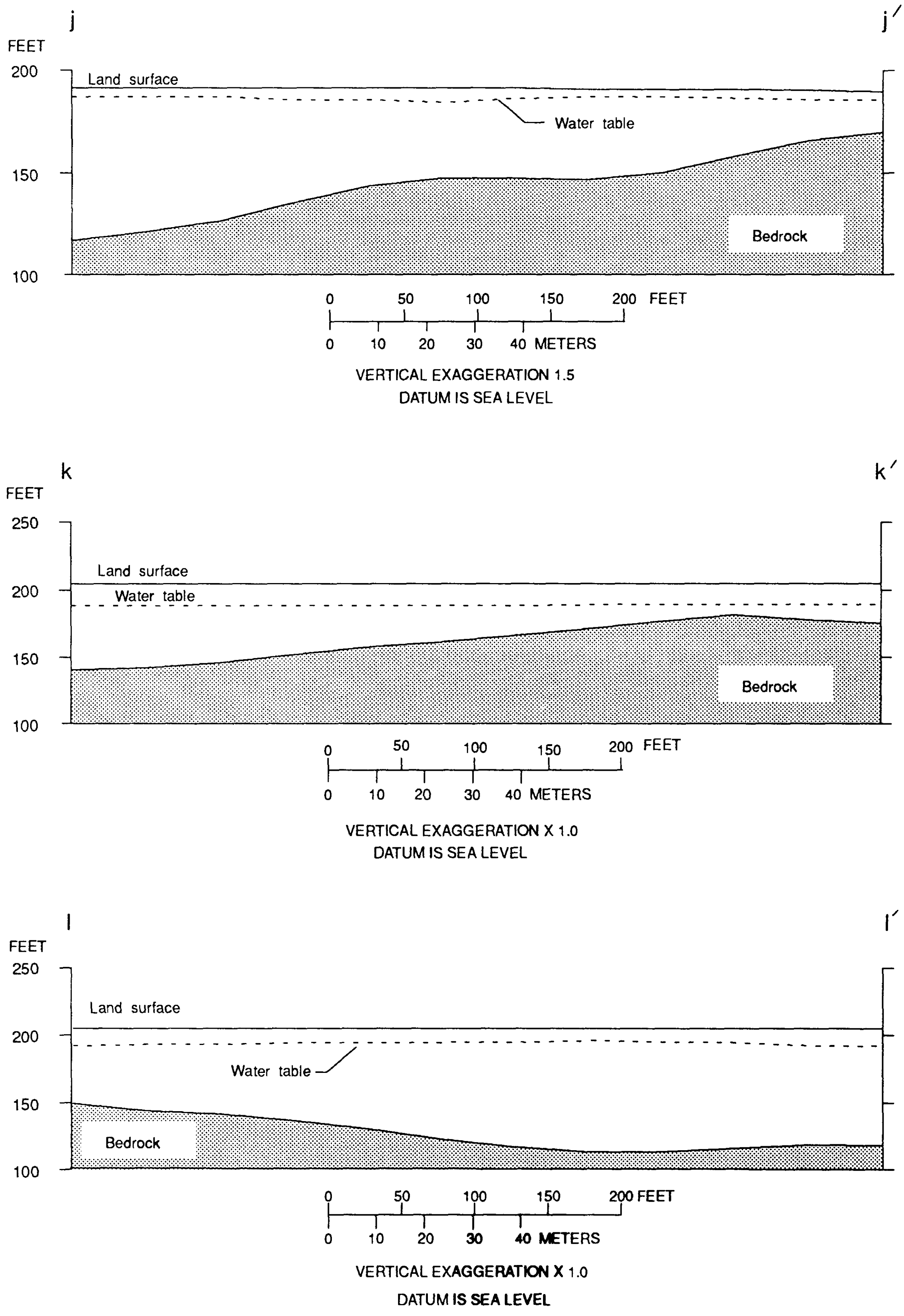


Figure 4.--Geologic sections interpreted from seismic-refraction data for Barrington j-j', k-k', and l-l'.

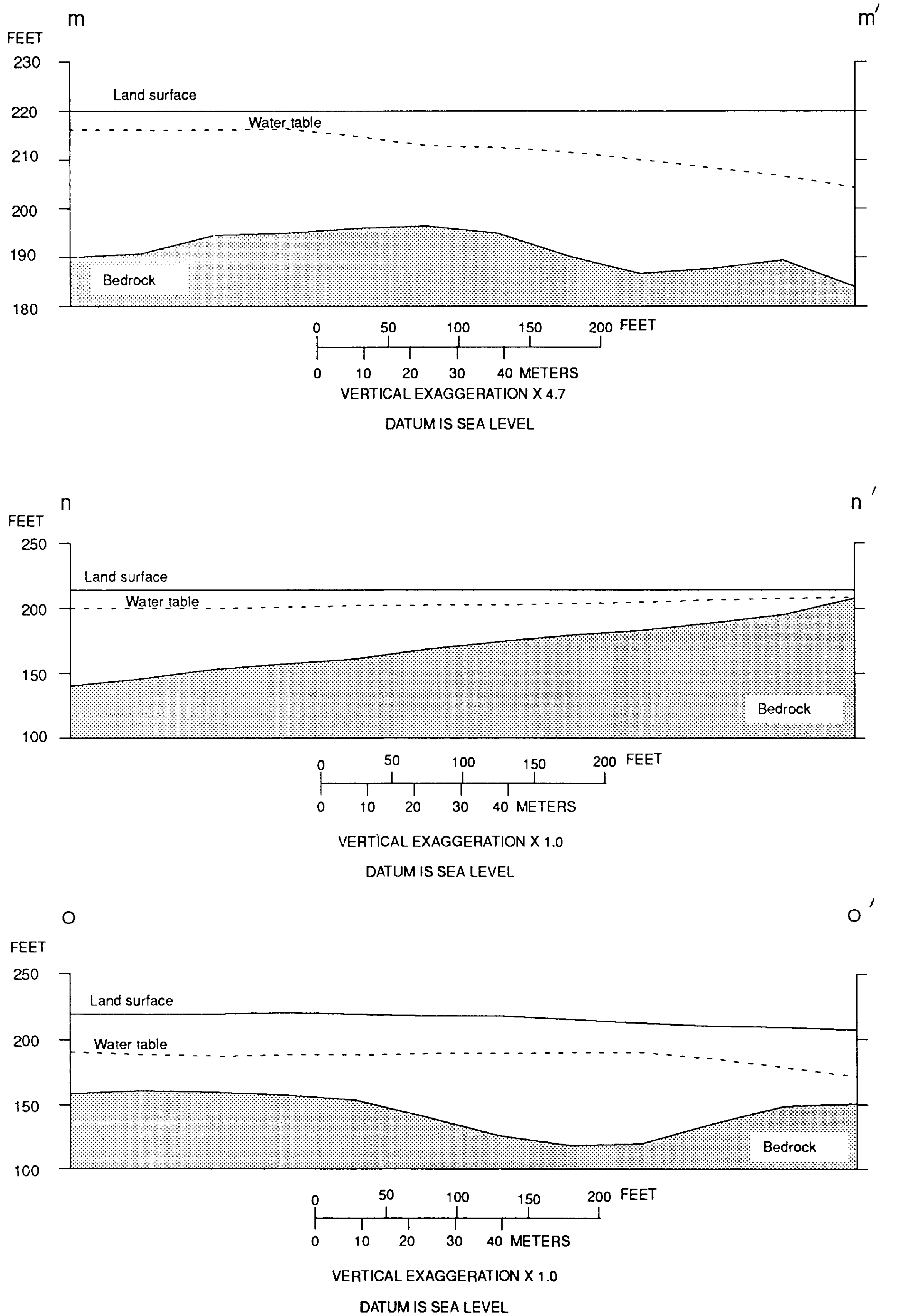


Figure 5.--Geologic sections interpreted from seismic-refraction data for Barrington m-m', n-n', and Rochester o-o'.

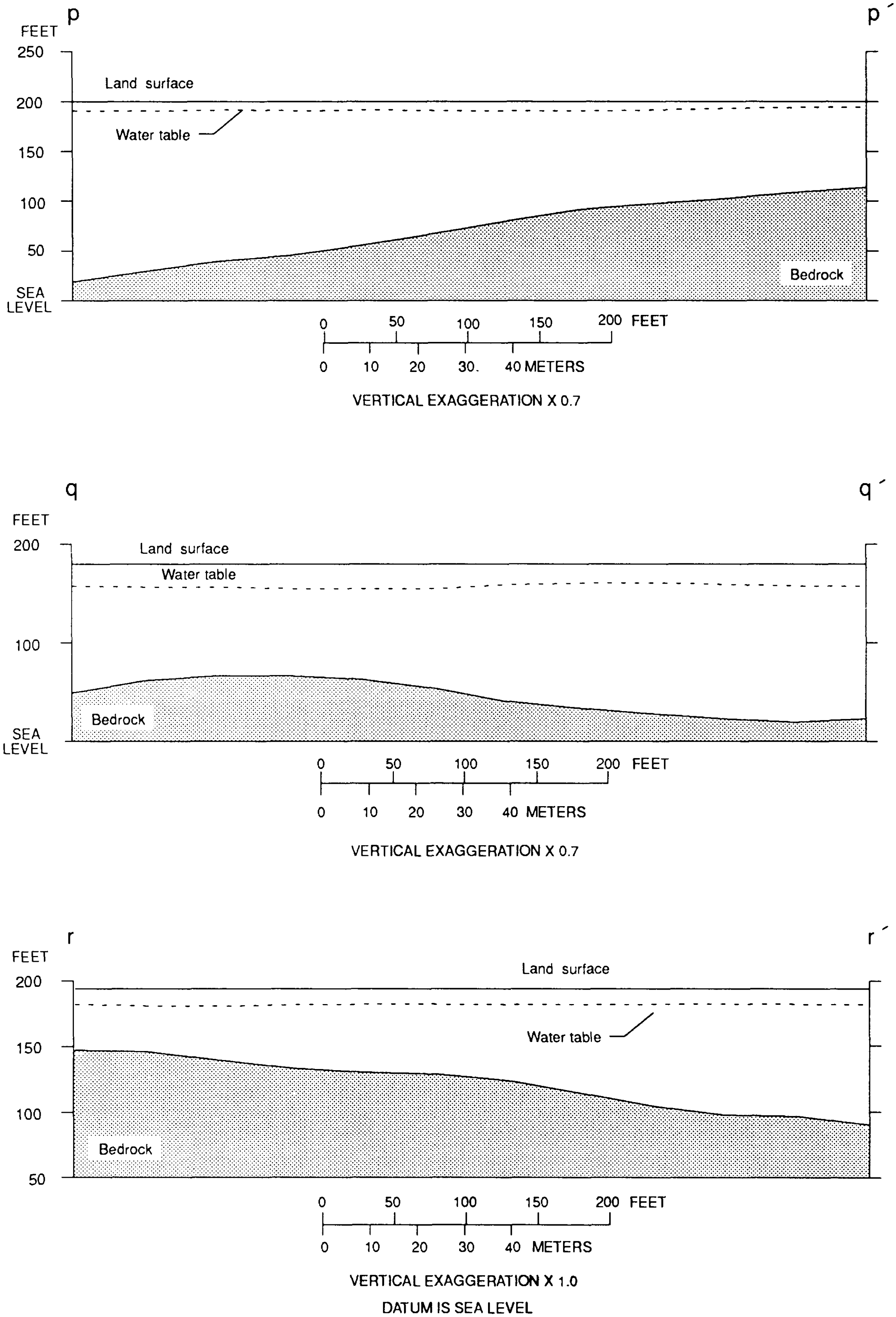


Figure 6.--Geologic sections interpreted from seismic-refraction data for Rochester p-p', q-q', and r-r'.

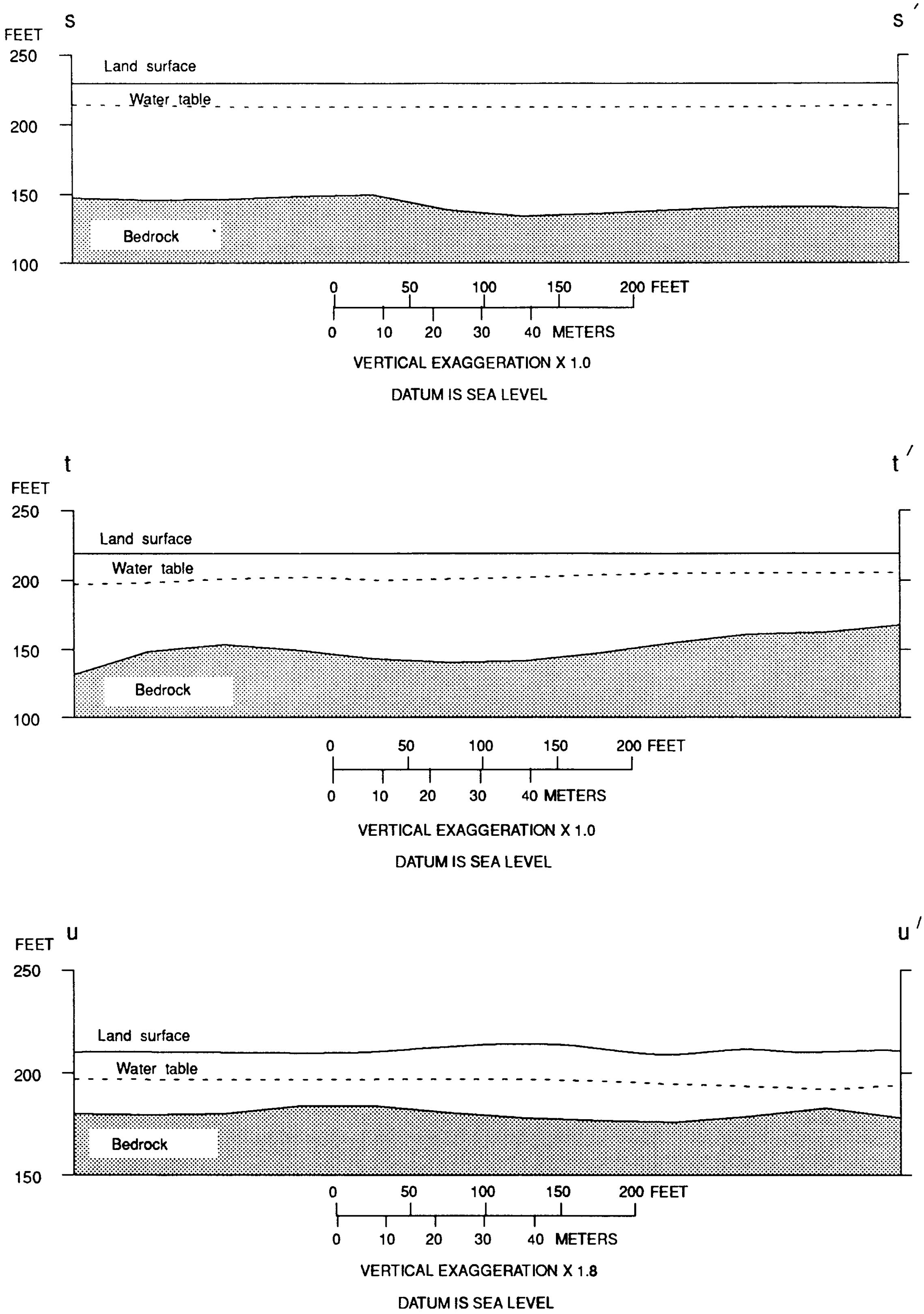


Figure 7.--Geologic sections interpreted from seismic-refraction data for Rochester s-s', t-t', and u-u'.

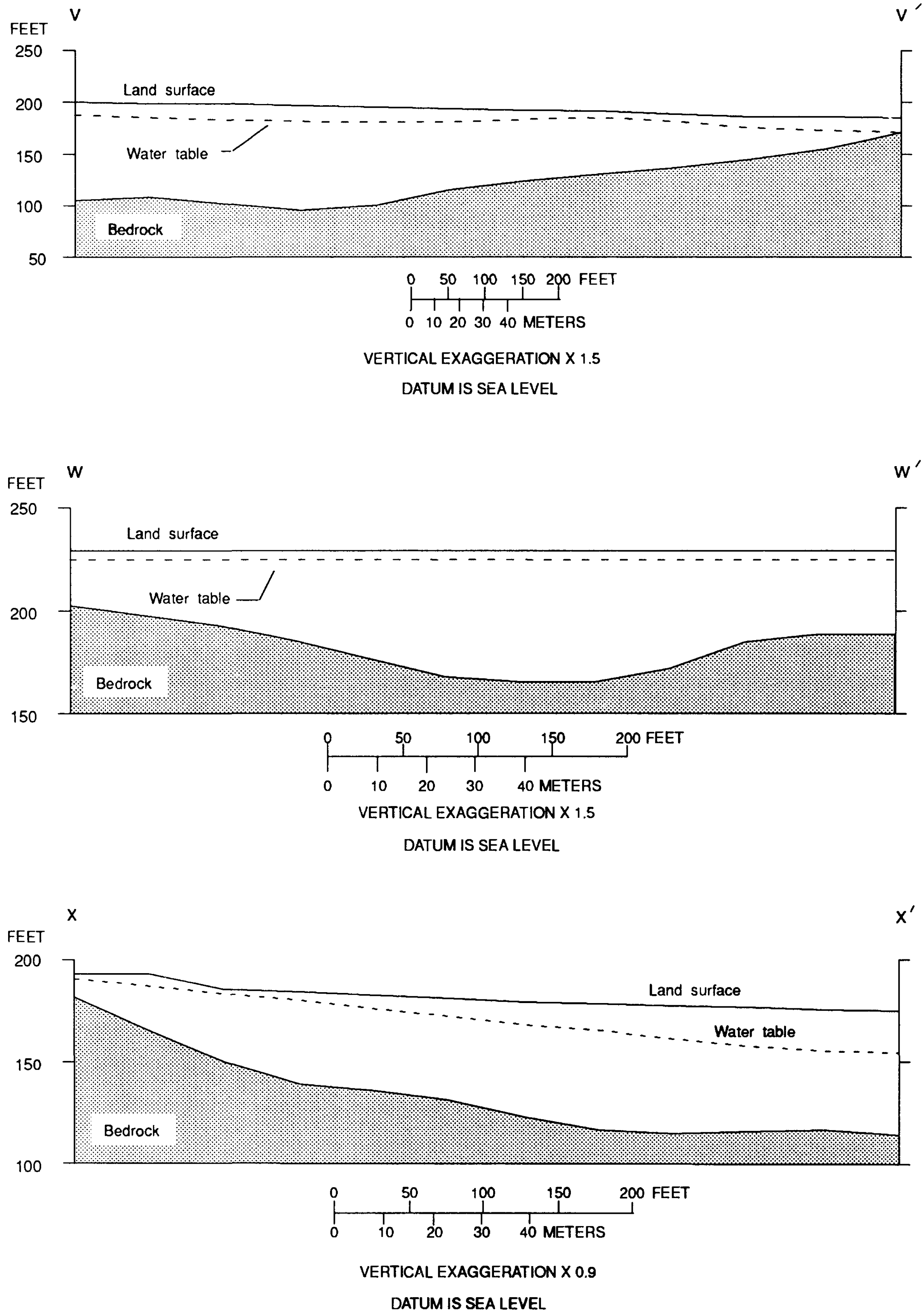


Figure 8.--Geologic sections interpreted from seismic-refraction data for Rochester v-v', w-w', and x-x'.

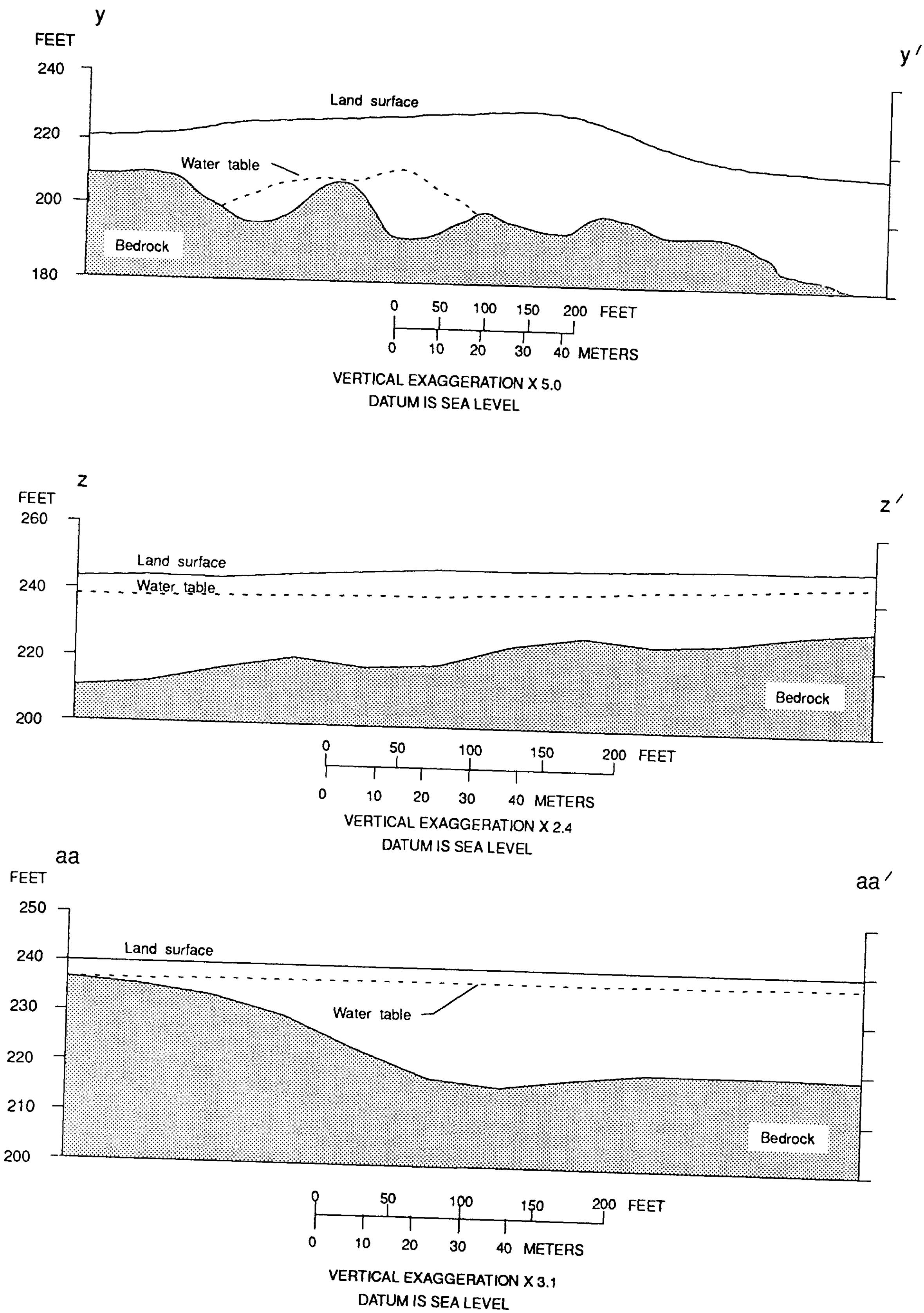


Figure 9.--Geologic sections interpreted from seismic-refraction data for Rochester y-y', z-z', and aa-aa'.

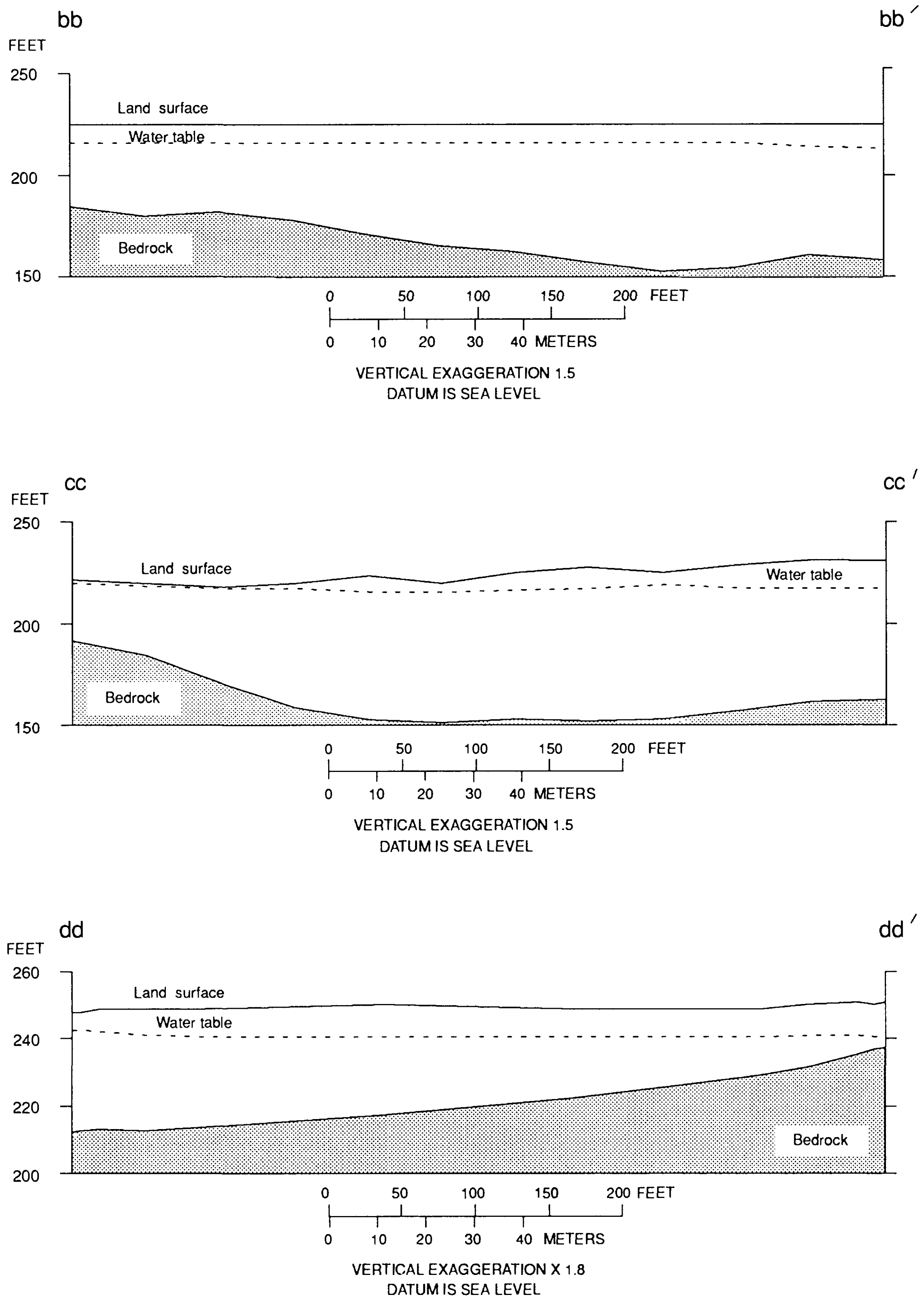
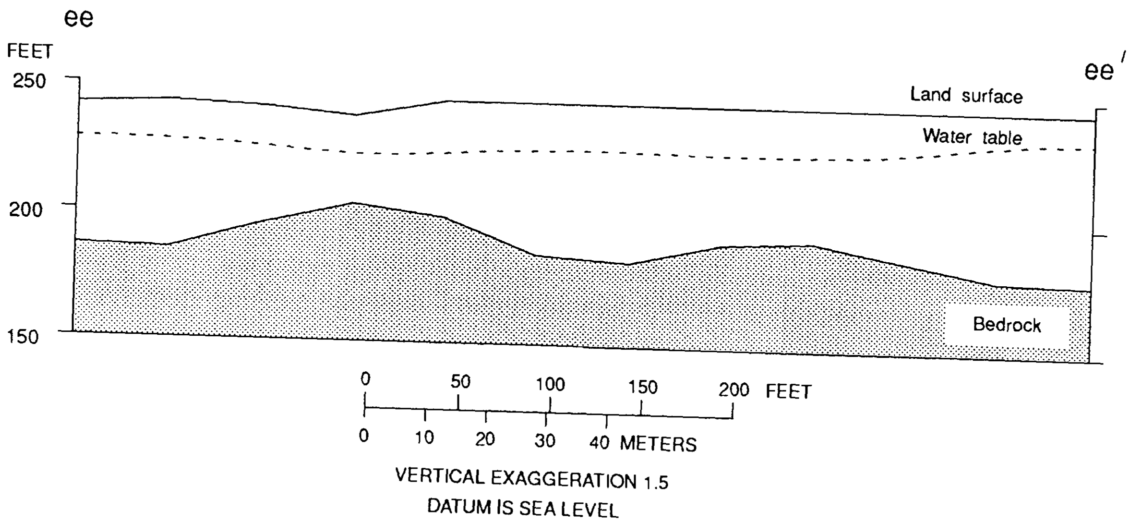
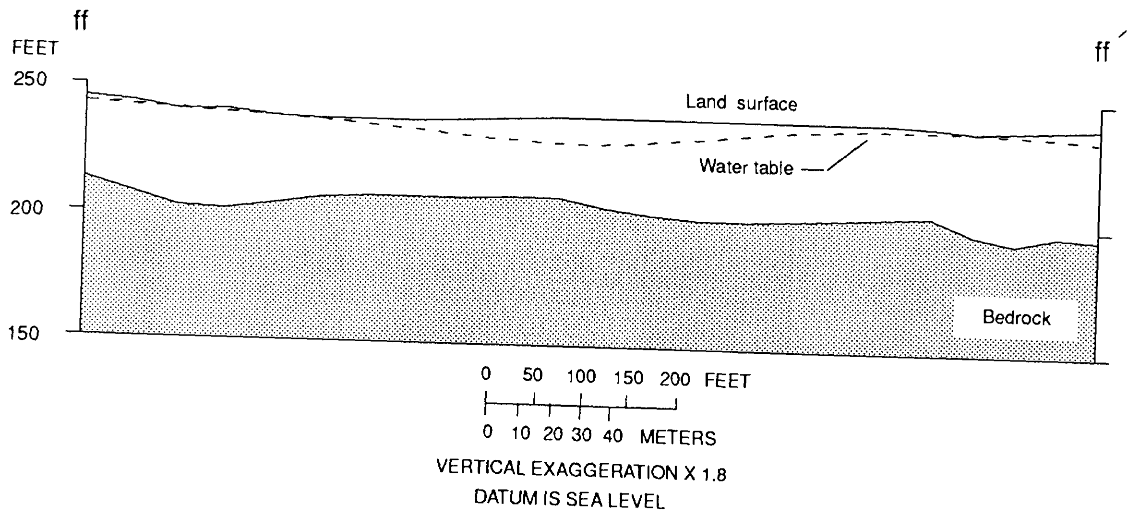


Figure 10.--Geologic sections interpreted from seismic-refraction data for Rochester bb-bb', cc-cc', and dd-dd'.





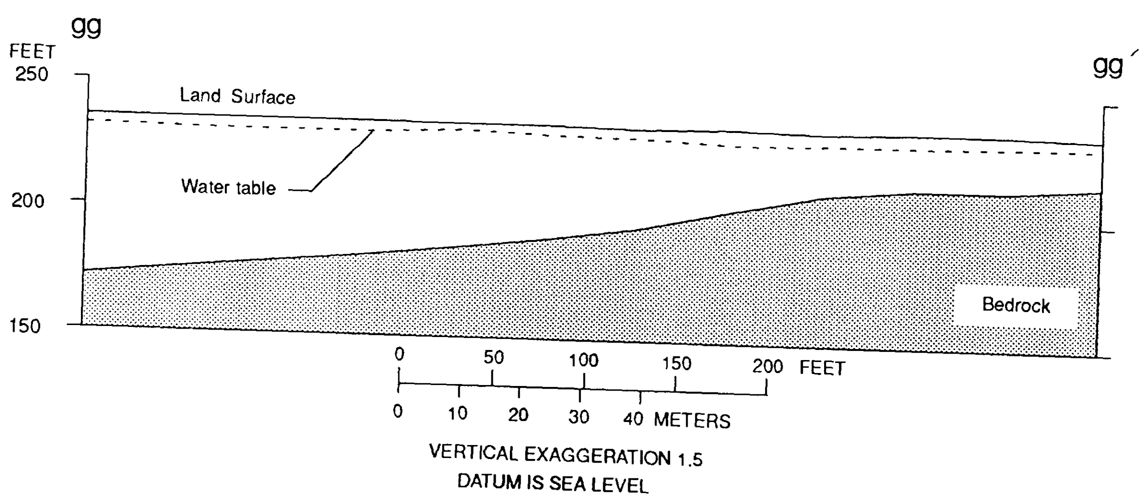


Figure 11.--Geologic sections interpreted from seismic-refraction data for Rochester ee-ee', ff-ff', and gg-gg'.

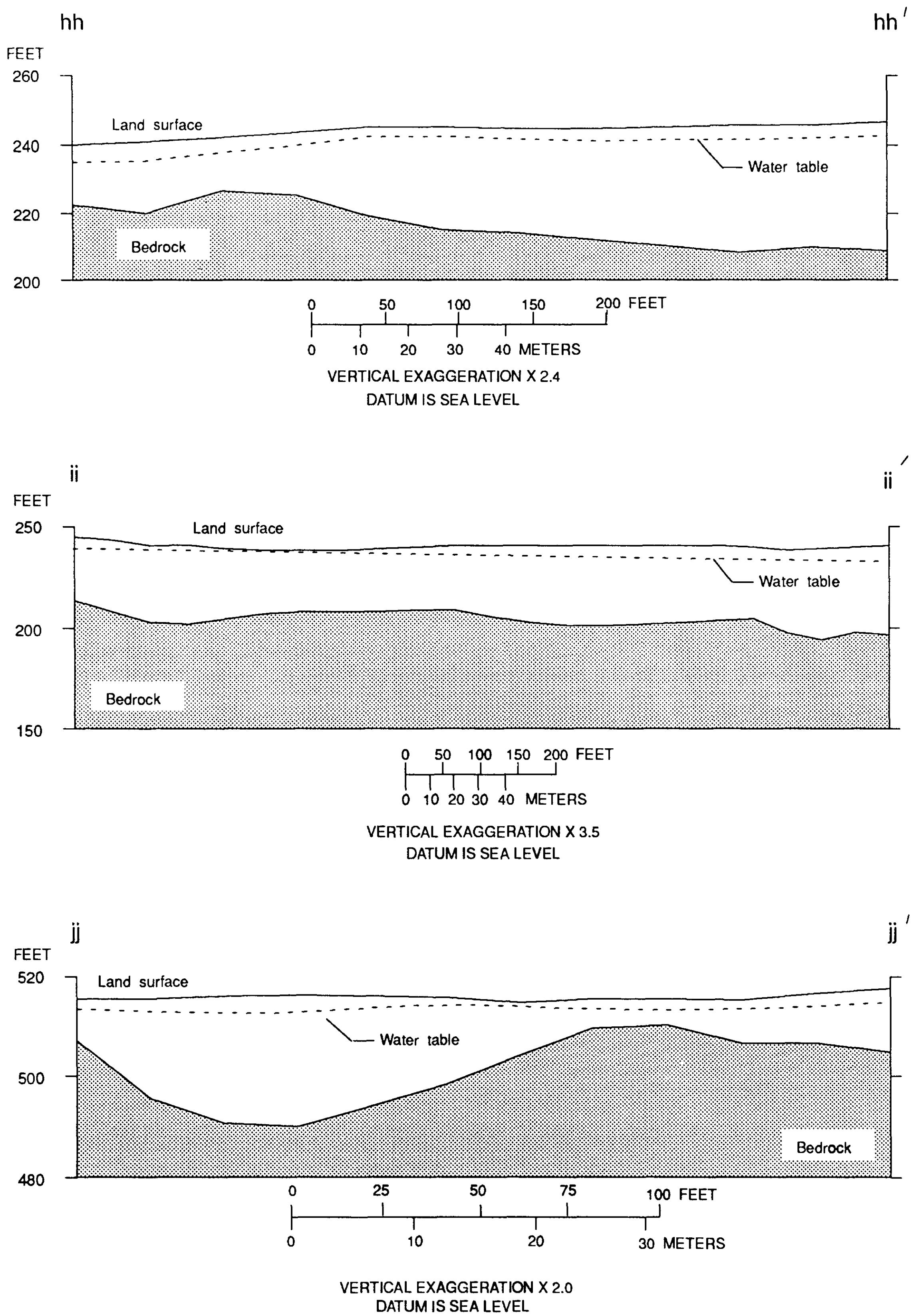
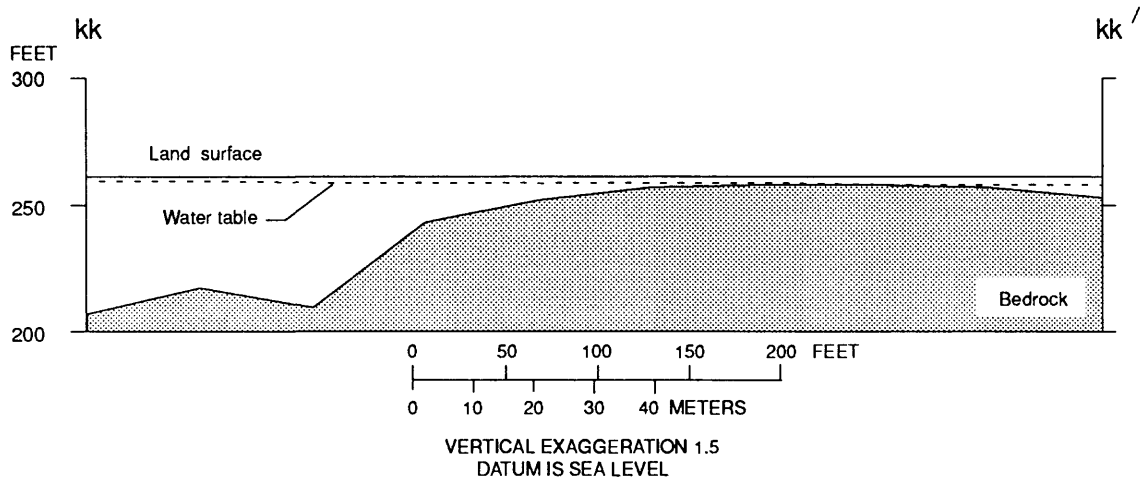
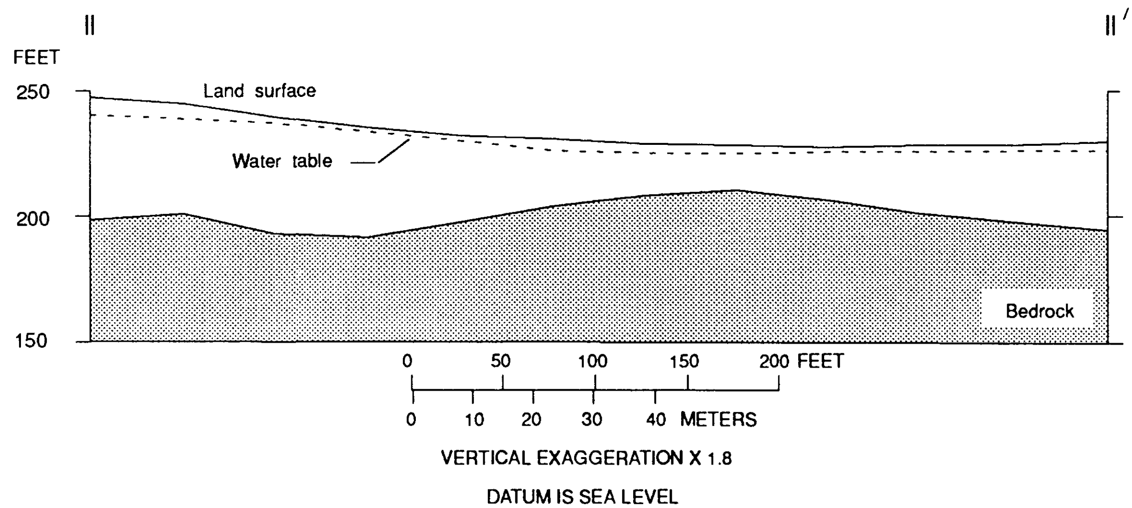


Figure 12.--Geologic sections interpreted from seismic-refraction data for Rochester hh-hh', Farmington ii-ii', and Strafford jj-jj'.





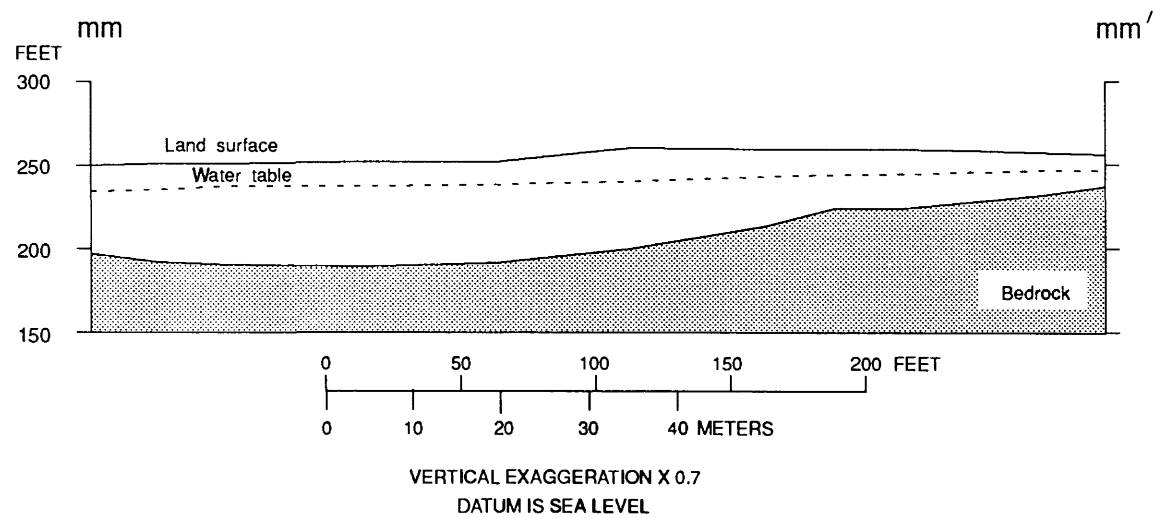
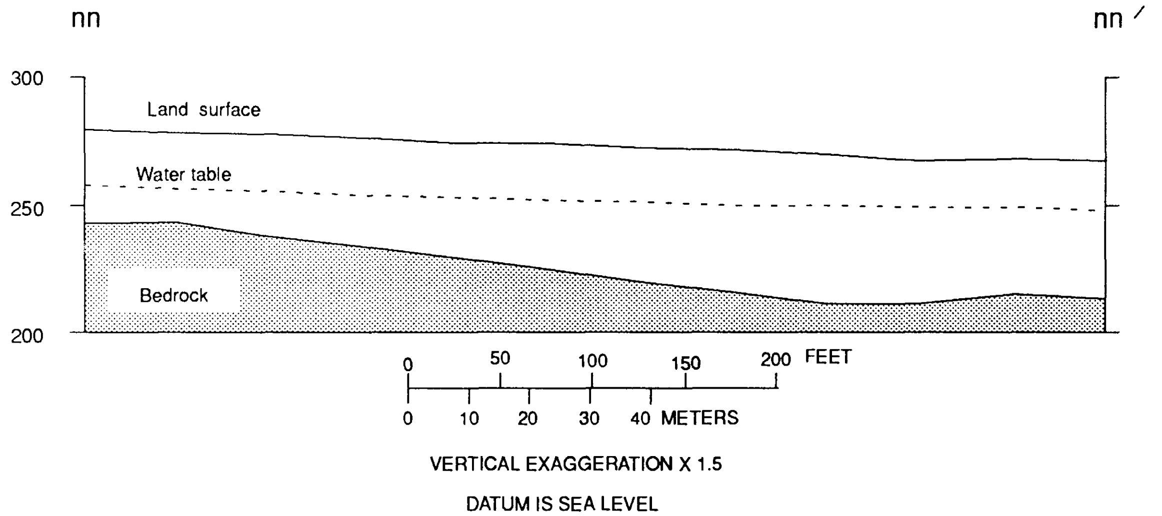
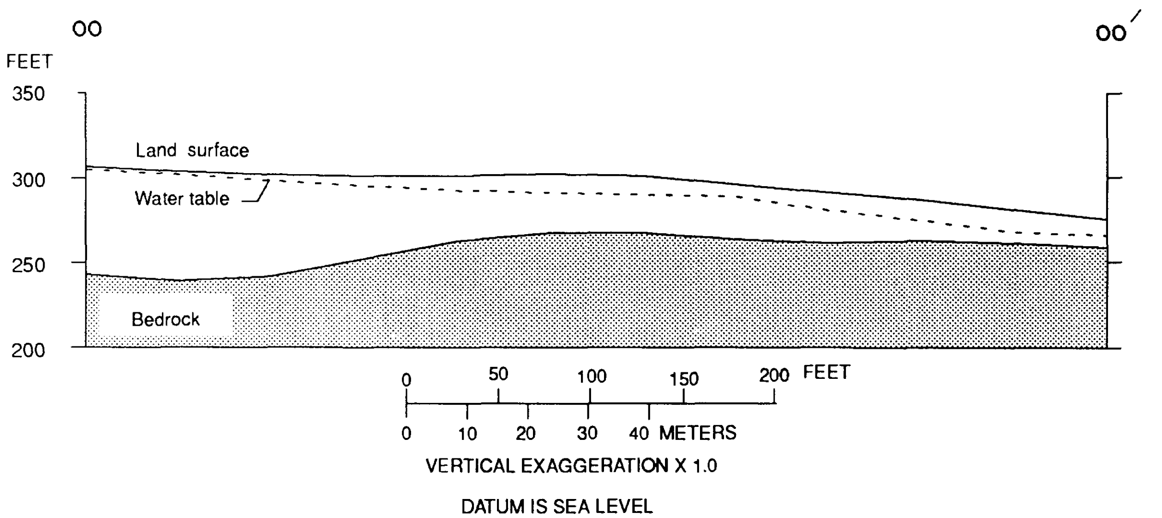


Figure 13.--Geologic sections interpreted from seismic-refraction data for Strafford kk-kk', Rochester ll-ll', and mm-mm'.





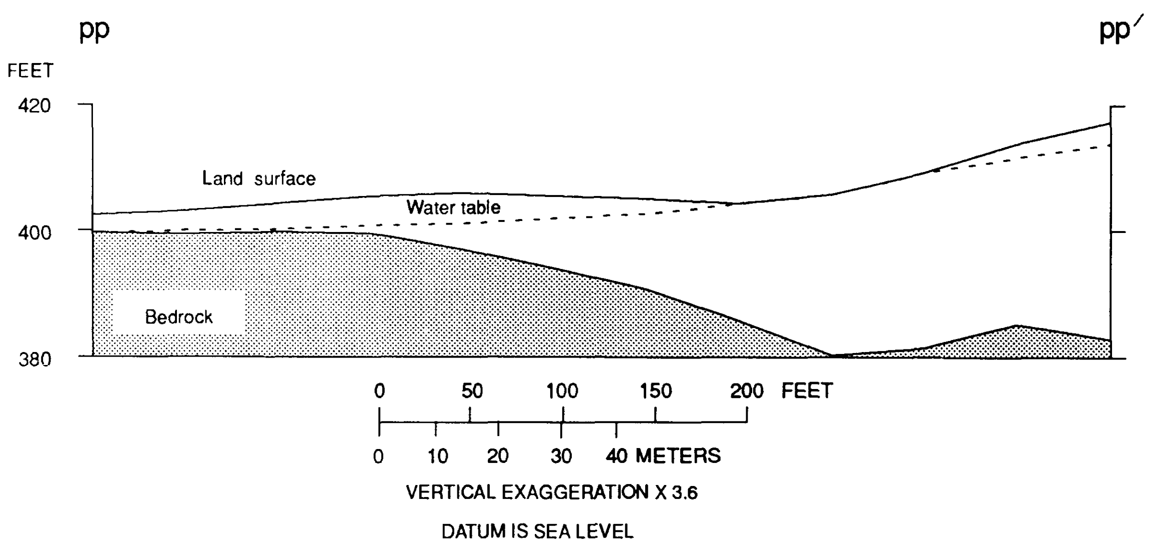


Figure 14.--Geologic sections interpreted from seismic-refraction data for Farmington nn-nn', oo-oo', and pp-pp'.

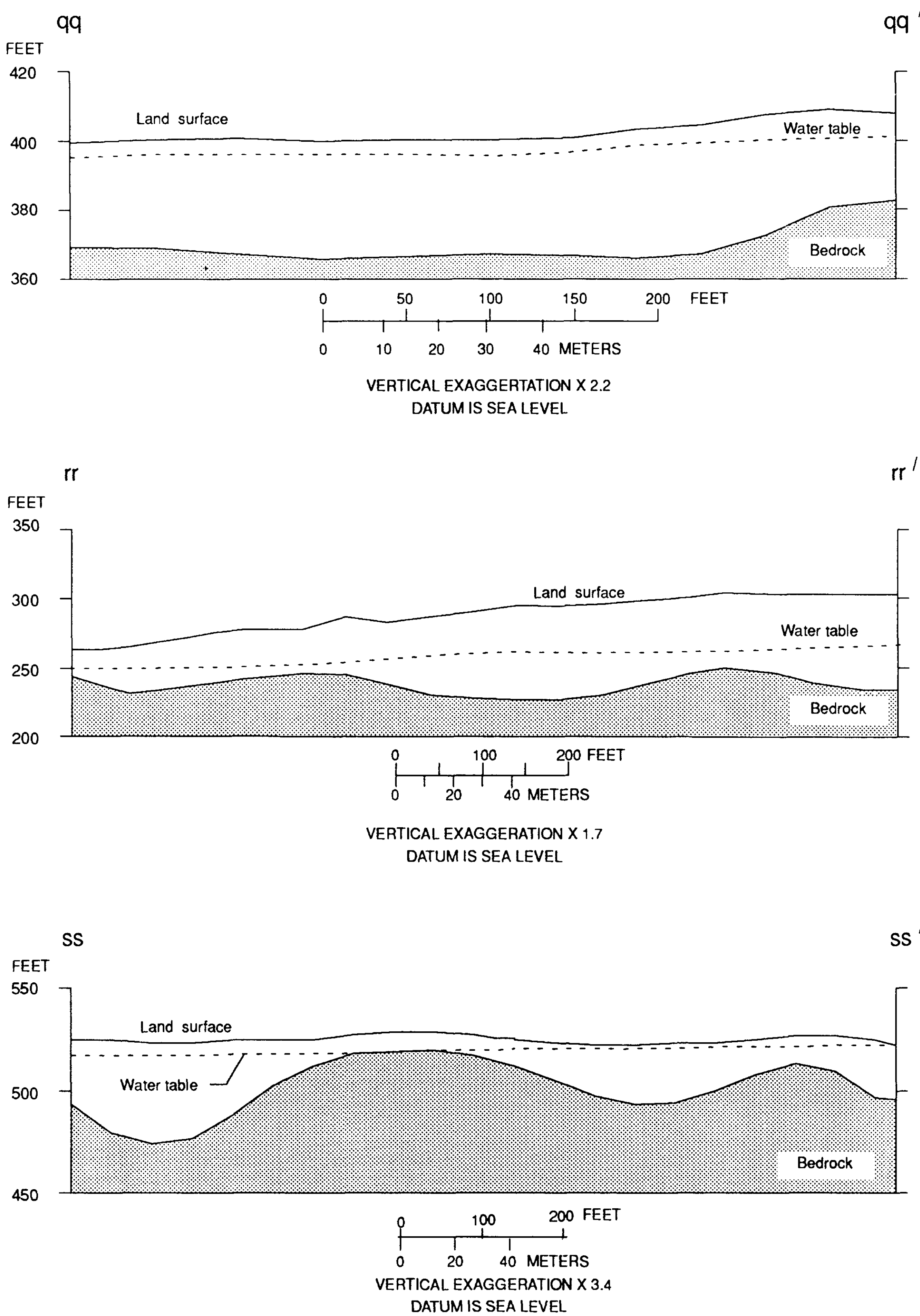


Figure 15.--Geologic sections interpreted from seismic-refraction data for Farmington qq-qq', rr-rr', and New Durham ss-ss'.

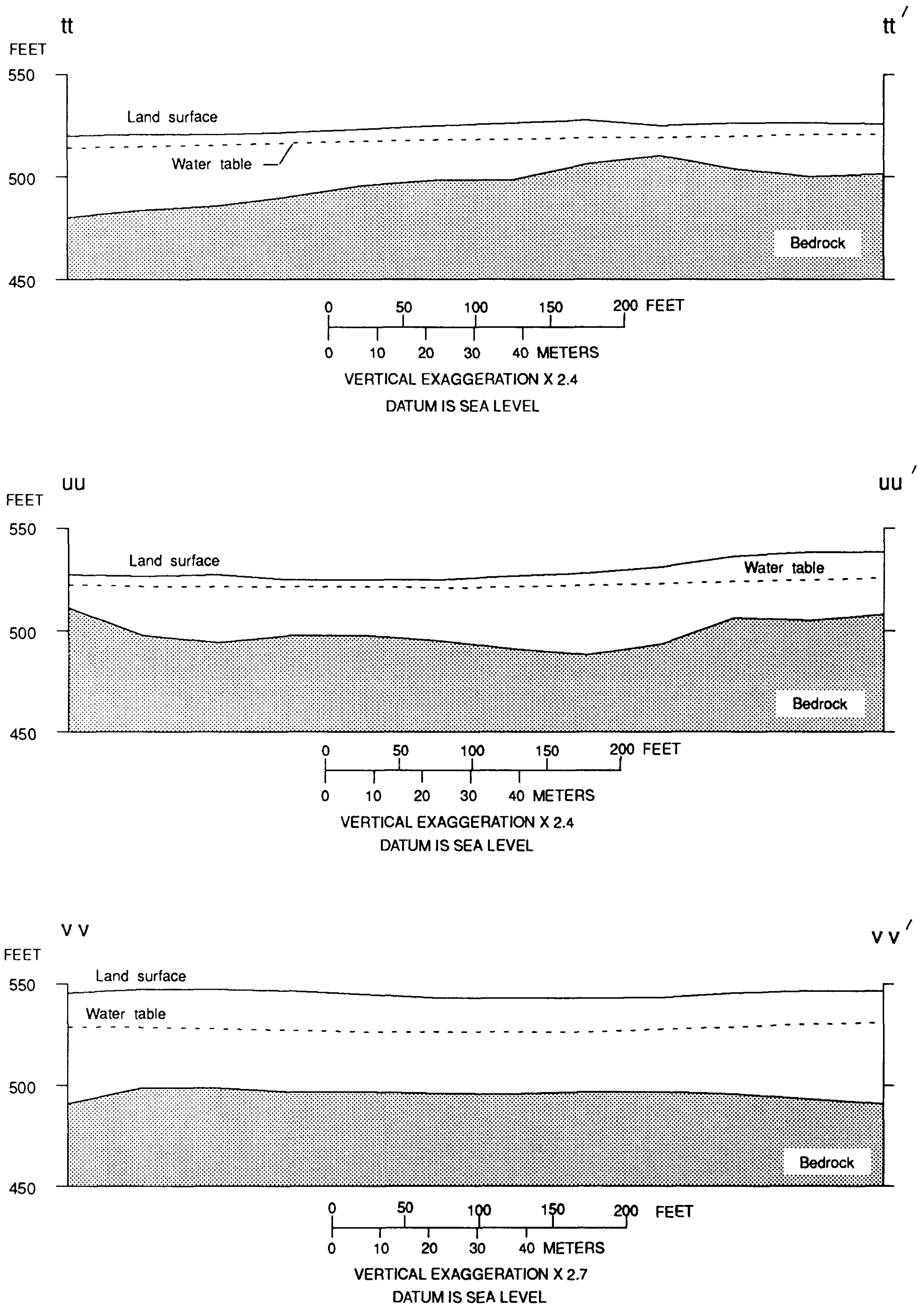


Figure 16.--Geologic sections interpreted from seismic-refraction data for New Durham tt-tt', uu-uu', and vv-vv'.

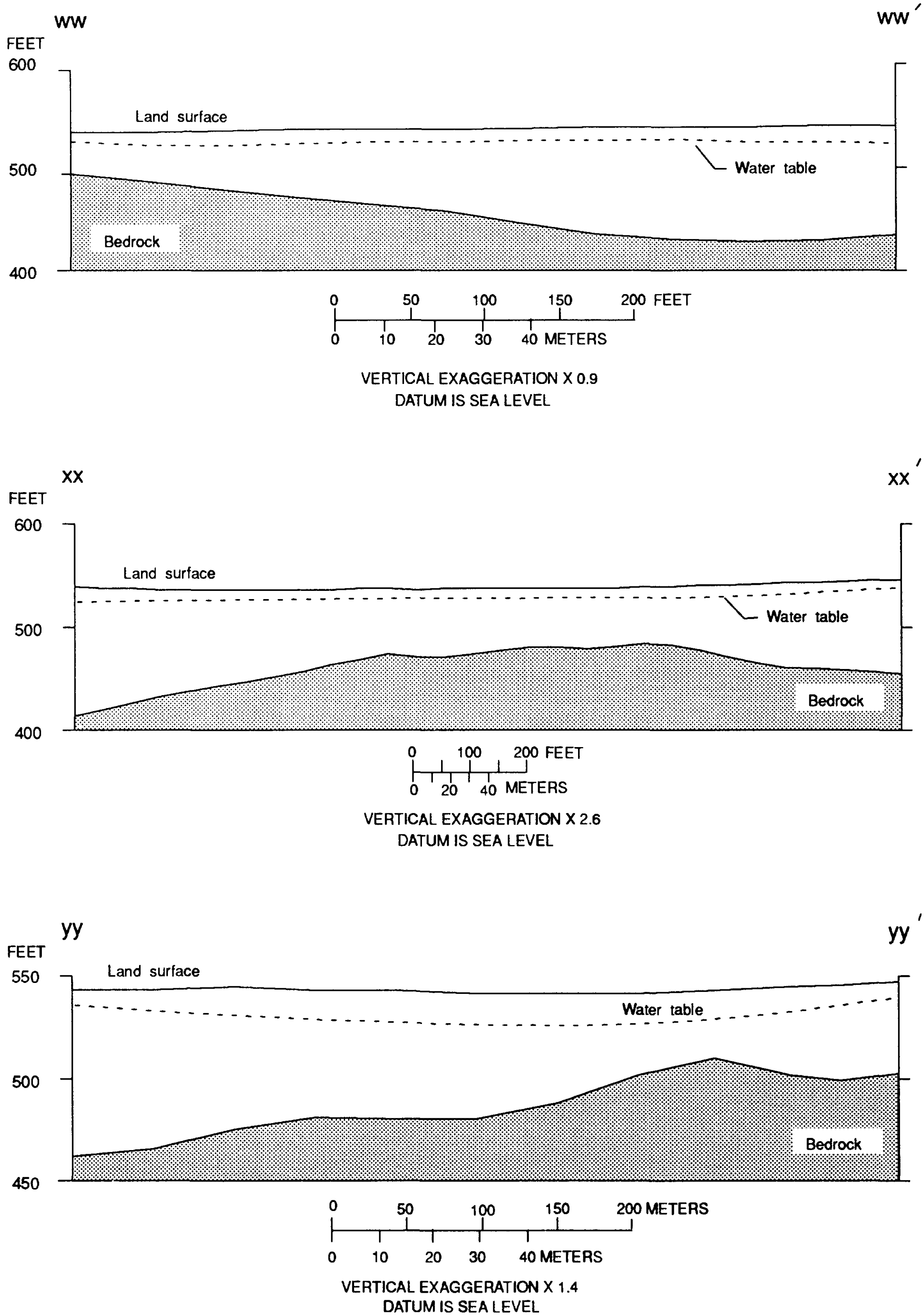
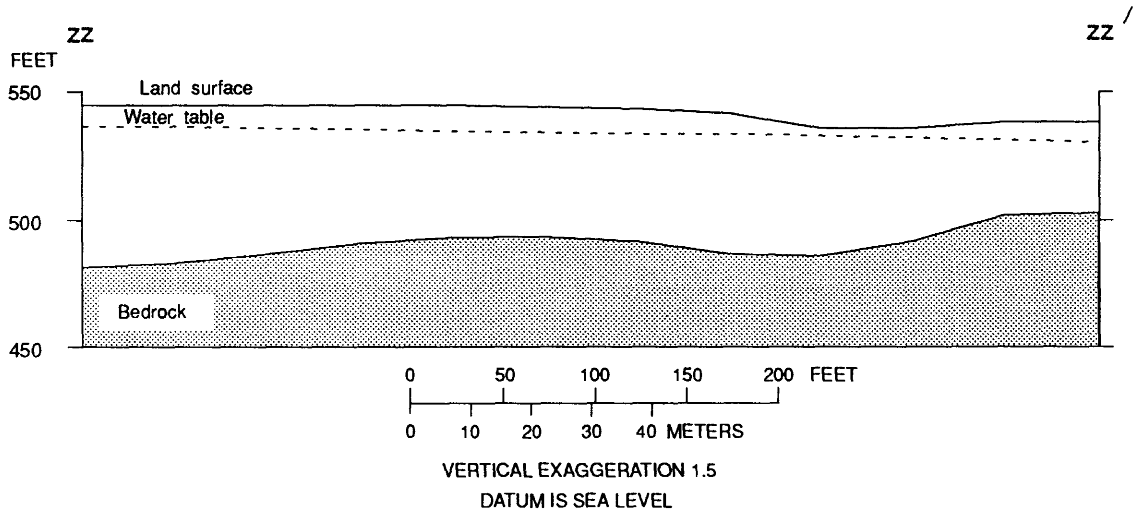
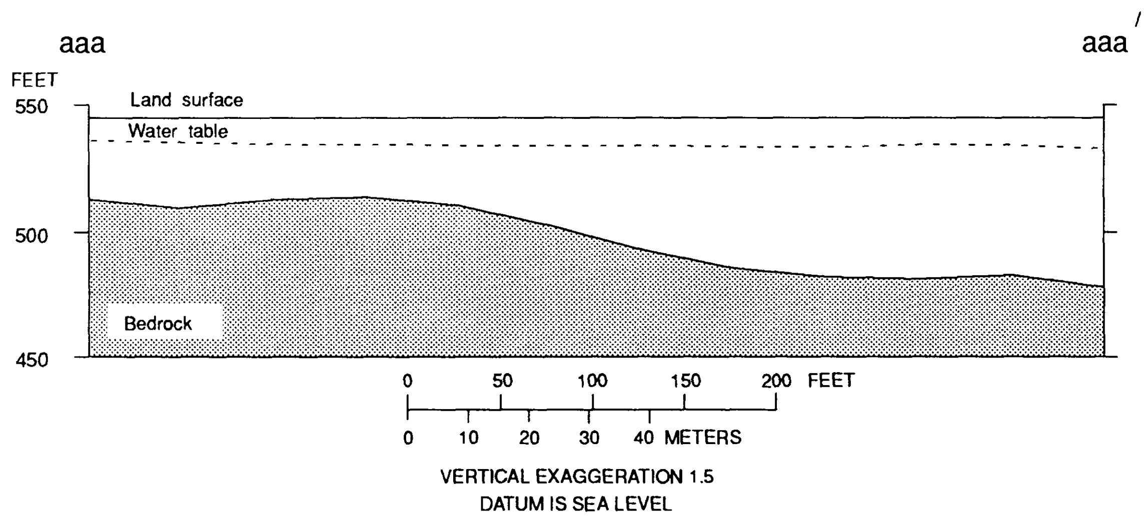


Figure 17.--Geologic sections interpreted from seismic-refraction data for New Durham ww-ww', xx-xx', and yy-yy'.





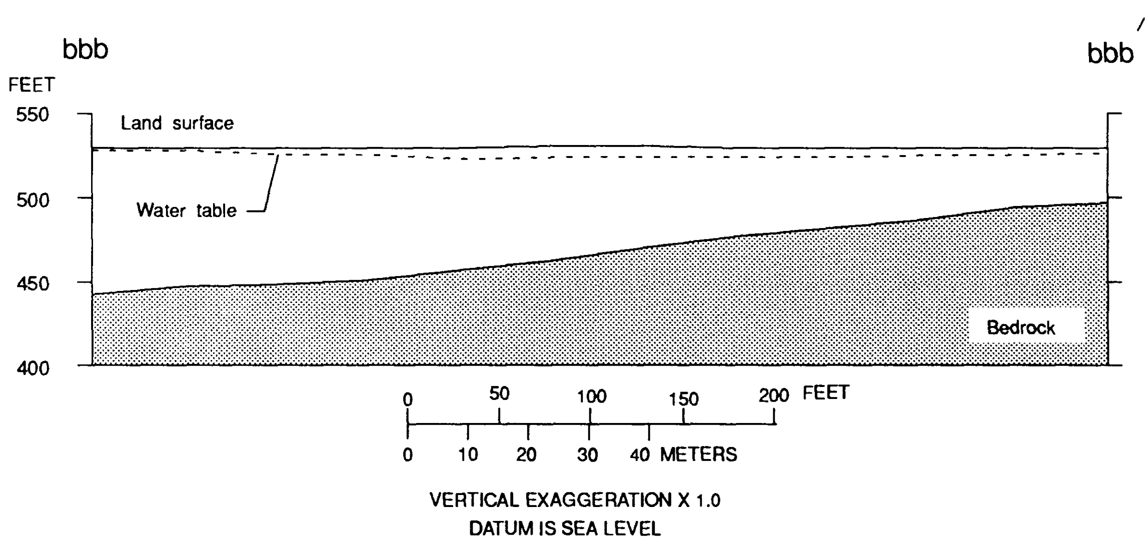
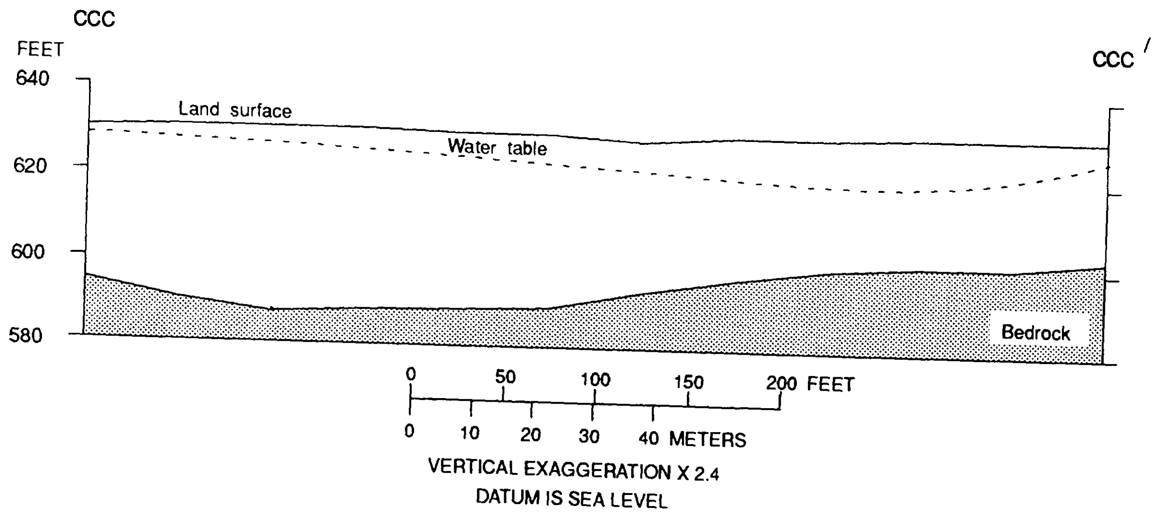
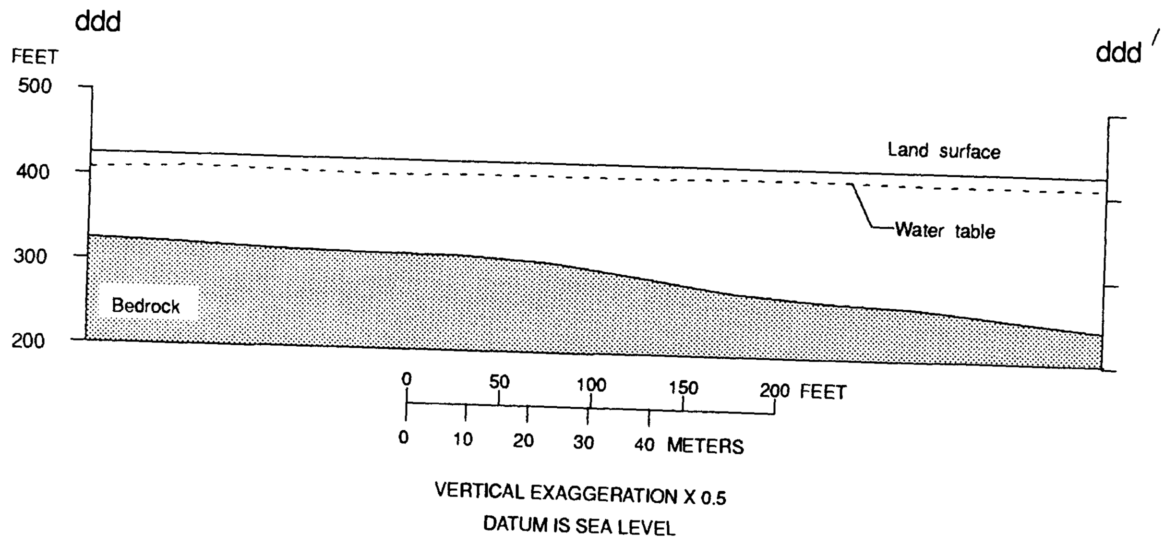


Figure 18.--Geologic sections interpreted from seismic-refraction data for New Durham zz-zz', aaa-aaa', and bbb-bbb'.





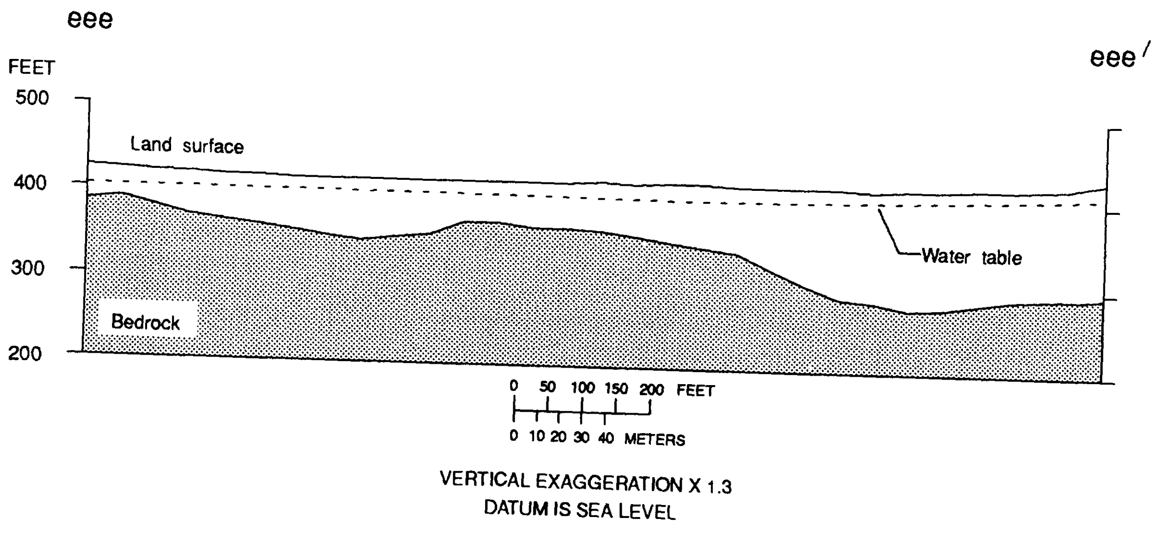


Figure 19.--Geologic sections interpreted from seismic-refraction data for New Durham ccc-ccc', Middleton ddd-ddd', and Milton eee-eee'.

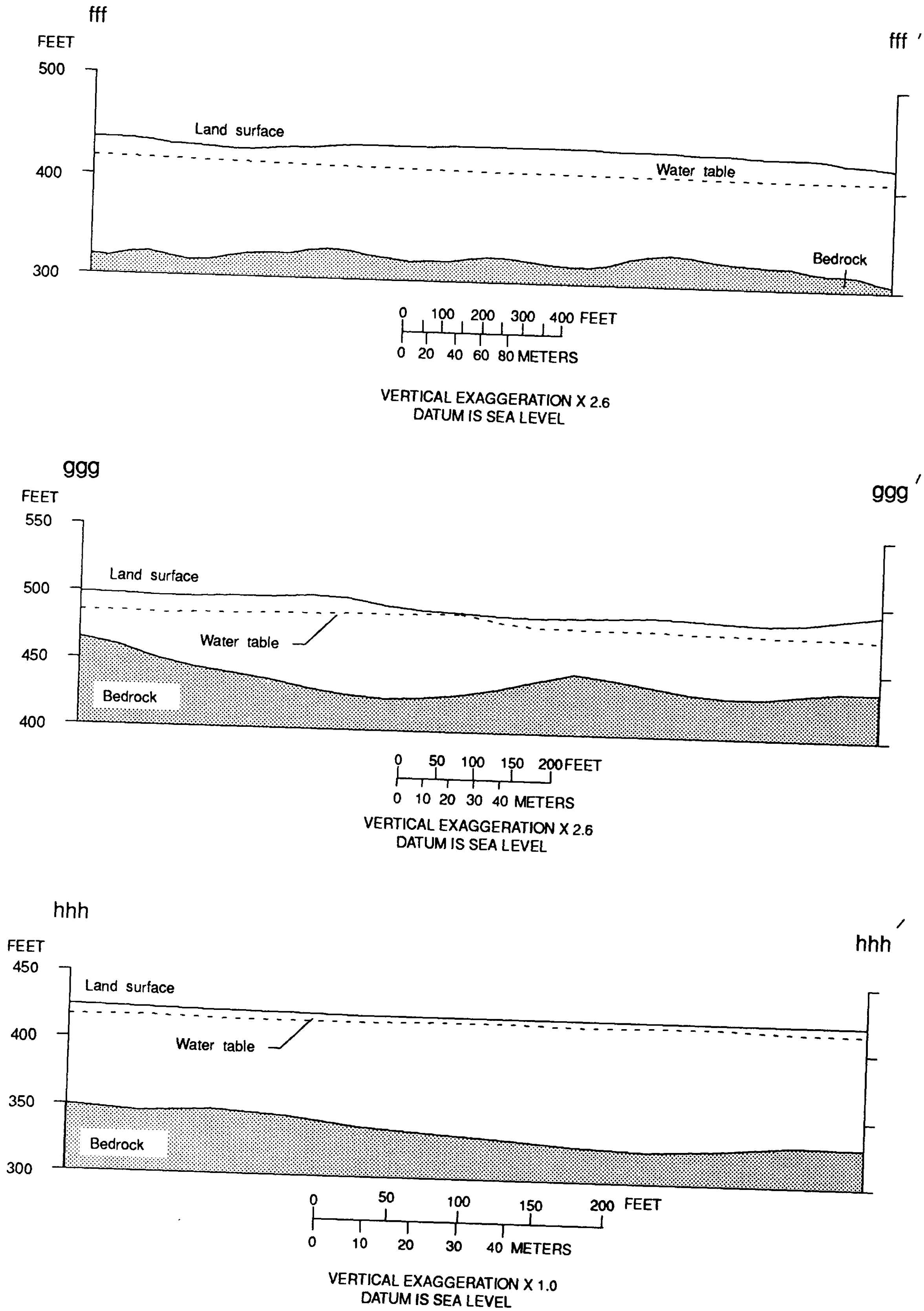


Figure 20.--Geologic sections interpreted from seismic-refraction data for Milton fff-fff', ggg-ggg', and hhh-hhh'.

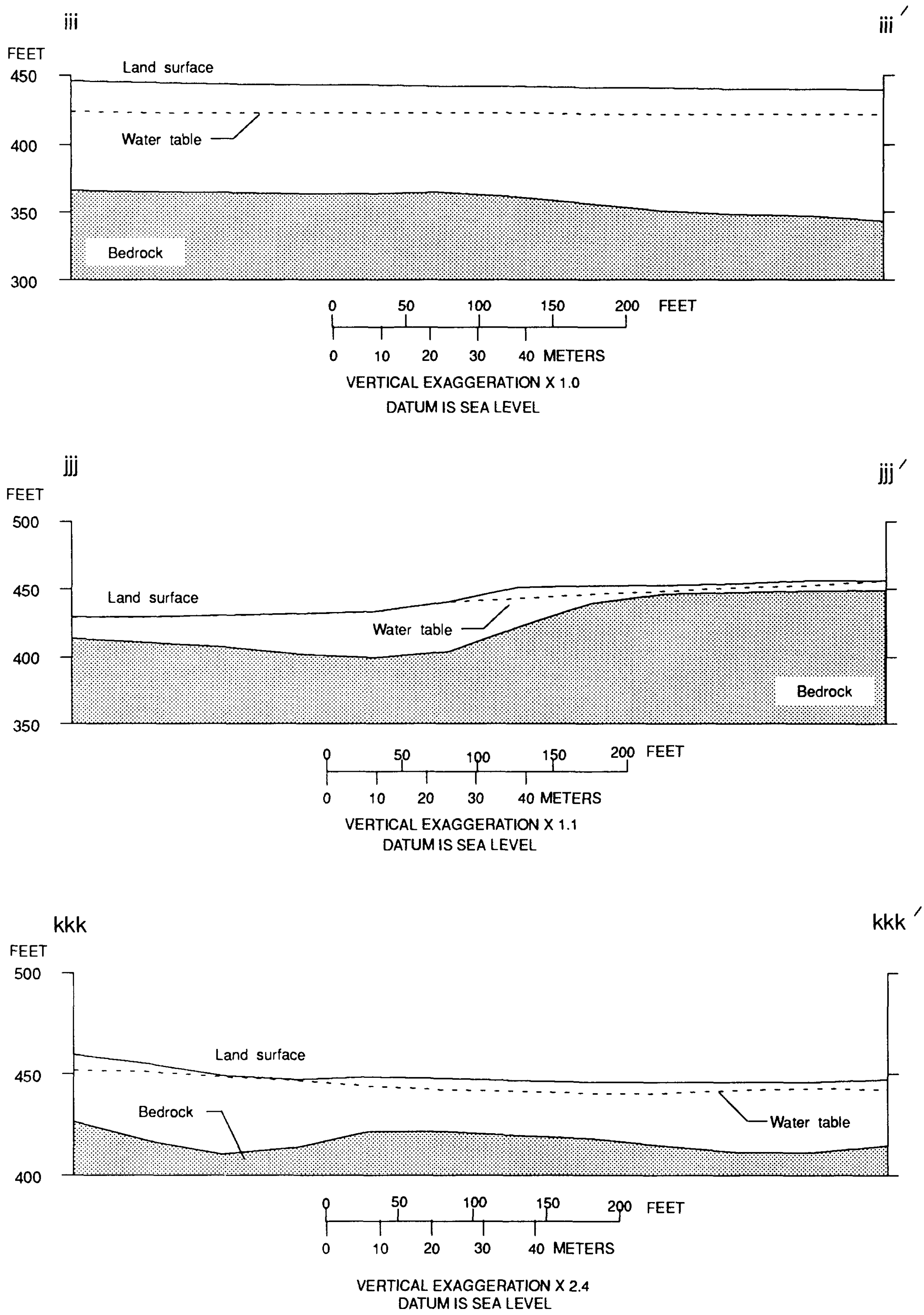


Figure 21.--Geologic sections interpreted from seismic-refraction data for Milton iii-iii', jjj-jjj', and kkk-kkk'.

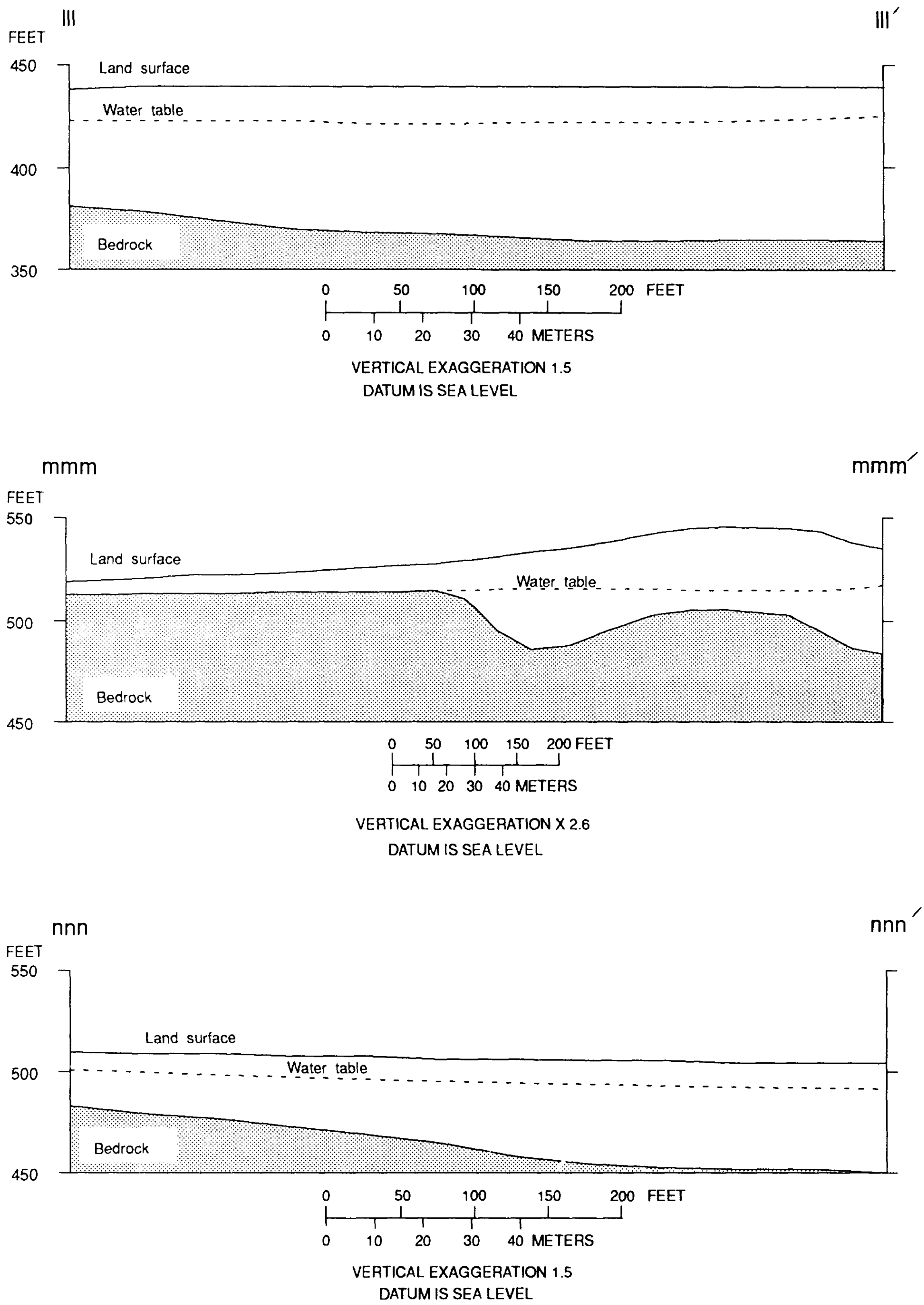


Figure 22.--Geologic sections interpreted from seismic-refraction data for Milton lll-lll', Brookfield mmm-mmm', and Wakefield nnn-nnn'.

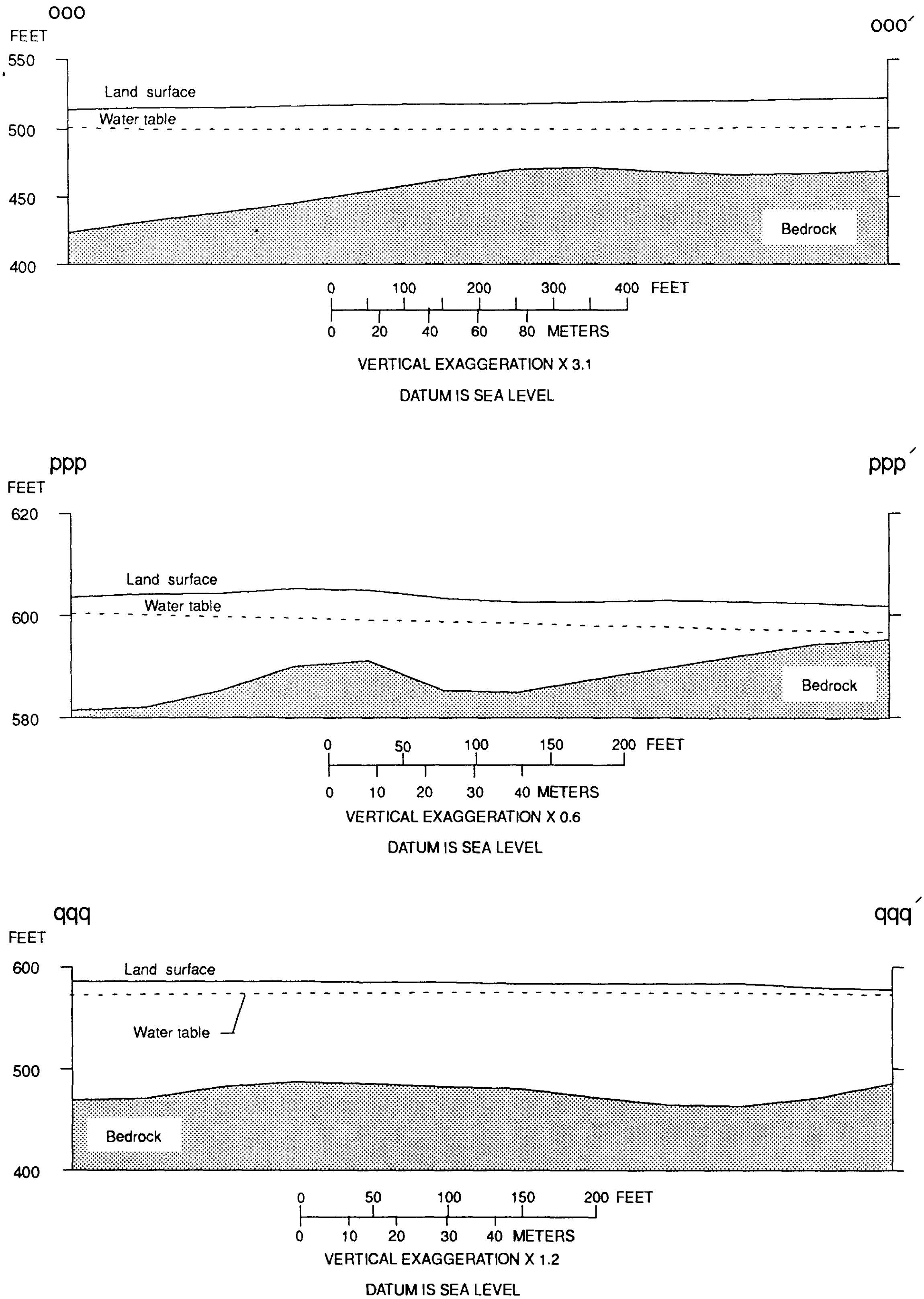
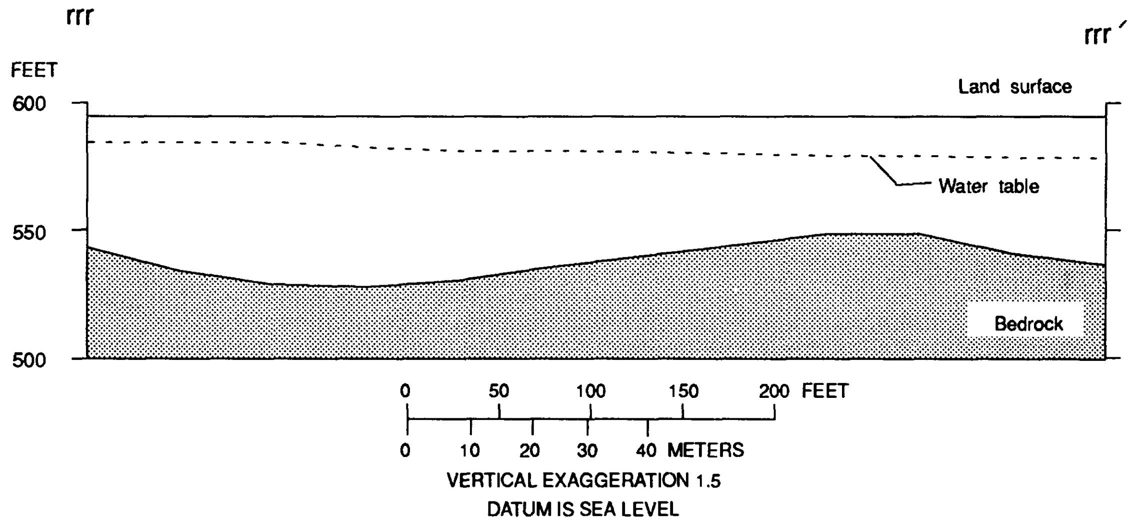


Figure 23.--Geologic sections interpreted from seismic-refraction data for Wakefield ooo-ooo', ppp-ppp', and qqq-qqq'.



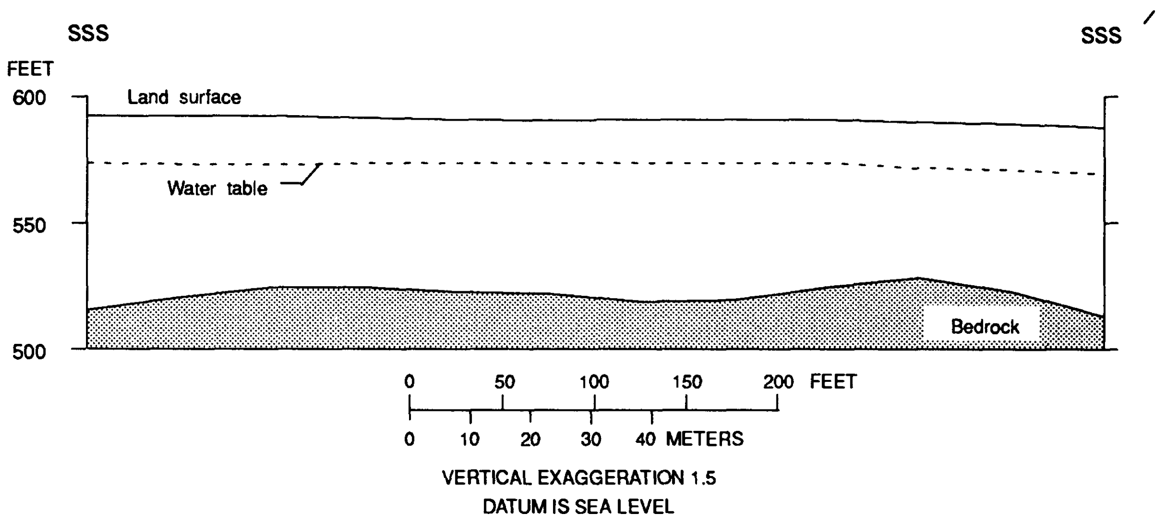


Figure 24.--Geologic sections interpreted from seismic-refraction data for Wakefield rrr-rrr' and sss-sss'.

ERRATA SHEET
WRIR 90-4161
GEOHYDROLOGY AND WATER QUALITY OF STRATIFIED-DRIFT AQUIFERS IN THE BELLAMY, COCHECO, AND SALMON FALLS RIVER BASINS, SOUTHEASTERN NEW HAMPSHIRE

PLATES 1-6 Add to EXPLANATION:

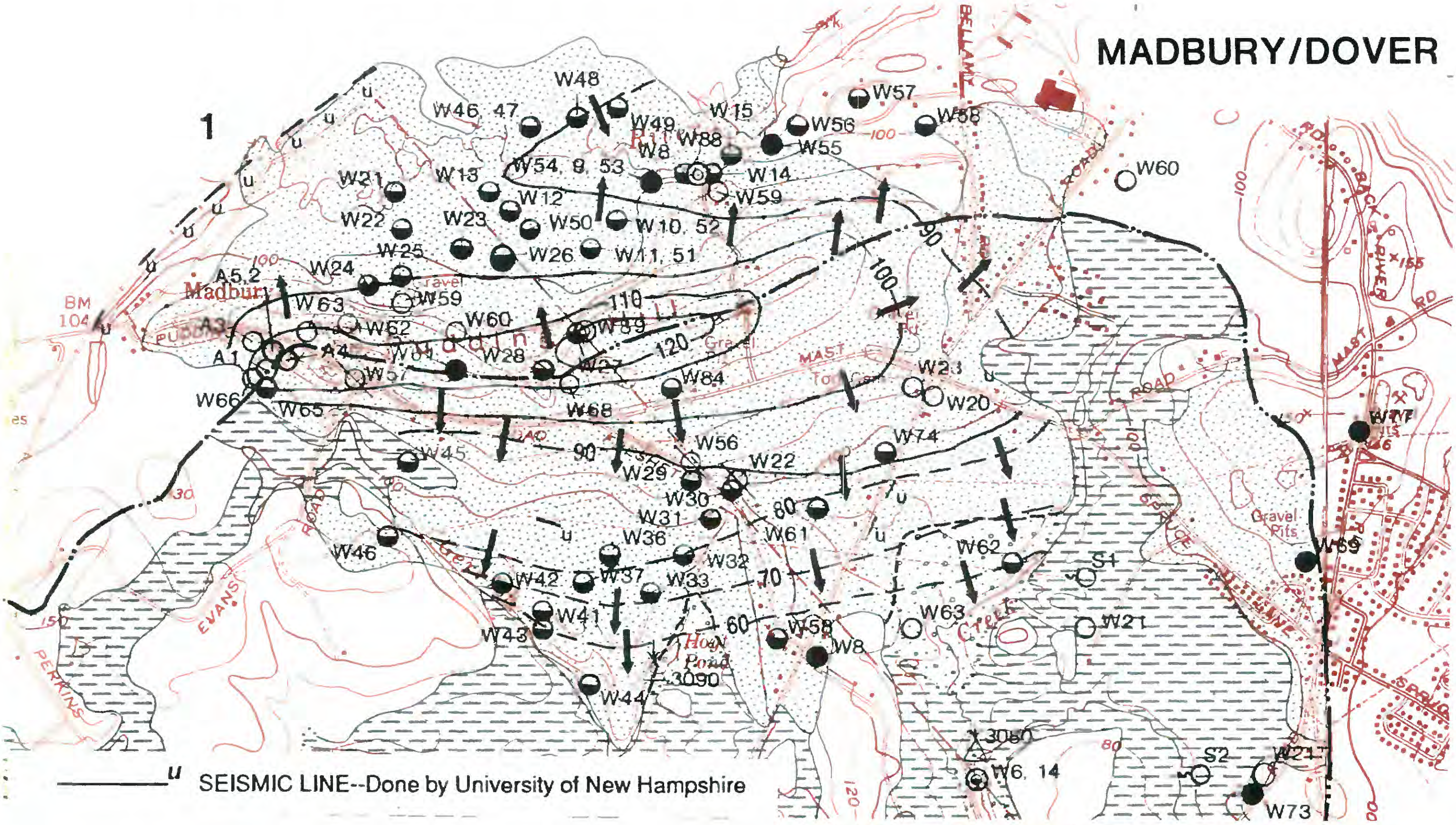
——— AQUIFER BOUNDARY AND (OR) GEOLOGIC CONTACT--Approximately located; dashed where inferred; dotted where concealed

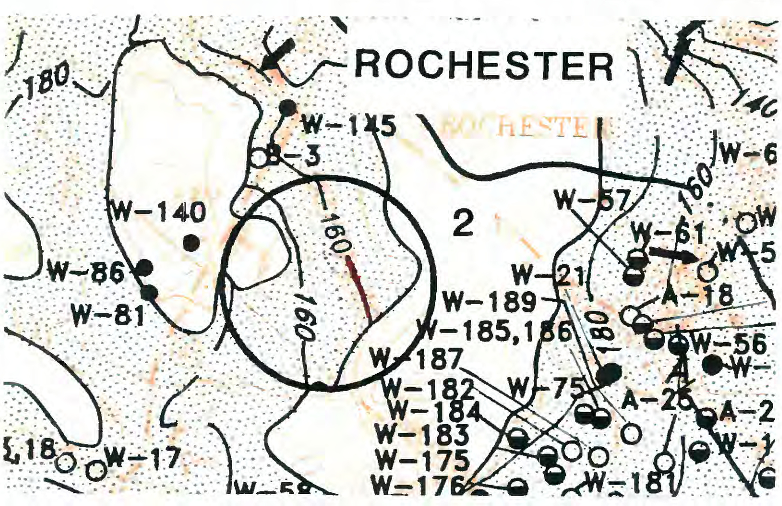
PLATES 2 AND 5 Change in latitude from 43°12'50" to 43°12'30":

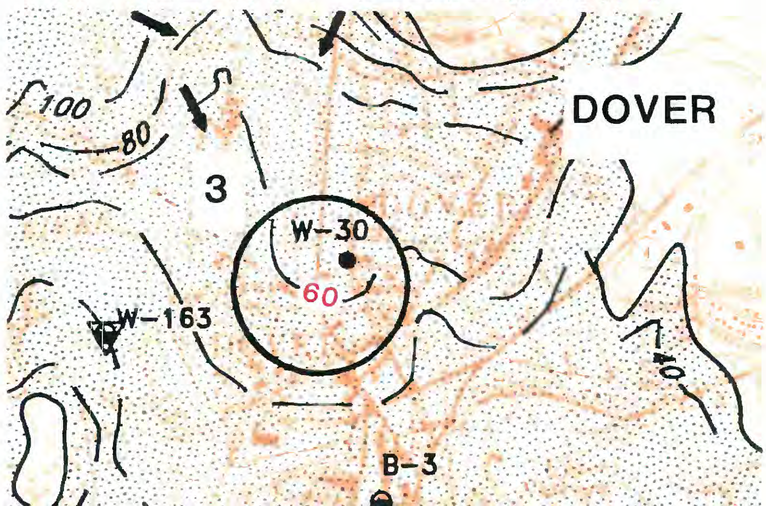
43°12'30" ⊢ ⊣ 43°12'30"

ERRATA SHEET
WRIR 90-4161 PLATE 1

ERROR	TOWN	NEAREST LANDMARK	CORRECTION
1	Madbury/Dover	Pudding Hill	Add missing data
2	Rochester	Isinglass River at Rochester-Barrington town line	Relocate 160 water-table contour
3	Dover	Sawyer School	Water-table contour 40 changed to 60



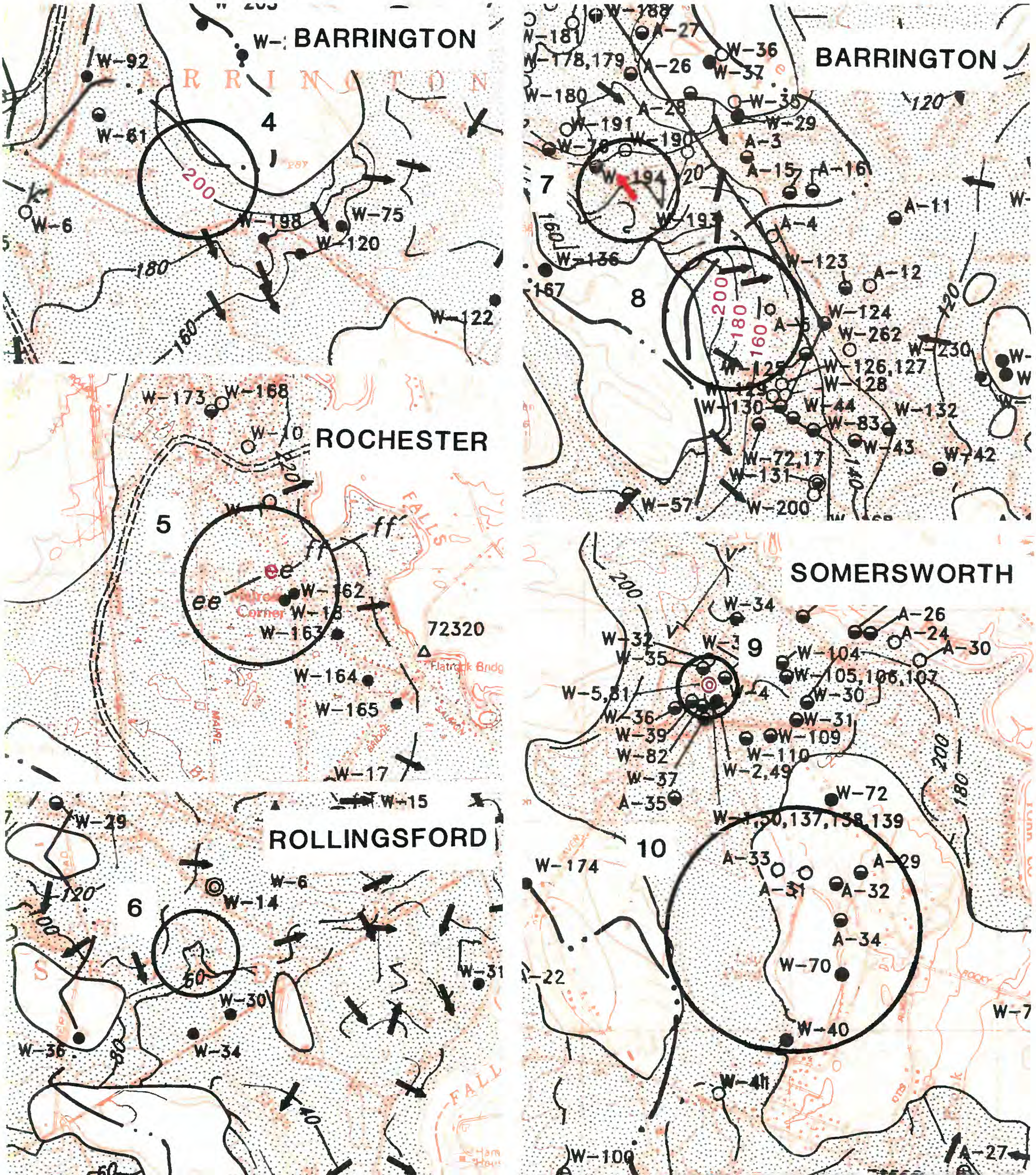




WRIR 90-4161 PLATE 1

GEOHYDROLOGY AND WATER QUALITY OF STRATIFIED-DRIFT AQUIFERS IN THE BELLAMY, COCHECO, AND SALMON FALLS RIVER BASINS, SOUTHEASTERN NEW HAMPSHIRE

ERROR	TOWN	NEAREST LANDMARK	CORRECTION
4	Barrington	East Barrington	Water-table contour 180 changed to 200
5	Rochester	Melrose Corner	Seismic line ee-e' changed to ee-ee'
6	Rollingsford	Southeast of St. Michaels Cemetery	Delete flow arrow on water-table contour 80
7	Barrington	East of Green Hill	Flow arrow on water-table contour 120 changed to opposite direction
8	Barrington	East of Green Hill	Water-table contours 140, 160, 180 changed to 160, 180, 200, respectively
9	Somersworth	Northwest of Lily Pond	Well symbol for W-5, 81 changed to municipal well symbol
10	Somersworth	Lily Pond	Lines around pond are deleted

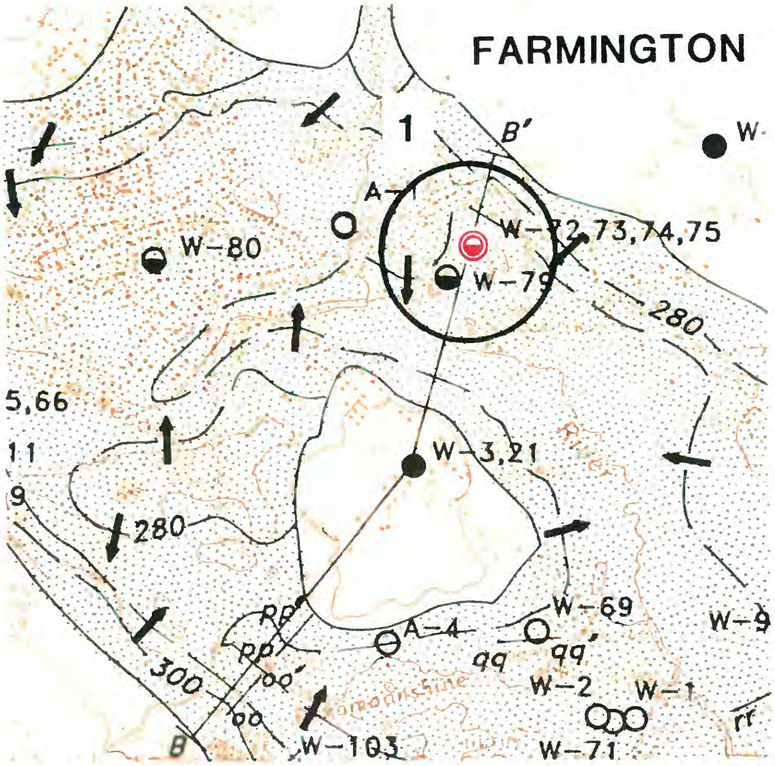


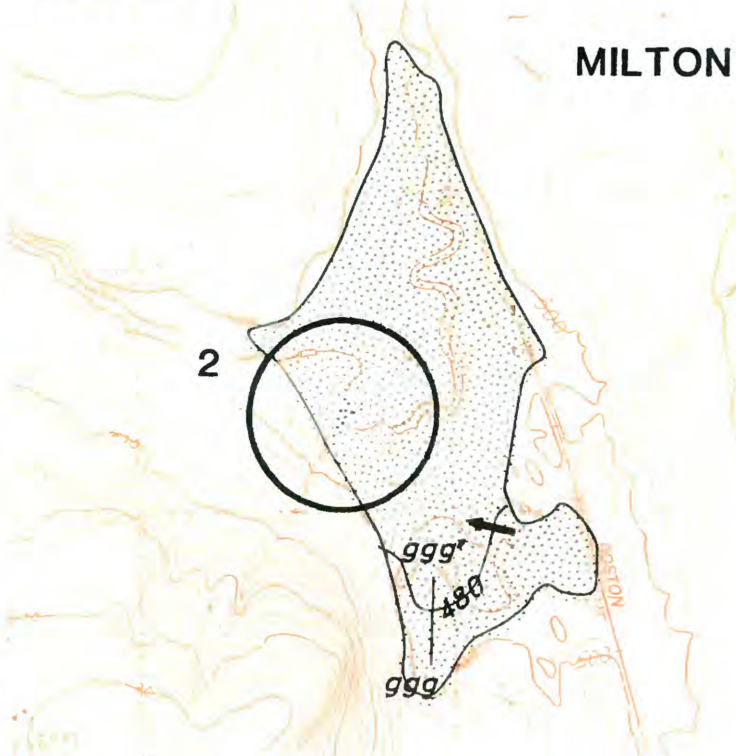
ERRATA SHEET

WRIR 90-4161 PLATE 3

GEOHYDROLOGY AND WATER QUALITY OF STRATIFIED-DRIFT AQUIFERS IN THE BELLAMY, COCHECO, AND SALMON FALLS RIVER BASINS, SOUTHEASTERN NEW HAMPSHIRE

ERROR	TOWN	NEAREST LANDMARK	CORRECTION
1	Farmington	Sewage disposal plant	Well symbol for Well-72,73,74,75 changed to municipal well
2	Milton	West of Milton Ridge	Delete flow arrow



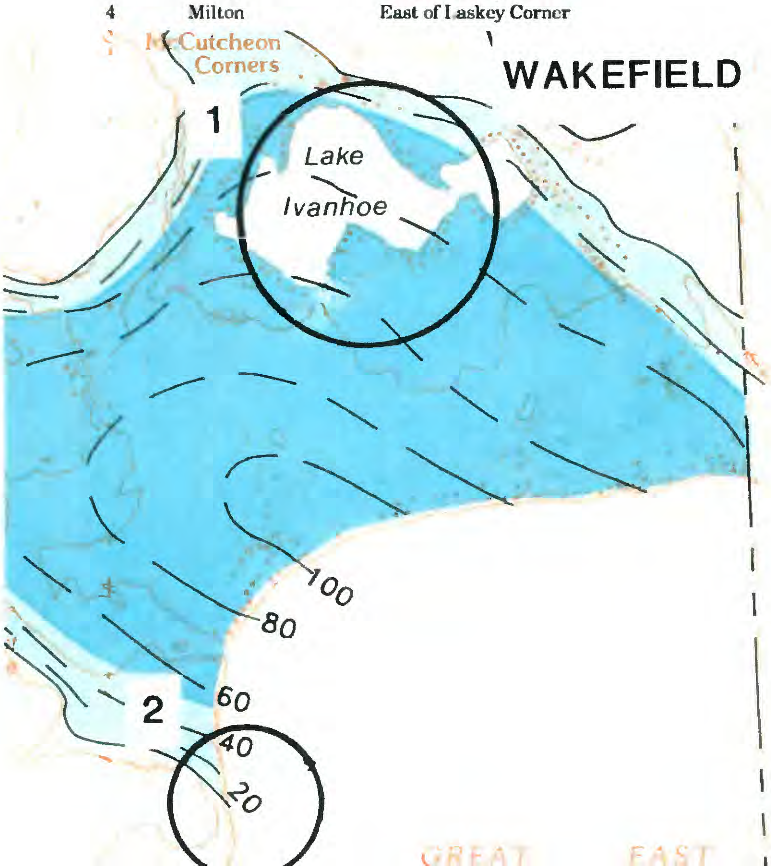


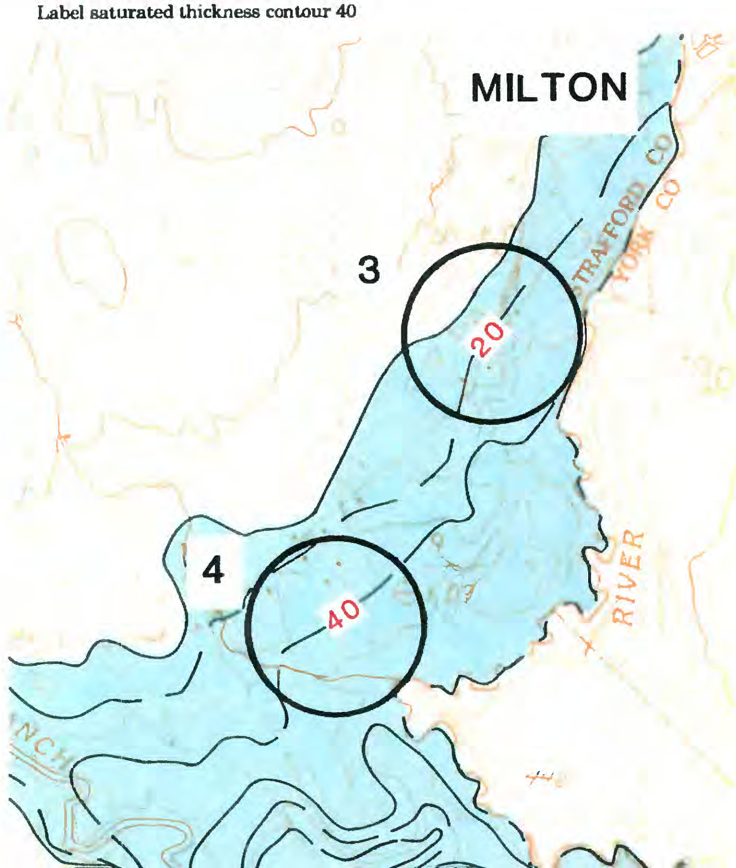
ERRATA SHEET

WRIR 90-4161 PLATE 6

GEOHYDROLOGY AND WATER QUALITY OF STRATIFIED-DRIFT AQUIFERS IN THE BELLAMY, COCHECO, AND SALMON FALLS RIVER BASINS, SOUTHEASTERN NEW HAMPSHIRE

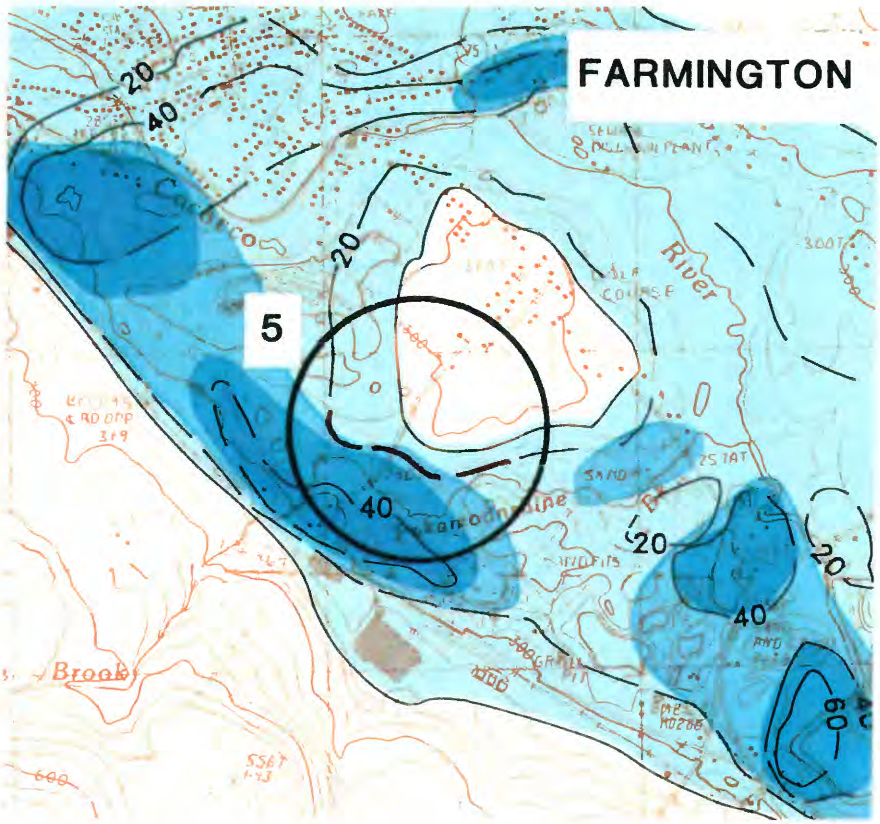
ERROR	TOWN	NEAREST LANDMARK	CORRECTION
1	Wakefield	Lake Ivanhoe	Delete blue tint in Lake Ivanhoe
2	Wakefield	Great East Lake	Delete aquifer boundary in Great East lake
3	Milton	East of Laskey Corner	Label saturated thickness contour 20
4	Milton	East of Laskey Corner	Label saturated thickness contour 40

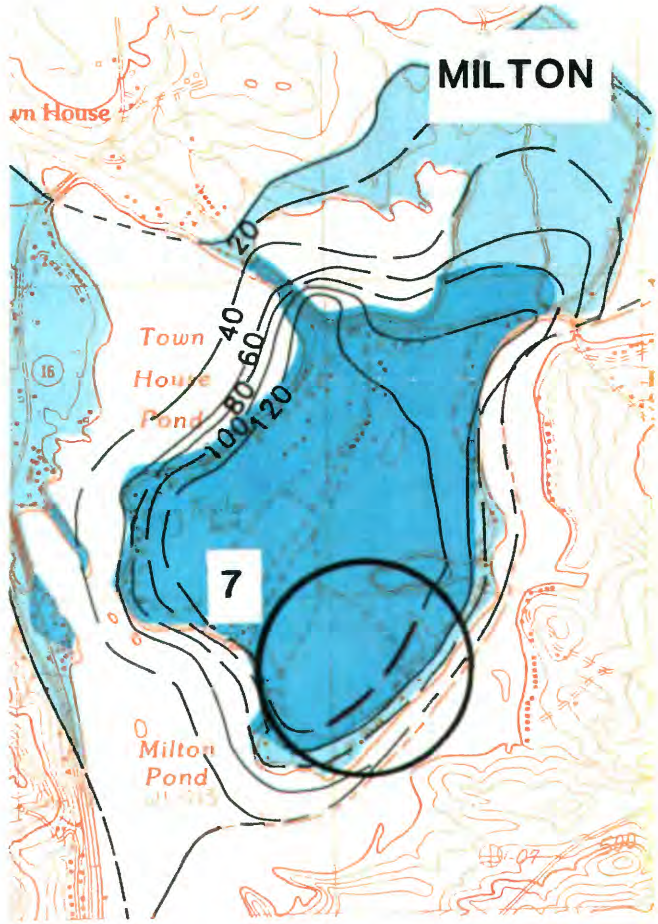


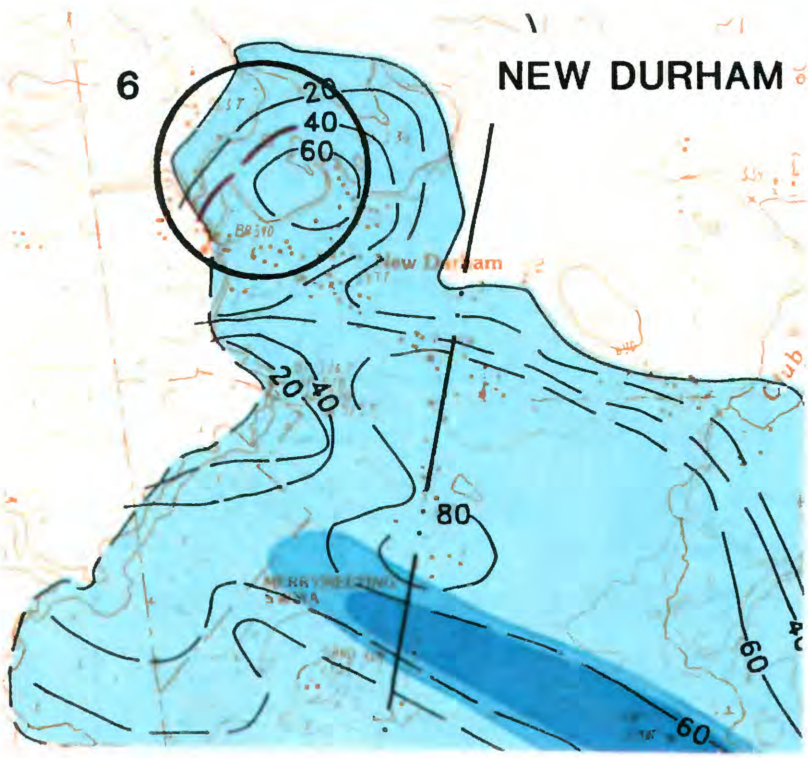


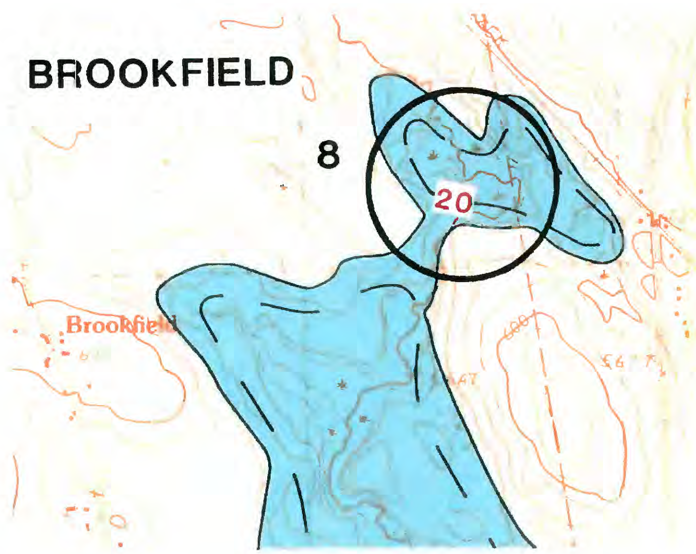
ERRATA SHEET
WRIR 90-4161 PLATE 6
GEOHYDROLOGY AND WATER QUALITY OF STRATIFIED-DRIFT AQUIFERS IN THE BELLAMY, COCHECO, AND SALMON FALLS RIVER BASINS, SOUTHEASTERN NEW HAMPSHIRE

ERROR	TOWN	NEAREST LANDMARK	CORRECTION
5	Farmington	Pokamoonshine Brook	Add saturated thickness contour 20
6	New Durham	1 mile west of Club Pond	Add saturated thickness contour 40
7	Milton	Milton Pond	Add saturated thickness contour 120
8	Brookfield	1 1/2 miles east of Kingswood Lake	Label saturated thickness contour 20







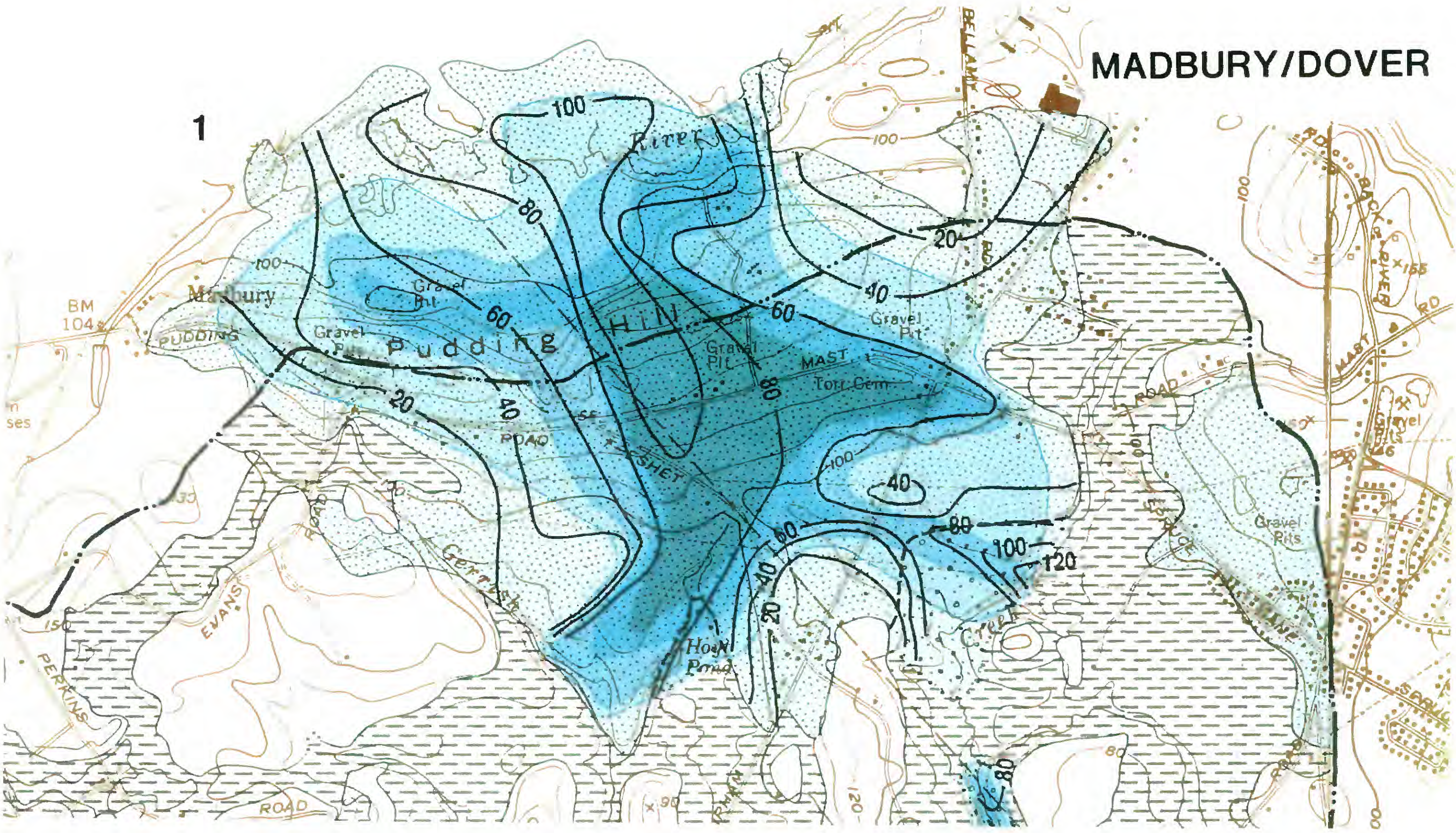


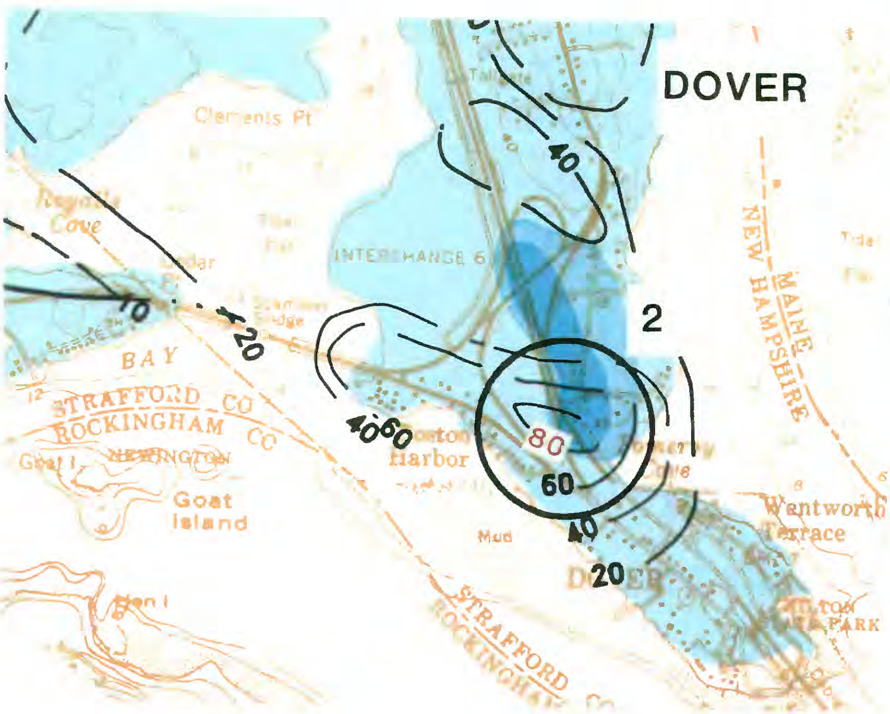
ERRATA SHEET

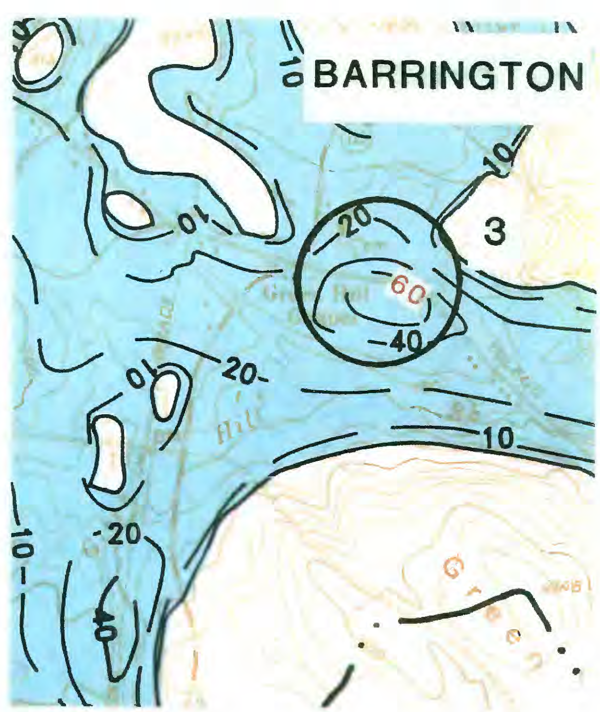
WRIR 90-4161 PLATE 4

GEOHYDROLOGY AND WATER QUALITY OF STRATIFIED-DRIFT AQUIFERS IN THE BELLAMY, COCHECO, AND SALMON FALLS RIVER BASINS, SOUTHEASTERN NEW HAMPSHIRE

ERROR	TOWN	NEAREST LANDMARK	CORRECTION
1	Madbury/Dover	Pudding Hill	Add missing data
2	Dover	Pomeroy Cove	Label saturated thickness contour 80
3	Barrington	Green Hill Chapel	Label saturated thickness contour 60





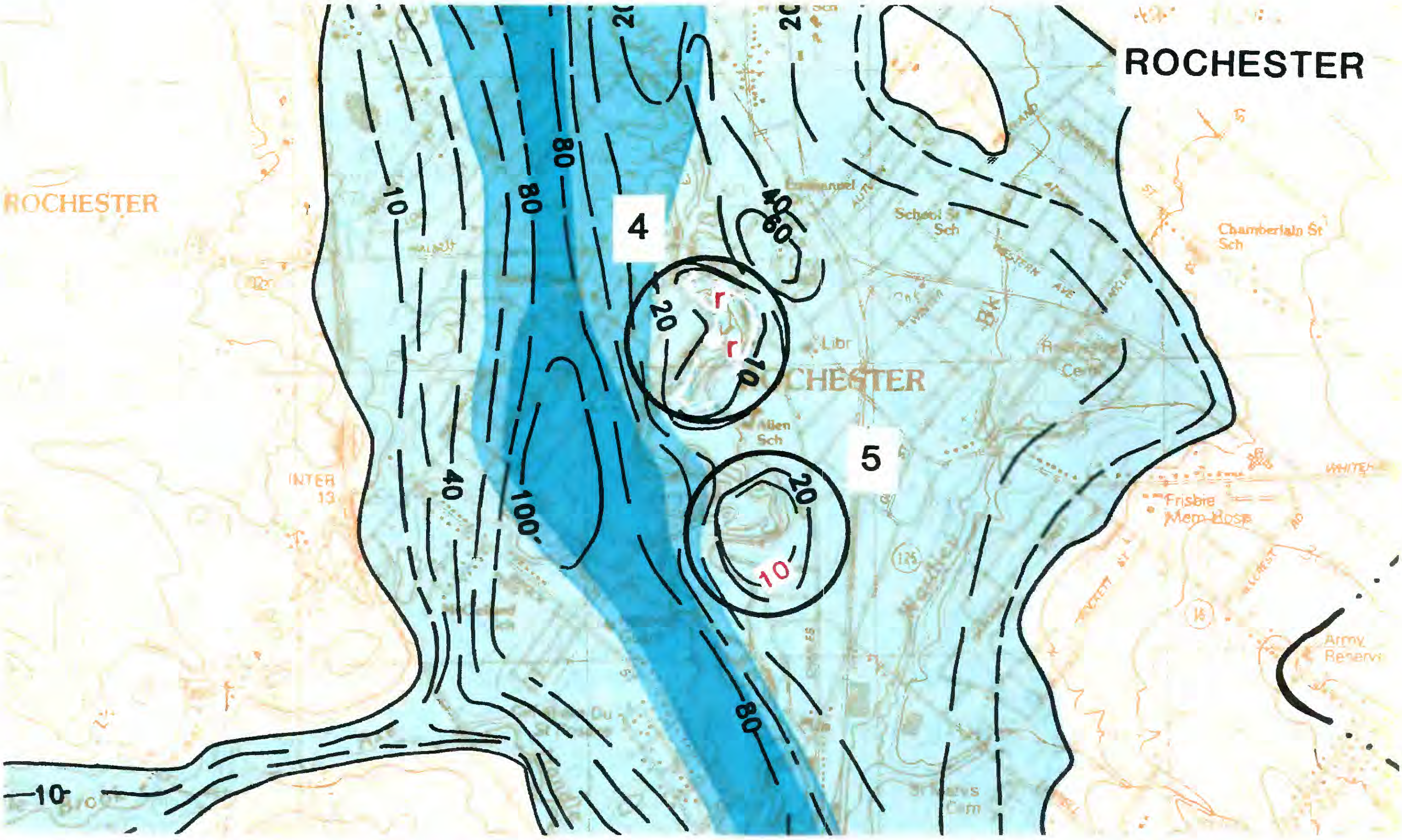


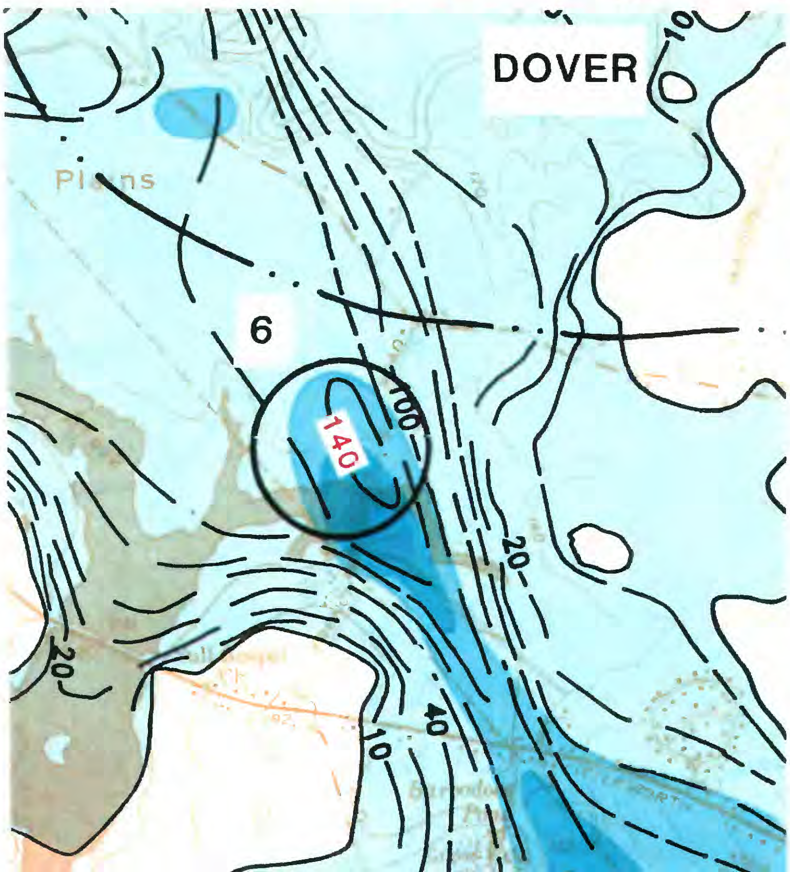
ERRATA SHEET

WRIR 90-4161 PLATE 4

GEOHYDROLOGY AND WATER QUALITY OF STRATIFIED-DRIFT AQUIFERS IN THE BELLAMY, COCHECO, AND SALMON FALLS RIVER BASINS, SOUTHEASTERN NEW HAMPSHIRE

ERROR	TOWN	NEAREST LANDMARK	CORRECTION
4	Rochester	Northwest of Allen School	Delete 0 saturated thickness contour and add 2 bedrock outcrops
5	Rochester	South of Allen School	Label saturated thickness contour 10
6	Dover	Southeast of Mallego Plains	Change saturated thickness contour from 120 to 140
7	Rollingsford	Fletcher Hill	Label saturated thickness contour 10





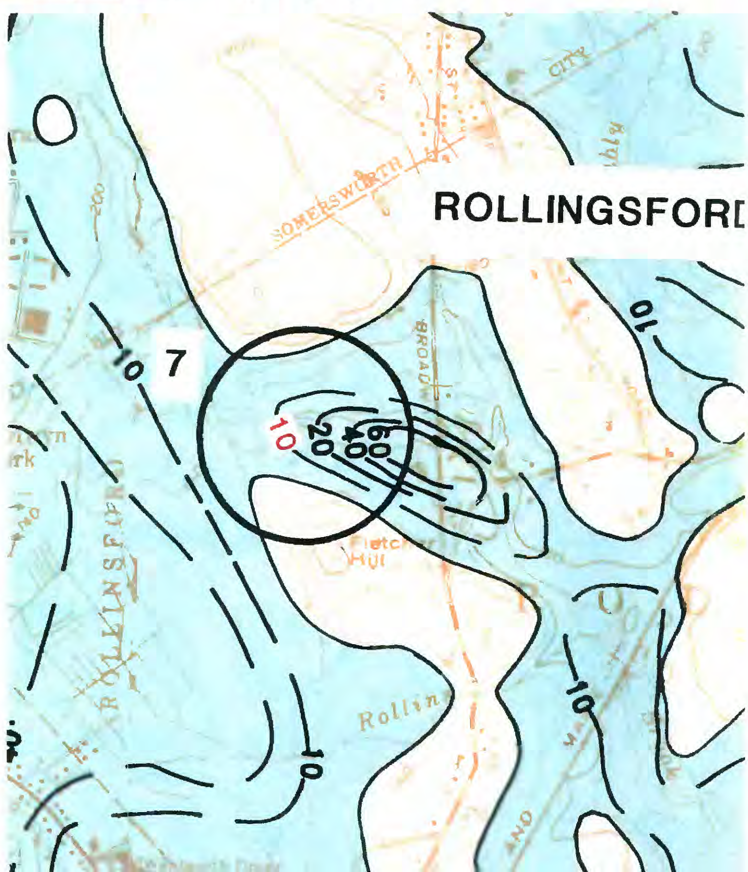


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Table 3.--*Average saturated thickness and estimated transmissivity and horizontal hydraulic conductivity according to published reports*

[ft²/d, feet squared per day; ft, foot; ft/d, foot per day]

Aquifer and location	Transmis-sivity (or range of) (ft²/d)	Average saturated thickness (or range of) (ft)	Horizontal hydraulic conductivity (ft/d)	Source of information
Willand Pond, Dover	6,700 to 5,300	37	162	(1)
Willand Pond, Dover	4,700	40	117	(2)
Pudding Hill, Dover	6,600 to 14,700	36	182 to 408	(1)
Barbadoes Pond, Dover	13,300	85	157	(1)
The Hoppers, Dover	13,300 to 26,700	54	245 to 490	(1)
West side, Farmington	12,600	40	315	(3)
East side, Farmington	[4]9,900	46	[4]215	(4)
Chestnut Hill Rd, Rochester	5,800 to [4]13,800	90	65 to 153	(5)
Willand Pond, Somersworth	2,400	44	54	(6)
Lily Pond, Somersworth	4,900 to 6,300	55	89 to 114	(7)

[1] Camp, Dresser and McKee, Inc. (1979).
[2] Caswell, Eichler, and Hill (1987).
[3] Layne-New England (1982).
[4] Layne-New England (1974).
[5] Ranney Water Collection Corporation (1947).
[6] Layne-New England, 1969.
[7] BCI Geonetics (1987).

Table 10.--*Summary of results of water-quality-sample analyses*

[A "less than symbol" proceeds values below a detection limit. The routines of Helsel and Gilliom (1986) were used to compute statistics on data containing "less thans"; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degree Celsius; mg/L, milligram per liter; µg/L, microgram per liter; --, no standard (or statistics cannot be calculated because sample populations are too small)]

(Detection Limit) Constituent or property (or accuracy)	[1]SMCL	[2]MCL	Number of samples	Number below detection limit	Mean	Median	Standard deviation	Minimum	Maximum	First quartile	Third quartile
Specific conductance, field (1 µS/cm at 25 °C)	--	--	23	0	138	140	96	20	330	40	220
Temperature (0.1 degrees Celsius)	--	--	23	0	10.2	10.0	2.4	7.0	17.5	8.0	11.5
Dissolved Oxygen (0.00 mg/L as O_2)	--	--	23	0	5.6	5.2	4.0	.0	13.1	2.1	9.1
pH, field (0.01 standard units)	6.5-8.5	--	23	--	--	6.18	.47	5.26	7.14	5.84	6.53
Color (1 platinum-cobalt units)	15	--	23	0	9	2	21	1	98	1	3
Alkalinity, field (1 mg/L as $CaCO_3$)	--	--	23	0	20	11	23	3	106	8	29
Hardness, total (mg/L as $CaCO_3$)	--	--	23	0	32	22	30	6	120	11	45
Solids, sum of constituents, dissolved, residue on evaporation at 180 °C (mg/L)	500	--	23	0	90	80	58	25	235	34	125
Calcium, dissolved (0.1 mg/L as Ca)	--	--	23	0	9.1	6.0	7.9	1.7	31.0	3.3	11.0
Magnesium, dissolved (0.1 mg/L as Mg)	--	--	23	0	2.34	1.70	2.58	.38	11.00	.60	3.00
Chloride, dissolved (0.1 mg/L as Cl)	250	--	23	0	22.5	18.0	21.6	1.6	83	2.6	35.0
Sodium, dissolved (0.1 mg/L as Na)	--	--	23	0	13.0	11.0	11.6	1.8	41	3.0	18.0
Nitrogen, ammonia, dissolved (0.01 mg/L)	--	--	23	16	.02	--	.03	< .01	.13	--	--
Potassium, dissolved (0.1 mg/L as K)	--	--	23	0	1.7	1.3	1.1	.3	4.1	1.0	2.7
Sulfate, dissolved (0.1 mg/L as SO_4)	250	--	23	0	11.6	8.8	10.4	.3	38	4.9	14
Fluoride, dissolved (0.1 mg/L as F)	2	4	23	5	.1	.1	.1	<.1	.2	.10	.15
Carbon, organic, dissolved (0.1 mg/L as C)	--	--	23	0	1.1	.8	1.0	.4	5.6	.7	1.1
Silica, dissolved (0.1 mg/L as SiO_2)	--	--	23	0	14.3	12.0	5.8	7.1	26	9.2	20.0
Arsenic, dissolved (1 mg/L as As)	--	50	23	15	3	--	5	<1	20	--	--
Barium, dissolved (2 µg/L as Ba)	--	1,000 ([3]500)	23	3	7	7	4	<2	16	4	10
Beryllium, dissolved (0.5 µg/L as Be)	--	--	23	18	--	--	--	< .5	.9	--	--
Boron, dissolved (10 µg/L as B)	--	--	23	16	7	--	9	<10	40	--	--
Cadmium, dissolved (1 µg/L as Cd)	--	10 ([3]5)	23	21	--	--	--	<1	3	--	--
Chromium, dissolved (10 µg/L as Cr)	--	50 ([3]100)	23	20	--	--	--	<10	20	--	--

Table 10.--*Summary of results of water-quality-sample analyses*--Continued

(Detection Limit) Constituent or property (or accuracy)	[1]SMCL	[2]MCL	Number of samples	Number below detection limit	Mean	Median	Standard deviation	Minimum	Maximum	First quartile	Third quartile
Cobalt, dissolved (1 µg/L as Co)	--	--	23	13	1	1	2	<1	10	0.4	1.0
Copper, dissolved (1 mg/L as Cu)	1,000	--	23	11	4	1	10	<1	44	.3	1.5
Iron, dissolved (3 µg/L as Fe)	300	--	23	2	2,109	20	4,771	<3	19,000	6	2,050
Lead, dissolved (5 mg/L as Pb)	--	50 ([3]5)	23	22	--	--	--	<5	110	--	--
Manganese, dissolved (1 µg/L as Mn)	50	--	23	0	300	84	645	3	3,100	23	420
Molybdenum, dissolved (1 mg/L as Mo)	--	--	22	16	--	--	--	<1.0	3	--	--
Mercury, dissolved (0.1 µg/L as Hg)	--	2	23	22	--	--	--	< .1	.1	--	--
Nickel, dissolved (1 mg/L as Ni)	--	--	23	12	2	1	4	<1.0	15	--	--
Silver, dissolved (1 µg/L as Ag)	--	50	23	23	--	--	--	<1	<1	--	--
Strontium, dissolved (3 µg/L as Sr)	--	--	13	1	69	59	41	<3	1,140	34	100
Zinc, dissolved (3 µg/L as Zn)	5,000	--	23	8	4	3	3	<3	12	--	--
Antimony, dissolved (1 mg/L as Sb)	--	--	23	21	--	--	--	<1	2	<1.0	<1.0
Aluminum, dissolved (10 µg/L as Al)	50	--	23	14	38	5	134	<10	650	2	20
Selenium, dissolved (1 µg/L as Se)	--	10 ([3]5)	23	21	--	--	--	<1	<3	--	--

[1] Secondary maximum contaminant level, set by the U.S. Environmental Protection Agency (1988d). Equivalent to USEPA secondary drinking-water regulation.
[2] Maximum contaminant level, set by the U.S. Environmental Protection Agency (1988a).
[3] Proposed maximum contaminant level set by the U.S. Environmental Protection Agency (1989b).