HYDROGEOLOGY, WATER QUALITY, AND EFFECTS OF INCREASED MUNICIPAL PUMPAGE OF THE SACO RIVER VALLEY GLACIAL AQUIFER: BARTLETT, NEW HAMPSHIRE TO FRYEBURG, MAINE

By Dorothy H. Tepper, Daniel J. Morrissey, Carole D. Johnson, and Thomas J. Maloney

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

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
	0.02832	cubic meter (m^3)
	Flow	
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
foot per second (ft/s)	3.048	decimeter per second (dm/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	3.785	liter per minute (L/min)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter or micrograms per liter. Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water; 1,000 μg/L (micrograms per liter) is equivalent to 1 mg/L (milligram per liter). For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

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CONVERSION FACTORS AND ABBREVIATIONS (continued)

Bacterial determinations are expressed as counts per hundred milliliters of sample, where a milliliter is 1/1,000 of a liter.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$F = 1.8\,(°C) + 32$$

Specific-conductance data are reported in μS/cm (microsiemens per centimeter at 25 degrees Celsius). Identical units are used for this analysis in the inch-pound and metric systems of measurement.

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."

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Hydrogeology, Water Quality, and Effects of Increased Municipal Pumpage of the Saco River Valley Glacial Aquifer: Bartlett, New Hampshire to Fryeburg, Maine

By Dorothy H. Tepper, Daniel J. Morrissey, Carole D. Johnson, and Thomas J. Maloney

ABSTRACT

The extensive, unconfined sand and gravel aquifer located along the Saco River from Bartlett, New Hampshire to Fryeburg, Maine, is an important water supply for this region. The aquifer ranges in width from 1 to 3 miles, covers a surface area of 39 mi^2 (square miles) and is located in the foothills of the White Mountains. Saturated thicknesses ranged from 10 ft (feet) or less near the valley walls to approximately 280 ft near the center of the valley in Fryeburg. Hydraulic-conductivity values based on grain-size distribution ranged from 11 ft/d (feet per day) for silt and very fine sand to 97 ft/d for very coarse sand and gravel. Hydraulic-conductivity values determined using a slug-test method designed for use in highly permeable sediments ranged from 2 ft/d for silt and very fine sand to 210 ft/d for very coarse sand and gravel.

The principal flow path in the aquifer is in a cross-valley direction from the till-covered or bedrock uplands toward the Saco River, the major ground-water discharge zone. Gradients are steepest near the valley walls and flatten towards the center of the valley. A ground-water flow divide, which coincides with a surface-water divide, is located to the northeast of Pine Hill in the Redstone area of Conway, New Hampshire. Another ground-water flow divide is located in the area from north of Swans Falls to northwest of Fryeburg Center, Maine, and has an approximate southwest-northeast trend.

The average annual recharge from precipitation falling directly on the aquifer is approximately 24 in/yr (inches per year), or half the average annual precipitation. The average annual runoff from upland sources is about 32 in/yr. Seepage to the aquifer from tributary streams also is an important source of recharge.

Ground-water quality in uncontaminated areas was characterized by low specific conductance (median = 54 microsiemens per centimeter at 25 degrees Celsius), moderate acidity (median pH = 5.8), and low alkalinity (median = 9.0 mg/L (milligrams per liter) as $CaCO_3$). The ground water generally was soft (median hardness = 12.2 mg/L as $CaCO_3$). The principal cations were calcium and sodium, and the principal anions were bicarbonate and chloride. Ground-water samples from agricultural areas had the highest median concentrations of calcium, magnesium, and total phosphorus, and the highest concentrations of total orthophosphorus and potassium. The high concentrations probably resulted from the use of fertilizers. Ground-water samples from a heavily developed area along State Route 16 in Conway had the highest median values of sodium and chloride, primarily as a result of use of deicing salts on the roads. The highest median values and highest maximum values for nitrite and nitrate, ammonium, ammonium and organic nitrogen, and organic nitrogen also were found in ground-water samples from this area. These high concentrations and the elevated levels of MBAS (methylene blue active substances), used in detergents, probably resulted from septic-tank discharges.

Dissolved-solids concentrations at medium streamflow conditions in the Saco River increased approximately 20 percent in a downstream direction. The highest concentrations of fecal coliform and fecal streptococci were found immediately downstream from populated areas along the mainstem of the Saco River. Degradation of water quality along the Old Course of the Saco River was indicated by increased nutrient and decreased dissolved-oxygen concentrations and by elevated bacteria counts.

A two-dimensional finite-difference model of ground-water flow in the Saco River valley aquifer was developed and calibrated to long-term water-level conditions. The pattern of recharge simulated in the model, in which runoff from upland areas provides most of the recharge, is conceptually different from other models of stratified-drift river valley aquifers in New England, which derive most of their recharge from precipitation falling directly on the aquifer. Water levels computed with the model were most sensitive to decreases in aquifer hydraulic conductivity.

The calibrated model was used to predict the effects of present (1985) and increased pumpage under varying recharge conditions on ground-water levels and on the size of contributing areas to municipal wells. The maximum pumpage simulated with the model was 11.1 cubic feet per second from 7 wells located in Lower Bartlett, North Conway, and Conway Village, New Hampshire. During periods of low recharge, this pumpage comprised 23 percent of the ground water flowing through the aquifer. Under the various pumpage scenarios used to simulate low recharge periods, water levels declined up to 17 ft along aquifer boundaries and from 0.3 to 11.1 ft near municipal wells.

Contributing areas for present (1985) and proposed municipal wells were estimated with a particle-tracking model that was coupled with the ground-water flow model. The contributing areas within the aquifer for a scenario of proposed pumpage under low recharge conditions ranged from 0.2 to 1.0 mi^2*. These contributing areas are much larger than the present 400-ft-radius zones commonly protected by legislation in New Hampshire. The total contributing areas to pumped wells in this scenario are much larger than the contributing areas within the aquifer itself because upland areas adjacent to the aquifer also contribute significant quantities of recharge. The East Branch of the Saco River, Lucy Brook, Kearsarge Brook, and the Saco River are important sources of induced infiltration for the municipal wells in this scenario.*

INTRODUCTION

Background

The extensive, unconfined sand and gravel aquifer located along the Saco River from Bartlett, New Hampshire to Fryeburg, Maine (fig. 1) is an important water supply for this region. Municipal wells in the Lower Bartlett Water Precinct, North Conway Water Precinct, Conway Village Fire District, and the Fryeburg Water Company pump approximately 3 Mgal/d (million gallons per day) of ground water. In addition, numerous domestic wells tap the aquifer. Increased water-quality demands are anticipated because the area is experiencing rapid growth.

Municipalities are concerned with the effects of land-use practices on ground-water quality. Increased septic-system discharge is of particular concern as a result of rapid development in the Conway area. In Fryeburg, the primary concern is the effects of agriculture on water quality.

Purpose and Scope

This report presents results of a detailed investigation of the Saco River valley glacial aquifer initiated in 1983 by the U.S. Geological Survey in cooperation with the Maine Geological Survey (Department of Conservation), the New Hampshire Water Supply and Pollution Control Commission, the New Hampshire Water Resources Board, and the Town of Conway, New Hampshire. The objectives of the study were to determine the dimensions of the aquifer, the effect of various land-use practices on ground-water quality, and the effects of increased pumpage at municipal wells on ground-water levels and on the size of contributing areas to the wells.

The scope of the work included inventorying of wells; mapping of surficial geology to determine aquifer boundaries; drilling of exploration holes to obtain information on stratigraphy, grain size, depths to the water table and to the bedrock surface, and water quality; slug tests and analyses of grain-size distribution to determine hydraulic conductivity; seismic-refraction and seismic-reflection profiling to determine depths to the water table and to the bedrock surface, and gross aquifer stratigraphy; monthly water-level measurements to monitor changes in head over time; water-quality analyses of ground water and surface water; installa-

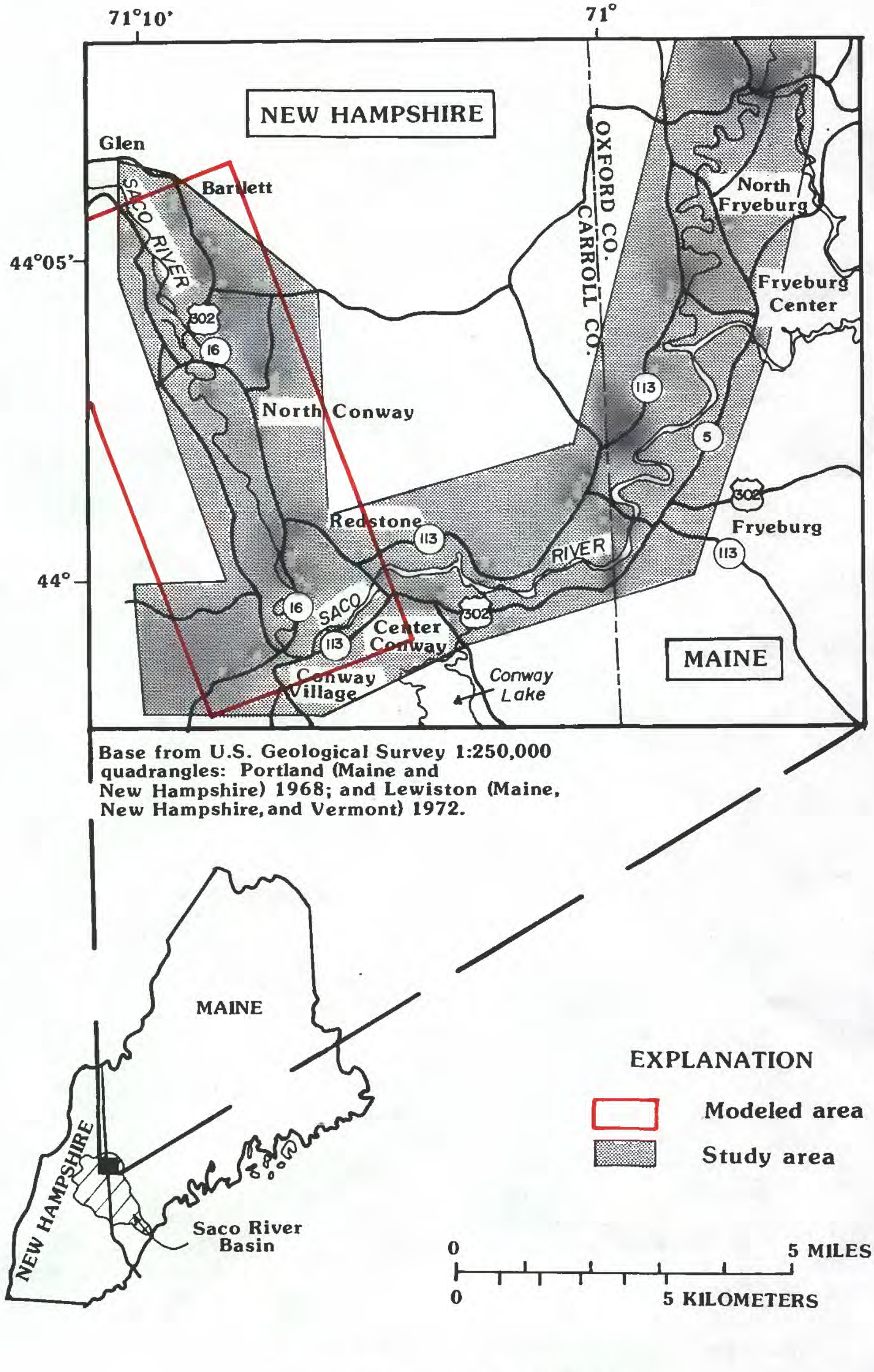

Figure 1.--Location of the study area

tion of temporary streamflow-gaging stations to monitor surface-water inflow and outflow; and discharge measurements to identify gaining and losing reaches of streams. A two-dimensional ground-water flow model was constructed to simulate flow in the aquifer under steady-state conditions. A series of pumping scenarios utilizing differing amounts of recharge and pumpage was used to predict the effects of increased pumpage on ground-water levels and on the size of contributing areas to municipal wells.

Hydrogeologic interpretations in this report were based on information from previous investigations and on data collected from October 1983 through January 1986 as part of this study. Basic data for this study, including observation-well logs, grain-size analyses, and information on water levels, water quality, and streamflow, are presented in a companion report by Johnson and others (1987). Marine-reflection data collected in 1984 are presented in Morrissey and others (1985).

Previous Investigations

Several previous investigators have studied the hydrogeology, water resources, and surficial and bedrock geology of the study area. Aquifer-yield zones were mapped in the Conway area by Cotton (1975) as part of a study of ground-water availability in the Saco River basin in New Hampshire. Well-inventory data were collected by Prescott (1979) as part of a study of the Royal, Upper Presumpscot, and Upper Saco River basins in Maine. Ground-water availability for this same region was mapped by Prescott (1980). Test-hole logs, seismic-refraction data, water-level data, water-quality data, aquifer boundaries, estimated yield zones, depths to the water table and to the bedrock surface, well-inventory data, and locations of potential ground-water contamination sites for the Fryeburg area are presented in Tepper and Lanctot (1987a,b) and in Williams and others (1987). The hydrogeology of the study area has been the subject of many recent site investigations including studies by Metcalf & Eddy, Inc. (1986), Geotechnical Engineers, Inc. (1986), Bradley (1985), DuBois and King, Inc. (1978, 1985), and Anderson-Nichols, Inc. (1980). Investigations at an industrial site near Pequawket Pond were on-going at the time of this study (1985). The site is on the national priority list for cleanup under the U.S. Environmental Protection Agency's Superfund Program. There is particular concern with possible hazardous-waste migration off-site because the two Conway Village municipal wells are located less than 1 mile northwest of the site.

Other studies have provided information relating to water resources in the study area. The U.S. Army Corps of Engineers (1982) completed a water-supply study for the Saco and other southern Maine coastal river basins. The U.S. Department of Agriculture (1983a,b) studied the water, forest, fish and wildlife, economic, social, land, and flood-plain resources of the Saco River basin in Maine and New Hampshire.

Surficial deposits in the Ossipee Lake quadrangle in New Hampshire were mapped by Newton (1974). The surficial geology in the Fryeburg area was mapped by Leavitt and Perkins (1935) as part of a statewide study of glacial geology. Additional surficial mapping in the Fryeburg area was done at a reconnaissance level by Prescott (1980) and at a detailed level by Thompson (1987).

The bedrock geology of the North Conway quadrangle, in the northwestern part of the study area, was mapped by Creasy (1986). Wilson (1969) described the bedrock geology of the Ossipee Lake quadrangle, in the southwestern part of the study area. The bedrock geology of the Fryeburg quadrangle, in the southeastern part of the study area, was mapped by Moench and others (1982).

Methods of Investigation

The methods of investigation are discussed in more detail in Johnson and others (1987). Fieldwork for the study was conducted from October 1983 through January 1986. All data-collection sites are shown on plate 1.

Well-inventory information was collected from owners of domestic wells and from well-drillers' records. The aquifer boundaries were mapped at the surface by delineating the contact between the sand and gravel deposits and the till.

A total of 69 exploration holes were drilled to obtain information on stratigraphy, hydraulic properties, depths to the water table and to the bedrock surface, and water quality. Split-spoon samples were collected and logged every 5 to 20 ft (feet) below the water table. Data on grain-size distribution of 130 sediment samples were collected to estimate hydraulic conductivity. Sixty-eight of the exploration holes were cased and screened and are referred to in this report as "observation wells"; the remaining exploration hole that was not cased is referred to as a "test hole."

Hydraulic conductivity also was determined in situ at 18 selected observation wells using a technique developed by Prosser (1981) and modified by Fish (Fish, J. E., U.S. Geological Survey, written commun., 1985). With this technique, pneumatically induced head change is measured by an electronic pressure transducer and recorded on an analog chart recorder. Hydraulic conductivity was calculated using an equation developed by Hvorslev (1951).

An observation-well network was established that included domestic wells, municipal observation wells, 3 wells installed by the U.S. Geological Survey for other studies, and the 68 observation wells drilled for this study. Ground-water levels were measured monthly at 100 locations and continuously at 7 sites equipped with recorders. Land-surface datum at all wells in the network was determined with respect to sea level.

Ground-water samples from selected observation, domestic, and municipal wells were analyzed for common inorganic and organic constituents. Forty-eight wells were sampled from July through September 1984 and 82 wells (including 37 wells that were previously sampled) were sampled from August through September 1985. Samples collected in 1985 from selected wells in the vicinity of State Route 16 near North Conway were analyzed for detergents and volatile organics. Analyses for common inorganic constituents and bacteria were performed on 12 surface-water samples collected from September 30 through October 4, 1985 from sites along the Saco River and its tributaries.

Four temporary streamflow-gaging stations installed for this study and two gages already in operation were used to monitor surface-water inflow to and outflow from the study area. Discharge was measured along the mainstem of the Saco River during low-flow periods to identify losing and gaining reaches. In addition, 46 seepage runs and 15 miscellaneous discharge measurements were conducted on 6 tributary streams under a variety of flow conditions to determine recharge to the aquifer. Five miscellaneous discharge measurements were made on the Old Course of the Saco River.

Seismic-refraction surveys were used to determine the depths to the water table and to the bedrock surface, and the bedrock-surface topography. These surveys, which were conducted using methods described in Haeni (1986), were completed at 67 sites and had a combined total linear coverage of 23.7 mi (miles). The interpretation of field data was based on time-delay and ray-tracing techniques described by Scott and others (1972).

Seismic-reflection profiles were used to map the altitude of the bedrock surface, to determine the saturated thickness of the aquifer, and to define gross aquifer stratigraphy. The methods of investigation used in this study are discussed in detail in Morrissey and others (1985). Twenty miles of marine seismic-reflection data were collected on the Saco River. An 8-mi-long profile was completed from the River Road bridge in North Conway downstream to the mouth of the Swift River. A 12-mi-long profile was completed from Center Conway to the State Route 5 bridge in Fryeburg.

A two-dimensional digital ground-water flow model was constructed to simulate the flow system under steady-state conditions in a 15 mi^2 (square mile) section of the aquifer in New Hampshire. A series of pumpage scenarios using differing amounts of recharge and pumpage at municipal wells was used to predict the effects of increased pumpage on ground-water levels and on the size of contributing areas to municipal wells.

Well- and Site-Numbering System

The numbering of wells and observation wells is consistent with the U.S. Geological Survey's grid-numbering system, which is based on latitude and longitude. The 15-digit identification number is composed of 6 digits for latitude, 7 digits for longitude and 2 digits (assigned sequentially) for adjacent sites located within the same 1-square-second area.

A project well-numbering system also was used. Sites are classified with the appropriate two-or three-letter code as follows: OW (observation well); MW (municipal well); MOW (municipal observation well); DW (domestic well); TH (test hole); and SP (spring). The sites are numbered roughly sequentially from north to south in Conway and from south to north in Fryeburg, following the direction of flow in the Saco River. At several sites, a deep-screened observation well was installed adjacent to a shallow-screened observation well. These wells are denoted as "D" for deep and "S" for shallow. For example, "OW22D" is a deep well and "OW22S" is a shallow well installed adjacent to it. Where a well cluster was installed, the wells are denoted alphabetically. For example, "OW21A," "OW21B," "OW21C," and "OW21D" are all located at the same site but are screened at different depths. Municipal wells are denoted with the "MW" code followed by a number and proposed municipal wells are denoted as above but followed by a letter. For example, the Lower

Bartlett municipal well is denoted "MW1" and the proposed municipal well is denoted "MW1A."

The surface-water sites are numbered in downstream order. Stations are listed in order in a downstream direction along the mainstem. All stations on a tributary that enters between two mainstem stations are listed between them. A detailed description of this numbering system is presented in Blackey and others (1985).

Hydrogeologic data for observation wells drilled for this study were entered into the U.S. Geological Survey's Ground Water Site Inventory (GWSI) data base. Each well and boring entered into the data base is referenced by a 15-digit identification number, project identification number, and by the individual State identification numbering system (county code and sequential number in Maine; town code and sequential number in New Hampshire).

Description of Study Area

Physiography and Climate

The study area (fig. 1) is located in the Central Highlands physiographic province of New England (Denny, 1982). The land surface is characterized by the broad, relatively flat valley of the Saco River. The valley ranges in width from about 1 to 3 mi. The valley walls, which are foothills of the White Mountains, rise as much as 2,700 ft above the valley floor.

The Saco River provides primary drainage for the study area. It originates in the White Mountains of eastern New Hampshire and flows southeasterly approximately 130 mi to the coast of southwestern Maine, where it discharges into the ocean. The Saco River enters the study area in Bartlett and flows southward to Center Conway and then northeastward into Fryeburg, Maine. It drops approximately 120 ft from the mouth of the East Branch of the Saco River in Lower Bartlett to the State Route 5 bridge in Fryeburg, a distance of 29 river miles. It flows over a power-utility dam at Swans Falls in the Fryeburg area.

The Saco River previously flowed through North Fryeburg, Fryeburg Harbor, and Fryeburg Center (pl. 1). This old channel, now abandoned and referred to as the Old Course of the Saco River, is characterized by extensive meander development, bars, cut-off meanders, small oxbow lakes, and relatively stagnant flow. The Saco River now flows between the former Bear Pond (no longer in existence) and Bog Pond through a canal, which was built in 1819 to control flooding and to increase agricultural acreage (Souther, 1861). In 1820, a spring flood widened and deepened the canal.

Major tributaries of the Saco River within the study area (pl. 1) include the East Branch of the Saco River, Lucy Brook, Kearsarge Brook, Moat Brook, Swift River, and Mason Brook. The Swift River is the largest of these tributaries and has a drainage area of 114 mi^2 (U.S. Department of Agriculture, 1983a). Other significant surface-water bodies within the study area include Echo Lake, Pudding Pond, Pequawket Pond, Lovewell Pond, Wards Pond, Bog Pond, Lower Kimball Pond, and Charles Pond (pl. 1).

The climate is characterized by mild summers and moderately severe winters. The long-term average annual precipitation is 48 in/yr (inches per year) on the basis of records from a rain gage in North Conway (U.S. Department of Commerce, 1959-85) and unpublished fire-danger and weather records collected in Conway Village at the Saco Ranger Station in the White Mountain National Forest. Free-water-surface evapotranspiration is approximately 28 in/yr (Farnsworth and others, 1982); most of the evapotranspiration occurs during the summer months.

Land Use and Population

Major land uses in the Conway area include small businesses, light industry, farming, and residences. The economy of the area depends largely on tourism. Most retail businesses and light industries are located along State Route 16. Land use in East Conway and Fryeburg is primarily agricultural.

The study area has experienced rapid population growth. In 1986, the year-round residential population of Conway was about 7,800 (New Hampshire Office of State Planning, 1987). During the peak tourist season, which occurs in July and August, the total population is almost 20,000. The lull in the tourist season occurs in March, at which time the total population falls to about 11,900 (Metcalf and Eddy, 1986).

The population of Fryeburg in 1980 was 2,715 (Tower Publishing Company, 1987). The present population is estimated to exceed 3,000 people (Shaw, T., Town of Fryeburg, oral commun., 1987).

Geologic Setting

Bedrock Geology

Lithology

The section of the Saco River valley aquifer that extends southward from Lower Bartlett approximately to Conway Village (fig. 1) is underlain by Jurassic biotite-granites, which belong to the White Mountain Plutonic-Volcanic Suite (Lyons and others, 1986). The remainder of the study area is underlain by Carboniferous binary (two-mica) granites, which belong to the Sebago pluton (Lyons and others, 1986; Osberg and others, 1985).

The bedrock under the entire study area is dense and has virtually no primary permeability. However, ground water may be obtained from secondary openings, such as joints and fractures (Prescott, 1980; Cotton, 1975). Although the bedrock is relatively impermeable compared with the overlying sand and gravel, many wells drilled into the bedrock are used for domestic water supplies in the valley. Yields in these domestic wells typically range from 2 to 20 gal/min (gallons per minute). No bedrock wells in the study area are known to yield more than 100 gal/min.

Extensively weathered bedrock, locally called "rottenrock," crops out in several places in the Conway area. Drillers also have reported encountering this material (Tasker, E., Tasker Well Drilling, oral commun., 1984). Newton (1974) postulated that the weathering occurred during the last interglacial period and that the weathered material was not completely removed by subsequent glaciation. The material typically crumbles easily and can be broken from an outcrop by hand. This weathered zone may yield substantial amounts of ground water; however, an investigation of this zone was beyond the scope of this study.

Bedrock-surface topography

The bedrock surface forms the lower boundary of the aquifer in the Conway area. In the Fryeburg area, the bottom of the aquifer was defined as the contact between till and stratified drift, which typically is within 20 ft of the bedrock surface. The altitude of the bedrock surface (pl. 2) was determined from seismic-refraction surveys (fig. 23, at back of report; pl. 1); seismic-reflection surveys (pl. 1) (Morrissey and others, 1985); observation-well logs (Johnson and others, 1987, table 2); well inventory (Johnson and others, 1987, table 1); and bedrock outcrops (pl. 2). The relief on the bedrock surface is greater than on the surface of the overlying sediments. In the Conway area, bedrock is exposed on Birch Hill and Pine Hill. The greatest depth to bedrock, based on well-inventory data (Johnson and others, 1987, table 1), is more than 185 ft at a well northwest of Echo Lake. Near Fryeburg, bedrock crops out on the unnamed hill north of Starks Mountain and at Swans Falls. The greatest depth to bedrock, based on seismic-refraction data in the vicinity of OW69 (fig. 23, SS-SS′, TT-TT′), is approximately 290 ft.

The topography of the bedrock surface reflects a preglacial drainage pattern that may have varied during the geologic past and that was, in places, quite different from the present surface-drainage pattern. The major bedrock valleys in both the Conway and Fryeburg sections of the study area trend approximately north-south, slope towards the south, and probably were deepened by glacial erosion. The bedrock-surface topography controlled the course of the preglacial river(s) but now, because of the thickness of glacial sediments filling the valleys, does not appreciably influence the present course of the river, except in a few areas where bedrock is at or close to the land surface.

Surficial Geology

A generalized stratigraphic section and interpreted environments of deposition are shown on figure 2. The entire depositional sequence usually is not found in any given locality; instead, what is observed in the field depends on the local conditions during deposition and on how much of the resultant sequence has been exposed to erosion. Stratigraphic information was obtained from well logs (Johnson and others, 1987, table 2), seismic-refraction profiles (fig. 23, at back of report), and from seismic-reflection profiles (fig. 3, pl. 1).

The surficial deposits along the Saco River valley consist of unconsolidated glacial sediments and Holocene alluvium. The area was covered at least twice by continental glaciers during the Pleistocene Epoch, which lasted from approximately 2,000,000 to 10,000 years ago. The last ice sheet advanced into the area from eastern Canada about 25,000 years ago, in late Wisconsinan time. The principal ice-flow direction was towards the southeast. As the glacier advanced, it eroded rock and soil debris and

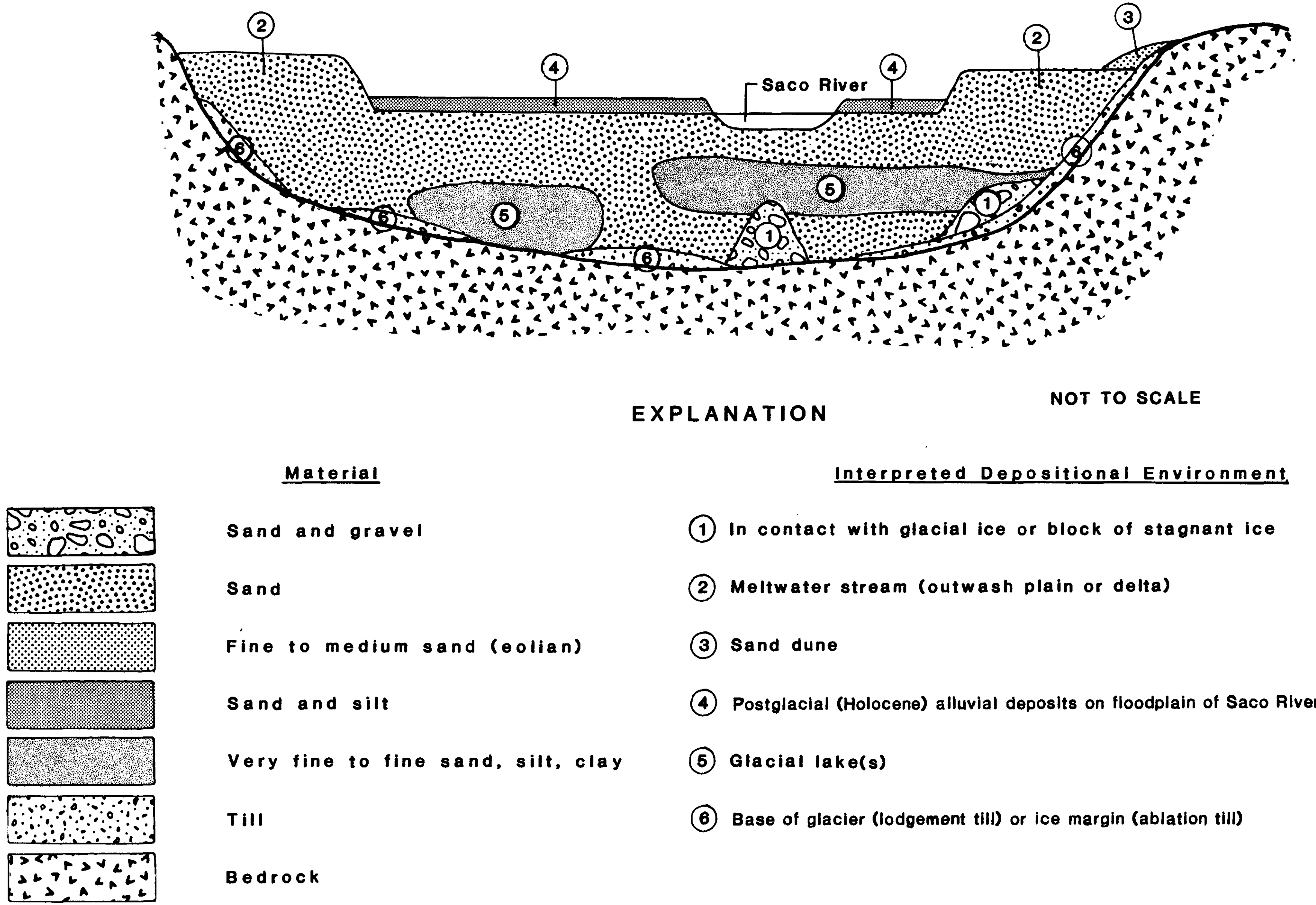

Figure 2.--Generalized stratigraphic section and interpreted environments of deposition.

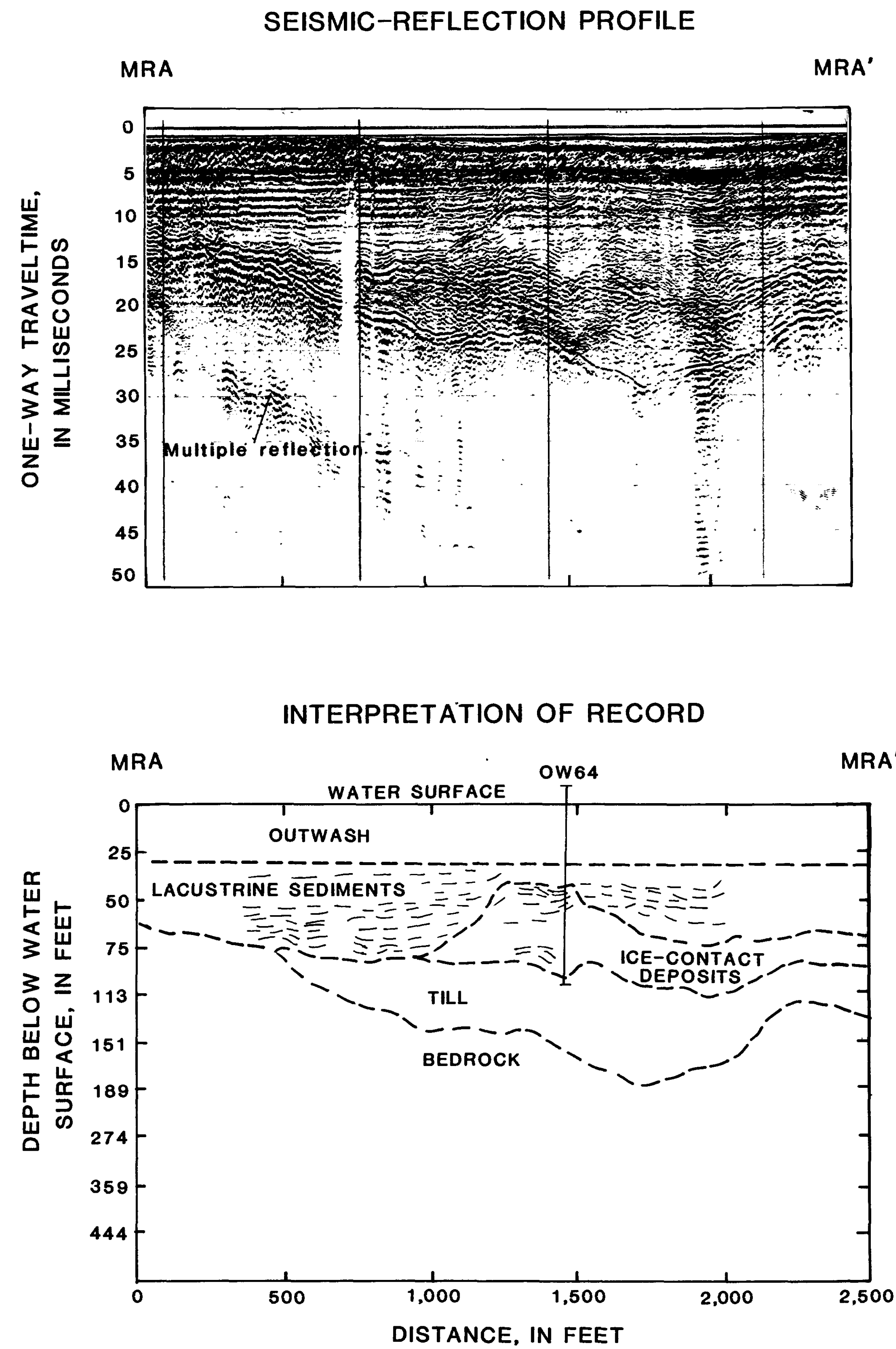

Figure 3.--Seismic-reflection profile MRA-MRA', with interpretation of record (locations of profile and site OW64 are shown on plate 1). The depth scale is based on the following velocities, estimated from seismic-refraction studies in the area: 5,020 ft/s (feet per second) in the water column and saturated sand and gravel deposits; 7,500ft/s in till; and 17,000 ft/s in bedrock.

incorporated it into the ice. This material was later deposited directly from the ice as till or from meltwater streams as stratified sediments. The ice sheet reached its maximum extent about 20,000 years ago (Goldthwait and others, 1951). As the climate warmed, the ice melted faster than it could advance, which caused the ice margin to recede.

In New Hampshire, downwasting of ice was rapid (Goldthwait, 1970; and Spear, 1981). Land at the highest elevations was exposed slightly more than 14,000 years ago (Davis and Jacobson, 1985), and Deer Lake Bog in the White Mountains, at an altitude of 4,346 ft, was free of ice at about 14,000 years ago (Spear, 1981). The downwasting ice sheet probably persisted farther south in the major valleys, but Davis and Jacobson (1985) estimate that by 13,000 years ago, the ice had melted away from most of New Hampshire and parts of western Maine.

As the ice margin receded, large volumes of sediment and meltwater were released. The coarser sediments that accumulated in channels within or beneath the ice, between the ice and adjacent valley walls, and at or near the ice margin formed deposits called "ice-contact stratified drift." Ice-contact landforms exposed in the study area include kame terraces and kettle holes. Kame terraces, which are numerous in the study area, are flat-topped, irregularly-shaped terraces of sand and gravel that were deposited by streams flowing between the glacier and the valley wall. A particularly good example of a kame terrace is located 0.2 mi north of the Conway/Bartlett town line, west of the Saco River (pl. 1). This terrace contains a kettle hole, as indicated by depression contours. Kettle holes result from the melting of blocks of glacial ice that were buried beneath glacial sediments. Eskers, another type of ice-contact deposit, are sinuous ridges of sand and gravel that were deposited by streams moving through tunnels within or beneath glacial ice. Although there are no eskers exposed at the surface in the study area, seismic-reflection data (fig. 3) and observation-well logs (Johnson and others, 1987, table 2) indicate that there may be buried esker segments or buried ice-contact or outwash deltas in the Fryeburg area. Outwash deposits were formed where meltwater streams deposited sediment in valleys at a distance from the ice margin. Much of the ice-contact and outwash sediments from this early stage of deglaciation are buried beneath younger deposits.

Temporary glacial lakes formed in valleys that were dammed by glacial sediments, stagnant ice, or local topographic barriers. Leavitt and Perkins (1935, p. 94) were the first to describe the existence of a large glacial lake in the valley of the Saco River, extending from Brownfield through Fryeburg, Maine, and into Conway, New Hampshire. Prescott (1980) identified glacial-lake deposits in four observation wells in the Fryeburg, Maine area. According to Holland (1986), clays and silts, which are usually deeply buried by sand and gravel, are generally continuous up the Saco valley from Hiram Falls, Maine, to Bartlett, New Hampshire. In Maine, a glacial lake or lakes may have extended to the northwest into the Cold River valley, to the north into the Lower Bay of Kezar Lake, to the northeast into the Kezar River valley, to the east beyond Kezar Pond, and to the south at least as far as Pleasant Pond and Lovewell Pond (Thompson, 1986).

It is not known whether the lacustrine (lake-related) sediments found in the study area were deposited in one large proglacial (ice marginal) lake or in a series of smaller glacial lakes. This question does not have to be resolved for the purposes of this study. However, an understanding of the distribution patterns of the lacustrine sediments is useful in determining ground-water flow patterns and in delineation of aquifer boundaries at depth.

Altitudes where both massive clay and clay interbedded with silt and sand are predominant, based on observation-well logs for the study area (Johnson and others, 1987, table 2), are shown on plate 3. In the Fryeburg area, deposition of lacustrine clay, silt, and very fine sand was observed at altitudes of 268 ft to 409 ft above sea level. However, there is no altitude beneath which clay and other lacustrine deposits are always found. It is not known whether deposition of lacustrine sediments occurred at altitudes less than 268 ft because the maximum depth penetration capability of the drilling equipment (120 ft) was exceeded. The observed altitudes of clay, silt, and very fine sand in the Conway area ranged from 344 ft to 496 ft above sea level. As in Fryeburg, no extensive surface of lacustrine sediments at any given depth was found in the Conway area.

This suggests several possibilities regarding the existence of a single, large glacial lake. There may have actually been one large glacial lake in the area; however, variations in bottom currents, in sediment supply, and in lake levels over time may not have allowed the deposition of a uniform blanket of lacustrine sediments over the entire lake bottom (Thompson, W. B., Maine Geological Survey, oral commun., 1987). In particular, clay may have been deposited only in the deepest basins, which may have formed at different altitudes. Another possibility is that clay may have been deposited uniformly but was eroded away in some areas by meltwater streams or by the Saco River as it has meandered across the valley during the Holocene.

Alternatively, there may have been a series of small proglacial lakes in the area, some of which were probably contemporaneous and at similar altitudes (Holland, W. R., Robert G. Gerber, Inc., oral commun., 1987). These small lakes may have been dammed by ice, drift, or local topographic features (fig. 4a). Their individual base-level controls may have been at different altitudes, which would account for the somewhat patchy distribution of lacustrine sediments in the area (figs. 4a, b). For example, lacustrine sediments were found at two distinct depth intervals in the section near OW75 (fig. 4a). These deposits were separated by 42 ft of either ice-contact stratified drift or outwash deposits. The bedrock knob on the profile to the east of OW75 might have acted as a topographic barrier, damming a lake when the deepest set of lacustrine sediments was deposited. The variability of the spatial distribution of the lacustrine sediments in the Conway area is illustrated in figure 4b. Although OW33 and OW34 are only 2,300 ft apart, lacustrine sediments comprised 75 percent of the section near OW33 but were not encountered in the section near OW34.

The lake sediments commonly overlie and sometimes interfinger with glacial outwash, which was deposited by meltwater streams as the ice margin retreated up the valleys. In some areas, deltas built outward where meltwater streams entered the lake or lakes. A large delta of this type is located in the Fryeburg quadrangle, southwest of the intersection of State Route 5 and Highland Park Road (Thompson, W. B., Maine Geological Survey, oral commun., 1987). The coarsest sediments were deposited where the stream current slackened as it entered the lake. Finer-grained sand and gravel was carried farther, and the finest sediment (very fine to fine sand, silt, and clay) was deposited on the lake floor. Some of the outwash was deposited in large plains that buried the older deposits. An outwash plain in the vicinity of the Fryeburg Fairgrounds has been mapped by Thompson (1987).

Eolian deposits formed after deposition of the outwash. Strong winds swept across the valley floors, eroded the outwash deposits, and redeposited the outwash sand in dunes on the downwind sides of the valleys. These dunes formed before the vegetation cover was sufficiently developed to prevent wind erosion. Eolian sand is exposed in several places along the valley wall on the east side of the Saco River in the Fryeburg quadrangle. It is abundant in an area north of U.S. Route 302 near Jockey Cap, from 0.1 to 0.5 mi east of State Route 5, and south of Highland Park Road (Thompson, 1987), and in an area near the intersection of Fish Street and McNeil Road, in the northern part of the Fryeburg quadrangle.

Holocene alluvium consisting of flood-plain, stream-terrace, and alluvial-fan deposits has been deposited by postglacial streams as they have downcut through the glacial sediments that filled their valleys. Stream terraces have formed as a result of abandonment of former floodplain and stream levels. Alluvium covers much of the surface in the study area (Prescott, 1980; Newton, 1974). Some alluvium has been deposited in elongate fan-shaped patterns in areas where the sediment-carrying capacity of large streams has decreased as they encounter a relatively dramatic decrease in gradient. A good example of this type of deposit is located where the East Branch of the Saco River flows out of the till uplands onto the broad floodplain of the Saco River (pl. 1). Another example of this type of deposition is along Lucy Brook where it enters the floodplain of the Saco River (pl. 1). Similar fan-shaped features in the Ossipee Lake quadrangle have been reported by Newton (1974).

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The authors appreciate the cooperation of the U.S. Forest Service in supplying base-map materials for six quadrangles in the Conway area, which helped provide complete 7.5-minute coverage for the entire study area. Thanks are extended to Rita Thompson, Patrick Lovejoy, and Joseph Reinhardt of the U.S. Forest Service, White Mountain National Forest, and to Valerie Treuting and Carl Fonnesbeck of the U.S. Forest Service Geometronics Service Center.

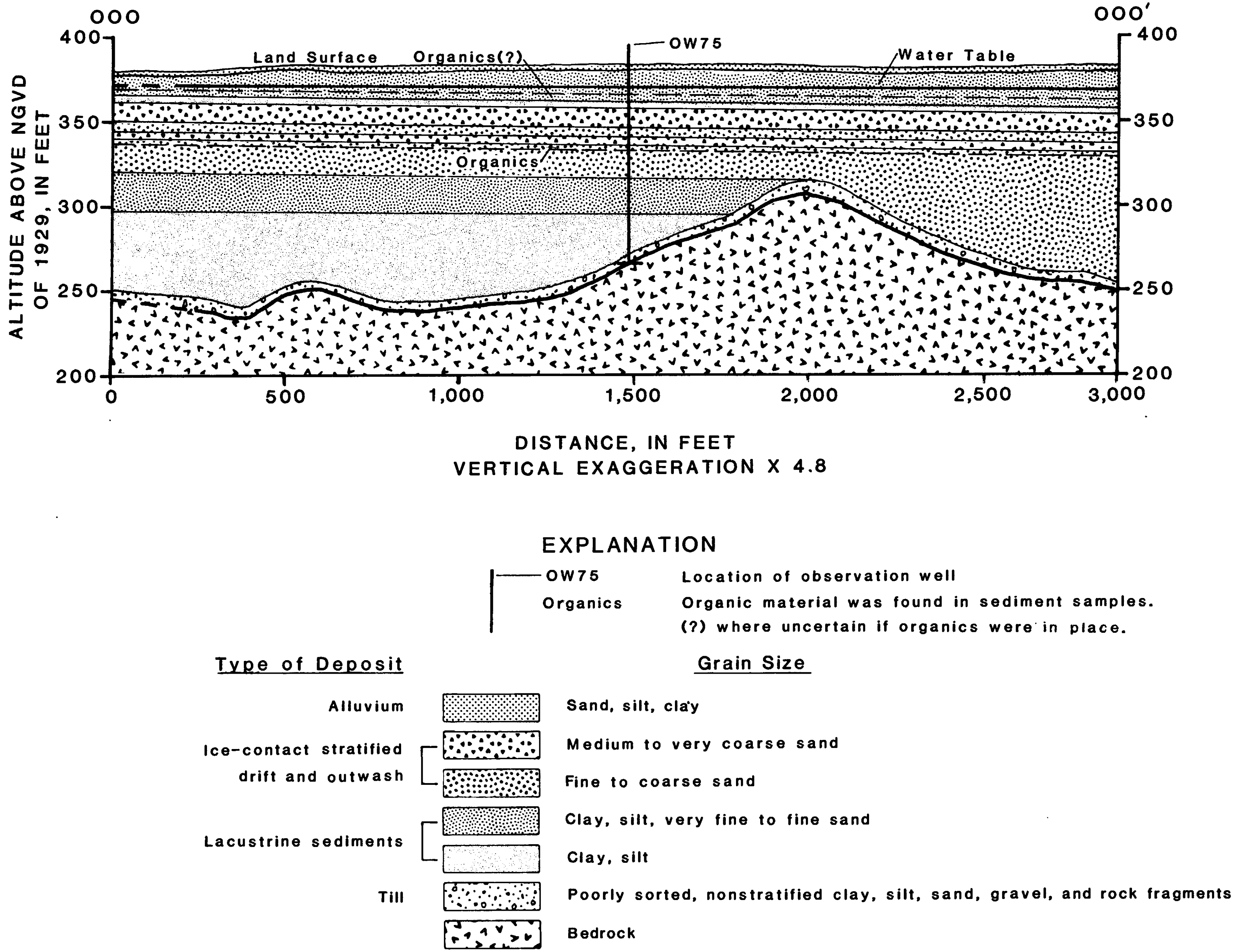


Figure 4a.--Generalized geologic section along seismic line OOO-OOO', in Fryeburg Harbor area (location shown on plate 1).

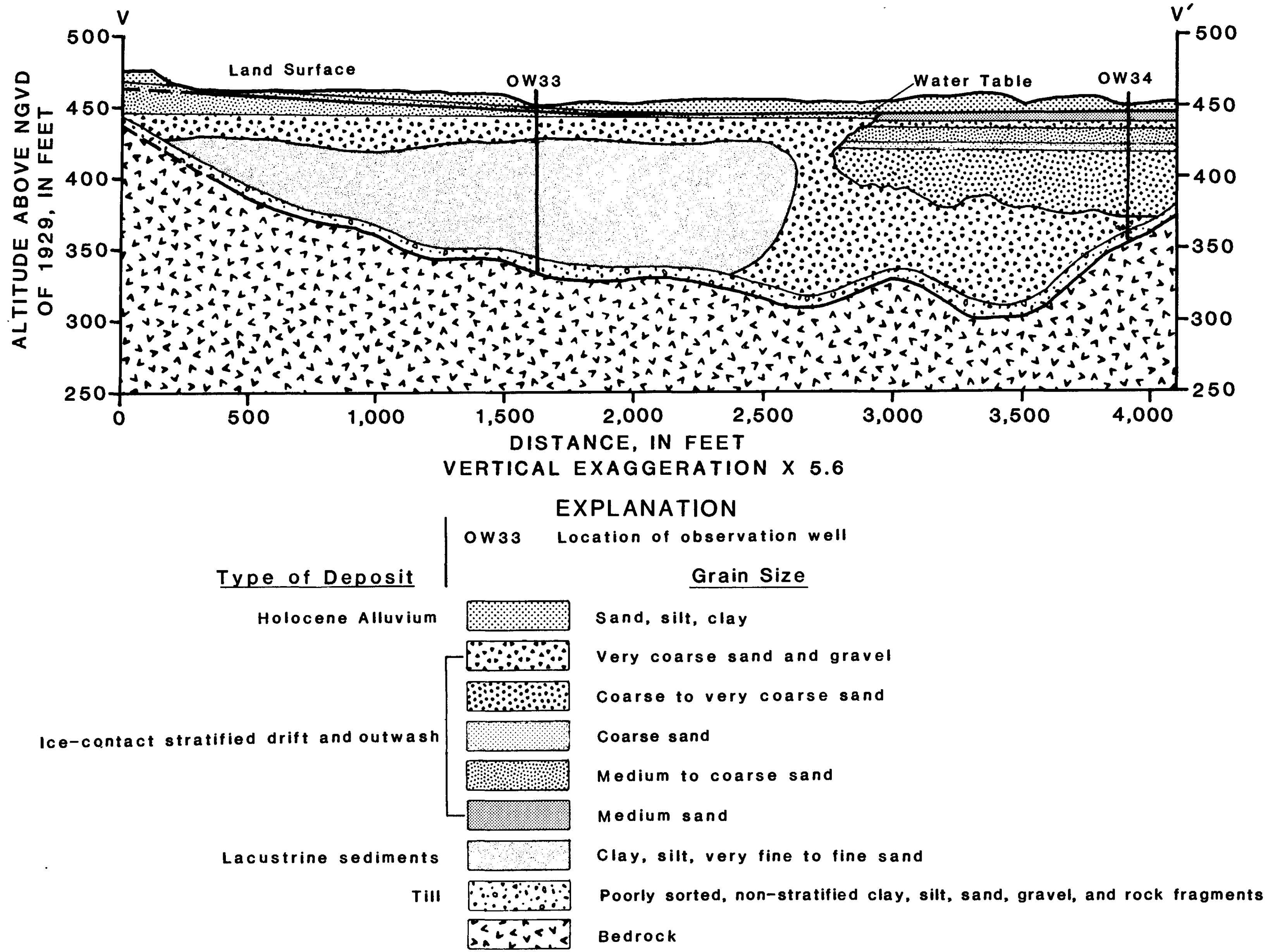


Figure 4b.--Generalized geologic section along seismic line V-V′, across west section of valley, west of Pine Hill, in Conway (location of seismic line shown on plate 1).

In addition, the authors thank the following individuals: Woodrow Thompson, Maine Geological Survey, for making available his unpublished map of the Fryeburg Quadrangle; Martin Smith, Colby College, for compiling slug-test data; and John Fish, U.S. Geological Survey, for providing equipment and technical assistance with slug tests.

HYDROGEOLOGY

The Saco River valley glacial aquifer ranges in width from 1 to 3 mi., has a surface area of 39 mi^2, and is located in the foothills of the White Mountains of New Hampshire. The aquifer is unconfined, and the contours of the water-table surface generally follow the contours of the land surface but are more subdued. Flow rates are dependent on hydraulic conductivity, hydraulic gradient, and porosity. Water that recharges the aquifer moves downgradient and is discharged primarily as streamflow; the rest discharges into lakes, ponds, and wetlands or is lost through evapotranspiration. The principal flow direction in the aquifer is from the till-covered or bedrock uplands toward the Saco River. There also is a less significant down-valley component of flow.

The water table fluctuates in response to changes in amounts of recharge, discharge, and storage. Precipitation, infiltration from tributary streams, and unchanneled runoff from adjacent till-covered or bedrock uplands provide the primary sources of recharge to the aquifer. Other sources include septic systems that discharge directly into the aquifer and induced infiltration from surface-water bodies near pumped wells. Discharge from the aquifer occurs primarily as leakage to the Saco River. Less significant amounts of discharge result from pumpage and from evapotranspiration, which occurs in areas where the water table is close to the land surface or within reach of plant roots.

Saturated Thickness

The saturated thickness of an unconfined aquifer is the depth from the water table to the bottom of the aquifer. Saturated thickness values for the Saco River valley aquifer are shown on plate 3. Although there are seasonal variations in the altitude of the water table, these fluctuations are generally less than 5 ft and are therefore not significant enough to cause other than minor changes in the positions of the saturated-thickness contours shown on plate 3, which has been contoured with a 20-ft contour interval.

In the Conway area, the bedrock surface was considered to be the bottom of the aquifer. The till has been included in the saturated thickness because of the predominantly sandy matrix observed in surface exposures and in sediment samples obtained from exploration-hole drilling. Till thicknesses based on drilling logs for this area range from 3 to 25 ft (Johnson and others, 1987, table 2). In contrast, the till in the Fryeburg area tends to have a more silty, denser matrix that is not sufficiently permeable to yield water to a supply well and, therefore, was not included in the saturated thickness. The top of the till was considered to be the bottom of the aquifer in this area.

In the entire study area, lacustrine sediments were included in the saturated thickness because of their relatively patchy and unpredictable distribution (fig. 4a,b) and because stratified sand and gravel was encountered beneath these deposits in the following observation wells, which are distributed throughout the study area: OW16, OW22D, OW29D, OW43D, OW51, OW52, OW55, OW56, TH63, OW64, OW65, and OW75 (pl. 1).

Saturated-thickness values for the Conway area (pl. 3) range from 10 ft or less near the aquifer boundaries to approximately 185 ft along the deepest bedrock valley, northwest of Echo Lake. Saturated-thickness values for the Fryeburg area (pl. 3) range from 10 ft or less near the valley walls to approximately 280 ft near OW69 (fig. 23, profile TT-TT'). Because the drill rig could only penetrate a maximum of 120 ft, the strati ·aphy beneath this depth is unknown.

Hydraulic Conductivity

Values of hydraulic conductivity for the aquifer were estimated from grain-size distribution characteristics of the sediments and from slug-test and pump-test data. Values used in the modeled area are shown on plate 4.

Hydraulic conductivity for very fine to very coarse sand was estimated using a technique developed by Masch and Denny (1966) that relates hydraulic conductivity to median grain size and degree of sorting. Grain-size distributions for sediments in the study area are presented in Johnson and others (1987, table 3). Values of hydraulic conductivity obtained using this method ranged from 11 ft/d (feet per day) for silt and very fine sand to 97 ft/d for very coarse sand and gravel. Estimates from this technique may be low compared to those derived from other techniques (Olimpio and de Lima, 1984).

Hydraulic conductivity also was determined in situ at 18 observation wells using a slug-test method developed by Prosser (1981) and modified by Fish (Fish, J. E., U.S. Geological Survey, written commun., 1985). This method was designed for use in highly permeable aquifers, where rapid response to induced head change occurs. This rapid response is difficult to monitor with conventional slug-test techniques. However, with this technique, pneumatically induced head change is measured by a pressure transducer and recorded on an analog chart recorder. The data were interpreted using an equation developed by Hvorslev (1951). Values for hydraulic conductivity obtained with this method ranged from 2 ft/d for silt and very fine sand to 210 ft/d for very coarse sand and gravel.

There are several significant differences between these two techniques, and each has limitations. The grain-size-distribution analysis is done on a small sample of sediment which has been removed from the aquifer. However, the sample is representative of a particular grain-size range (for example, medium sand). In contrast, the slug-test method is performed in situ on a relatively undisturbed sample. Hydraulic conductivity determined with a slug test reflects the bulk value for all the sediment near the well screen. This may give misleading results when the material near the well screen is not known along the entire length of the screen, is poorly sorted, or is stratified with significant grain-size variations between layers, as is typical in the study area. Hvorslev's (1951) method assumes uniform material between the water table and the well screen. Therefore, if grain size of the material near the screen is significantly different from aquifer sediments above and below or at a short lateral distance from the screen, hydraulic conductivity values obtained by this technique may not be representative of the entire aquifer near the well.

Results from the two techniques are summarized in table 1. The hydraulic-conductivity values from the two methods agreed best in the grain-size range from "fine to medium sand" to "medium to very coarse sand, with some gravel." Below this interval, in the range of "fine to medium sand with some silt and clay," values from the slug tests were low compared with the values from the analyses of grain-size distribution, which were closer to values in Todd (1980). However, the slug-test value of 2 ft/d in the "very fine to fine sand and silt" size range was closer to values in Todd (1980) than the value of 17 ft/d calculated from analyses of grain-size distribution. The sample under discussion contained some silt, and it should be pointed out that the Masch and Denny (1966) technique is not designed for use on grain sizes smaller than 0.0625 mm (millimeters) (very fine sand). The value of 17 ft/d calculated with this method may therefore be somewhat high because it was based on an extrapolation of the technique beyond its intended limits.

The slug-test values are significantly higher than the grain-size distribution values for the grain-size interval starting with "coarse to very coarse sand" and ending with "coarse to very coarse sand with some gravel." The slug-test method used in this study was designed primarily for use in highly permeable sediments, and it appears to have worked well when these values were compared to values in Todd (1980). In contrast, the values from analyses of the grain-size distributions in this size range were quite low compared to those in Todd (1980).

In summary, in comparison to results in Todd (1980), the grain-size distribution method seems to provide more reliable results in the fine grain-size ranges, the two methods provide comparable results in the medium grain-size ranges, and the slug-test method appears to provide the most reliable results in the coarse grain-size ranges. However, it should be emphasized that this summary is based on the comparison of limited grain-size data to only 10 slug tests.

Using the equation developed by Thiem (1906), hydraulic conductivity was estimated to be 175 ft/d at the municipal well in Lower Bartlett (MW1 on pl. 1). Using a relation between saturated thickness and well yield developed by Mazzaferro (1980), hydraulic conductivity was estimated to be 185 ft/d at the municipal well in Conway Village (MW5 on pl. 1). The latter value was in close agreement with the slug-test value of 190 ft/d in OW37, which is approximately 1,200 ft from the municipal well. However, on the basis of grain-size data, the average hydraulic conductivity near OW37 was only 140 ft/d.

Average hydraulic-conductivity values, based on results from the techniques described above, are shown on plate 4 for the modeled area. The highest values of hydraulic conductivity generally are adjacent to the Saco River and typically decrease towards the valley walls. In addition, the hydraulic-conductivity values generally decrease from north to south, although some values in the area northwest of Conway Village are comparatively high.

Table 1.--*Comparison of hydraulic conductivity values determined by analyses of grain-size distribution and by slug tests*

[Only those grain-size ranges are shown for which both techniques were used]

	Analysis by grain-size distribution			Analysis by slug tests		
Grain-size range	Observation well	Interval sampled, in feet below land surface	Hydraulic conductivity, in feet per day	Observation well	Screened interval, in feet below land surface	Hydraulic conductivity, in feet per day
Very fine to fine sand and silt	OW31	27-29	17	OW36	16-20	2
Fine to medium sand, with some silt and clay	OW13	32-37	12			
	OW23C	27-29	12	OW23B	32-36	5
	OW23C	32-34	18			
	OW29	72-74	10	OW29	72-76	3
	OW36	27-29	22			
Fine to medium sand, well-sorted	OW23C	87-89	15	OW21B	56-60	19
Medium to coarse sand	OW26D	22-24	24	OW26D	38-42	24
	OW29D,S	57-59	30			
Medium to very coarse sand, some gravel	OW51	27-29	30	OW2	35-39	55
Coarse to very coarse sand	OW13	27-29	59			
	OW29D	42-44	50	OW29S	38-42	190
	OW37	12-14	72			
Coarse to very coarse sand, some gravel	OW2D	32-34	97			
	OW7E	7-12	34	OW7F	10-14	155, 161
	OW31	2-7	24	OW33	13-17	210
	OW37	32-34	70	OW37	27-31	190

Availability of Ground Water

Hydraulic conductivity and saturated thickness of aquifer materials are the most important factors influencing aquifer yield. The product of hydraulic conductivity multiplied by aquifer thickness is termed transmissivity. Areas of high transmissivity, where both the average hydraulic conductivity and saturated thickness are high, may be favorable sites for development of ground-water supplies. If materials are suitable, the areas of an aquifer with saturated thicknesses of at least 40 ft have the highest potential for sustained yields of 200 gal/min or more from individual wells (Mazzaferro, 1986). Saturated thicknesses in the study area are shown on plate 3.

Continuous sections of medium to very coarse sand and gravel with saturated thickness exceeding 40 ft were found near eight observation wells in Conway. These wells, in order of increasing thickness, are OW37 (40 ft), OW2 (42 ft), OW29D (44 ft), OW23C (45 ft), OW21A (48 ft), OW35 (52 ft), OW22D (64 ft), and OW34D (70 ft). Observation wells OW37 and OW23C are near high-yield municipal wells and OW2D, OW21A, OW22D, and OW34D are along the Saco River or tributary streams where there also is potential for high yield from induced infiltration (pl. 1).

In Fryeburg, continuous saturated thicknesses of at least 40 ft of medium to very coarse sand and gravel were found only at OW72 (40 ft), OW76 (54 ft), and OW64 (58 ft); saturated thicknesses equal to or exceeding 30 ft were found at OW57 (30 ft), OW53 (35 ft), and OW61 (35 ft). Except for OW64, these observation wells are all located in the northern part of the valley in the vicinity of the Old Course of the Saco River. The area near OW64 has potential as a high-yield site because of its thick saturated section of medium to very coarse sand and gravel, its potential for induced recharge from the river, and its proximity to Fryeburg.

Specific yield is a measure of the ability of an unconfined aquifer to store or yield water. It is defined as the ratio of the volume of water yielded by gravity drainage to the volume of material drained. Specific yields for unconfined aquifers usually range from 0.1 to 0.3 (Johnson, 1967). On the basis of values in Johnson (1967), the average specific yield in the Saco River valley aquifer was estimated to be 0.25 for sand and gravel, and from 0.03 to 0.08 for the fine-grained material such as silt and clay.

Water-Table Configuration and Generalized Directions of Ground-Water Flow

The approximate configuration of the water table in the Saco River valley aquifer in December 1985 is shown on plate 5. The data were obtained from project observation wells, municipal observation wells, and domestic wells. The altitudes of surface-water bodies were assumed to approximate the altitude of the water table. Relief on the water-table surface is generally similar to but more subdued than that of the land surface.

Horizontal ground-water flow directions (indicated by arrows on pl. 5) are in the direction of the maximum hydraulic gradient, which is perpendicular to lines of equal water-table altitude. Relative differences in flow rates are determined by hydraulic conductivity, hydraulic gradient, and porosity. Generalized directions of ground-water flow in the aquifer are illustrated in figure 5. The actual direction of flow in nature is more complex than shown, primarily because of variations in hydraulic conductivity of sediments.

The principal direction of flow in the aquifer is in a cross-valley direction, from the till-covered or bedrock uplands toward the Saco River, the major zone of ground-water discharge. Gradients are steepest near the valley walls and flatten toward the center of the valley. The cross-valley gradients in Conway generally are steeper than those in Fryeburg. This may be attributed to differences in amounts of recharge from upland areas, in values of hydraulic conductivity near aquifer boundaries, and in cross-sectional areas of the two valleys.

In addition to the principal cross-valley flow directions, there are less significant down-valley components of flow approximately parallel to the course of the Saco River. Down-valley gradients are less steep than cross-valley gradients.

Ground-water flow divides have been identified in two locations in the study area (pl. 5). A divide, which coincides with a surface-water divide, is located to the northeast of Pine Hill, in the Redstone area of Conway. Ground water north of the divide flows northwestward toward the Saco River and ground water south of the divide flows southeastward toward Redstone Brook, a tributary of the Saco River.

Another ground-water flow divide trends approximately southwest-northeast, from north of Swans Falls to northwest of Fryeburg Center (pl. 5). The actual location of this divide is somewhat uncertain due to the low relief on the water-table surface in the Fryeburg area and because the position of the

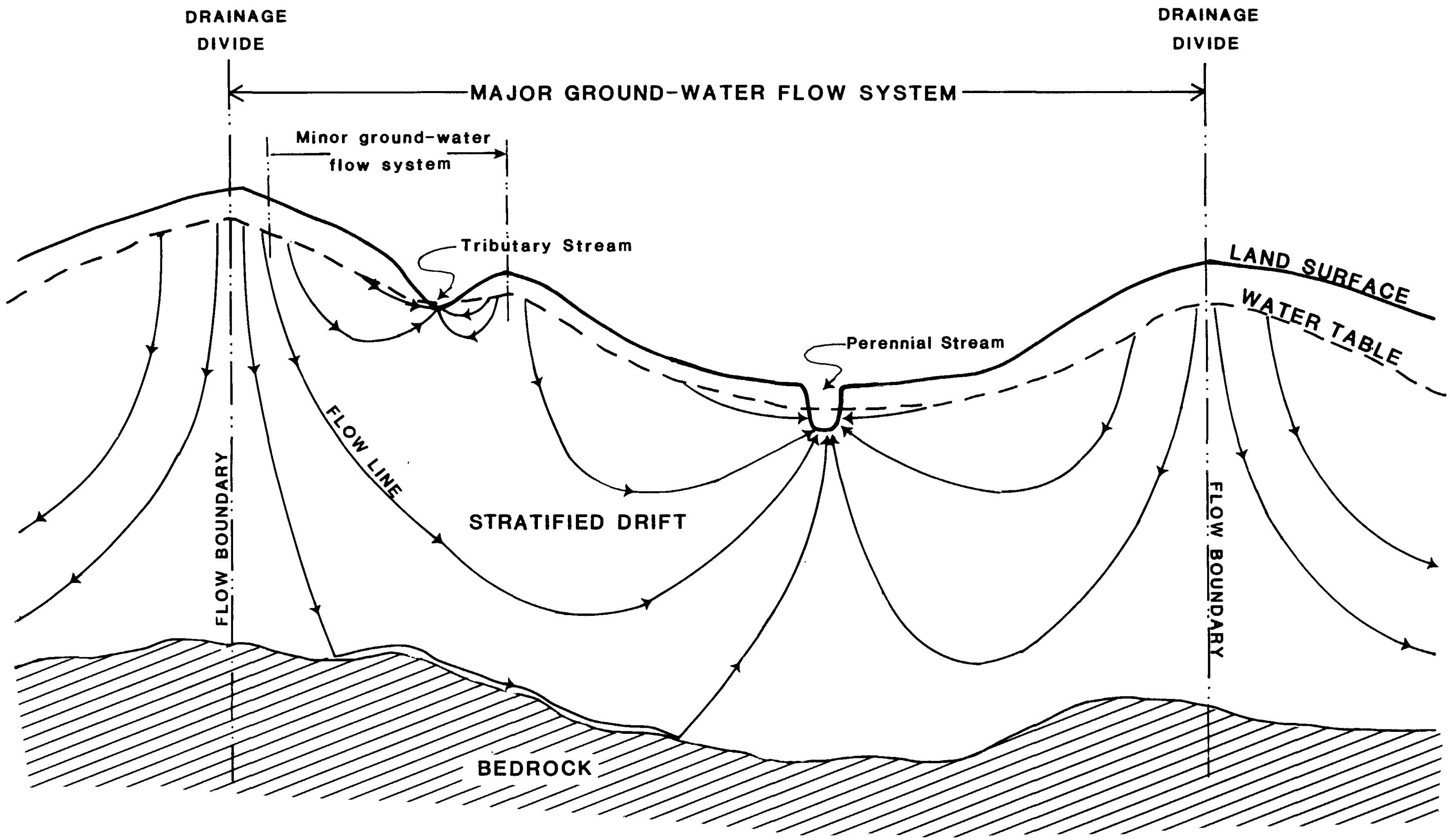


Figure 5.--Idealized pattern of ground-water circulation in stratified drift. The directions of flow in stratified drift are depicted by flow lines. The actual configuration of these lines in nature is more complex than shown, principally because of variations in hydraulic conductivity of sediments. From Cervione and others (1972).

water table may vary seasonally. However, the general direction of ground-water flow is towards the present course of the Saco River on the south and east side of the divide and towards the Old Course of the Saco River on the north and west side of the divide. This divide probably is a result of the major change in local surface-water drainage directions caused by diversion of the mainstem of the Saco River through a canal dug in 1819. The history of the diversion is discussed in the Introduction section of this report.

Most observation wells constructed for this study were screened near the water table. However, in order to detect vertical-flow directions, a deep-screened well was installed adjacent to a shallow-screened well at 13 sites distributed throughout the study area (pl. 5). At two of the sites, OW22D,S (D = deep, S = shallow) and OW75D,S, no significant vertical head difference was observed during the period of record.

At six of these sites, OW2D,S; OW21B,C; OW23A,C; OW26D,S; OW30D,S; and OW51D,S, the altitude of the water table generally was higher than the piezometric head in deeper sections of the aquifer throughout the period of record, which indicates a downward flow direction. Recharge was occurring at these sites, which are all distant from the Saco River.

At five of the sites, OW7E,F; OW29D,S; OW34D,S; OW43D,S; and OW72D,S, the deeper piezometric head was higher throughout the period of record than the altitude of the water table, which indicates an upward flow direction. Discharge was occurring at these sites, three of which (OW34D,S; OW43D,S; and OW72D,S) are located along the banks of the Saco River. Discharge also may be occurring at the site of OW7E,F because of its proximity to both Lucy Brook and the Saco River.

Differences in head for December 1985 for the shallow and deep wells listed above ranged from 0.04 to 8.0 ft in the recharge areas and from 0.00 to 1.57 ft in the discharge areas. Vertical flow gradients ranged from 0.001 to 0.34 ft/ft (feet per foot) in the recharge areas and up to 0.05 ft/ft in the discharge areas.

Although OW29D,S and OW30D,S are only 800 ft apart (pl. 1), the vertical-flow directions at these two well clusters were in opposite directions over the period of record. The flow direction was upward at OW29D,S, with an average head difference between the two wells of 1.00 ft. However, the flow direction at OW30D,S was downward, with an average head difference between the two wells of 3.34 ft. The heads at depth for OW29D and OW30D were similar; they show an average difference of only 0.86 ft, with the head in OW30D always slightly higher than in OW29D. However, the average difference in head between the shallow observation wells OW29S and OW30S was 5.12 ft, and the head in OW30S was always higher than in OW29S.

This difference in the shallow heads is probably related to a change in the steepness of the hydraulic gradient between the two well clusters rather than to the location of recharge or discharge zones (pl. 5). Differences in topography and stratigraphy are probably causing this change in the hydraulic gradient. Observation well OW30S is at the base of a terrace, in an area where the heads are higher because the hydraulic gradient is relatively steep. In contrast, OW29S is farther away from the terrace, in an area where the heads are lower because the hydraulic gradient is relatively flat. In addition to topographic influences, the difference in vertical hydraulic gradients between the two wells is probably partially caused by differences in stratigraphy. The overburden above the screen at OW30S is predominantly fine to medium sand but consists of coarse to very coarse sand above the screen at OW29S.

In a few areas where sand and gravel is overlain by a clay layer and underlain by bedrock, the aquifer acts as a confined system. For example, OW65 is screened in sand beneath a clay layer and overflows almost continuously year-round. The water level in this well is at the level of the potentiometric surface of the confined aquifer rather than at that of the unconfined aquifer (the water table).

Water-Level Fluctuations

Seasonal change in recharge from precipitation is an important factor influencing fluctuations of the water table. Water-level fluctuations are also caused by changes in the following: the amount of recharge from till-covered or bedrock uplands; seepage from tributary streams; and pumpage of nearby wells. The hydrographs presented in figures 6-9 illustrate water-level fluctuations caused by these factors.

Water-level fluctuations monitored at OW76 in North Fryeburg (pl. 1) from August 1978 through December 1985 are shown in a hydrograph in figure 6. This long-term record was available because this well is part of the Maine observation-well network operated by the U.S. Geological Survey. Water-level fluctuations in OW76 were attributable to effects of seasonal recharge directly on the aquifer. This hydrograph illustrates that most of the recharge occurs in early spring (March and April) and late fall

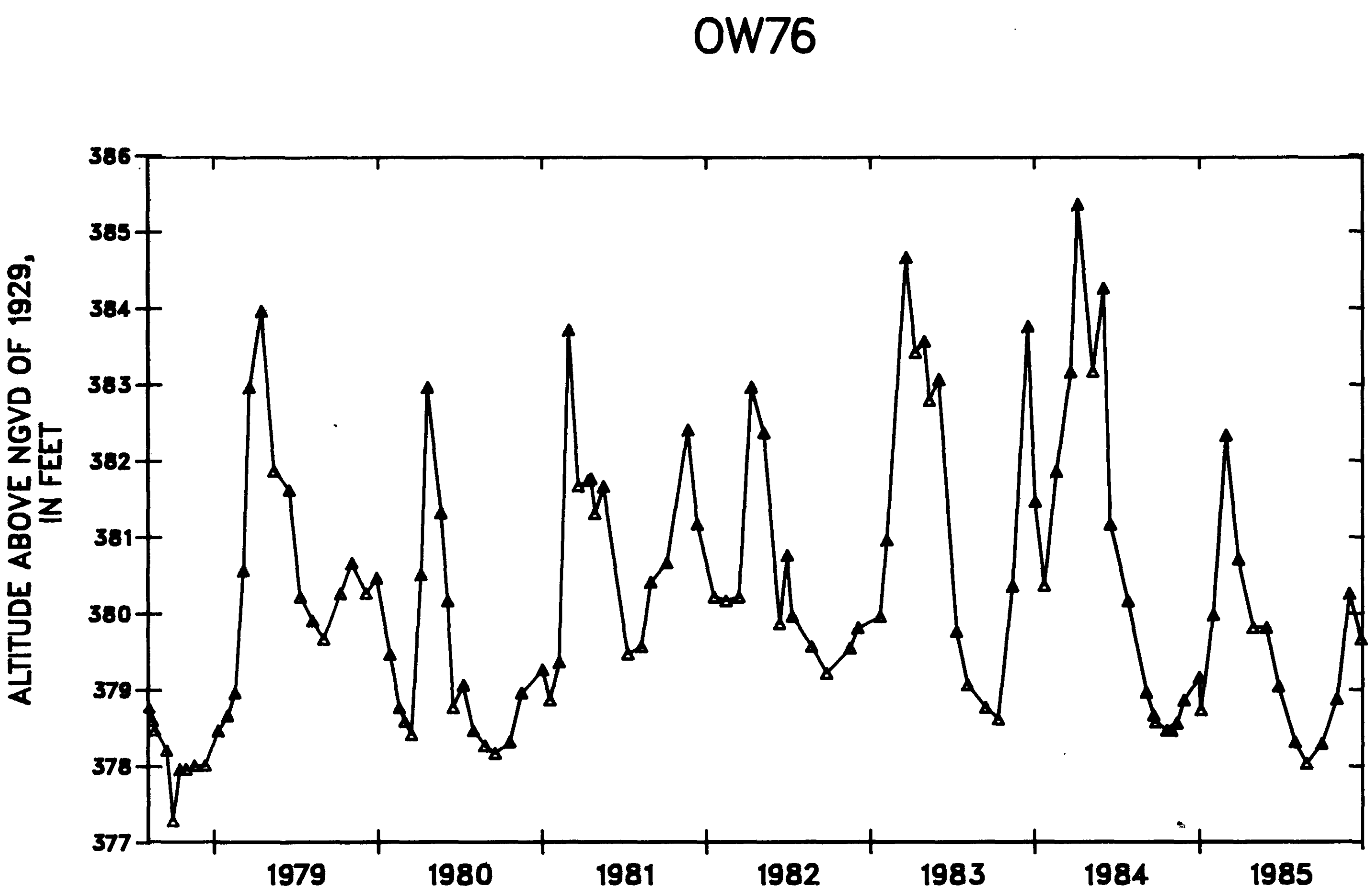


Figure 6.--Long-term hydrograph based on monthly readings for observation well OW76. Measured water levels are indicated with a triangle. Data from U.S. Geological Survey (1979-1987).

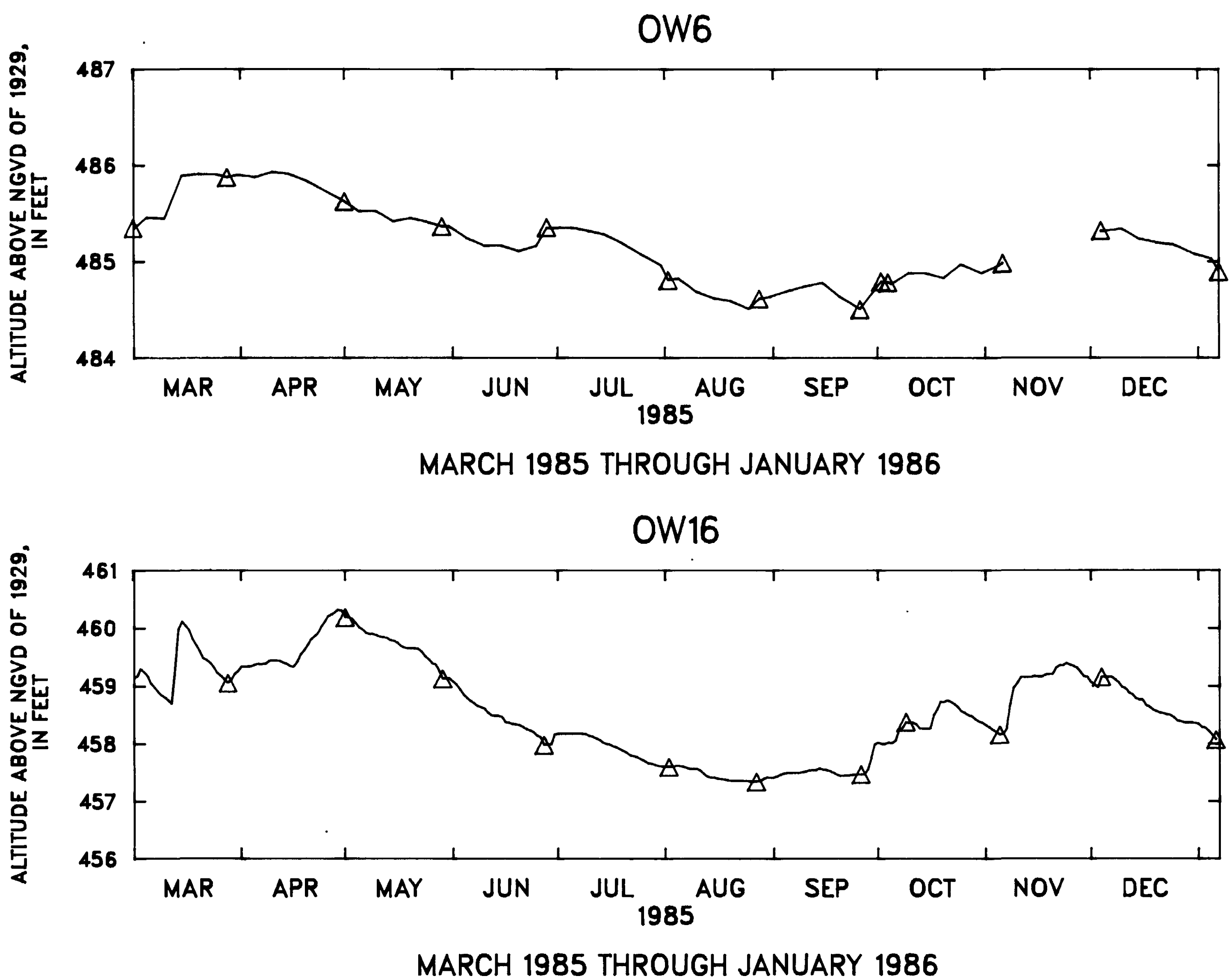


Figure 7.—Comparison of hydrographs for observation wells OW6 and OW16 from March 1985 through January 1986. Water levels measured by an observer are indicated with a triangle. Water levels determined from continuous water-level recorders are represented with a solid line. Periods of missing record are shown as a gap in the hydrograph.

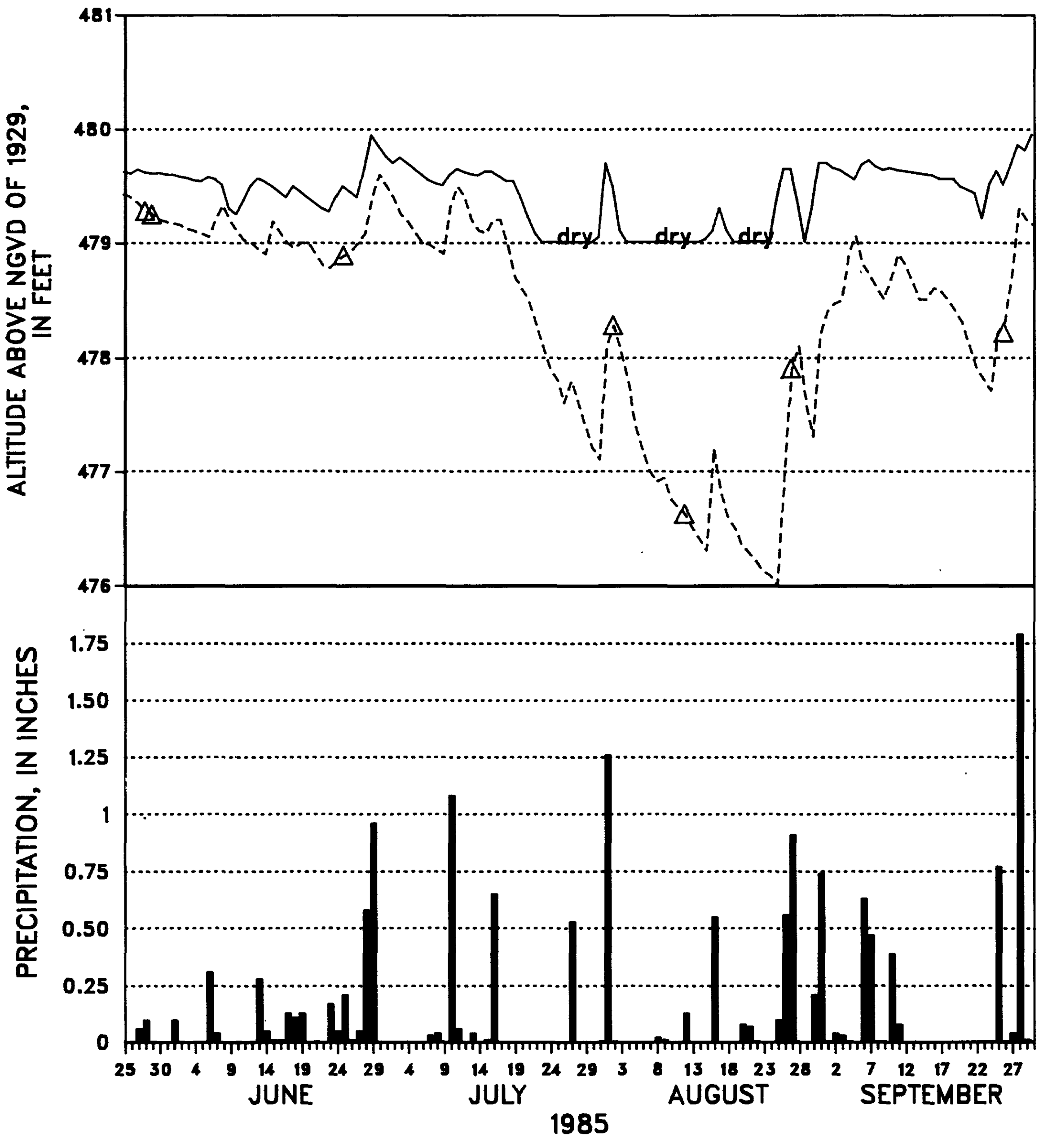


Figure 8.--Graphs showing relations between stage in Lucy Brook (at station 010644400.7), water levels in observation well OW7C (located approximately 50 feet from the stream), and precipitation from June through September 1985. [Source of precipitation data is U.S. Department of Commerce (1959-1985)]. The stage in Lucy Brook is indicated by a solid line. Water levels determined from a continuous recorder are indicated by a dashed line, and water levels measured by an observer are indicated with a triangle.

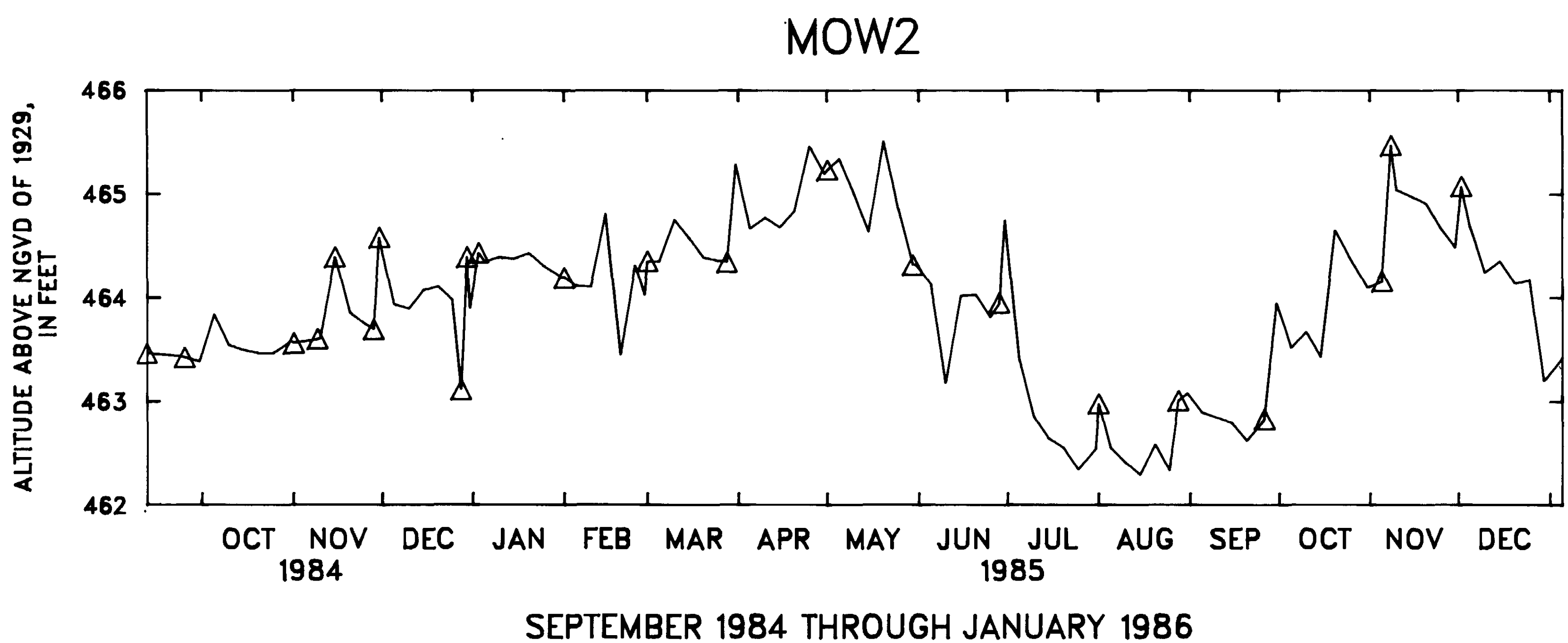


Figure 9.—Hydrograph for municipal observation well MOW2 from September 1984 through January 1986. Water levels measured by an observer are indicated with a triangle. Water levels determined from continuous water-level recorders are represented with a solid line.

(November and December). Ground-water levels decline during the winter and summer, with the lowest levels occurring during September and October. The average annual range in water level for the period of record was 5.2 ft.

The hydrograph from OW6, located in North Conway 0.15 mi from the contact between the sand and gravel and the till-covered or bedrock uplands (pl. 1), is contrasted in figure 7 with the hydrograph from OW16, located in North Conway near the center of the valley (pl. 1). The period of record for both wells was from March 1985 through January 1986. The water level in OW6 had a smaller total range of fluctuation and typically varied less from month to month than in OW16. The hydrograph from OW6 shows the combined effects of direct recharge on the aquifer and of inflow from the till-covered uplands; however, the hydrograph for OW16 shows only the effects of direct recharge to the aquifer.

Hydrographs showing the relations between stage in Lucy Brook (station number 010644400.7), water levels in OW7C (located approximately 50 ft from the brook), and precipitation are shown in figure 8. The total range of water-level fluctuations in OW7C was 3.7 ft. Changes in the water level in OW7C were a function of the amount of recharge received from infiltration of streamflow from Lucy Brook into the aquifer. For example, the highest water level in OW7C was measured on June 29, 1985, and corresponds with the highest stage measured in Lucy Brook. In July 1985, Lucy Brook was dry and the water level in OW7C dropped dramatically. On August 1, 1985, 1.5 in. (inches) of rainfall caused a rapid rise in stage in Lucy Brook. Infiltration of streamflow from the brook into the aquifer caused the water level in OW7C also to rise rapidly in response to this recharge event.

The hydrograph for MOW2 (pl. 1), a municipal observation well located near North Conway Water Precinct municipal well #3 (MW7 on pl. 1), shows water-level fluctuations influenced by a pumped well (fig. 9). The municipal well is used as a supplemental supply and is therefore only pumped periodically. The hydrograph shows the effects of sporadic pumping superimposed on seasonal fluctuations in the water table.

Recharge

Major sources of recharge to the aquifer include precipitation that falls directly on the aquifer, unchanneled runoff from adjacent till-covered or bedrock uplands, and infiltration from tributary streams. Other sources include recharge from septic systems and induced infiltration from the Saco River.

Precipitation

A major source of recharge to the Saco River valley aquifer is infiltration from precipitation that falls directly on the aquifer. The average annual recharge is estimated to be 24 in/yr, or half the average annual precipitation, on the basis of work by MacNish and Randall (1982).

Upland Runoff

Runoff from till-covered or bedrock upland areas not drained by tributary streams recharges the aquifer near the base of the valley walls. In a study of the hydrologic effects of a catastrophic flood in the Cold River basin of southwestern New Hampshire, Caldwell and others (1987) determined that recharge from upland areas was a more significant component of the total recharge than direct precipitation. The average annual runoff from uplands adjacent to the aquifer is approximately 32 in/yr, on the basis of long-term annual-runoff data from the streamflow-gaging stations on Lucy Brook (01064400) and on the Saco River at Conway (01064500) (Blackey and others, 1985).

Tributary-Stream Infiltration

Observations made by Wetterhall (1959), Ku and others (1975), Crain (1966), and Randall (1978) have shown that recharge from small upland tributary streams in New York can be an important part of the water budget for stratified-drift aquifers along major river valleys. Tributary-stream recharge was investigated in the Saco River valley by Morrissey and others (1988) as part of the U.S. Geological Survey's Northeast Regional Glacial Aquifer Systems Analysis (Lyford and others, 1984). Six tributary streams in the Saco River valley, with drainage areas ranging from 1.2 to 40 mi^2, were measured to determine the magnitude of seepage losses to the Saco River valley aquifer. The measurements were made using standard streamflow-gaging techniques at several locations on each tributary stream.

A summary of the average seepage losses for each of the streams studied is shown in table 2. These losses ranged from 6.7 ft^3/s (cubic feet per second) on the East Branch of the Saco River to no losses on Tributary B (unnamed tributary, referred to as "B" for the purposes of this study) and Mason Brook (pl. 1). Both Mason Brook and Tributary B have channels that are incised in silt or clay, which limits seepage.

In general, seepage losses were greatest in the northern part of the valley where the stratified drift is most permeable. At these locations, tributary streams cross coarse-grained alluvial fans or terraces where the stream channel is well above the water table. Observed losses were smallest in areas of fine-grained deposits where the tributary-stream channels have graded down to the water table.

Seepage to the Saco River valley aquifer from tributary streams is an important source of recharge, especially during the summer when recharge from precipitation is limited by soil-moisture demand and by evapotranspiration. Approximately 70 to 80 percent of the ground water discharged from the aquifer along a 4-mi reach in the northern part of the valley during low-flow periods is replaced by recharge from tributary-stream infiltration (Morrissey and others, 1988).

Recharge from Septic Systems

As of 1985, wastewater is discharged through septic systems throughout the study area, except in Conway Village where a municipal sewage-treatment facility discharges into the Saco River. An estimated 80 percent of the water pumped from municipal wells is returned to the aquifer through septic systems; the remaining 20 percent is lost through consumptive use or evapotranspiration.

Induced Infiltration

Induced infiltration can occur in areas where the cone of influence of a pumped well intersects a surface-water body. On the basis of results from the calibrated, steady-state ground-water flow model for the Conway area (discussed in "Model Calibration"

Table 2.--*Observed streamflow losses from tributary streams in the Saco River valley near Conway, N.H.*

[mi^2, square miles; ft^3/s, cubic feet per second]

Stream	Upland drainage area (mi^2)	Stream gradient (percent)	Number of measurement sets	Average total loss (ft^3/s)
East Branch Saco River	40	1.3	8	6.7
Tributary A[1]	.33	3.5	6	.6
Tributary B[1,2]	1.2	2.7	7	.0
Lucy Brook	5.4	1.8	11	1.8
Kearsarge Brook	12.0	.67	8	1.4
Mason Brook[2]	2.9	1.6	6	.0

[1] Unnamed tributary, location shown on plate 1.

[2] Channel incised in silt or clay.

section), the only area where induced infiltration was occurring was near the North Conway Water Precinct municipal well #1 (MW2 on pl. 1). The infiltration rate was approximately 130 gal/min over a 1500-ft reach of the Saco River. Induced infiltration rates under varying pumpage and recharge conditions are discussed in the "Model Applications" section.

Discharge

Ground-water discharge is primarily to the Saco River. Lesser amounts of discharge result from pumpage and evapotranspiration.

Ground-Water Discharge to the Saco River

Several sets of streamflow measurements were made along the Saco River to determine ground-water discharge from the aquifer. The measurements were made after extended periods without precipitation, when most of the flow in the river was contributed by ground-water discharge. During these periods, the streamflow in the Saco River was low enough so that the volume of ground-water discharge between measuring sites was greater than that attributable to measurement errors (plus or minus 5 percent).

A summary of ground-water discharge to the Saco River is shown in table 3. Streamflow-measurement data are reported in Johnson and others (1987, tables 14-23) and in Blackey and others (1984, 1985). Total observed ground-water discharge to the Saco River ranged from 49 to 58 ft^3/s along a reach from the mouth of the East Branch Saco River to the gage at Conway. Considering that these measurements were made during low-flow periods, the average ground-water discharge to the aquifer is probably greater. Measurement of ground-water discharge during "average" streamflow conditions would be dif-

Table 3.--*Ground-water discharge to the Saco River*

[See plate 1 for locations of measurement sites]

	Discharge, in cubic feet per second		
	8/30/84	9/10/84	9/27/84
Reach 1 site 01064391 to site 01064392	9.0	3.7	4.9
Reach 2 site 01064392 to site 01064402.3	13.1	16.3	11.2
Reach 3 site 01064402.3 to site 01064410	12.1	7.6	4.1
Reach 4 site 01064410 to site 01064500	15.1	23.0	38.0[1]
Total	49.3	50.6	58.2

[1] Discharge from the Swift River to the Saco River estimated on this date.

ficult because errors in the streamflow-gaging measurements could be large enough to mask the gains in streamflow due to ground-water discharge.

Ground-Water Withdrawals by Municipal Water-Supply Systems

The Town of Fryeburg and the precincts of Lower Bartlett, North Conway, and Conway Village each have municipal water-supply systems that depend totally on ground-water withdrawals from the Saco River valley aquifer. Combined pumpage is about 3 Mgal/d but varies seasonally with tourism and agricultural demands. The average annual pumpage from each municipal system is shown in table 4. Locations of the municipal wells are shown on plate 1. In Lower Bartlett and North Conway, almost all pumped water is returned to the aquifer through septic systems. In Conway Village, pumped water is discharged to the Saco River after processing by a sewage-treatment plant.

Evapotranspiration

The total evapotranspiration from the Saco River drainage area is approximately 24 in/yr, or 50 percent of the total precipitation. The amount of evapotranspiration from the aquifer itself is not known, but is probably not significant because the water table is typically below the root zone.

WATER QUALITY

Ground Water

The chemical quality of ground water in the Saco River valley aquifer is influenced by the following: the chemical composition of the precipitation that recharges the aquifer; chemical reactions which occur as recharge passes through the unsaturated zone; chemical reactions which occur between ground water and the matrix material of the aquifer; residence time (the amount of time available for ground water to react chemically with the aquifer matrix); land-

Table 4.--*Average annual pumpage from the Saco River valley aquifer by municipal suppliers*

[Dashes indicate no data available]

	Pumpage, in million gallons per day					
	1980	1981	1982	1983	1984	1985
Lower Bartlett Water Precinct	--	0.161	0.150	0.162	--	--
North Conway Water Precinct[1]	2.0	2.0	2.0	2.0	2.0	2.0
Conway Village Fire District	.420	.925	.664	.672	--	--
Fryeburg Water Company	.155	.159	.166	.147	.156	.158

[1] Estimated (Richard Chinook, North Conway Fire Precinct, oral commun., 1987).

use above the aquifer; and ground-water flow directions.

Ground-water samples from selected observation, domestic, and municipal wells were analyzed for common inorganic and organic constituents. Forty-eight wells were sampled from July through September 1984, and 82 wells (including 37 wells previously sampled) were sampled from August through November 1985. Ground-water samples collected in 1985 from 15 wells in the vicinity of State Route 16 near North Conway were analyzed for detergents and volatile organics. Locations of sampling sites are shown on plate 1, and the results of the chemical analyses are presented in Johnson and others (1987, tables 5-11).

The objectives of the sampling program were to (1) characterize the uncontaminated "background" water quality, (2) characterize water quality in agricultural areas, and (3) assess the effects of development along State Route 16, the major highway in North Conway.

To accomplish these objectives, the ground-water samples were sorted by land use and location of the sample sites. Samples collected in Conway were divided into three groups: "Conway--background" (CB), "Conway--agricultural" (CAG), and "Conway--development" (DEV). Samples collected in Fryeburg were divided into two groups: "Fryeburg--background" (FB) and "Fryeburg--agricultural" (FAG).

The Wilcoxon-Mann-Whitney rank sum test (Ryan and others, 1985) was used to determine whether significant differences existed in the median values of 13 properties and constituents in the background groups and in 14 properties and constituents in the agricultural groups. This nonparametric statistical procedure was used because the distribution of most water-quality data values is nonnormal. No significant differences were found between the background groups (CB and FB), so they were therefore combined into one background group. Only 2 of 14 properties or constituents showed significant differences when the agricultural groups (CAG and FAG) were compared, so these groups were combined into one agricultural group. By combining sites into the final background and agricultural groups, the number of samples per group, and therefore the statistical reliability of each group, was increased. The areal distribution of the wells in the background, agricultural, and development groups, the three final land-use groups, is shown in figure 10.

The Wilcoxon-Mann-Whitney rank sum test also was used to test for differences between the background, agricultural, and development groups. The results are summarized in table 5. Statistical differences greater than a 95-percent confidence level between the background group and either the agricultural or development group indicate an increase in constituent concentration above that observed in the background water quality. Comparison of the background and agricultural groups showed that agricultural land use has resulted in increased specific conductance and increased concentrations of chloride, sulfate, ammonia, calcium, magnesium, and sodium. Comparison of the background and development groups showed that development in the North Conway area has resulted in increased specific conductance and increased concentrations of chloride, nitrate plus nitrite, total nitrogen, calcium, and sodium.

Descriptive statistics for 25 properties and constituents in each of the three groups are presented in tables 6a-c. The statistics were based on averaged values for each well that was resampled. The statistics used to describe the water-quality data were the minimum, median, maximum, and the 25th and 75th percentiles. Because the data for each group did not show a normal distribution, these quartile values provided a better description of the water quality than did the mean and standard deviation. Stiff diagrams based on median concentrations of major cations and anions and specific conductance for each of the three groups are shown in figure 11. Drinking-water standards set by the U.S. Environmental Protection Agency and the Maine Department of Human Services are presented in Johnson and others (1987, table 12).

Background Water Quality

The 26 wells in the background group are located in areas that have not been influenced by development or agricultural land-use (fig. 10). Descriptive statistics for this group are shown in table 6a and a Stiff diagram of major ions based on median values is presented in figure 11. The background water quality was characterized as low in specific conductance, somewhat acidic, and soft. The principal cations were calcium and sodium and the principal anions were bicarbonate and sulfate.

Although the median concentrations of dissolved iron and dissolved manganese did not exceed limits recommended by the U.S. Environmental Protection Agency (1986), these limits were exceeded at several wells. The recommended limit of 300 μg/L (micrograms per liter) for dissolved iron

Table 5.--*Results from the Wilcoxon-Mann-Whitney rank sum test on data from the background, agricultural, and development land-use groups*

[D, statistical difference at 95-percent-confidence level between the medians for a given parameter; ND, no difference; dashes indicate insufficient sample size]

	Background compared with agricultural	Background compared with development	Agricultural compared with development
Specific conductance	D	D	D
Chloride	D	D	D
Sulfate	D	ND	ND
Phosphorus, total (as P)	ND	ND	ND
Orthophosphorous, total (as P)	ND	ND	ND
Nitrite (as N)	ND	ND	ND
Nitrate plus nitrite, total (as N)	ND	D	D
Ammonia, total (as N)	D	ND	ND
Ammonia plus organic nitrogen, total (as N)	ND	ND	ND
Nitrogen, total (as N)	ND	D	D
Nitrogen, organic, total (as N)	ND	ND	D
Calcium	D	D	ND
Magnesium	D	ND	D
Sodium	D	D	D
Total organic carbon	--	--	D

was exceeded at 5 observation wells (OW17, OW35, OW48, OW65, OW67) and the recommended limit of 50 $\mu g/L$ for dissolved manganese was exceeded at 11 observation wells (OW13, OW20, OW27, OW31, OW35, OW40, OW44, OW49, OW50, OW65, OW67). Elevated iron and manganese concentrations in ground water pumped from glacial deposits are a common problem in New England. Although humans are not known to suffer any effects from drinking water that contains excessive iron or manganese, ground water may be unsuitable for some uses if it contains only a few tenths of a milligram per liter of iron and a few hundredths of a milligram per liter of manganese. Iron and manganese can cause problems in distribution systems by supporting growth of iron bacteria and can stain clothes and plumbing fixtures. However, filtration units can be installed by well owners to remove iron and manganese.

Effects of Agriculture

Irrigation return flows, the use of soil amendments, fertilizers, and pesticides, and the storage of animal wastes are the major causes of water-quality degradation in agricultural areas. The 42 wells in the agricultural group are located in areas where corn, potatoes, or beans are planted (fig. 10). Descriptive statistics for chemical analyses from this group are shown in table 6b, and a Stiff diagram of major ions is presented in figure 11.

Ground water in the agricultural group was characterized by increases above background levels in the concentrations of major cations and anions

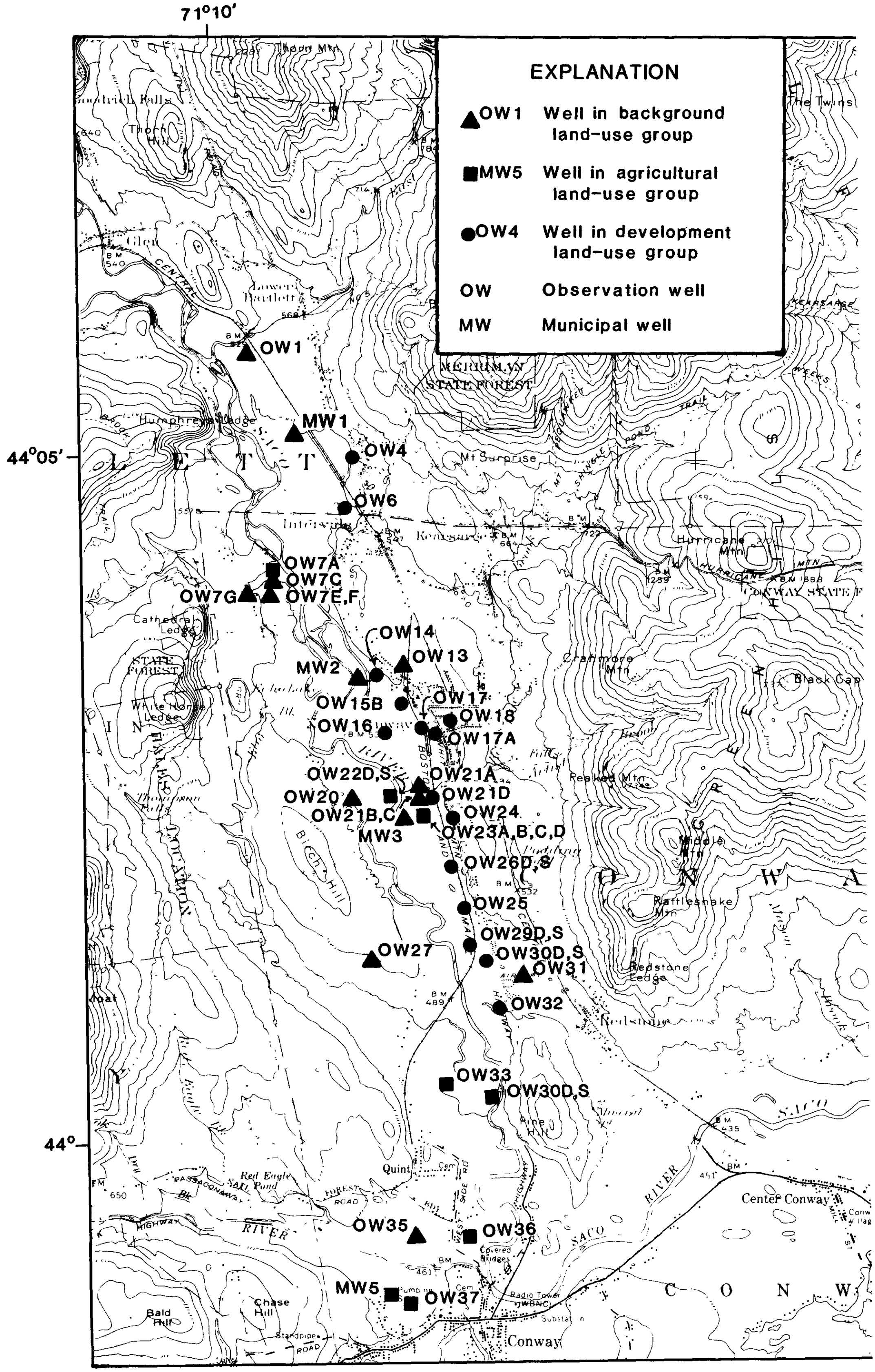
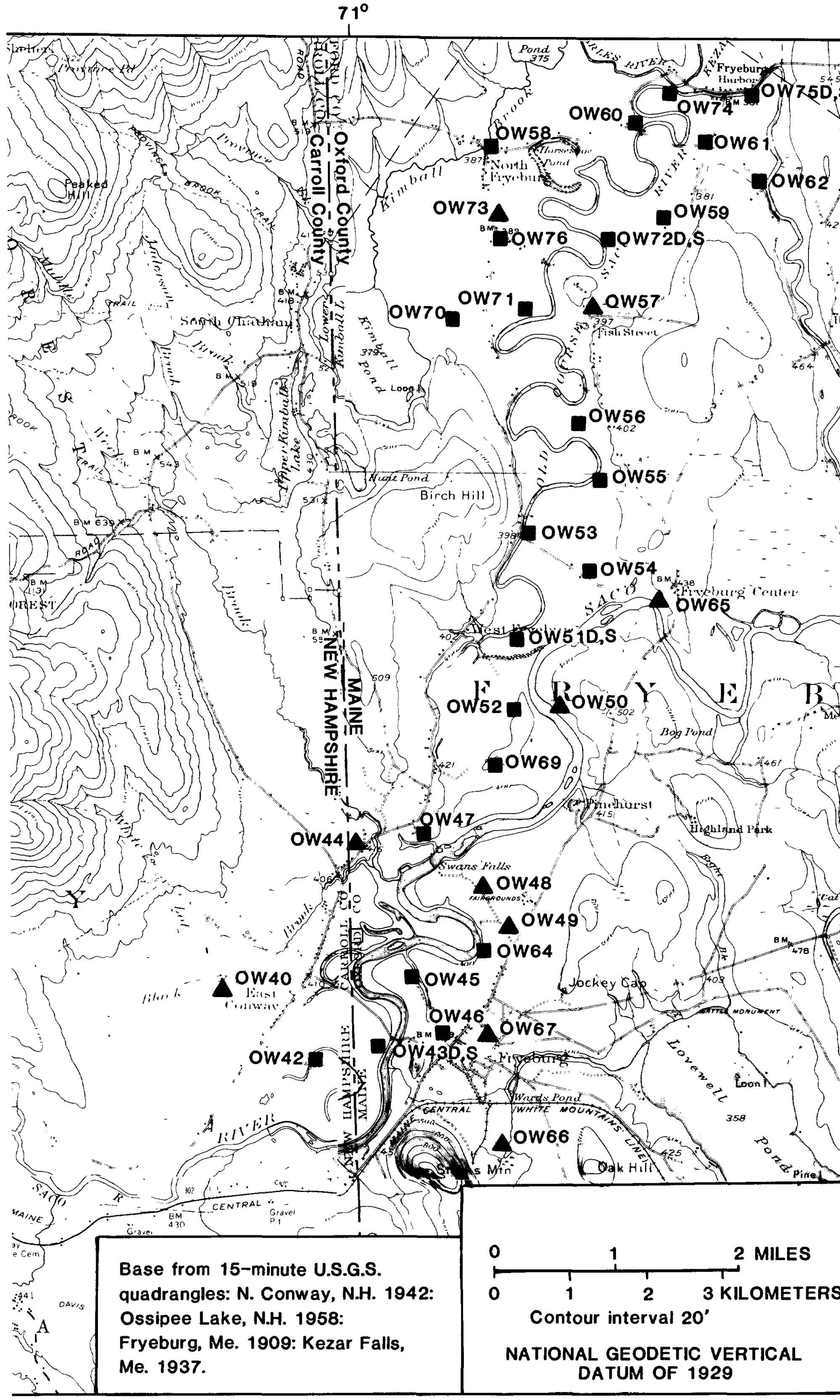


Figure 10.--Land-use groups (background, agricultural, and development) activities on



assigned to observation and municipal wells to assess effects of land-use ground-water quality.

Table 6a.--*Descriptive statistics of ground-water quality for the background land-use group*

[Units are milligrams per liter unless otherwise noted. °C, degrees Celsius; μg/L, micrograms per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius]

Number of samples	Property or constituent	Minimum	Percentile 25th	Percentile 50th (median)	Percentile 75th	Maximum
26	Temperature (°C)	7.5	8.9	10.8	12.9	17.5
26	Specific conductance (μS/cm)	20	34	54	80	255
26	pH (pH units)	5.2	5.7	5.8	6.0	7.1
26	Alkalinity (as $CaCO_3$)	2.5	6.5	9.0	13	38
25	Chloride, dissolved	.30	.77	1.8	8.7	61
26	Sulfate, dissolved	1.5	3.0	4.6	5.9	13
26	Phosphorus, total (as P)	.001	.006	.020	.044	3.60
19	Orthophosphorus, total (as P)	.001	.004	.010	.030	.420
19	Nitrite, total (as N)	.01	.01	.01	.01	.30
26	Nitrite + nitrate, total (as N)	.01	.15	.30	.51	3.3
19	Ammonia, total (as N)	.01	.01	.02	.04	.15
19	Ammonia + organic nitrogen, total (as N)	.10	.20	.20	.30	.90
10	Nitrogen, organic, total (as N)	.16	.18	.20	.29	.73
14	Nitrogen, total (as N)	.10	.28	.45	.66	3.3
15	Nitrogen, total (as NO_3)	.01	.89	1.8	2.7	15
26	Calcium, dissolved	.70	2.5	4.0	5.8	20
26	Magnesium, dissolved	.19	.30	.54	.93	2.6
26	Sodium, dissolved	1.2	2.2	3.7	7.5	28
26	Potassium, dissolved	.60	.80	1.0	1.5	4.8
26	Iron, dissolved (μg/L)	3.0	22	30	50	1,100
12	Iron, total (μg/L)	30	102	270	920	4,700
26	Manganese, dissolved (μg/L)	3.0	6.0	32	230	950
12	Manganese, total (μg/L)	5.0	10	41	260	930
5	MBAS detergents	.01	.02	.02	.02	.02

Table 6b.--*Descriptive statistics of ground-water quality for the agricultural land-use group*

[Units are milligrams per liter unless otherwise noted. °C, degrees Celsius; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Number of samples	Property or constituent	Minimum	Percentile 25th	Percentile 50th (median)	Percentile 75th	Maximum
42	Temperature (°C)	8.5	10.0	11.0	11.6	19.0
42	Specific conductance (µS/cm)	34	92	125	190	415
42	pH (pH units)	5.2	5.6	5.8	6.1	7.8
42	Alkalinity (as $CaCO_3$)	1.0	10	15	25	86
42	Chloride, dissolved	.50	5.5	12	17	92
42	Sulfate, dissolved	3.0	4.7	8.6	12	20
42	Phosphorus, total (as P)	.001	.011	.032	.170	5.30
39	Orthophosphorus, total (as P)	.001	.005	.010	.020	.590
39	Nitrite, total (as N)	.01	.01	.01	.01	.02
42	Nitrite + nitrate, total (as N)	.01	.10	.50	3.5	15
39	Ammonia, total (as N)	.01	.02	.04	.24	1.5
31	Ammonia + organic nitrogen, total (as N)	.10	.20	.22	.30	.60
23	Nitrogen, organic, total (as N)	.01	.16	.20	.26	.48
25	Nitrogen, total (as N)	.20	.27	.70	2.9	8.6
26	Nitrogen, total (as NO_3)	.84	1.2	3.1	16	38
41	Calcium, dissolved	3.1	5.4	10	17	26
41	Magnesium, dissolved	.55	1.1	1.7	2.5	5.0
41	Sodium, dissolved	1.1	3.6	4.9	10	60
41	Potassium, dissolved	.40	1.2	1.6	2.9	21
41	Iron, dissolved (µg/L)	3.0	30	40	2,450	17,000
21	Iron, total (µg/L)	50	1,150	2,900	4,450	45,000
41	Manganese, dissolved (µg/L)	5	33	215	550	6,100
21	Manganese, total (µg/L)	20	155	330	675	5,700
5	MBAS detergents	.02	.03	.03	.05	.05

Table 6c.--*Descriptive statistics of ground-water quality for the development land-use group*

[Units are milligrams per liter unless otherwise noted. °C, degrees Celsius; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Number of samples	Property or constituent	Minimum	Percentile 25th	Percentile 50th (median)	Percentile 75th	Maximum
18	Temperature (°C)	8.2	10.0	11.3	12.6	14.0
18	Specific conductance (µS/cm)	22	111	170	320	570
18	pH (pH units)	4.9	5.4	5.6	6.0	6.6
18	Total organic carbon	.1	.6	.8	1.4	4.6
18	Alkalinity (as $CaCO_3$)	4.0	6.0	12	18	26
18	Chloride, dissolved	1.4	18	31	57	156
18	Sulfate, dissolved	.9	3.6	5.8	8.9	13
18	Phosphorus, total (as P)	.006	.009	.020	.077	6.52
18	Orthophosphorus, total (as P)	.010	.010	.010	.020	.020
18	Nitrite, total (as N)	.01	.01	.01	.01	.02
18	Nitrite + nitrate, total (as N)	.10	.37	1.6	8.4	14
18	Ammonia, total (as N)	.01	.01	.06	.07	.17
18	Ammonia + organic nitrogen, total (as N)	.10	.20	.35	.53	3.4
14	Nitrogen, organic, total (as N)	.05	.18	.31	.52	3.2
16	Nitrogen, total (as N)	.70	1.0	1.5	9.3	15
16	Nitrogen, total (as NO_3)	3.1	4.5	6.7	41	64
18	Calcium, dissolved	1.7	4.2	6.6	14	20
18	Magnesium, dissolved	.32	.48	.95	1.6	3.2
18	Sodium, dissolved	1.6	14	23	38	84
18	Potassium, dissolved	.50	1.6	2.1	4.5	7.9
18	Iron, dissolved (µg/L)	7	15	20	41	255
18	Iron, total (µg/L)	80	222	600	2,000	15,000
18	Manganese, dissolved (µg/L)	5	13	43	149	390
18	Manganese, total (µg/L)	10	18	95	173	360
16	MBAS detergents	.02	.03	.06	.09	.11

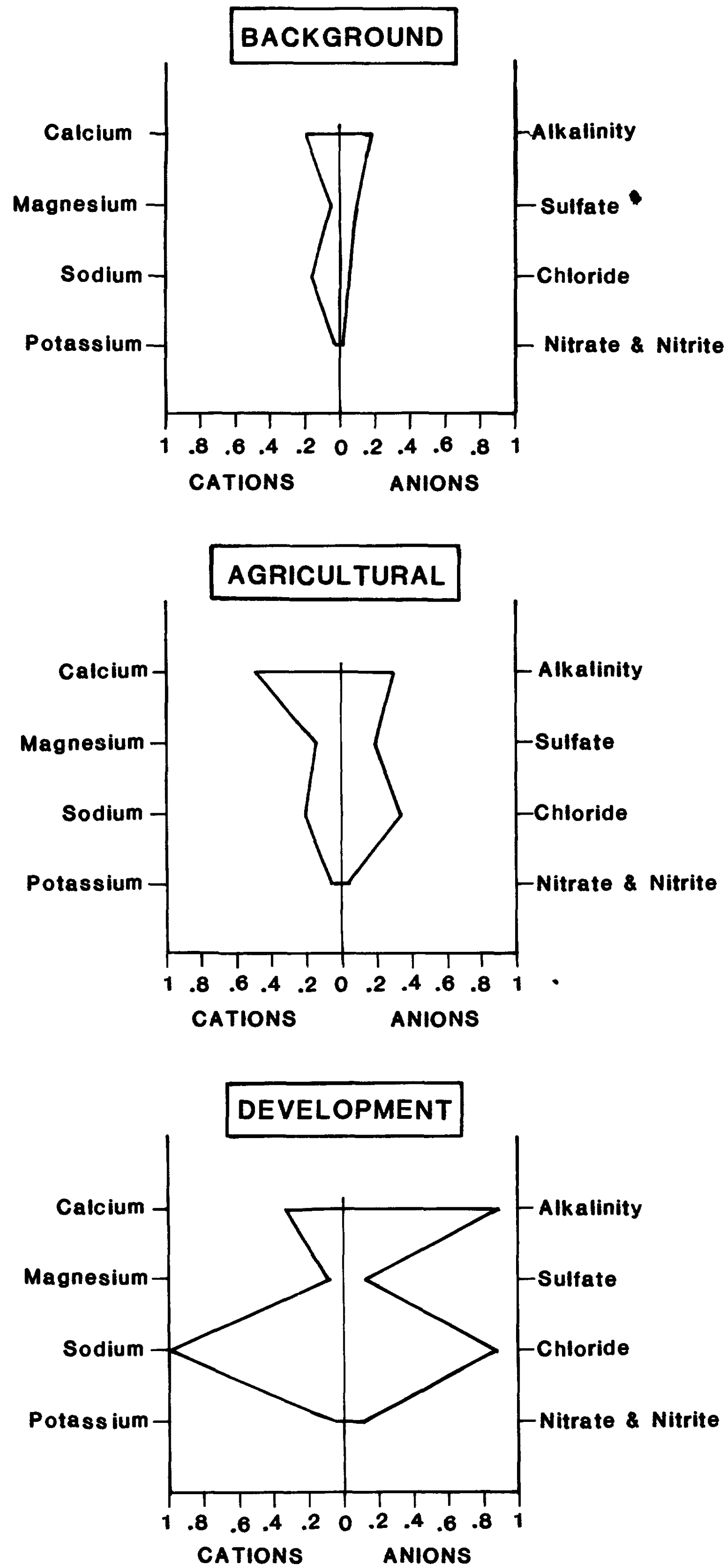


Figure 11.--Stiff diagrams showing differences in median concentrations of major cations and anions for the three land-use groups (background, agricultural, and development). Units are in milliequivalents per liter.

and by the replacement of sulfate by chloride as a major anion (fig. 11). The median specific conductance of 123 μS/cm (microsiemens per centimeter at 25 degrees Celsius) was more than double the median level for the background group (54 μS/cm). Irrigation return flow can result in increased concentrations of calcium, magnesium, sodium, bicarbonate, sulfate, chloride, and nitrate (Todd, 1980). Concentrations of each of the above ions were significantly higher in the agricultural group than in the background group.

Calcium and magnesium are major components of lime and gypsum, which are used to adjust the physical or chemical properties of the soil. The median concentrations of calcium and magnesium in the agricultural group were the highest of the three groups.

Ground water in agricultural areas may become contaminated by the major nutrients nitrogen, phosphorus, and potassium through the use of fertilizers and the spreading and storage of animal wastes. Ammonia and other nitrogen compounds are commonly used in synthetic fertilizers. Concentrations of total ammonia and total nitrogen were significantly higher in the agricultural group than in the background group. Nitrate leaching in areas where animal wastes are stored or spread also is a problem.

The cluster of observation wells OW23A-D was located in an area where manure had been stored for several years. The vertical gradient is downward at this site. The two observation wells in the cluster at intermediate depth, OW23B and OW23D, had mean nitrate plus nitrite and total nitrogen concentrations of 3.3 mg/L (milligrams per liter) and 3.5 mg/L, respectively. The median background concentrations of nitrate plus nitrite and total nitrogen were 0.30 mg/L and 0.45 mg/L, respectively. The concentrations observed in the intermediate zone did not exceed the U.S. Environmental Protection Agency (1986) proposed RMCL (recommended maximum concentration limit) of 10 mg/L for nitrate-nitrogen. Evidently the contaminants have migrated downward beyond the shallow ground-water zone but have not yet affected the zone near the screen of OW23C, the deepest well in the cluster. Septic tanks in North Conway may cause some additional nitrogen loading in the intermediate zone at this site, as evidenced by slightly higher levels of MBAS (methylene blue active substances), used in detergents, than are found above and below this zone.

Phosphate and potassium fertilizers are readily adsorbed on soil particles and seldom cause pollution problems (Todd, 1980). Animal wastes also are a source of phosphorus contamination. The agricultural group had the highest median concentration of total phosphorus and the highest maximum value for total orthophosphorus. The agricultural group also had the highest concentrations of potassium.

Effects of Development

The 29 wells in the development group are located near or downgradient from State Route 16, the major highway in North Conway (fig. 10). This area has experienced rapid growth as a year-round tourist attraction. Although there are plans to build a municipal sewage system, the area currently (1985) is serviced only by septic tanks. Nutrient loading from these septic tanks and use of highway deicing salts have caused localized changes in ground-water quality. Descriptive statistics for this group are shown in table 6c, and a Stiff diagram of the major ions is presented in figure 11.

The principal cations were calcium and sodium and the principal anions were bicarbonate and chloride. The concentrations of all major ions were well above those observed in the background group. The development group had the highest median specific conductance (169 μS/cm) of the three groups. The highest observed value in the development group for specific conductance was 810 μS/cm at OW26D in 1984.

The highest median values of sodium (23 mg/L) and chloride (31 mg/L) also were observed in this group. The median sodium value exceeded the maximum concentration level of 20 mg/L recommended for people who have heart, kidney, or hypertension problems (Maine Department of Human Services, 1983). The concentrations of sodium and chloride in this group are primarily attributed to the use of salt to deice State Route 16 and adjoining roads. However, some of the sodium and chloride also may come from discharges from septic systems. In a study of a sewage plume on Cape Cod, LeBlanc (1984) found higher concentrations of sodium and chloride, common constituents of the human diet, in the treated sewage than in the uncontaminated ground water. LeBlanc also found that both sodium and chloride are conservative species and move through the aquifer without significant retardation by chemical reactions and adsorption.

Problems with septic systems typically cause elevated concentrations of phosphorus, nitrogen, metals, and detergents. A detailed discussion of the transport and fate of contaminants from septic systems is provided in Canter and Knox (1985). Because phosphorus in septic-system effluent usually is removed from solution by chemical precipitation and adsorption and is retained effectively in underlying soil, only low concentrations are typically introduced into the ground-water system. The median values for total phosphorus (as P) and total orthophosphorus (as P), the predominant form of dissolved inorganic phosphorus in water, were the same for the background group and the development group. However, the maximum concentration of total phosphorus (as P), 6.52 mg/L, was in OW21D, a well in the development group.

Contamination by nitrogen from septic-tank effluent is of concern because it can contribute to eutrophication of surface-water bodies, and excessive levels can be a health hazard. The two forms of major concern for ground-water pollution are ammonium (NH_4^+) and nitrate (NO_3^-) ions.

According to Canter and Knox (1985), nitrogen from septic-tank systems enters the soil primarily in the form of ammonium ions. Ammonium ions also can be generated within the upper soil layers by conversion of organic nitrogen to ammonia nitrogen. Ammonium ions may be adsorbed onto negatively charged soil particles, involved in cation-exchange reactions, incorporated into microbial biomass, or released in gaseous form to the atmosphere. In the Cape Cod sewage plume study, LeBlanc (1984) found that ammonia moved readily in the aquifer and that oxidation of ammonia to nitrate is the primary cause of decreased ammonia concentrations in the plume.

Nitrate can be discharged directly from septic systems to the subsurface. It also can be generated within the upper soil layers during nitrification, as ammonium is converted to nitrite and then to nitrate. Nitrate is more mobile than ammonium in both the unsaturated and the saturated zones because of its solubility and anionic charge (Canter and Knox, 1985). Nitrate is the stable nitrogen species in an oxidizing ground-water environment and can move through the aquifer without reacting with other chemical constituents or with the sediments (Freeze and Cherry, 1979). According to Canter and Knox (1985), nitrate can be transported long distances in highly permeable subsurface materials containing dissolved oxygen. However, denitrification (conversion of nitrates back to nitrites and then to nitrogen gas) can occur if there is a decline in the redox potential of the ground water.

As a result of septic-tank discharges, the development group had the highest median concentrations and highest maximum concentrations for nitrite and nitrate, ammonium, ammonium and organic nitrogen, and organic nitrogen (table 6c). The U.S. Environmental Protection Agency (1986) proposed RMCL of 10 mg/L for nitrate-nitrogen was exceeded at OW25, where the concentration was 14 mg/L. Concentrations of nitrate-nitrogen (as N) above 10 mg/L have been known to cause infant methemoglobinemia, a potentially lethal disease (National Research Council, 1977). There is some evidence that high concentrations of nitrate in drinking water for livestock have resulted in abnormally high mortality rates in baby pigs and calves and in abortions in brood animals (Lehr and others, 1980).

Detergents from laundry and dishwashing wastes are a definite indication of contamination of ground water by waste-water disposal. The MBAS test was used to measure the concentration of detergents in water. The median and maximum levels in the background group were 0.02 mg/L MBAS, which is considered a background level. The development group had MBAS concentrations slightly above background values. The median concentration of MBAS for the development group was 0.06 mg/L MBAS, and the highest concentrations of MBAS in the Conway area were found in three observation wells in this group: OW17A (0.11 mg/L MBAS), OW24 (0.11 mg/L MBAS), and OW25 (0.11 mg/L MBAS).

A scan for 28 volatile organics was performed on ground-water samples from six wells along State Route 16. These observation wells are in the development group and include OW14, OW17, OW30D, OW30S, OW25, and OW32. No concentrations exceeded the detection limit of any compound analyzed (Johnson and others, 1987, table 8).

Measurements of total organic carbon (TOC) that exceed background levels provide a rapid, inexpensive indication of the extent of contamination by synthetic organic compounds. The nonvolatile organic carbon levels of uncontaminated ground water are generally within the range of 0.1 to 4 mg/L (Barcelona, 1984). The median value for the development group was 0.8 mg/L, and the only sample containing over 4 mg/L was from OW17A (8.0 mg/L).

Surface Water

In order to describe the surface-water quality in the study area, samples were collected from nine sites along the main course of the Saco River, two sites along the Old Course of the Saco River in Maine, and one site near the mouth of the Swift River in New Hampshire (pl. 1). The samples were obtained from September 30 through October 4, 1985, during a period of receding streamflow conditions that followed runoff from Hurricane Gloria. The precipitation from the storm resulted in a peak flow of 9,310 ft^3/s at the Conway streamflow-gaging station on September 28. On the basis of the long-term record for that station, this discharge is expected to be exceeded less than 0.8 percent of the time. At the time the samples were collected, streamflow at the Conway gage had receded to levels that are exceeded about 50 percent of the time. Although streamflow conditions statistically represented "median" flow conditions, the water was largely runoff from the storm and thus had a short residence time in the watershed. The chemistry of the samples collected may therefore be slightly more dilute than that of samples with longer residence time in the watershed but with similar flow levels.

Chemical analyses of the surface-water samples collected for this study are presented in Johnson and others (1987, table 13). The chemical analyses indicated that water-quality conditions were excellent in the Saco and Swift Rivers. All analyses met chemical standards for drinking water set by the U.S. Environmental Protection Agency (1986). The water was characterized as very soft (median hardness, 8 mg/L as $CaCO_3$), near neutral pH (median, 6.9), and had low concentrations of dissolved solids and nutrients, and dissolved-oxygen concentrations near saturation. Dissolved-solids concentrations and specific conductance both increased about 20 percent from the most upstream collection sites (27 mg/L and 35 μS/cm, respectively) to the most downstream collection sites (33 mg/L and 42 μS/cm, respectively) on the Saco River.

Fecal coliform and fecal streptococcus bacteria were detected at all sample locations. Along the main course of the Saco River, elevated bacteria counts were observed downstream from the populated areas. The highest counts (60 fecal coliform colonies per 100 mL (milliliter) and 76 fecal streptococcus colonies per 100 mL) were observed at the Conway streamflow-gage, which is the closest downstream site to Center Conway's sewage-treatment facility. Elevated bacteria counts observed along the Old Course of the Saco River (130 fecal coliform colonies per 100 mL and 67 fecal streptococcus colonies per 100 mL) at station 440629070580100 probably resulted from stagnant streamflow along this abandoned river channel.

Agricultural land-use along the Old Course of the Saco River has degraded surface-water quality. At the Old Fish Street site (pl. 1) (station 440629070580100), nutrient concentrations were elevated (0.13 mg/L phosphorus (as P) and 1.2 mg/L nitrogen (as N)) and dissolved-oxygen concentrations were low (37-percent saturation). Dissolved-solids concentrations at both stations on the Old Course were three times greater than observed along the mainstem. The Old Fish Street site had a dissolved-manganese concentration (340 μg/L) above the 50 μg/L limit recommended by the U.S. Environmental Protection Agency (1986). Water-quality problems may limit uses of the aquifer in areas recharged by this surface water. However, development of an irrigation supply from the aquifer may be feasible.

EFFECTS OF INCREASED MUNICIPAL PUMPAGE

A computer model was developed to predict the effects of increased municipal pumpage on ground-water levels and on the extent of contributing areas to municipal wells. The area modeled covered approximately 15 mi^2 and extended from a point near the junction of the Saco and Ellis Rivers to the junction of the Swift and Saco Rivers near Conway Village (pl. 1). This section of the aquifer was modeled because major pumpage occurs within this area, and commercial and residential development is concentrated in this part of the valley.

A diagram of steady-state flow in the aquifer is shown in figure 12. The aquifer consists of unconsolidated sand and gravel bounded by clay, till, or bedrock on the sides and bottom and by the water table on top. Major sources of recharge are precipitation falling directly on the aquifer and runoff from adjacent upland areas. Recharge also occurs from septic systems and infiltration of streamflow. Ground-water discharge is to the Saco River, which partially penetrates the aquifer, and to pumped wells. Because the aquifer does not contain any extensive confining layers, flow was assumed to be two-dimensional in the horizontal direction.

Description of the Numerical Model and Model Construction

The numerical model used for this study is based on a block-centered finite-difference method for solving the differential equations that describe ground-water flow. The model allows simulation of flow in two or three dimensions in confined or unconfined aquifers, and has a variety of options for simulating recharge or discharge. The computer

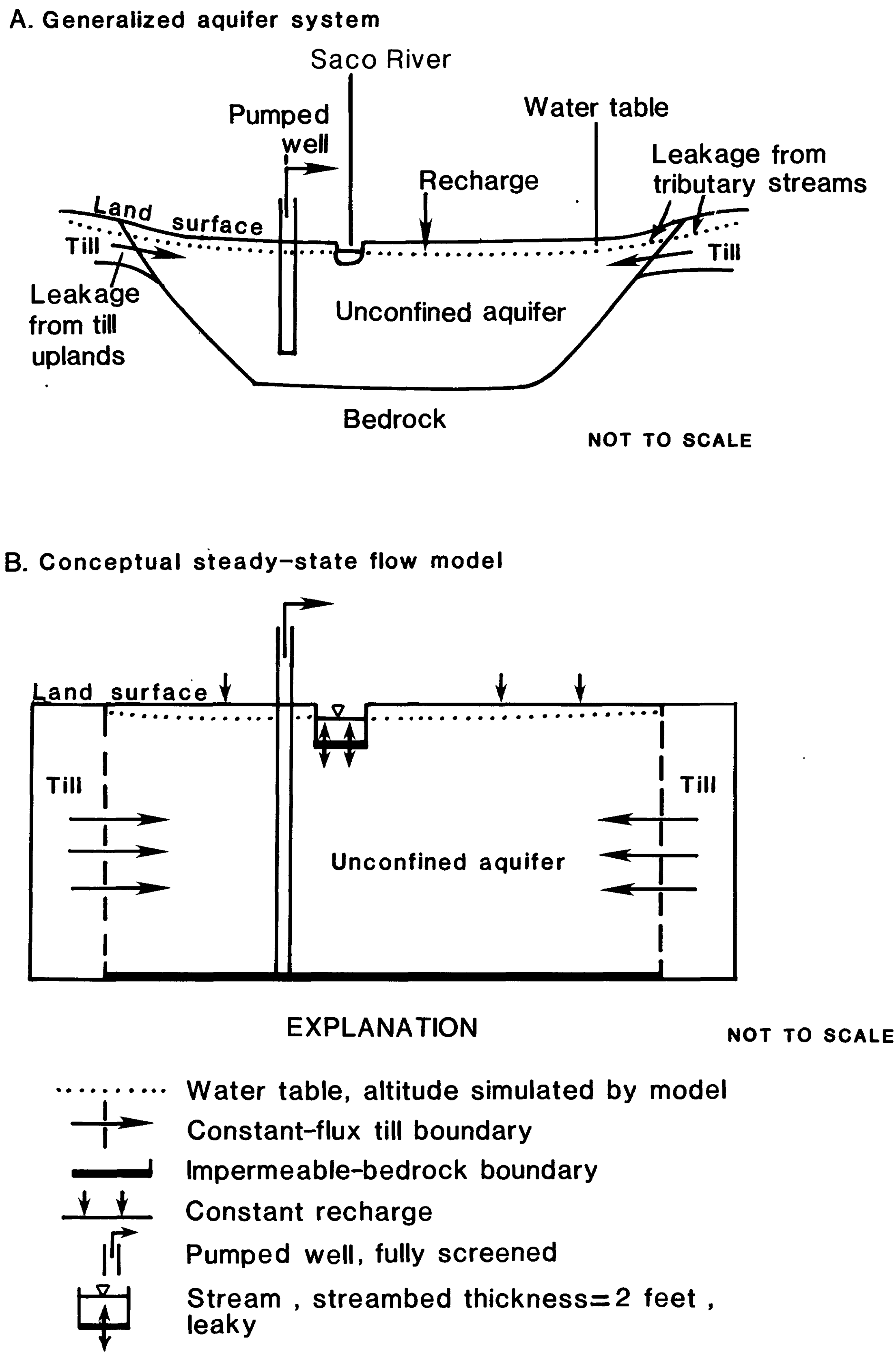


Figure 12.--Generalized aquifer system and conceptual model of steady-state ground-water flow for the Saco River valley aquifer. Modified from Olimpio and de Lima (1984).

code was developed by McDonald and Harbaugh (1984) and allows use of independent modules for simulation of specific geohydrologic features of an aquifer.

The grid used to discretize the Saco River valley aquifer is shown on plate 6. The grid has 68 rows and 162 columns, or a total of 11,016 blocks, with uniform spacing of 300 ft on a side. Only the blocks located on the stratified-drift aquifer were considered active and were included in the computations. The total number of active blocks was 4,625.

Major assumptions made in developing a ground-water flow model of the Saco River valley aquifer include the following:

(1) Flow in the aquifer is horizontal. This is not the case everywhere in the aquifer, especially in the vicinity of recharge or discharge areas; however, this assumption applies reasonably well throughout most of the modeled area. In areas with significant vertical components of flow, the model results will be less reliable than in areas where flow is predominantly horizontal.

(2) Recharge to the aquifer from precipitation is distributed uniformly over the modeled area. Because most of the modeled area is underlain by permeable sand and gravel and the scale of the model is sufficiently large, this assumption should have little effect on model results.

(3) The altitudes of surface-water bodies in the model remain constant with time. Because all of the model calibration and predictions were done with steady-state simulations, the use of average, constant surface-water altitudes is reasonable and appropriate. The surface-water altitudes were obtained from U.S. Geological Survey topographic maps.

(4) Evapotranspiration from the aquifer has been implicitly modeled. This is accomplished in the model by adjusting recharge from precipitation and upland areas to account for evapotranspiration losses. Likewise, recharge from septic systems is adjusted to account for evapotranspiration losses.

(5) Aquifer properties are uniform within each block of the model grid. However, hydraulic conductivity of the aquifer, aquifer-bottom elevation, and other physical and hydraulic properties of the aquifer may differ from block to block.

(6) The aquifer has been modeled as an unconfined system. Transmissivity was adjusted in the model as a function of saturated thickness.

Boundary Conditions

Accurate definition of aquifer boundaries in terms of location and hydrologic conditions is a critical step in the modeling procedure. If it is not done correctly, the model may give results that do not match actual conditions. The boundaries of a ground-water flow model should correspond with natural aquifer boundaries. If this is not possible and arbitrary boundaries are used in a model analysis, these artificial boundaries should be located far enough from the areas of interest, such as pumped wells, as to have little effect on model results. A detailed discussion of boundary conditions is provided by Franke and others (1987). Boundary conditions used in the Saco River valley aquifer model (pl. 6) include the following:

(1) Valley walls. The boundary between the stratified-drift aquifer and till or bedrock valley walls was treated as a specified-flux boundary in the model. "Flux" refers to the volume of water per unit of time crossing a unit cross-sectional area. This flux, simulated in the model by recharge wells (pl. 6), represents ground-water and surface-water runoff from adjacent upland areas that recharge the aquifer at its boundaries. Because all model simulations were run to steady state, the boundary flux was assigned a constant, average value. The amount of flux varies along the model boundary as a function of the size of the upland area adjacent to a given model cell.

(2) Aquifer bottom. The bottom of the aquifer was treated as a no-flow boundary in the model because of the large permeability contrast between till or bedrock and stratified drift. Any flux that might cross this boundary is considered to be very small with respect to the water budget for the entire aquifer. The aquifer bottom in the modeled area was defined by the bedrock altitudes shown on plate 2.

(3) Water table. The top of the aquifer was defined by the water table and was treated in the model as a free-surface recharge boundary, where recharge from precipitation was applied uniformly at each block in the model grid. The water table fluctuated depending upon the overall balance of stresses within the modeled area.

(4) Surface water. Surface-water bodies that overlie the aquifer were simulated either as constant-head, specified-flux, or head-dependent-flux boundaries. Locations where these boundary conditions have been applied are shown on plate 6. The position of the Saco River and its tributaries as shown on the original base map (pl. 6) was adjusted within the model to reflect the more recent stream locations shown on the following U.S. Geological Survey provisional 1987 1:24,000-scale quadrangle maps: North Conway West, NH; North Conway East, NH-ME; and Conway, NH. A constant-head boundary was used to simulate the average altitude of the water surface at Echo Lake, which is on the western edge of the modeled area just north of Birch Hill. Small high-gradient upland streams that provide significant amounts of ground-water recharge where they cross from the uplands onto the aquifer were treated as specified-flux boundaries. This was accomplished by distributing recharge wells along the reaches of the stream channel where recharge to the aquifer occurs.

The Saco River and several low-gradient tributaries were treated as head-dependent-flux boundaries in the model (pl. 6). In this type of simulation, flow between the aquifer and surface water depends on the head gradient between the streambed and aquifer and on their respective values of hydraulic conductance.

The hydraulic conductance includes coefficients for the vertical hydraulic conductivity of the streambed and for the aquifer beneath the streambed. Reilly and others (1983) developed equations 1-5 below. They define hydraulic conductance as

$$C = \frac{KA}{L}, \qquad (1)$$

where C is hydraulic conductance (L^2/T, where T is time),
K is hydraulic conductivity of aquifer or streambed or both (L/T),
A is cross-sectional area through which flow is taking place (L^2), and
L is length of flow path (L).

Hydraulic conductances are averaged in series to determine a lumped hydraulic conductance for the streambed and the aquifer beneath the stream. The equation takes the following form:

$$\frac{1}{C_{EQ}} = \frac{1}{C_{BED}} + \frac{1}{C_{VERT}}, \qquad (2)$$

where C_{EQ} is equivalent or average vertical hydraulic conductance,
C_{BED} is vertical hydraulic conductance of the streambed, and
C_{VERT} is vertical hydraulic conductance of the aquifer beneath the streambed.

Substitution of each conductance term for equivalent terms in equation 2 yields

$$\frac{1}{C_{EQ}} = \frac{Ts}{KsAs} + \frac{0.5Dz}{KzDxDy}, \qquad (3)$$

where Ts is thickness of streambed,
Ks is vertical hydraulic conductivity of streambed,
As is area of seepage into stream for the entire block (wetted perimeter by length),
Kz is vertical hydraulic conductivity of aquifer, and
Dx, Dy, Dz are dimensions of block represented in model.

Combining and rearranging terms gives

$$C_{EQ} = \frac{KsKzAsDxDy}{KzTsDxDy + 0.5KsAsDz} \ . \qquad (4)$$

Finally, the flow between the aquifer and stream can be expressed as:

$$Q = C_{EQ}(ha - hs) \ , \qquad (5)$$

where Q is flow between the aquifer and stream,
ha is altitude of water table, and
hs is altitude of the stream surface.

When the head in the aquifer falls below the bottom of the streambed, the flux from the surface-water body into the aquifer reaches a maximum, constant rate. When the head in the aquifer is higher than the head in the stream, flow is from the aquifer to the stream.

(5) Arbitrary boundaries. An arbitrary boundary in the model occurs where a model boundary does not coincide with a natural aquifer boundary. Arbitrary boundaries were used where the Saco and Swift Rivers enter the northern and southwestern edges of the model, respectively. The arbitrary boundaries were simulated as "no flow" in the model because they are approximately coincident with flow lines in the aquifer. Furthermore, these boundaries are far enough away from pumping stresses to not affect model results.

Aquifer Properties

The average physical and hydraulic properties of the aquifer were specified for each cell in the model grid. Properties include aquifer-bottom altitude, average hydraulic conductivity, and water-table altitude. At cells in which surface water was simulated as a head-dependent-flux boundary, the area, thickness, vertical hydraulic conductivity of the streambed, and the average stage in the stream were specified.

Because the bottom of the aquifer was assumed to be the top of the bedrock surface, aquifer-bottom altitudes were determined for each cell in the model by overlaying the model grid on a map of the bedrock surface (pl. 2) and estimating the average bedrock altitude within each cell. In some locations, thick deposits of silt and clay overlie the bedrock. However, these fine-grained deposits are not extensive (fig. 4b); therefore, their surface was not used to define the aquifer bottom. Instead, the presence of these deposits has been taken into account when assigning average horizontal hydraulic-conductivity values for each cell of the model.

The average hydraulic-conductivity values that were used in the final, calibrated, steady-state model are shown on plate 4. In general, hydraulic conductivity decreased in a down-valley direction, with values ranging from 200 to 5 ft/d. The original estimates of hydraulic conductivity based on grain-size analyses, stratigraphic logs of observation wells, slug tests, and pump tests were modified during model calibration. Original estimated values of hydraulic conductivity, especially those based on grain-size analyses, generally were increased during calibration to obtain a reasonable match between computed and observed heads.

The starting water-table altitudes used for the steady-state model simulation are shown on plate 5. These water levels were measured in December 1985 and, on the basis of a comparison to long-term water-level observations in the area, were assumed to represent average conditions in the aquifer.

The vertical hydraulic conductivity of the streambed material in the Saco River and its tributaries initially was assumed to be 2 ft/d and the vertical hydraulic conductivity of the aquifer was assumed to be one-tenth the horizontal hydraulic conductivity. The Saco River was estimated to average 50 ft in width and 5 ft in depth throughout the modeled area. During model calibration, streambed vertical hydraulic conductivity in the Saco River was increased to 5 ft/d to improve agreement between observed and computed values of head and of streamflow.

Recharge and Discharge

Natural recharge to the aquifer includes recharge from precipitation falling directly on the aquifer and recharge from runoff originating in till-covered or bedrock uplands adjacent to the aquifer.

The average annual recharge from precipitation falling directly on the aquifer was assumed to equal 24 in/yr, or half of the average annual precipitation. This estimate was based on work in New York by

MacNish and Randall (1982) but is reasonable to apply to the study area based on the similarity of climates. The other half of the total precipitation is assumed to be lost to evapotranspiration. Recharge from upland sources was subdivided into seepage from upland tributary streams that cross alluvial fans or terraces and flow out onto the stratified-drift aquifer and total runoff (ground water and surface water) from upland areas not drained by streams or rivers.

Constant-flux recharge wells were used in the model to simulate the average observed recharge to the aquifer from tributary-stream seepage. The amount of recharge applied to the model from upland streams was based on surface-water measurements made along six tributary streams in the Saco River valley from October 1983 through September 1985 (Johnson and others, 1987, tables 14-15, 17-18, 22-23). The average observed seepage losses are summarized in table 3, and locations where seepage losses were simulated in the model are shown on plate 6. Differences in seepage losses between upstream and downstream reaches were simulated where identifiable. At Elm Brook and the upper reach of Moat Brook (pl. 1), no seepage measurements were made; instead, average seepage losses from nearby tributaries were used to estimate seepage losses at these sites.

It was assumed in the model that all runoff from upland areas not drained by tributary streams recharged the aquifer at the base of the valley walls. The average annual runoff from uplands in the study area was approximately 32 in/yr, on the basis of the average long-term annual runoff observed at streamflow-gaging stations 01064400 on Lucy Brook and 01064500 on the Saco River (Blackey and others, 1985).

Constant-flux recharge wells were used on the boundaries of the model (pl. 6) to simulate recharge from upland areas not drained by streams. The amount of water that was applied at each cell was based on the average annual runoff (32 in/yr) and the amount of upland area adjacent to each cell. The total amount of recharge from unchanneled upland areas was determined by the following procedure. Upland drainage areas were first divided into subdrainage areas between tributary streams and the total area of each subdrainage was then determined by planimeter. Next, the total area was multiplied by the runoff per unit area to determine the total volume of water available from each subdrainage. Finally, the total volume of water from each subdrainage was applied uniformly at each block in the model bordering that particular area.

Recharge to the aquifer from septic systems was simulated in Lower Bartlett and North Conway (pl. 6) where there are municipal water supplies and all waste is disposed through septic systems (as of 1985). Recharge from this source was assumed to equal 80 percent of the water pumped at the municipal wells in Lower Bartlett and North Conway, and it was assumed that the remaining 20 percent is used consumptively or lost through evapotranspiration. This recharge is distributed along cells in the model grid which overlie areas served by public water supplies in Lower Bartlett and North Conway. Recharge from septic systems is distributed nonuniformly to reflect large amounts from areas where restaurants and motels are concentrated along State Route 16 in North Conway.

Discharge from the aquifer is to municipal supply wells and to the Saco River. The average annual pumpage for each municipal supply well is shown in table 4. Locations of the municipal wells are shown on plate 1.

Model Calibration

Model calibration is the process of adjusting model parameters so that computed-head values agree with those observed in the field. Water levels observed in December 1985 were the reference-head altitudes that were the basis for calibration of the model. These water levels approximate average water levels in the aquifer based on an analysis of data from OW76 in Fryeburg, Maine (Bartlett and others, 1988), and well LCW-1 in Lancaster, New Hampshire (Blackey and others, 1985). Water-level data were available from August 1978 through December 1985 for OW76; for well LCW-1, water-level data were available from November 1966 through May 1980 and from April 1981 through December 1985.

"Best estimate" values of aquifer properties (hydraulic conductivity, aquifer-bottom altitude, and streambed hydraulic conductivity) and average annual recharge rates were assigned as initial input to the model. Steady-state model simulations were run, and computed heads were compared with observed heads at 35 observation wells in the modeled area. Input parameters were adjusted to decrease the average absolute difference (the average of the absolute values of the differences) between computed and observed heads. Recharge to the model and depth to bedrock were held constant and changes were made to the estimated hydraulic properties of the aquifer, particularly aquifer and streambed hydraulic conductivity. The final average absolute differences between observed and computed heads ranged from 0.03 to 4.69 ft with an average absolute difference of 1.7 ft (table 7). The final steady-state, calibrated heads computed with the model are shown in figure 13. This head distribution was used as the starting head distribution for the various pumpage scenarios.

The final steady-state water budget computed with the model is shown in table 8. The computed total ground-water budget (65.3 ft^3/s) seems reasonable compared with ground-water discharge measured during base-flow conditions (table 3). Approximately 54 percent of the natural recharge to the aquifer is derived from upland sources (tributary stream leakage and runoff from unchanneled areas), whereas only 37 percent of natural recharge is from precipitation. This pattern of recharge, in which runoff from the upland areas provides most of the recharge, is conceptually different from other models of stratified-drift river valley aquifers in New England, which derive most of their recharge from precipitation falling directly on the aquifer (Haeni, 1978; Morrissey, 1983; Olimpio and de Lima, 1984; Mazzaferro, 1986). The conceptual differences in recharge patterns between the Saco model and previous models are that in the previous models, recharge from tributary streams has been ignored and only ground-water runoff (vs. total runoff) from upland areas has been allowed to recharge the aquifer. Differences in the distribution of recharge could also result if the ratio of upland areas to aquifer areas has been significantly smaller in the previous models than in the Saco model. Upland recharge areas that contribute to the Saco model area are shown in figure 14.

Model Sensitivity

Before the calibrated model was used for predictive purposes, a series of runs were made to test the sensitivity of the model to changes in input data. The purpose of sensitivity testing is to determine the effects that errors in various input data can have on model results. Future data-collection efforts can be directed to aquifer properties to which the model is most sensitive.

Key aquifer properties--streambed hydraulic conductivity, aquifer hydraulic conductivity, recharge, and the depth to the aquifer bottom--were varied one at a time to observe the effect on computed water levels. Results of sensitivity testing are shown graphically in figure 15. The vertical axis on this graph shows the average absolute difference between computed and observed heads at 35 observation wells in the aquifer, and the horizontal axis shows the multiplication factor used to change each property. The average absolute difference between computed and observed heads in the model, calibrated to average conditions, is shown at a multiplication factor of 1.0.

Recharge to the aquifer during model calibration was based on the average values of precipitation and runoff observed in the study area from 1959 through 1985. During sensitivity testing, recharge was adjusted on the basis of the observed high and low values of annual precipitation and runoff from 1975 through 1985. The driest year was 1978 when total annual precipitation was 36.4 in. and runoff was 20.5 in.; the wettest year was 1983 when precipitation and runoff were 59.6 in. and 42.3 in., respectively. For the steady-state sensitivity analysis, it was assumed that half of the annual precipitation recharged the aquifer, and that all of the observed runoff from uplands recharged the aquifer along the valley-wall boundaries. Recharge to the aquifer from tributary streams was adjusted to account for changes in runoff from upland areas. The increased recharge caused an increase of 0.9 ft in the average absolute difference between computed and observed heads in the aquifer. Decreased recharge also caused an increase of 0.9 ft in this parameter.

A 50-percent decrease in aquifer hydraulic conductivity (Kaq in fig. 15) had the most dramatic effect on model results for all parameters tested during sensitivity analyses. A 30-percent increase in hydraulic conductivity had much less effect than a proportional decrease. In general, decreases in hydraulic conductivity caused computed groundwater levels to rise throughout the model, whereas increases had the opposite effect. When hydraulic conductivity was increased to 50 percent above values used in the calibrated model, computed water levels along the boundaries of the model dropped so much that numerous cells went dry and caused the model to halt computations.

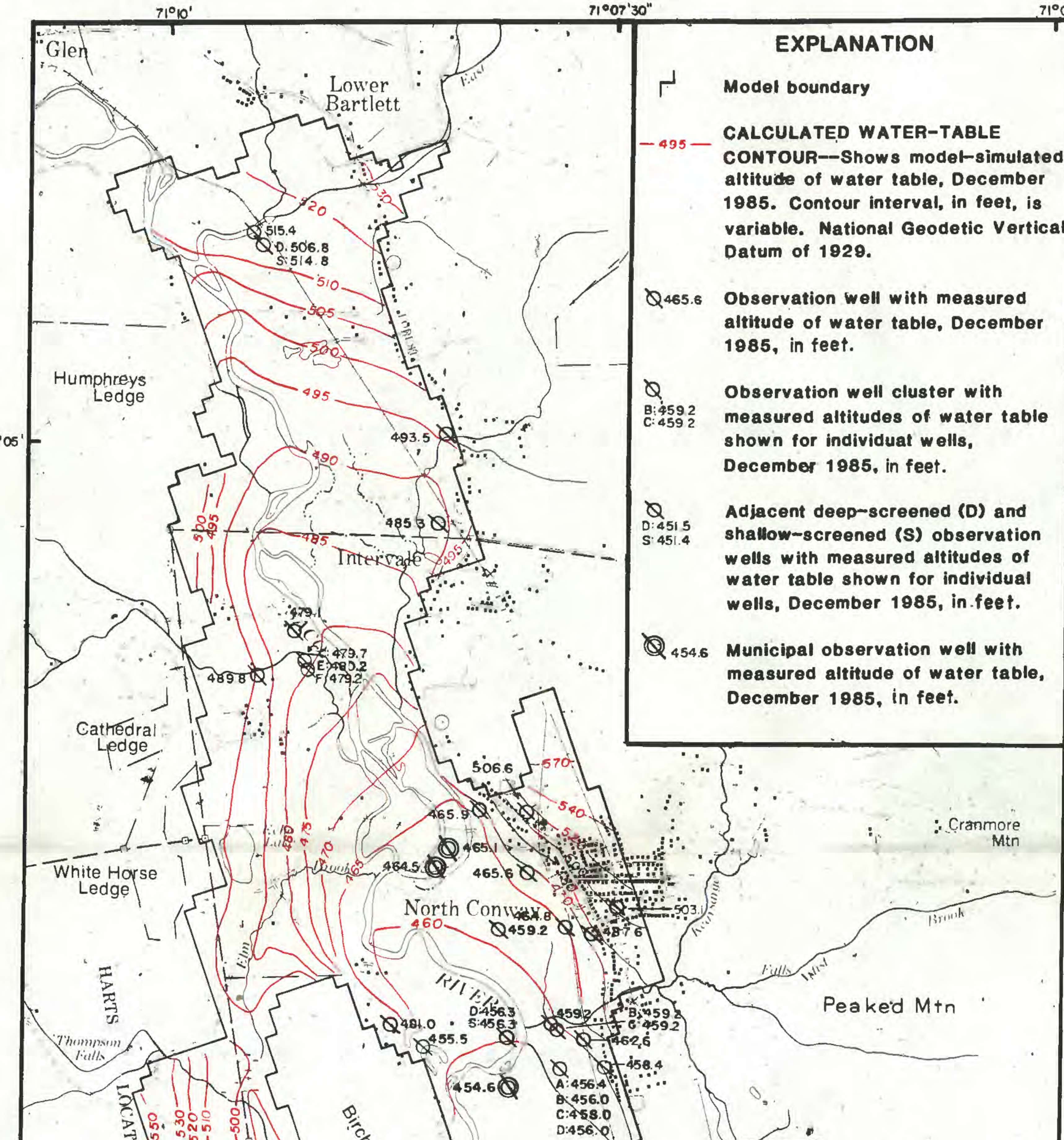
The vertical hydraulic conductivity of the deposits in the bed of the Saco River (Ks in fig. 15) have a direct effect on the movement of water between the aquifer and river. On the basis of published values for similar deposits, the vertical hydraulic conductivity was estimated to be approximately 5 ft/d. Because streambed hydraulic conductivity was not measured directly and may vary considerably, it was tested over a wider range than other model parameters. When Ks was decreased to one-tenth of its original value, computed heads increased

Table 7.--*Difference between observed and computed heads, average head difference, and average absolute head difference at 35 observation wells, in the final steady-state calibration*

Row	Column	Observation well	Observed head (in feet)	Computed head (in feet)	Difference (in feet)
13	72	18	503.13	505.77	-2.64
14	30	4	493.48	495.67	-2.19
15	109	31	478.67	476.96	1.71
16	72	17A	487.55	484.21	3.34
17	37	6	485.32	489.31	-3.99
18	62	13	506.63	508.37	-1.74
18	72	17	464.82	466.11	-1.29
18	84	24	458.42	461.04	-2.62
19	66	15	465.60	468.41	-2.81
19	81	21D	462.56	462.59	-.03
20	93	26S	451.41	454.72	-3.31
20	98	25	450.52	454.12	-3.60
20	105	30S	452.62	452.28	.34
20	113	32	447.35	451.19	-3.84
21	60	14	465.94	466.61	-.67
21	79	21A	459.23	460.78	-1.55
21	80	21C	459.22	459.45	-.23
21	103	29S	447.85	448.97	-1.12
22	83	23A	456.39	456.15	.24
23	9	1	515.36	515.25	.11
23	10	2S	514.78	513.04	1.74
23	70	16	459.15	461.25	-2.10
25	79	22S	456.27	455.05	1.22
25	124	34S	442.57	443.59	-1.02
29	101	28	448.94	449.00	-.06
31	41	7A	479.14	481.57	-2.43
31	44	7C	479.43	480.10	-.67
32	77	20	455.45	458.42	-2.97
32	122	33	445.81	446.81	-1.00
34	75	19	480.98	482.82	-1.84
35	44	7G	489.78	489.29	.49
36	101	27	469.16	464.47	4.69
36	144	36	443.05	441.78	1.27
43	142	35	452.41	451.26	1.15
48	151	37	451.74	452.44	-.70

Average head difference between observed and computed heads
Total head difference = -28.1
Average head difference = -0.80

Average absolute head difference between observed and computed heads
Total absolute head difference = 60.7
Average absolute head difference = 1.7


EXPLANATION
Model boundary
495
CALCULATED WATER-TABLE CONTOUR--Shows model-simulated altitude of water table, December 1985. Contour interval, in feet, is variable. National Geodetic Vertical Datum of 1929.
465.6
Observation well with measured altitude of water table, December 1985, in feet.
B:459.2
C:459.2
Observation well cluster with measured altitudes of water table shown for individual wells, December 1985, in feet.
D:451.5
S:451.4
Adjacent deep-screened (D) and shallow-screened (S) observation wells with measured altitudes of water table shown for individual wells, December 1985, in feet.
454.6
Municipal observation well with measured altitude of water table, December 1985, in feet.
71°10'
71°07'30"
71°05'
44°05'
Glen
Lower Bartlett
Humphreys Ledge
Cathedral Ledge
White Horse Ledge
HARTS
Thompson Falls
Intervale
North Conway
Cranmore Mtn
Peaked Mtn
Birch
RIVER
Brook
Falls
Elm
520
530
510
505
500
495
490
485
480
475
470
465
460
570
540
550
515.4
D:506.8
S:514.8
493.5
485.3
479.1
479.7
489.8
506.6
465.9
465.1
464.5
465.6
459.2
481.0
455.5
D:456.3
S:456.3
454.6
462.6
458.4
A:456.4
B:456.0
C:458.0
D:456.0
503.1

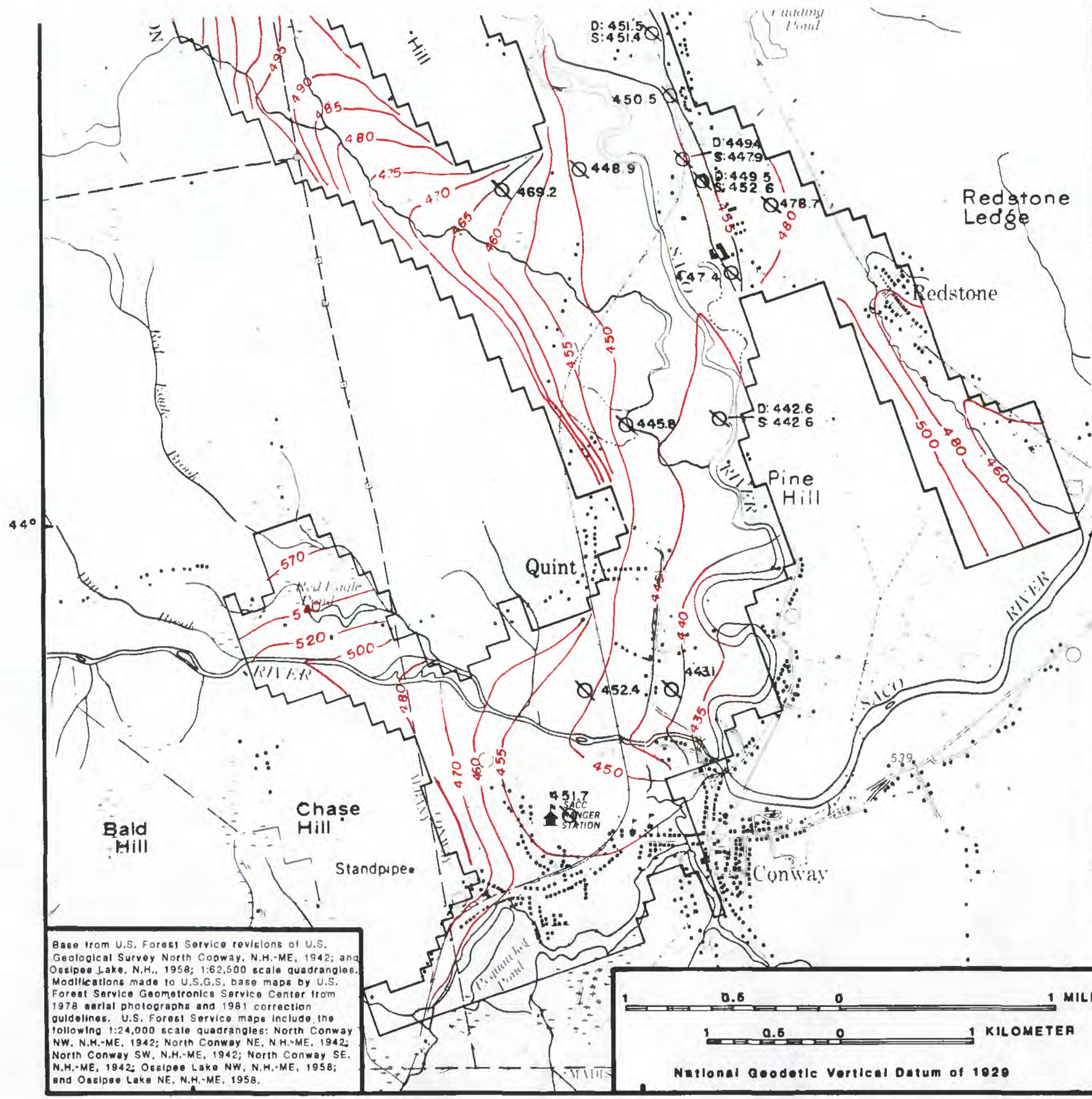


Figure 13.--Simulated water table for steady-state conditions, December 1985.

Table 8.--*Computed steady-state water budget for long-term average conditions in the Saco River valley aquifer*

	Amount of water	
	Cubic feet per second	Percent
Recharge		
Upland sources		
Tributary stream leakage	10.8	16.5
Upland runoff from unchanneled areas	24.5	37.5
Precipitation	24.4	37.4
Returned pumpage	2.6	4.0
Induced infiltration	3.0	4.6
Total	65.3	100.0
Discharge		
Leakage to Saco River and tributaries	61.0	93.4
Pumpage	4.3	6.6
Total	65.3	100.0

throughout the model. The average absolute difference between computed and observed heads increased to 4.7 ft, and the amount of surface water recharging the aquifer through natural seepage and induced infiltration decreased by 2.7 ft^3/s. A tenfold increase in Ks caused very little change in the average absolute difference between computed and observed heads. The head match actually improved very slightly (0.01 ft) for the sensitivity run. The amount of recharge to the aquifer from surface water increased by 1.4 ft^3/s. Increasing the streambed vertical hydraulic conductivity ultimately will cause the surface water to act like a constant-head boundary. This type of boundary will limit the drawdowns caused by pumped wells, which may or may not result in a realistic simulation depending on actual field conditions.

The bedrock surface was assumed to be the bottom of the aquifer. The model uses aquifer-bottom altitudes to calculate saturated thickness and aquifer transmissivity. For sensitivity testing, the depth to bedrock was varied by plus or minus 10 percent. The accuracy of the seismic-refraction technique is approximately plus or minus 10 percent of the actual depth to bedrock (Haeni, 1986). The results of this testing show that changes in depth to bedrock within 10 percent of original values cause negligible changes in average absolute head differences. When depth to bedrock is increased, saturated thickness and transmissivity increase. When transmissivity is increased, computed water levels are lower throughout the model.

In summary, the calibrated, steady-state model is most sensitive to decreases in aquifer hydraulic

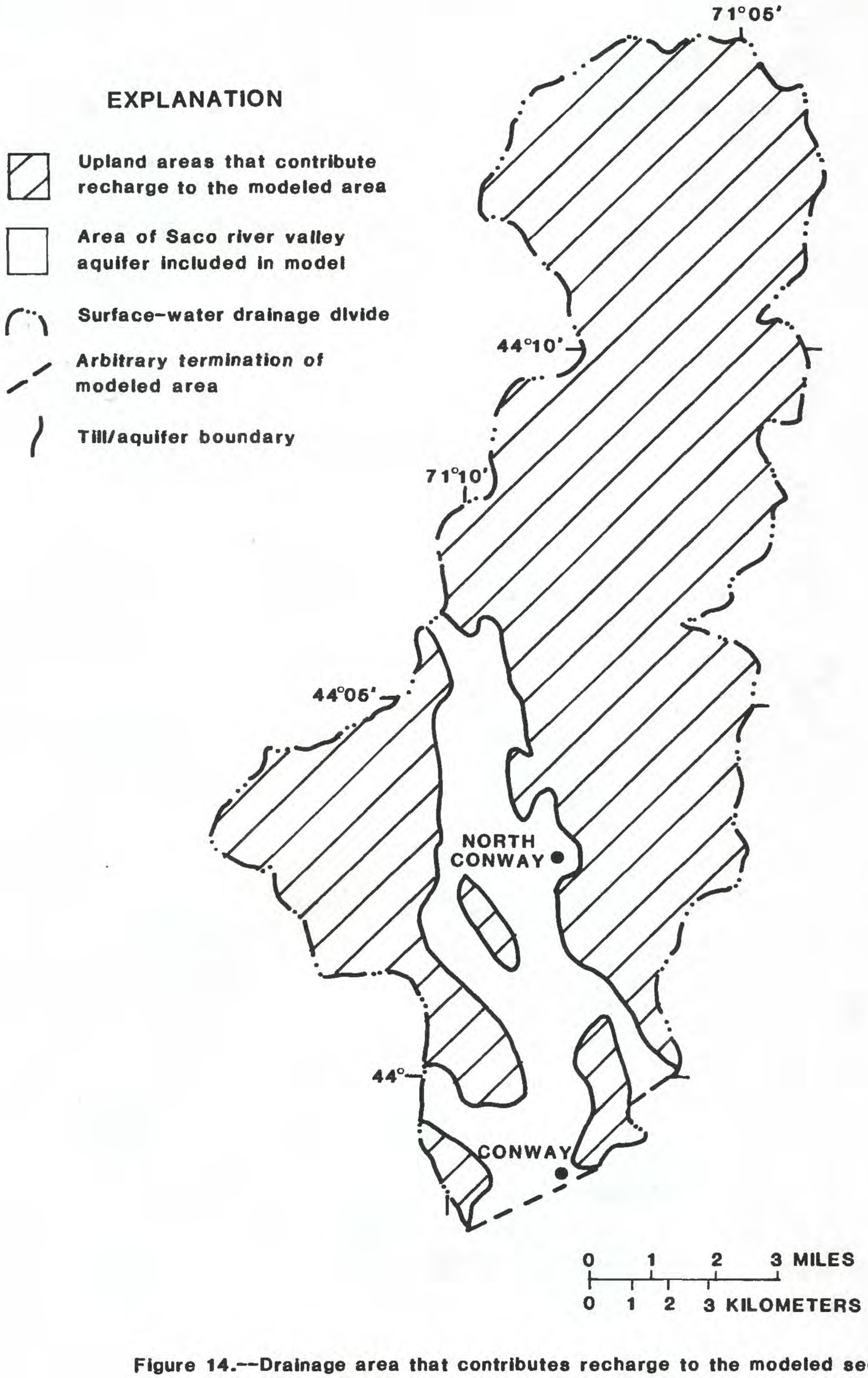


Figure 14.--Drainage area that contributes recharge to the modeled section of the Saco River valley aquifer.

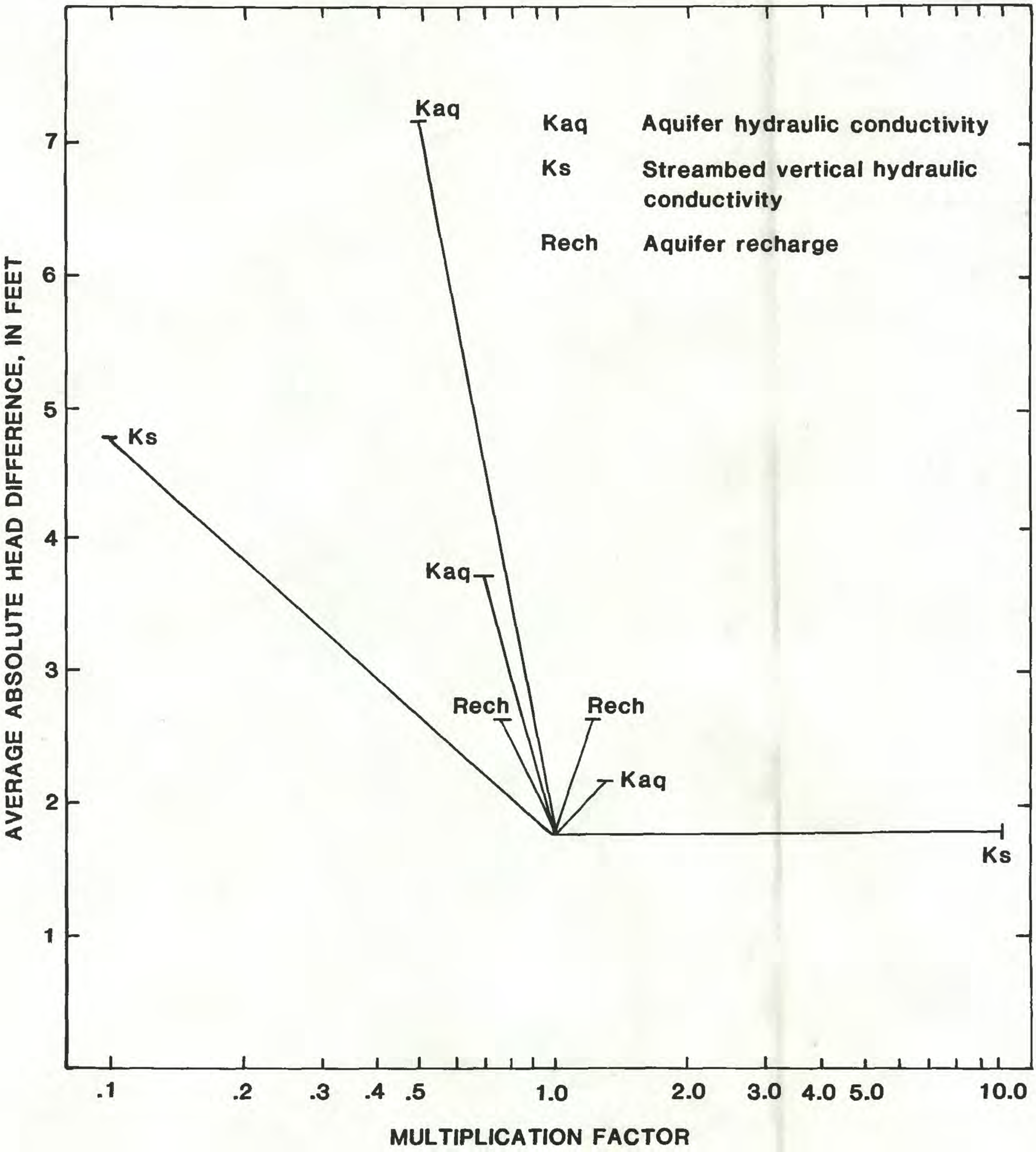


Figure 15.--Results of sensitivity analyses for the Saco River valley aquifer model.

conductivity. Increases in this property have much less effect on model results than proportional decreases. Decreases in hydraulic conductivity generally cause computed heads to increase. Conversely, computed heads will decrease if hydraulic conductivity increases. Increased recharge to the model caused greater changes than increases in other properties. Variations in depth to bedrock within the range of error expected for seismic-refraction profiling (plus or minus 10 percent) have little effect on model results.

The model was sensitive to variations in streambed vertical hydraulic conductivity. A tenfold increase improved the head match very slightly, whereas a tenfold decrease caused heads to build up throughout the model and increased the model error. Although the increased value of streambed vertical hydraulic conductivity decreased the model error slightly, it made the river act like a constant-head boundary.

The sensitivity analyses indicate the importance of knowing the lower limit of hydraulic conductivity for stratified-drift materials and stream-bottom deposits because decreases in these parameters affect the model more dramatically. The model generally is insensitive to errors within 10 percent in the depth to bedrock. The strategy of holding depth to bedrock and recharge fixed while altering other parameters during model calibration seems justified by the sensitivity analyses because the model generally is less sensitive to changes in depth to bedrock or recharge than to changes in the other properties tested.

Model Applications

The calibrated steady-state model was used to evaluate the effects of varying pumpage under average and low recharge conditions in the aquifer. The calculated heads from the calibrated model were used as starting heads in the pumpage scenarios. Each scenario was simulated with steady-state conditions to show the maximum possible drawdowns and extent of contributing areas.

The various components of the simulated recharge conditions are presented in table 9. Simulated pumpage amounts include present (1985) pumpage, twice the present pumpage, and proposed pumpage at existing and potential well sites. Proposed pumpage was formulated from estimates by local water-utility officials of future water demand. It provides an estimate of future demand rather than a prediction of maximum possible yield from the aquifer. Pumpage and cell coordinates in the model grid for municipal wells used in the various scenarios are shown in table 10. The total pumpage applied to the modeled area was 4.3 ft^3/s in

Table 9.--*Summary of recharge conditions used in pumpage scenarios*

[All values in inches per year]

Recharge source	Recharge amounts	
	Average conditions (1959-85)	Low conditions (1978)
Precipitation on aquifer[1]	24	18
Runoff from uplands not drained by tributary streams[2]	32	20
Tributary-stream leakage to aquifer	10.5 (1984-85)	6.6 (62.5% of 1984-85 amount)[3]

[1] Determined from National Oceanic and Atmospheric Administration station in North Conway with assumption that one-half of precipitation falling on aquifer recharges ground water.

[2] Determined from gaging stations 01064400 on Lucy Brook and 01064500 on the Saco River at Conway with assumption that all runoff from uplands not drained by a stream recharges the aquifer.

[3] Assumes recharge from tributary seepage is reduced by amount proportional to differences in total runoff between average and low recharge conditions.

Table 10.--*Pumpage and locations of municipal wells used in pumpage scenarios*

[ft^3/s, cubic feet per second; dashes indicate well not included in pumpage scenario]

Municipal well	Location in model grid		Pumpage rate (ft^3/s) for each scenario		
	Row	Column	1 and 4	2 and 5	3 and 6
Lower Bartlett well #1 (MW1[a])	22	18	0.24	1.11	0.48
Lower Bartlett well #2 (MW1A[a], proposed)	24	18	--	1.11	--
North Conway well #1 (MW2[a])	24	61	2.32	2.32	4.64
North Conway well #2 (MW3[a])	26	83	.62	1.55	1.24
North Conway well #3 (MW7[a])	25	63	.15	2.32	.30
Conway Village well[b] #1,2 (MW5[a])	49	149	.98	1.93	1.96
Conway Village well #3 (MW5A[a], proposed)	49	148	--	.77	--

[a] Well designation on figures 16-22.

[b] Municipal well (#1) in present (1985) use and adjacent well (#2) were treated as one well because they are located within the same cell in the model.

scenarios 1 and 4, 11.1 ft^3/s in scenarios 2 and 5, and 8.6 ft^3/s in scenarios 3 and 6. A matrix of pumpage and recharge conditions used in each of the six pumpage scenarios is presented in table 11.

Prediction of Water-Level Changes

The effect of proposed pumpage at existing and potential well sites (scenario 2 in table 11) on water levels in the aquifer under average recharge conditions is shown in figure 16. The total amount of water pumped from the aquifer in this scenario (and in scenario 5) was 11.1 ft^3/s, the greatest total pumpage stress tested. Water-level declines occurred around all of the major pumping centers, with the most dramatic declines (approximately 8 ft) occurring in the vicinity of North Conway Water Precinct well #3 (MW7). Maximum drawdowns in the vicinity of North Conway Water Precinct well #1 (MW2) were approximately 1.9 ft and were approximately 2.8 ft near well #2 (MW3). In the vicinity of the Lower Bartlett wells (MW1, MW1A), maximum drawdowns were approximately 4 feet. The maximum drawdowns in the vicinity of the Conway Village Fire District wells were approximately

Table 11.--*Pumpage and recharge conditions used in pumpage scenarios*

Scenario number	Pumpage: Present (1985)	Pumpage: Proposed	Pumpage: Twice present	Recharge rate: Average (1975-85)	Recharge rate: Low (1978)
1[a]	X			X	
2		X		X	
3			X	X	
4[b]	X				X
5		X			X
6			X		X

[a] Final calibrated steady-state model.

[b] Low recharge condition tested during sensitivity analysis.

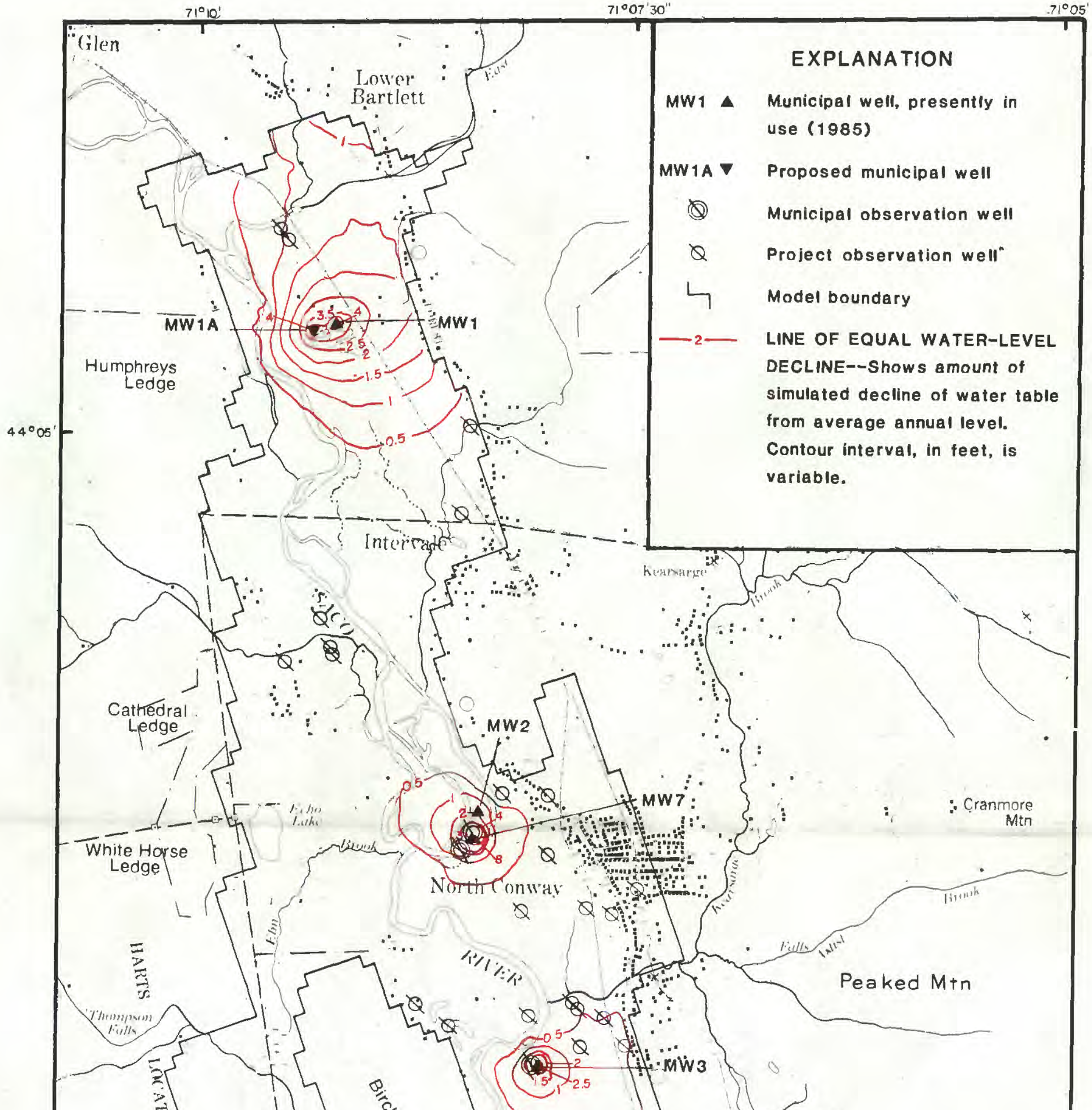
7.1 ft at wells #1 (MW5) and #2 (MW5) and 6.2 ft at well #3 (MW5A).

The effect of doubling present (1985) pumpage at existing wells under average recharge conditions (scenario 3 in table 11) is shown in figure 17. The total amount of water pumped from the aquifer in this scenario was 8.6 ft^3/s. With the exception of North Conway Water Precinct well #1 (MW2), where the pumpage was doubled above the amount in scenario 2, the maximum drawdowns around pumped wells were less than those observed for scenario 2 (fig. 16). The maximum drawdowns for the North Conway wells were approximately 10.6 ft near well #1 (MW2), 2.4 ft near well #3 (MW7), and 1.8 ft near well #2 (MW3). Drawdown around the Lower Bartlett well #1 (MW1) was approximately 0.7 ft. The present (1985) pumpage at the Lower Bartlett well is low enough (table 10) that a twofold increase had little effect on nearby water levels. The maximum drawdown in the vicinity of Conway Village well #1 (MW5, fig. 17) was approximately 4.7 ft.

The distribution of water-level declines which result from reducing recharge to the low condition (table 9) while varying pumpage are simulated in scenarios 4 through 6 (table 11). Varied pumpage under average recharge conditions produces symmetrical water-level declines around the pumping wells, as shown in scenarios 2 and 3 (figs. 16 and 17). However, water-level declines affected by both reduced recharge and varying pumpage (scenarios 4 through 6) are asymmetrical (figs. 18-20). Water levels in cells near the model boundaries may decline significantly due to decreases in both areally distributed precipitation and in recharge from upland areas.

The effects of reducing model recharge to the "low" condition (table 9) while maintaining present (1985) pumpage (scenario 4 in table 11) are illustrated in figure 18. The pattern of water-level declines is much different than those shown in figures 16 and 17. In general, the water-level declines were more areally distributed and therefore less concentrated around the wells. The effect of reducing recharge from upland areas was evident along the boundaries of the model, where water-level declines ranged from 2 to 17 ft. Water-level declines in the central part of the aquifer were 2 ft or less. This result shows the importance of upland sources of recharge in the water budget for the aquifer. The maximum drawdowns for the North Conway wells were approximately 0.4 ft near well #1 (MW2), 0.3 ft near well #3 (MW7), and 0.6 ft near well #2 (MW3). Drawdown around Lower Bartlett well #1 (MW1) was approximately 3.0 ft. The maximum drawdown in the vicinity of Conway Village well #1 (MW5) was approximately 1.1 ft.

Water-level declines that result from proposed pumpage combined with low recharge (scenario 5 in table 11) are shown in figure 19. Areal and localized water-level declines occur as a result of these com-


71°10'
71°07'30"
71°05'
44°05'
Glen
Lower Bartlett
Humphreys Ledge
MW1A
MW1
Intervale
Kearsarge
Cathedral Ledge
MW2
MW7
Echo Lake
White Horse Ledge
North Conway
Cranmore Mtn
RIVER
HARTS
Thompson Falls
LOCATI
Birch
MW3
Peaked Mtn
EXPLANATION
MW1 ▲ Municipal well, presently in use (1985)
MW1A ▼ Proposed municipal well
Municipal observation well
Project observation well
Model boundary
—2— LINE OF EQUAL WATER-LEVEL DECLINE--Shows amount of simulated decline of water table from average annual level. Contour interval, in feet, is variable.

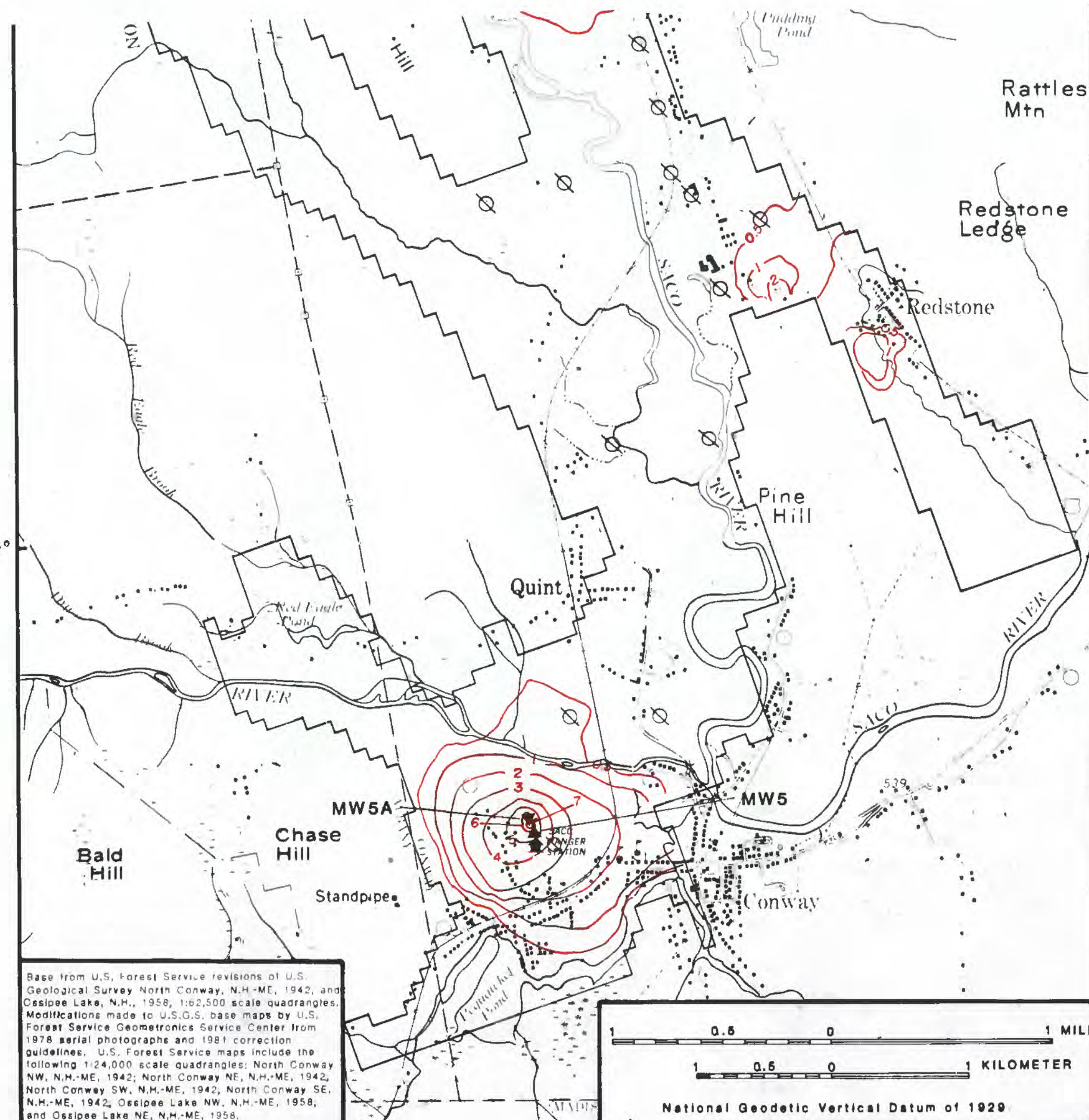
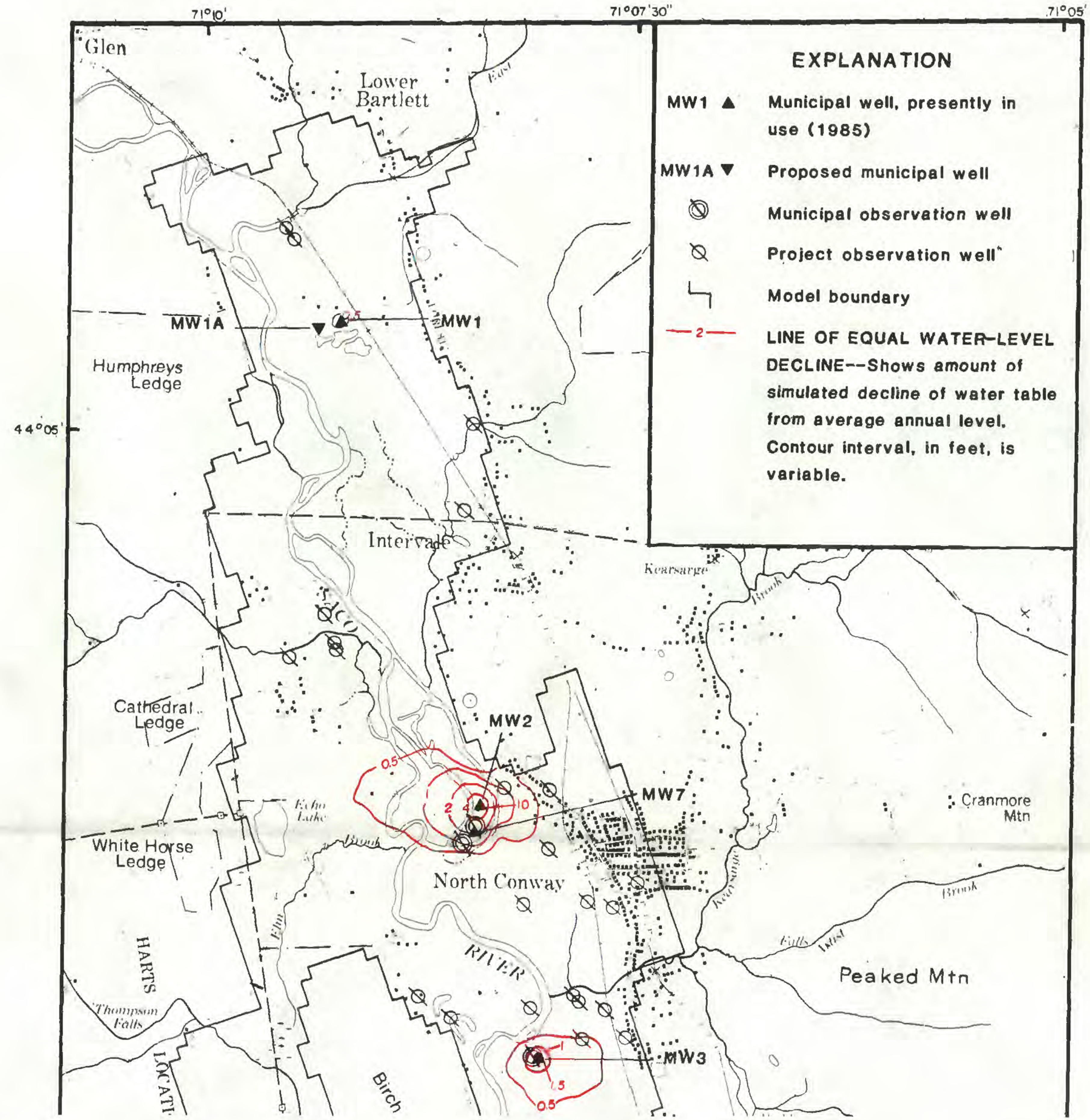


Figure 16.--Drawdown for scenario 2, simulation with proposed pumpage and average recharge conditions.


71°10'
71°07'30"
71°05'
44°05'
EXPLANATION
MW1 ▲ Municipal well, presently in use (1985)
MW1A ▼ Proposed municipal well
Municipal observation well
Project observation well
Model boundary
LINE OF EQUAL WATER-LEVEL DECLINE--Shows amount of simulated decline of water table from average annual level. Contour interval, in feet, is variable.
Glen
Lower Bartlett
Humphreys Ledge
MW1A
MW1
Intervale
Kearsarge
SACO
RIVER
Cathedral Ledge
MW2
MW7
Echo Lake
White Horse Ledge
North Conway
Cranmore Mtn
Peaked Mtn
HARTS
LOCATI
Thompson Falls
Birch
MW3
0.5
2
4
10
1
1.5

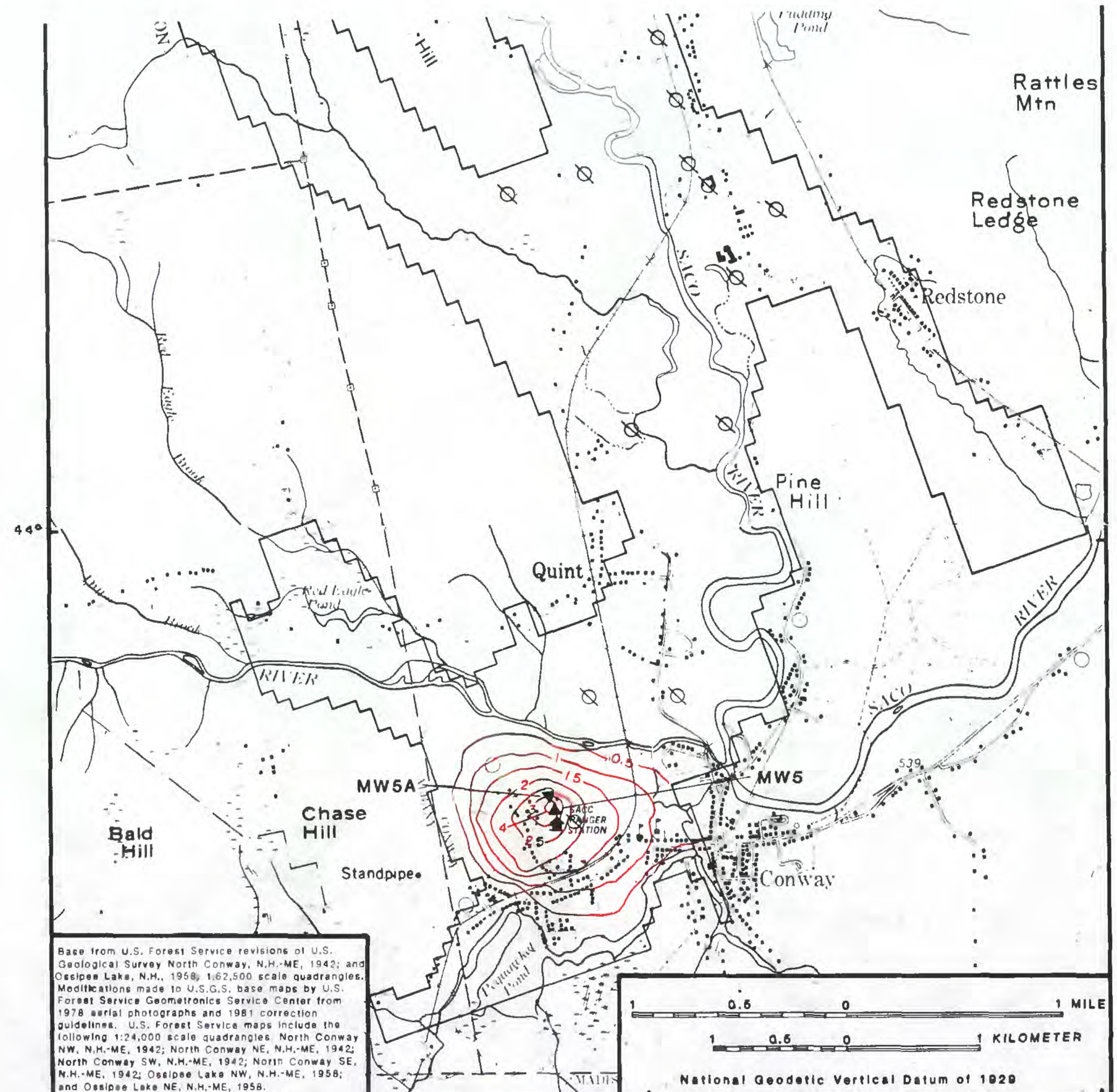
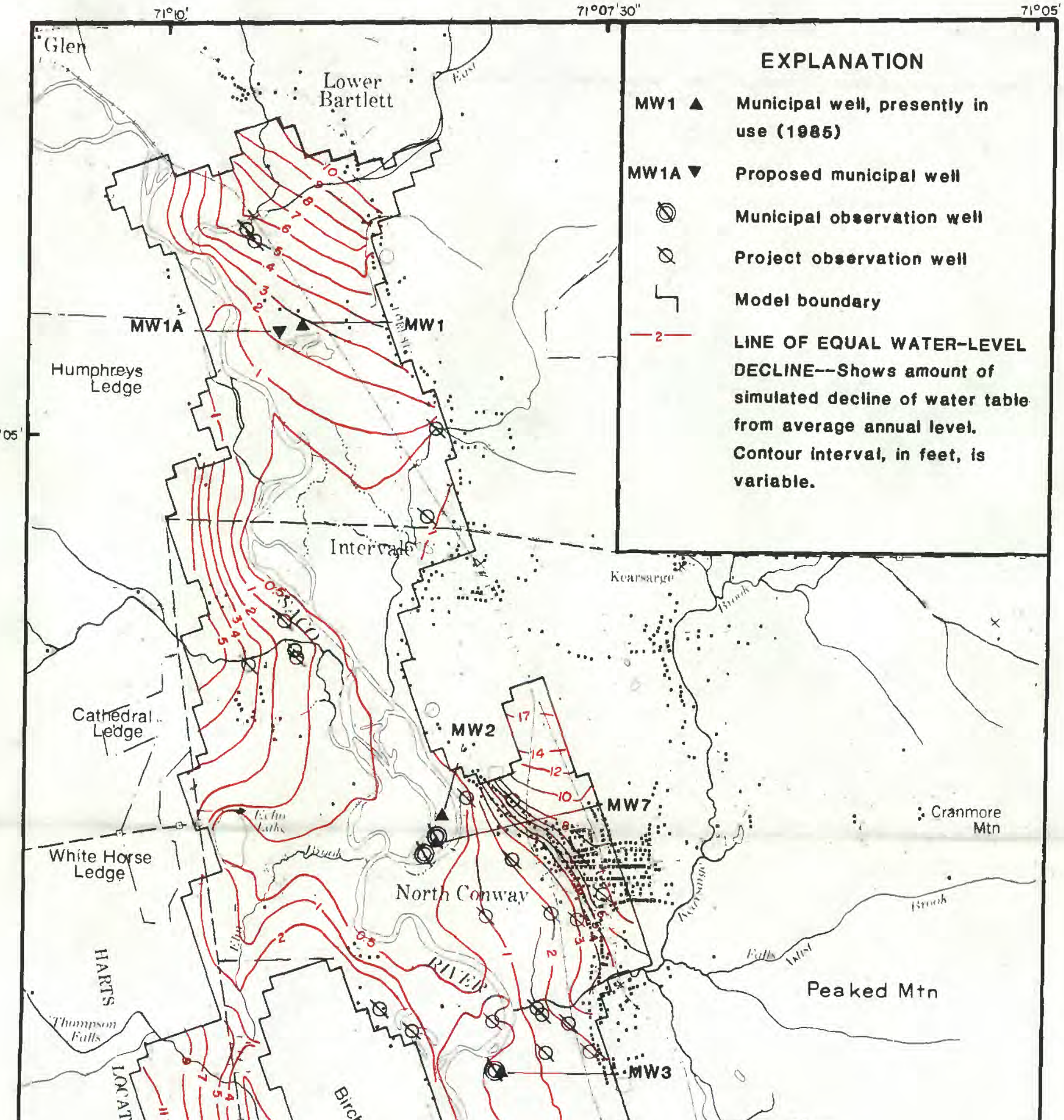


Figure 17.--Drawdown for scenario 3, simulation with twice the present (1985) pumpage and average recharge conditions.


EXPLANATION
MW1 ▲ Municipal well, presently in use (1985)
MW1A ▼ Proposed municipal well
Municipal observation well
Project observation well
Model boundary
LINE OF EQUAL WATER-LEVEL DECLINE--Shows amount of simulated decline of water table from average annual level. Contour interval, in feet, is variable.
71°10'
71°07'30"
71°05'
44°05'
Glen
Lower Bartlett
MW1A
MW1
Humphreys Ledge
Intervale
SACO
RIVER
Kearsarge
Cathedral Ledge
MW2
MW7
Cranmore Mtn
White Horse Ledge
North Conway
Peaked Mtn
HARTS
LOCATI
Thompson Falls
MW3
Birch

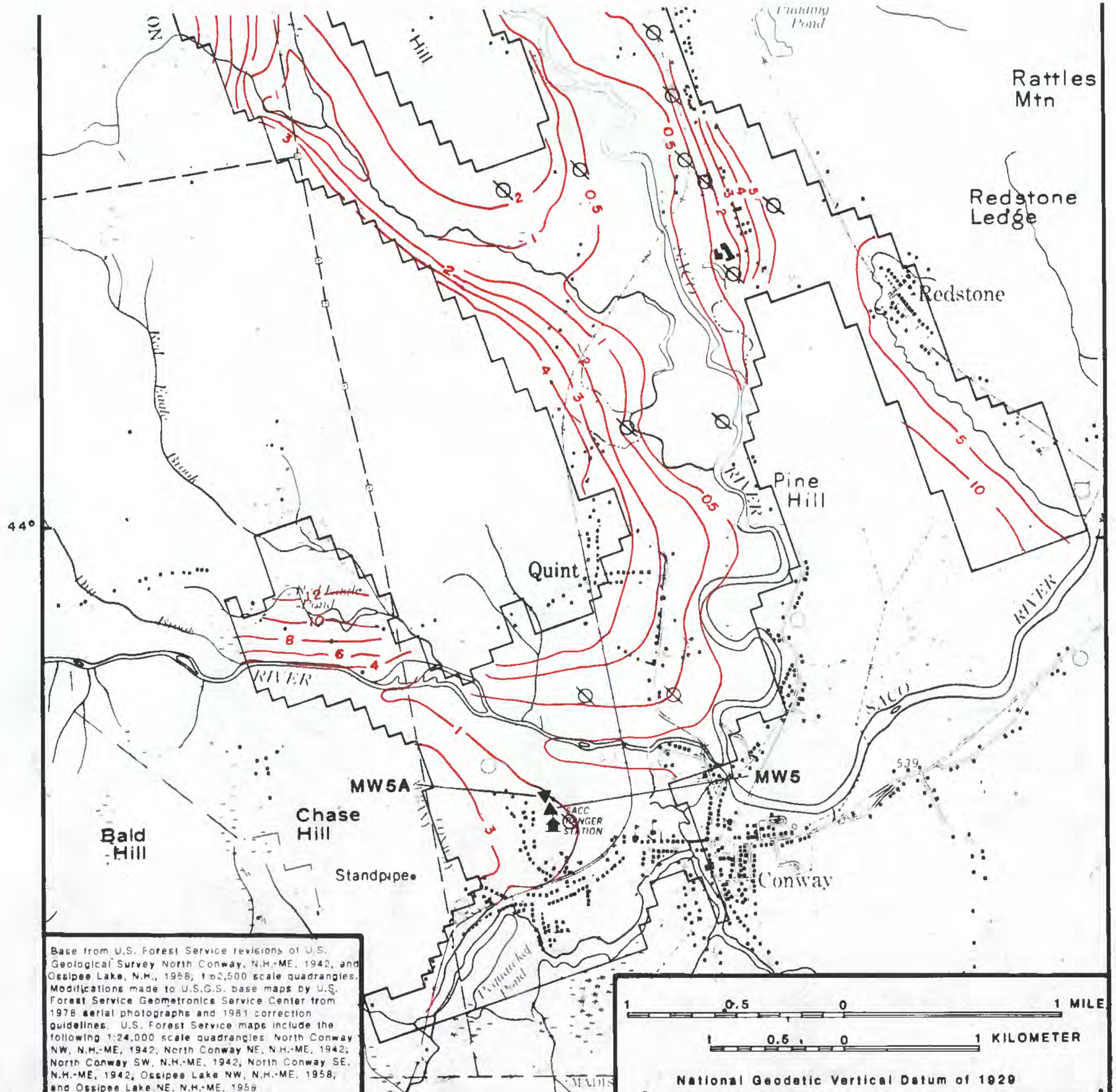
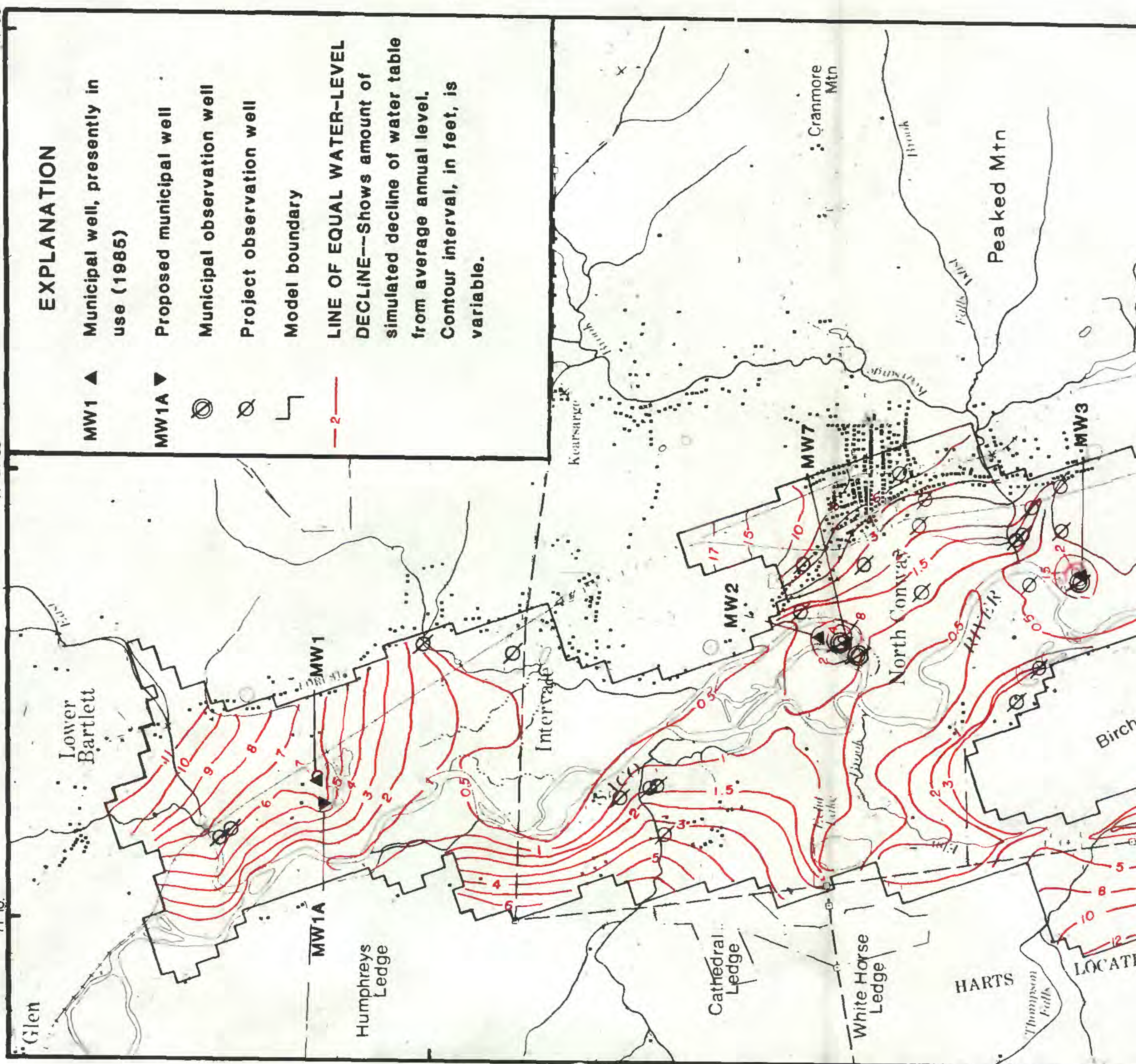


Figure 18.--Drawdown for scenario 4, simulation with present (1985) pumpage and low recharge conditions.


EXPLANATION
MW1 ▲ Municipal well, presently in use (1985)
MW1A ▼ Proposed municipal well
Municipal observation well
Project observation well
Model boundary
—2— LINE OF EQUAL WATER-LEVEL DECLINE--Shows amount of simulated decline of water table from average annual level. Contour interval, in feet, is variable.
71°05'
71°07'30"
71°10'
44°05'
Lower Bartlett
Glen
Humphreys Ledge
Intervale
Kearsarge
Cathedral Ledge
White Horse Ledge
North Conway
Cranmore Mtn
Peaked Mtn
Birch
HARTS
LOCATI
MW1
MW1A
MW2
MW7
MW3

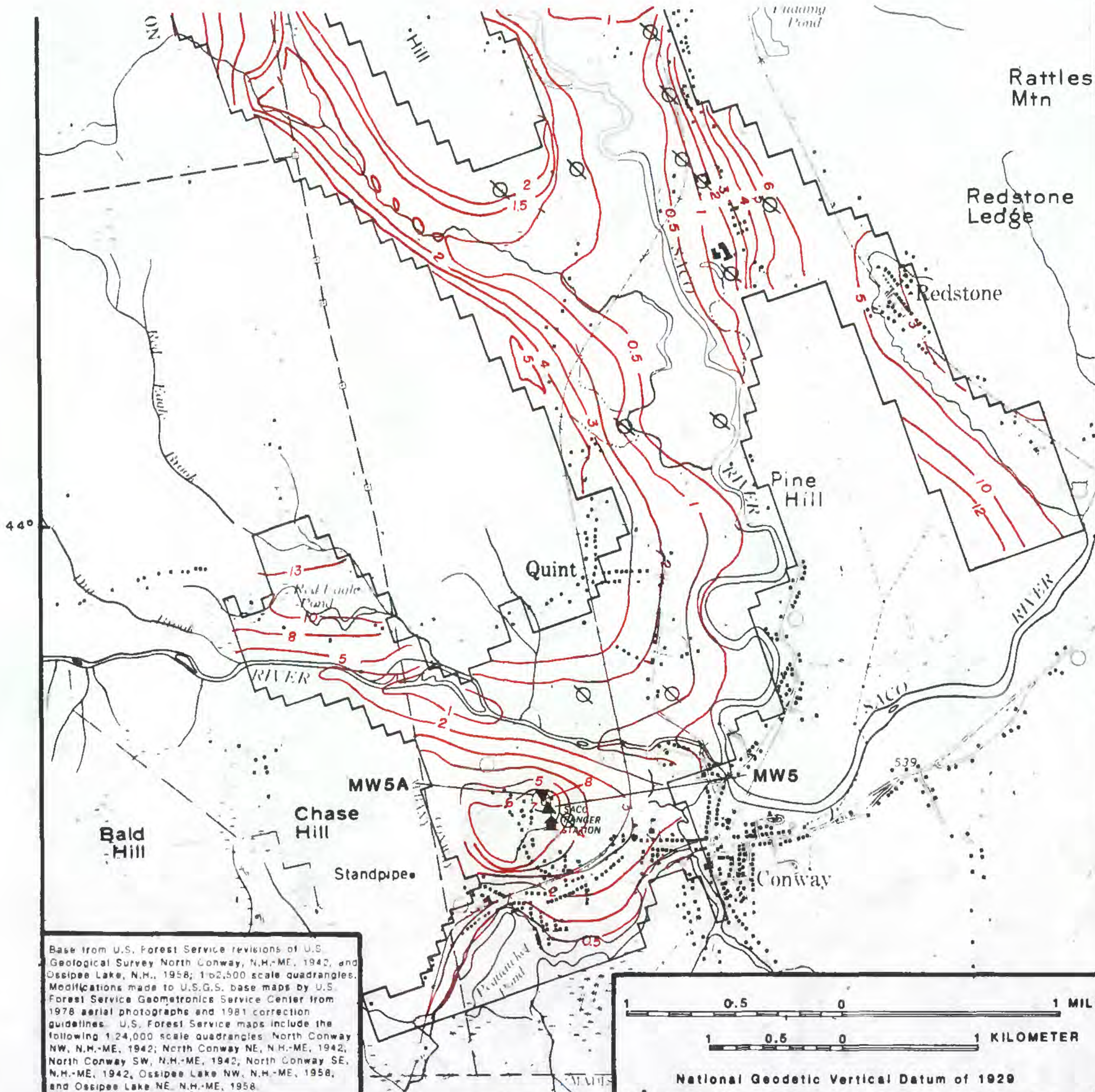


Figure 19.--Drawdown for scenario 5, simulation with proposed pumpage and low recharge conditions.

bined stresses. In scenario 5, 23 percent of the total ground water that flows through the aquifer was removed by pumpage. Some of the pumped water also was obtained by induced infiltration from the Saco River and its tributaries. Although water levels dropped along the model boundaries by as much as 17 ft from the average, declines in the middle of the aquifer ranged from only 0.5 to 2.0 ft. This pattern of drawdown is similar to that shown in figure 18 where low recharge was simulated with no change from present (1985) pumpage. With the exception of North Conway Water Precinct well #2 (MW3), the amounts of drawdown and the affected areas were larger than those observed for the same pumpage under average recharge conditions (scenario 2, fig. 16). For example, at the Conway Village wells (MW5, MW5A), drawdown increased approximately 1.2 ft between scenarios 2 and 5, and the area within the 6-ft drawdown contour increased by approximately 1,700 ft. The maximum drawdowns for the North Conway wells were approximately 2.3 ft near well #1 (MW2), 8.3 ft near well #3 (MW7), and 2.1 ft near well #2 (MW3). Maximum drawdown around Lower Bartlett well #1 (MW1) was approximately 7.3 ft and was approximately 6.5 ft near well #2 (MW1A). The maximum drawdown in the vicinity of the Conway Village wells was approximately 8.4 ft at wells #1 (MW5) and #2 (MW5) and 7.4 ft at well #3 (MW5A).

Water-level declines that result when the present (1985) pumpage is doubled under low recharge conditions (scenario 6 in table 11) are shown in figure 20. The water-level declines for this scenario were less around the Lower Bartlett (MW1) (approximately 3.7 ft) and the Conway Village well (MW5) (approximately 6.0 ft) than those observed in scenario 5 (fig. 19) because pumpage was significantly less. Water-level declines at North Conway well #2 (MW3) were similar (approximately 2.5 ft) because pumpage was similar for both scenarios. Increased pumpage at North Conway well #1 (MW2) and decreased pumpage at well #3 (MW7) in scenario 6 resulted in maximum drawdowns of approximately 11.1 ft near well #1 and of approximately 2.7 ft near well #3.

Analyses of Contributing Areas to Municipal Wells

The traditional approach to protection of water quality at municipal-supply wells in sand and gravel aquifers has been to control land use in a small circular area around the well. These circular areas are typically 200 to 400 ft in radius and cover an area of about 0.004 to 0.018 mi^2. More recent approaches for protection of ground-water quality in highly permeable sand and gravel aquifers have been directed toward the entire area that contributes recharge to pumped wells. A general discussion of this approach is included in a report by Morrissey (1987).

The contributing areas for present and proposed municipal-supply wells have been estimated for each of the pumpage scenarios shown in table 11. The areas were estimated from the output of the numerical model of the Saco River valley aquifer developed for this study used in conjunction with a particle-tracking model developed by Pollock (1988).

The particle-tracking model uses heads and intercell flows generated by the block-centered, finite-difference modular model and estimates of aquifer porosity to determine the velocity and position of water particles moving through the aquifer. The model allows forward or backward tracking of particles in two or three dimensions and has a variety of options for generating particles that are used to determine time of travel and flow paths in an aquifer.

The contributing areas for municipal wells in the Saco River valley aquifer for present (1985) pumpage under average recharge conditions are shown in figure 21. The Lower Bartlett well (MW1), located in the northern part of the modeled area, had a contributing area of about 0.1 mi^2 that extended upgradient from the well toward the East Branch of the Saco River. The well derived water from natural leakage out of the East Branch of the Saco River and from precipitation that recharged the ground water within the contributing area. The contributing area extended less than 300 ft downgradient from the well and did not capture induced infiltration from the Saco River.

The combined contributing area for the North Conway Water Precinct wells #1 (MW2) and #3 (MW7) under average conditions (scenario 1 in table 11) are shown in the central part of the aquifer in figure 21. North Conway Water Precinct well #3 (MW7) had a very low pumping rate (table 10) compared to North Conway Water Precinct well #1 (MW2) and consequently had a much smaller contributing area. The total contributing area for both wells covered approximately 0.5 mi^2. The contributing area extended beneath and beyond the Saco River and extended upgradient to Lucy Brook on the west and toward North Conway on the east. These wells derived water from induced infiltration from the Saco River, natural leakage from Lucy Brook, precipitation that fell on the contributing area within the aquifer, runoff from upland areas adjacent to the aquifer, and discharge from septic tanks within the contributing area.

North Conway Water Precinct well #2 (MW3) had a contributing area on the eastern side of the Saco River, extending upgradient toward the valley wall (fig. 21). The contributing area within the aquifer covered approximately 0.1 mi^2. Sources of water for this well included the following: recharge from precipitation that fell on the contributing area; runoff from upland areas adjacent to the aquifer; natural leakage from Kearsarge Brook; induced infiltration from the Saco River; and septic-system recharge within the contributing area.

The contributing area within the aquifer for the Conway Village well (MW5, fig. 21), located in the southwestern corner of the modeled area, covered about 0.4 mi^2 (fig. 21). The contributing area for this well under average pumpage and recharge conditions did not reach far enough to obtain water from induced infiltration from the Swift River or Pequawket Pond. The sources of water to the well included upland runoff from Chase Hill and recharge from precipitation within the contributing area. Under these conditions, the contributing area did not appear to include contaminated ground water from an industrial site near Pequawket Pond.

The contributing areas for existing and proposed wells under pumpage scenario 5 (table 11) are shown in figure 22. This scenario reflects the maximum stress tested with the model--that is, maximum pumpage rates at present and proposed wells, under low recharge conditions. As a result, the contributing areas were larger in this simulation than in the other pumpage scenarios.

The combined contributing areas within the aquifer for the existing and proposed Lower Bartlett wells (MW1, MW1A) covered a total area of about 0.4 mi^2. Till-covered or bedrock uplands adjacent to the aquifer were part of the contributing areas to these wells. In addition, the wells derived water from leakage from the East Branch of the Saco River. The pumping stress did not appear to be strong enough to capture induced infiltration from the Saco River.

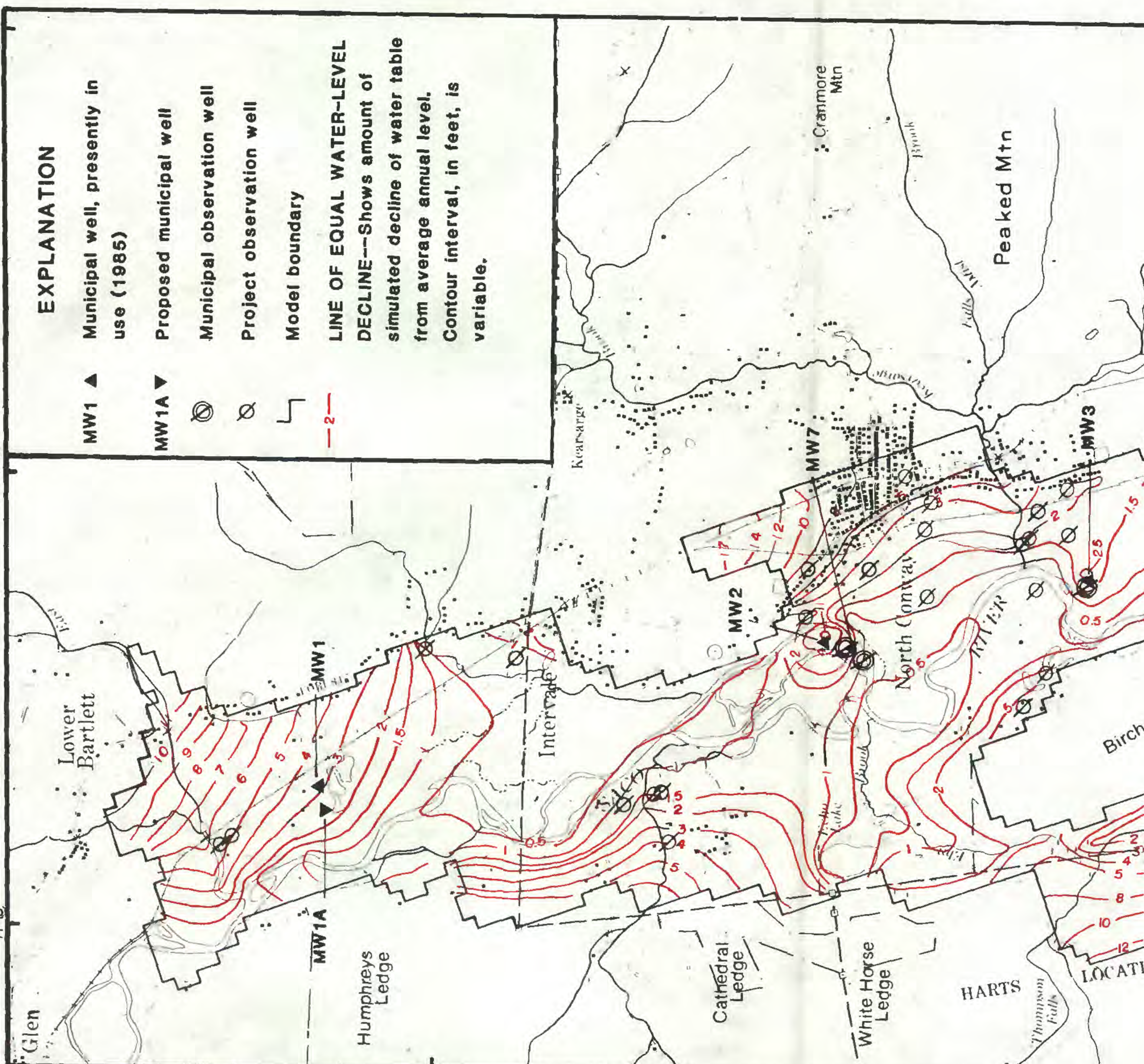
Because of their close proximity to each other and to the Saco River, North Conway Water Precinct wells #1 (MW2) and #3 (MW7) derived significant amounts of water from the Saco River from induced infiltration. The combined contributing area within the aquifer for both wells covered approximately 0.8 mi^2, was "U"-shaped, and extended from the area of Lucy Brook on the west side of the valley toward North Conway to the east. The major sources of water to these wells were the Saco River, Lucy Brook, precipitation in the contributing area, septic-tank recharge in the contributing area, and runoff from uplands adjacent to the aquifer.

The contributing area within the aquifer for North Conway Water Precinct well #2 (MW3) covered approximately 0.2 mi^2 for scenario 5 (fig. 22). This was twice as large as the area estimated for scenario 1 (fig. 21). The contributing area extended east from the well and included developed areas along State Route 16.

The contributing area in the aquifer for the Conway Village wells (MW5, MW5A) covered approximately 1.0 mi^2 (fig. 22). The contributing area for these wells estimated for average pumpage and recharge conditions (fig. 21) was considerably smaller. Furthermore, in the proposed pumpage under low recharge scenario, the wells derived water from the Swift River and Pequawket Pond. The capture zone also included the area of contaminated ground water around an industrial site (discussed in the "Previous Investigations" section).

These analyses showed that the recharge areas for the wells were much larger than the present 400-ft-radius zones commonly protected by legislation in New Hampshire. The contributing areas within the aquifer were not circular but instead extended upgradient in curved or "U"-shapes, and included large areas of till or bedrock adjacent to the aquifer. These upland areas may or may not be drained by tributary streams.

The contributing area analyses provide estimates of the sources of water for municipal wells in the aquifer. Recharge from tributaries of the Saco River, such as Lucy Brook, the East Branch of the Saco River, and Kearsarge Brook, was an important source of water for nearby wells. Induced infiltration from the Saco River also was an important source of water for the North Conway Water Precinct wells. To maintain good water quality at the municipal wells, the quality of the surface water in the contributing areas must be considered. At present, the drainage areas of the East Branch of the Saco River and Lucy Brook are largely in undeveloped areas of the White Mountain National Forest, and have excellent water quality. The Kearsarge Brook drainage is more developed, especially near North Conway. At present, most land uses within the contributing areas are related to forest or agricultural activities. Pesticides, fertilizers, and herbicides used in agriculture may affect the quality of recharge water and limit public supply uses. Based on samples collected for this study, most


EXPLANATION
MW1 ▲ Municipal well, presently in use (1985)
MW1A ▼ Proposed municipal well
Municipal observation well
Project observation well
Model boundary
—2— LINE OF EQUAL WATER-LEVEL DECLINE--Shows amount of simulated decline of water table from average annual level. Contour interval, in feet, is variable.
71°05'
71°07'30"
71°10'
44°05'
Lower Bartlett
Glen
Humphreys Ledge
Cathedral Ledge
White Horse Ledge
HARTS
LOCATI
Intervale
Kearsarge
North Conway
Cranmore Mtn
Peaked Mtn
Birch
RIVER
MW1
MW1A
MW2
MW7
MW3

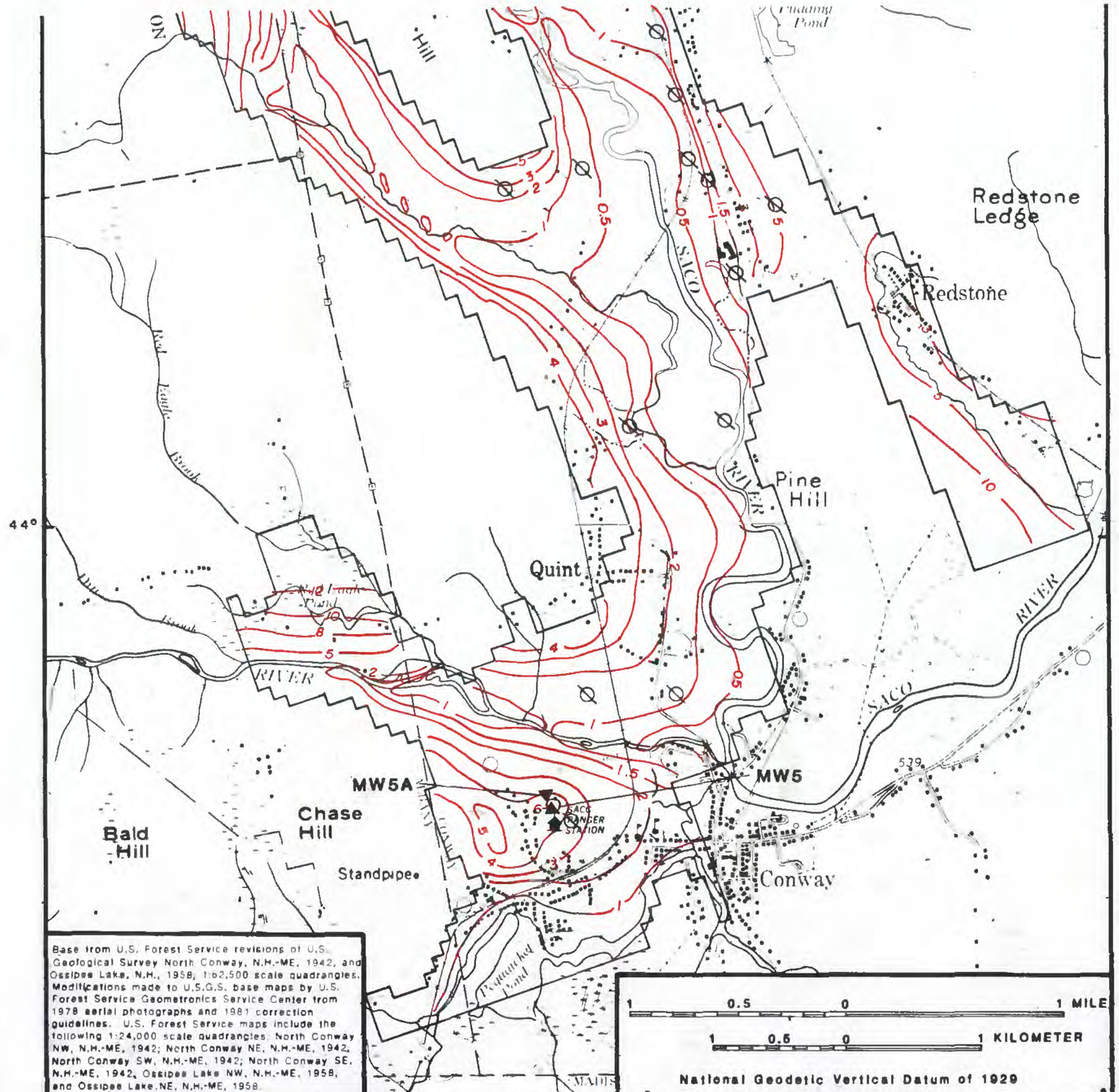
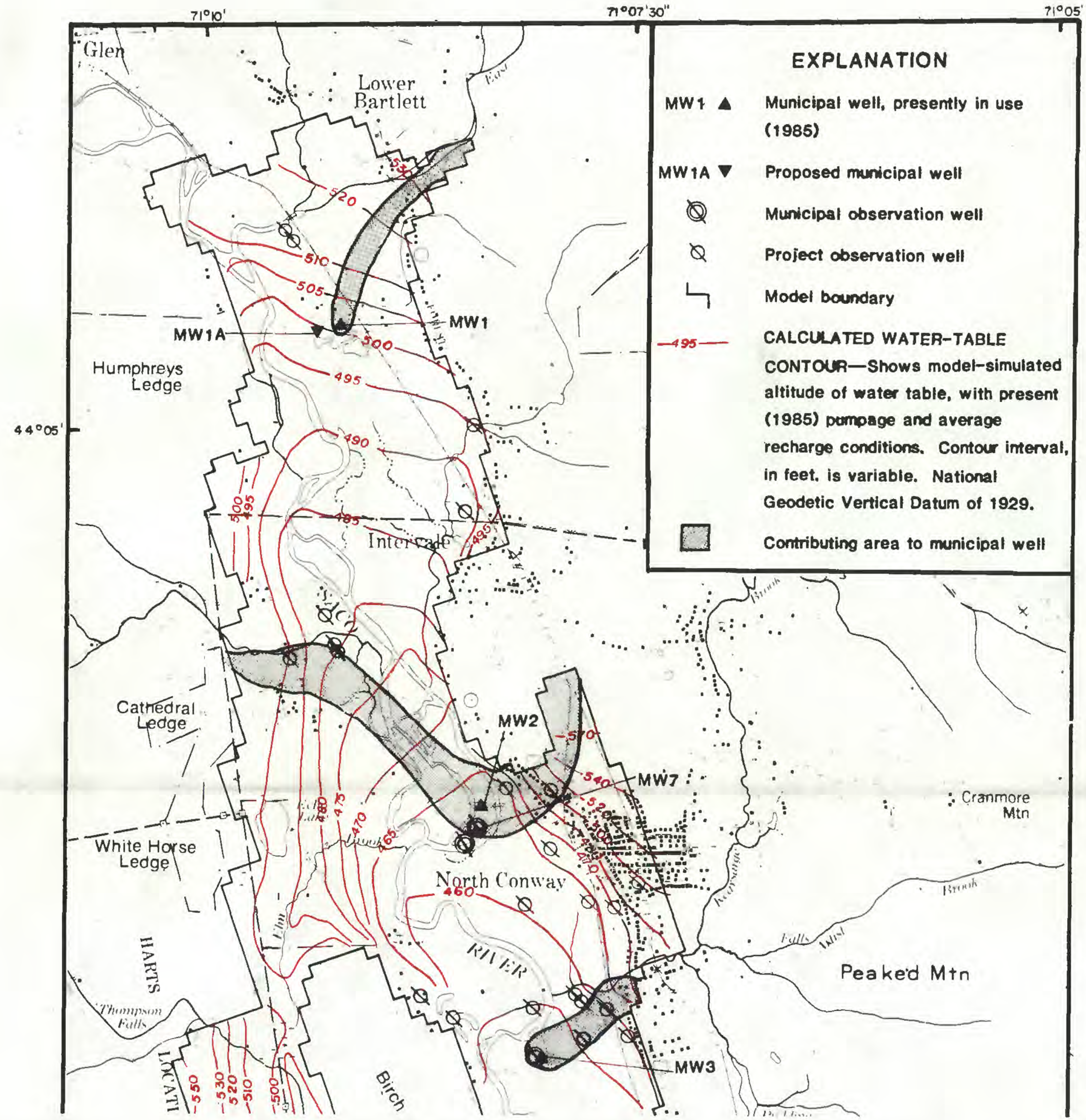


Figure 20.--Drawdown for scenario 6, simulation with twice the present (1985) pumpage and low recharge conditions.


71°10'
71°07'30"
71°05'
44°05'
EXPLANATION
MW1 ▲ Municipal well, presently in use (1985)
MW1A ▼ Proposed municipal well
Municipal observation well
Project observation well
Model boundary
—495— CALCULATED WATER-TABLE CONTOUR—Shows model-simulated altitude of water table, with present (1985) pumpage and average recharge conditions. Contour interval, in feet, is variable. National Geodetic Vertical Datum of 1929.
Contributing area to municipal well
Glen
Lower Bartlett
Humphreys Ledge
Intervale
Cathedral Ledge
White Horse Ledge
North Conway
RIVER
HARTS
LOCATI
Birch
Cranmore Mtn
Peaked Mtn
MW1
MW1A
MW2
MW7
MW3
530
520
510
505
500
495
490
485
475
470
465
460
480
550
540

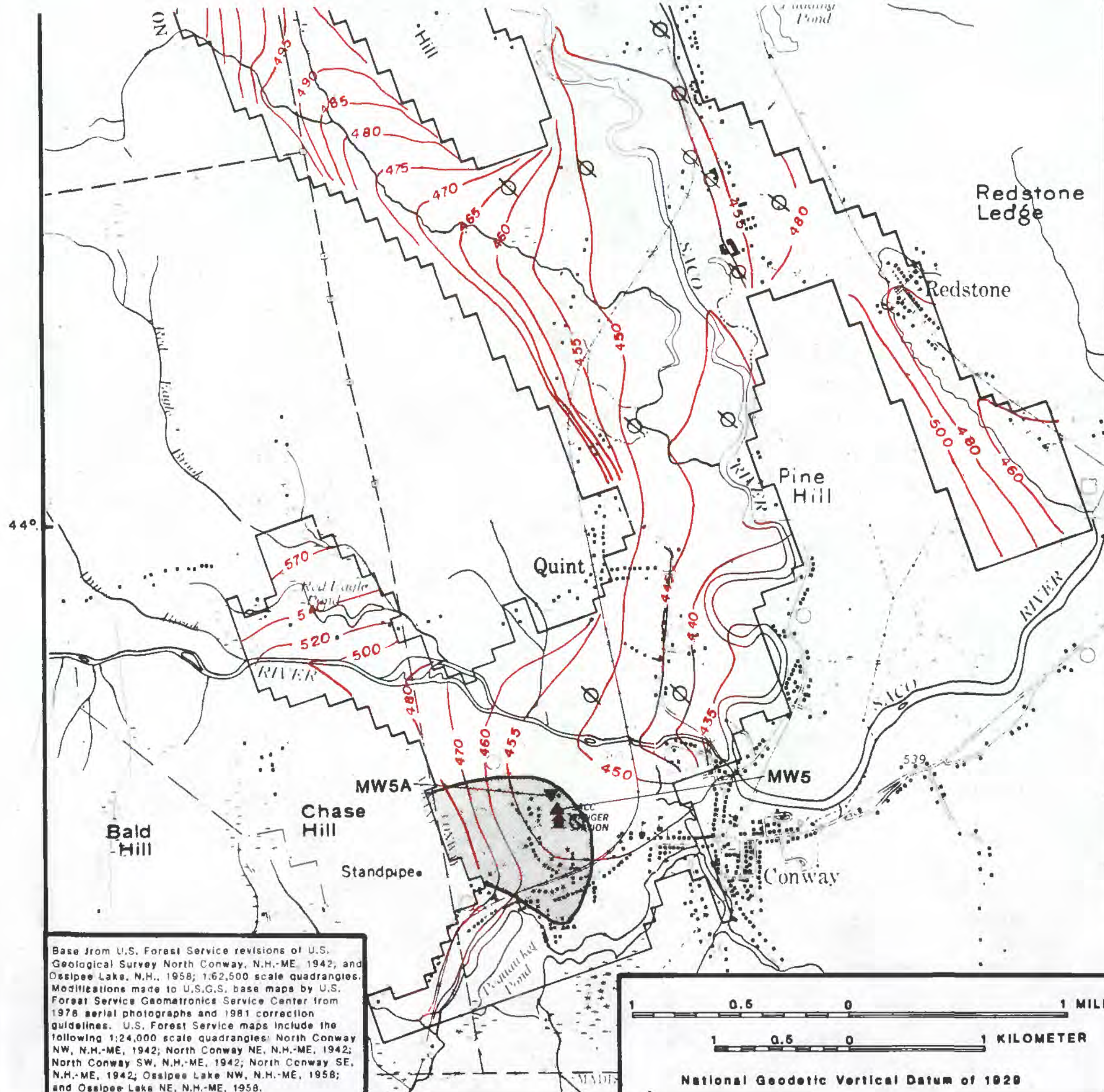
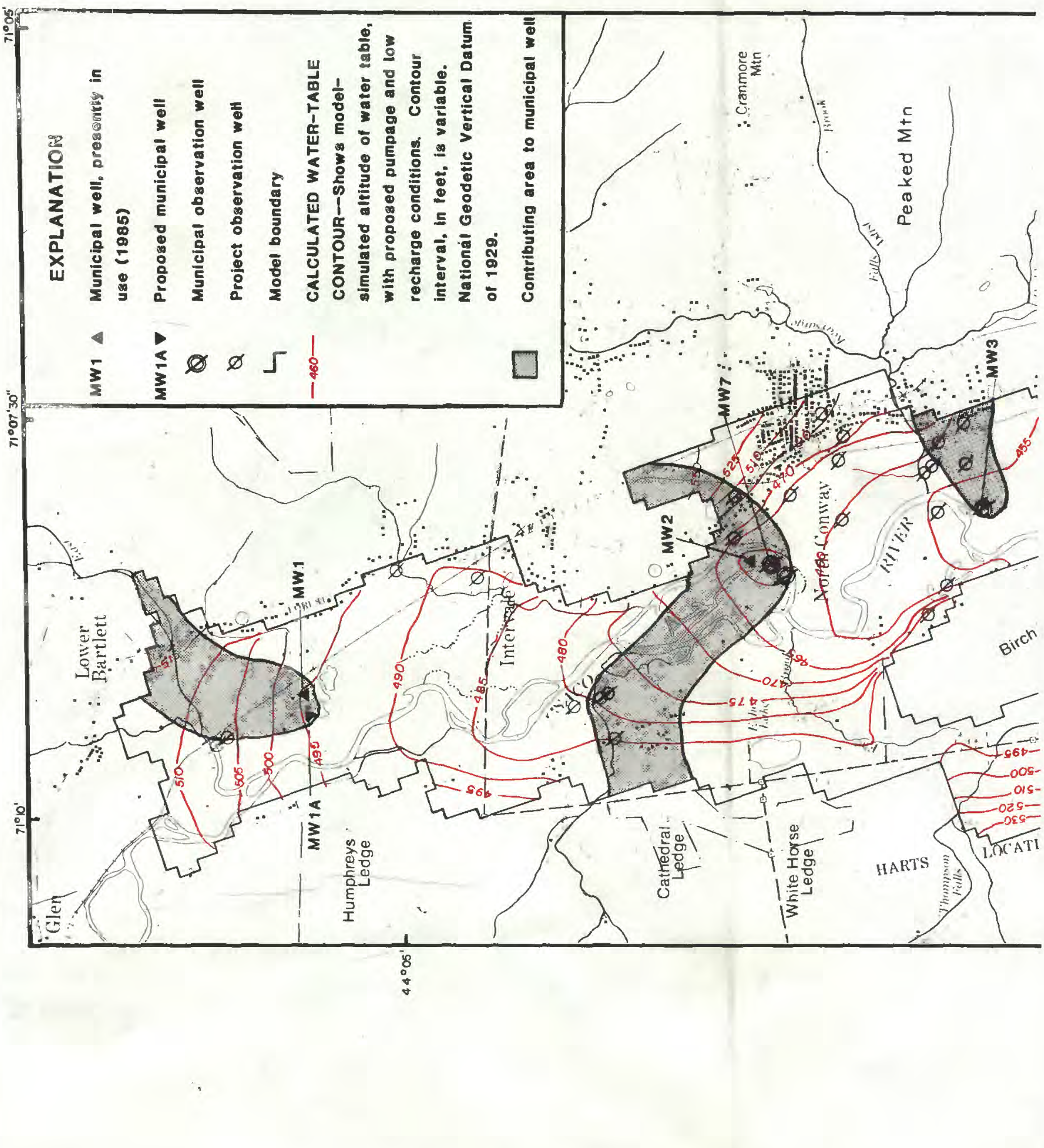


Figure 21.--Contributing areas for municipal wells, with present (1985) pumpage and average recharge conditions (scenario 1).


EXPLANATION
MW1 ▲ Municipal well, presently in use (1985)
MW1A ▼ Proposed municipal well
Municipal observation well
Project observation well
Model boundary
—460— CALCULATED WATER-TABLE CONTOUR--Shows model-simulated altitude of water table, with proposed pumpage and low recharge conditions. Contour interval, in feet, is variable. National Geodetic Vertical Datum of 1929.
Contributing area to municipal well
71°05'
71°07'30"
71°10'
44°05'
Lower Bartlett
Humphreys Ledge
Cathedral Ledge
White Horse Ledge
Cranmore Mtn
Peaked Mtn
North Conway
Intervale
RIVER
HARTS
LOCATI
Birch
Glen
MW1
MW1A
MW2
MW3
MW7

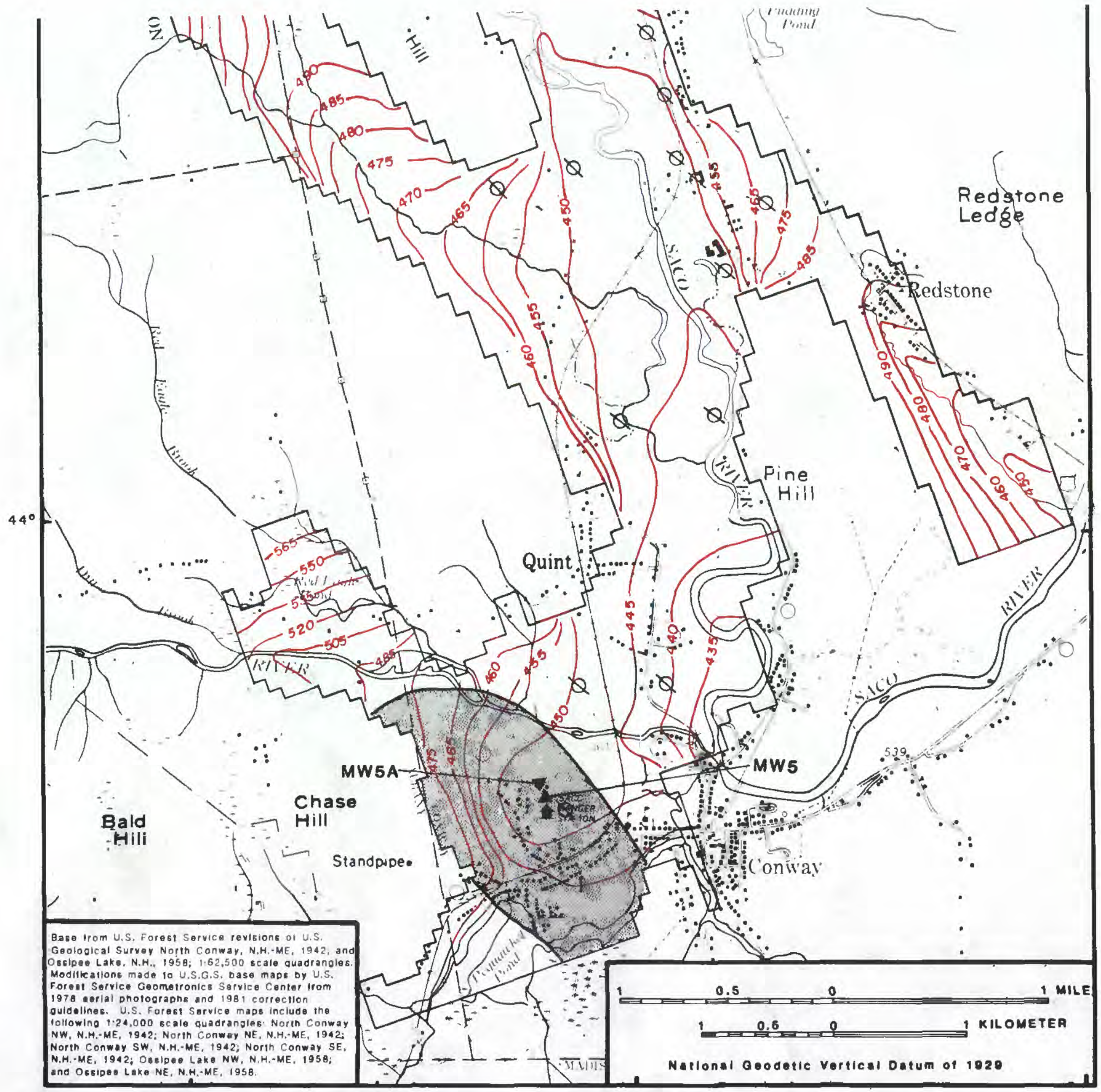


Figure 22.--Contributing areas for municipal wells, with proposed pumpage and low recharge conditions (scenario 5).

recharge water was of good chemical quality, particularly for the Lower Bartlett well (MW1), which derived water from the northeastern part of the valley, and for North Conway Water Precinct wells #1 (MW2) and #3 (MW7), which derived most of their water from the western part of the valley.

The contributing area for North Conway Water Precinct well #2 (MW3) is located on the eastern side of the valley, which has agricultural and commercial land uses that include underground petroleum storage, septic waste disposal, and manufacturing. As a result, this well could be more vulnerable to future contamination than the Lower Bartlett well (MW1) or North Conway Water Precinct wells #1 (MW2) and #3 (MW7).

In the extreme case of maximum pumpage at present and proposed wells under low recharge conditions (scenario 5 in table 11), the contributing area for the Conway Village wells included the contaminated water at the industrial site (fig. 22). If pumpage is increased at these wells, monitoring of the movement of contaminants toward the pumping center might be necessary. The accuracy of predictions regarding movement of contaminants from this site relative to the Conway Village wells could be improved by development of a refined model with smaller cell size. The model results given here are general because the model is regional rather than site-specific; however, this regional model can provide meaningful boundary conditions for a site-specific model.

All of the contributing areas shown in figures 21 and 22 are considered to be estimates. These estimates are affected not only by the conceptual understanding of the aquifer flow system but also by the models used to predict them. The two-dimensional model used in this study is limited with respect to delineation of flow paths beneath the streambeds. Furthermore, the level of discretization of the aquifer and the streambeds will also affect model predictions. A three-dimensional flow model with a finer horizontal discretization would more accurately simulate flow paths in the Saco River valley aquifer. However, given the amount of available data and the overall scale of the model, the two-dimensional approach was considered to be a reasonable compromise.

SUMMARY AND CONCLUSIONS

The Saco River valley aquifer consists of unconsolidated glacial sediments and Holocene alluvium. In a typical stratigraphic section, the bedrock is overlain by till, ice-contact stratified drift, or lacustrine sediments. These deposits are typically overlain by lacustrine sediments and (or) outwash, which, in turn, are overlain in some areas by eolian-sand deposits or Holocene alluvium. Although the lacustrine sediments consist of relatively impermeable clay, silt, and very fine to fine sand, they are included in the saturated thickness of the aquifer because they are unevenly distributed horizontally and vertically in the stratigraphic section. In addition, stratified sand and gravel was encountered beneath the lacustrine sediments at 12 observation wells distributed throughout the study area.

The saturated thickness of the aquifer in the Conway area ranged from 10 ft or less near the valley walls to approximately 185 ft along the deepest bedrock valley, to the northwest of Echo Lake. Saturated thickness in Fryeburg ranged from 10 ft or less near the aquifer boundaries to approximately 280 ft near OW69.

Values of hydraulic conductivity for the aquifer were estimated from analyses of grain-size distributions, slug tests, and pump tests. Hydraulic conductivity based on grain-size distributions ranged from 11 ft/d for silt and very fine sand to 97 ft/d for very coarse sand and gravel. Hydraulic conductivity determined using a slug-test method designed for highly permeable sediments ranged from 2 ft/d for silt and very fine sand to 210 ft/d for very coarse sand and gravel.

Areas of high transmissivity, where both hydraulic conductivity and saturated thickness are high, may be favorable sites for development of ground-water supplies. Hydraulic conductivity was typically highest adjacent to the Saco River and decreased towards the valley walls. In the Conway area, hydraulic conductivity generally decreased from north to south, although there were some high values (200 ft/d) in the area northwest of Conway Village. Aquifer sections in Conway with a saturated thickness of 40 ft or more of medium to very coarse sand were located near high-yield municipal wells and (or) were along the Saco River or its tributaries, where there is potential for high well yield from induced infiltration. In the Fryeburg area, the northern part of the valley in the vicinity of the Old Course of the Saco River is underlain by a thick saturated section of medium to very coarse sand and gravel. In addition, the area near OW64 may be favorable for ground-water development.

The principal flow path in the aquifer is in a cross-valley direction, from the till-covered or bedrock uplands toward the Saco River, the major ground-water discharge zone. Gradients are steepest near the valley walls and flatten towards the center of the valley. The cross-valley gradients in Conway generally are steeper than those in

Fryeburg. In addition to the principal cross-valley flow directions, there are less significant down-valley components of flow approximately parallel to the course of the Saco River. Down-valley gradients are less steep than cross-valley gradients.

A ground-water flow divide, which coincides with a surface-water divide, is located to the northeast of Pine Hill in the Redstone area of Conway. Another ground-water flow divide runs approximately southwest-northeast from north of Swans Falls to northwest of Fryeburg Center.

Major sources of recharge include precipitation that falls directly on the aquifer, unchanneled runoff from adjacent till or bedrock uplands, and infiltration from tributary streams. The average annual recharge from precipitation falling directly on the aquifer is approximately 24 in/yr. The average annual runoff from upland sources is estimated to be 32 in/yr. Seepage to the aquifer from tributary streams is an important source of recharge, especially during the summer months when recharge from precipitation is limited by soil-moisture demand and evapotranspiration. Other sources include recharge from septic systems and induced infiltration from the Saco River. Seasonal change in the amount of recharge from precipitation is an important factor influencing fluctuations in the water table. Water-level fluctuations also are caused by recharge from till-covered or bedrock uplands, seepage from tributary streams, and pumpage of nearby wells.

Discharge from the aquifer is primarily to the Saco River. Less significant amounts of discharge result from pumpage and evapotranspiration. Total observed ground-water discharge to the Saco River during low-flow conditions from a point near the mouth of the East Branch of the Saco River to the streamflow gage at Conway ranged from 49 to 58 ft^3/s.

In order to characterize ground-water quality in uncontaminated "background" areas and in agricultural areas, and to assess the effects of development along State Route 16 (the main highway through North Conway), ground-water samples were divided into three groups (background, agricultural, and development) on the basis of land use and location of sampling site. The principal cations in all groups were calcium and sodium. Bicarbonate was a major anion in all groups. Sulfate was a major anion in the background group, but was replaced by chloride as a major anion in the agricultural and development groups. The background water quality was characterized as low in specific conductance, somewhat acidic, and soft. Ground water in the agricultural group was characterized by increases above background levels in the concentrations of major cations and anions. The median specific conductance of 123 $\mu S/cm$ for the agricultural group was more than twice that for the background group (54 $\mu S/cm$). In comparison to the background and the development groups, the agricultural group had the highest median concentrations of calcium, magnesium, and total phosphorus, and the highest concentrations of total orthophosphorus and potassium, probably as a result of the use of fertilizers. In comparison to the background and agricultural groups, the development group had the highest median concentrations of sodium and chloride, primarily as a result of use of deicing salts on State Route 16. The development group also had the highest median and maximum concentrations for nitrite and nitrate, ammonium, ammonium and organic nitrogen, and organic nitrogen. These high concentrations and the somewhat elevated levels of MBAS (detergents) in this group probably resulted from septic-tank discharges.

Surface-water quality was observed at median streamflow conditions on the Saco River; however, flow conditions were largely influenced by storm runoff from Hurricane Gloria. Dissolved-solids concentrations and specific conductance increased about 20 percent from the most upstream to the most downstream stations along the Saco River. The highest fecal coliform and fecal streptococcus bacteria counts were found at the station immediately downstream from the Center Conway sewage-treatment facility and in the stagnant waters of the Old Course of the Saco River. The Old Course of the Saco River had elevated nutrient concentrations and depressed dissolved-oxygen concentrations.

A finite-difference model of two-dimensional ground-water flow was developed and calibrated to long-term water-level conditions. The calibrated model was used to predict the effects on ground-water levels of increased pumpage under different recharge conditions in the aquifer and on the size of contributing areas to municipal wells. The model covered an area of approximately 15 mi^2, extending from a point near the junction of the Saco and Ellis Rivers to Conway Village, near the junction of the Swift and Saco Rivers. This section of the aquifer was modeled because major pumping occurs within this area and because commercial and residential development is concentrated in this part of the valley. The active model area consisted of 4,625 nodes. The boundary between till and stratified drift was modeled as a specified-flux boundary; the bottom of the aquifer was modeled as a no-flow boundary; the water table was treated as a free-surface recharge boundary; and surface-water boundaries were simulated as either constant-head, specified-flux, or head-dependent-flux boundaries. The average absolute difference between computed and observed water levels for December 1985 was 1.7 ft; the maximum difference was 4.7 ft. The computed total ground-water budget (65.3 ft^3/s) is reasonable compared with ground-water discharge measured during base-flow conditions. Approximately 54 percent of the natural recharge to the aquifer is derived from upland sources (runoff from unchanneled areas and tributary stream leakage), whereas only 37 percent of natural recharge is from precipitation. This pattern of recharge, in which runoff from the upland areas provides most of the recharge, is conceptually different from other models of stratified-drift river valley aquifers in New England, which derive most of their recharge from precipitation falling directly on the aquifer.

The calibrated steady-state model was most sensitive to decreases in aquifer hydraulic conductivity. Increased recharge to the model caused greater changes than proportional increases in other parameters. The model was sensitive to changes in streambed vertical hydraulic conductivity. A tenfold increase in streambed vertical hydraulic conductivity improved the head match very slightly, whereas a tenfold decrease caused heads to rise throughout the model, resulting in increased model error. Variations in depth to bedrock within the range of error expected for seismic-refraction profiling had little or no effect on model results.

The calibrated model was used to predict the effects of present (1985) and increased pumpage under varying recharge conditions on ground-water levels and on the size of contributing areas to municipal wells. The maximum pumpage simulated with the model was 11.1 ft^3/s from 7 wells located in Lower Bartlett, North Conway, and Conway Village, New Hampshire. During periods of low recharge, this pumpage comprised 23 percent of the ground water flowing through the aquifer. Under the various pumpage scenarios used to simulate low recharge periods, water levels declined up to 17 ft along aquifer boundaries and from 0.3 to 11.1 ft near municipal wells.

The contributing areas for present and proposed wells were estimated for each of the pumpage scenarios with a particle-tracking model that was coupled with the ground-water flow model. The total contributing areas included parts of the aquifer itself and adjacent uplands. Estimated contributing areas within the aquifer ranged from 0.1 to 0.5 mi^2 for 1985 pumpage rates under average recharge conditions.

The largest contributing areas were those estimated for proposed pumpage under low recharge conditions. These contributing areas were much larger than the present 400-ft-radius zones commonly protected by legislation in New Hampshire. Furthermore, the contributing areas were not circular but extended upgradient from the wells in curved or "U"-shapes. Under the combined stresses of proposed pumpage and low recharge conditions, the size of the contributing areas within the aquifer ranged from 0.2 mi^2 at North Conway Water Precinct well #2 (MW3) to 1.0 mi^2 at the Conway Village wells (MW5, MW5A). The East Branch of the Saco River, the Saco River, Lucy Brook, Kearsarge Brook, the Swift River, and Pequawket Pond were sources of induced infiltration for the municipal wells in this scenario. The contributing area for the Conway Village wells included the area of contaminated ground water at the industrial site near Pequawket Pond.

Land uses within the contributing areas are related to forestry or agricultural activities. On the basis of samples collected for this study, the quality of surface waters that provided recharge within the contributing areas was suitable for drinking-water supplies. Wells with contributing areas on the eastern side of the valley are susceptible to contamination because ground-water quality in that area has been degraded by septic-waste disposal and road salting.

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GLOSSARY

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

Base flow (base runoff): Runoff composed largely of ground water.

Bedrock: Solid rock, commonly called "ledge" in New England, that forms the Earth's crust. It is locally exposed at the surface but more commonly buried beneath a few inches to more than 300 feet of unconsolidated deposits.

Coliform organisms: Any of a group of bacteria, some of which inhabit the intestinal tracts of vertebrates. Their occurrence in a water sample is regarded as evidence of possible sewage pollution and fecal contamination. These organisms are generally considered to be nonpathogenic.

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

Confined aquifer: An aquifer in which the water is under pressure significantly greater than atmospheric, whose upper limit is the bottom of a bed of distinctly lower hydraulic conductivity than that of the aquifer material.

Contributing area: The contributing area of a pumping well is defined as the land area that has the same horizontal extent as that part of an aquifer, or adjacent areas, from which ground-water flow is diverted to the pumping well. The contributing area consists of a two-dimensional area on the land surface.

Cubic foot per second (ft^3/s): A unit of flow or discharge; 1 ft^3/s is equal to the flow of a stream 1 foot wide and 1 foot deep flowing at an average velocity of 1 foot per second.

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

Divide: A line marking the boundary between two adjacent drainage basins, dividing the waters that flow in one direction from those that flow in the opposite direction.

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

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

Eolian: Pertaining to the wind; especially said of rocks, soils, and deposits whose constituents were transported (blown) and laid down by atmospheric currents or by geologic processes (such as erosion and deposition) accomplished by the wind.

Esker: Long ridge of sand and gravel that was deposited by meltwater in tunnels within or beneath glacial ice.

Evapotranspiration: Loss of water to the atmosphere by both direct evaporation from water surfaces and moist soil, and by transpiration from living plants.

Flux: Rate of flow.

Gage or gaging station: A site on a stream instrumented to measure the changing height of surface water.

Ground-water discharge: The discharge of water from the saturated zone by natural processes such as ground-water runoff, ground-water evapotranspiration, and underflow, and by discharge through wells and other manmade structures.

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

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

Ground-water runoff: Ground-water discharge into a stream channel by seepage from aquifer materials.

Hardness of water: A physical-chemical characteristic that is commonly recognized by the increased quantity of soap required to produce lather. It is computed as the sum of equivalents of polyvalent cations and is expressed as the equivalent concentration of calcium carbonate ($CaCO_3$).

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

Hydraulic conductance: The product of the hydraulic conductivity of the material in the direction of flow multiplied by the cross-sectional area perpendicular to the flow, divided by the length of the flow path.

Hydraulic conductivity: A measure of the ability of a porous medium to transmit a fluid. If a porous medium is isotropic and the fluid is homogeneous, the hydraulic conductivity of the medium is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

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

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

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

Induced infiltration: Process by which water in a stream or a lake moves into an aquifer by the establishment of a hydraulic gradient from the surface-water body toward a pumped well or wells.

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

Lacustrine: Pertaining to, produced by, or formed in a lake or lakes; e.g. "lacustrine clays" deposited on the bottom of a lake.

Lamina: The thinnest or smallest recognizable unit layer of original deposition in a sediment or sedimentary rock.

Land-surface datum (LSD): A level surface to which depths or heights are referred in leveling.

Micrograms per liter (μg/L): A unit for expressing the concentration of chemical constituents in solution as mass (microgram) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter.

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

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 "mean sea level." It is a level plane from which altitudes are measured.

Outwash deposits: Stratified deposits of sand and gravel carried beyond the glacial margin by meltwater streams. Usually found on flat or gently sloping plains.

Perennial stream: A stream that flows during all seasons of the year.

pH: A symbol denoting the negative logarithm (base 10) of the hydrogen ion concentration of a solution; pH values range from 0 to 14--the lower the value, the more acid the solution; i.e., the more hydrogen ions it contains.

Precipitation: The discharge of water from the atmosphere, either as rain, snow, ice, or mist.

Proglacial lake: A lake formed at or slightly beyond the ice margin.

Recharge: Water that infiltrates into the saturated zone. Recharge may be natural or artificial depending on the method by which the water infiltrates into an aquifer--for example, precipitation or stream infiltration vs. recharge wells, infiltration ponds, and septic systems.

Redox potential: A numerical index of the intensity of chemical oxidizing or reducing conditions within a system.

Runoff, total: That part of precipitation that appears in streams.

Saturated thickness: The subsurface zone in which all openings are filled with water. For an unconfined aquifer it is the zone from the water table to the bottom of the aquifer.

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

Seepage run: A set of discharge measurements used to determine gaining or losing reaches in a river or stream.

Sink: Area of ground-water discharge.

Solute: Any substance that is dissolved in water.

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

Specific conductance: A measure of the ability of a solution to conduct an electrical current. It is expressed in microsiemens per centimeter at 25 degrees Celsius. It is equivalent to the superseded term micromhos per centimeter at 25 degrees Celsius. Specific conductance is related to the type and concentration of ions in solution and can be used for approximating the dissolved-solids content of water. Commonly, the concentration of dissolved-solids (in milligrams per liter) is about 65 percent of the specific conductance (in microsiemens). This relation is not constant from one water source to another, and it may vary in the same source with changes in the composition of water.

Specific yield: The volume of water which saturated rock or soil will yield by gravity, divided by its own volume.

Steady state: A term that describes conditions in an aquifer when flow is essentially steady and water levels cease to decline. In nature, absolute steady-state conditions do not exist; however, if recharge and discharge to an aquifer are held constant over a sufficiently long period of time, steady-state conditions are approximated.

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 approximately equal to the specific yield.

Stratified drift: A predominately well-sorted sediment deposited in layers by or in bodies of glacial meltwater; includes gravel, sand, silt, or clay.

Surface runoff: Water that travels over the soil surface to the nearest stream channel.

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

Transmissivity: The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient. Equal to the average hydraulic conductivity multiplied by the saturated thickness.

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

Underflow: The movement of ground water through the permeable deposits that underlie a stream.

Varve: A sedimentary bed or lamina or sequence of laminae deposited in a body of still water within one year's time.

Volatile organic compound: A chemical that vaporizes when exposed to air. Many highly toxic solvents are volatile organic compounds.

Water budget: An accounting of the inflow to, the outflow from, and the storage of water in a flow system.

Water table: The upper surface of the saturated zone of an unconfined aquifer.

Water year: A 12-month period starting October 1 and ending September 30. The water year is designated by the calendar year in which it ends. Thus, the year beginning October 1, 1980, is called the "1981 water year."

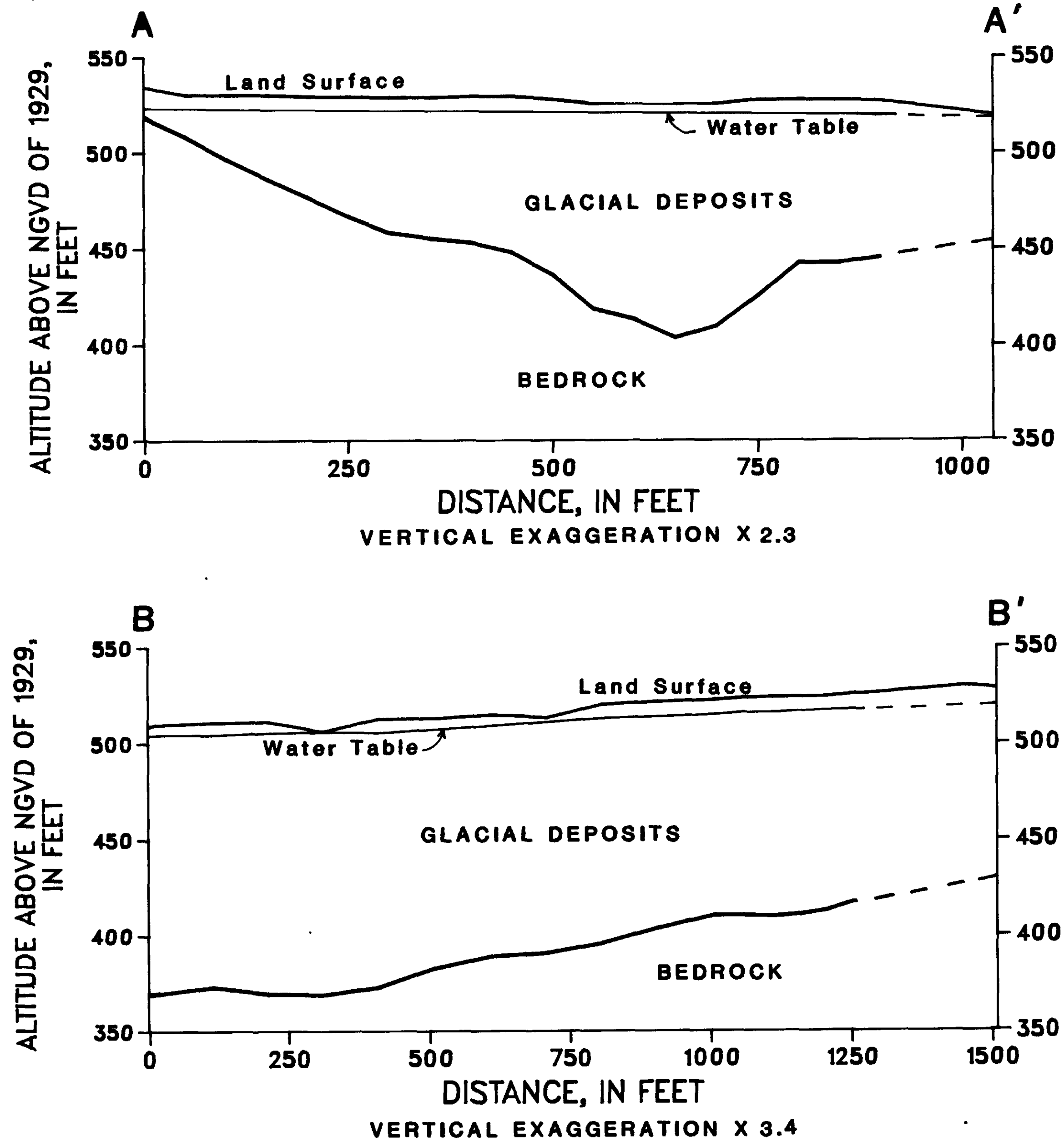
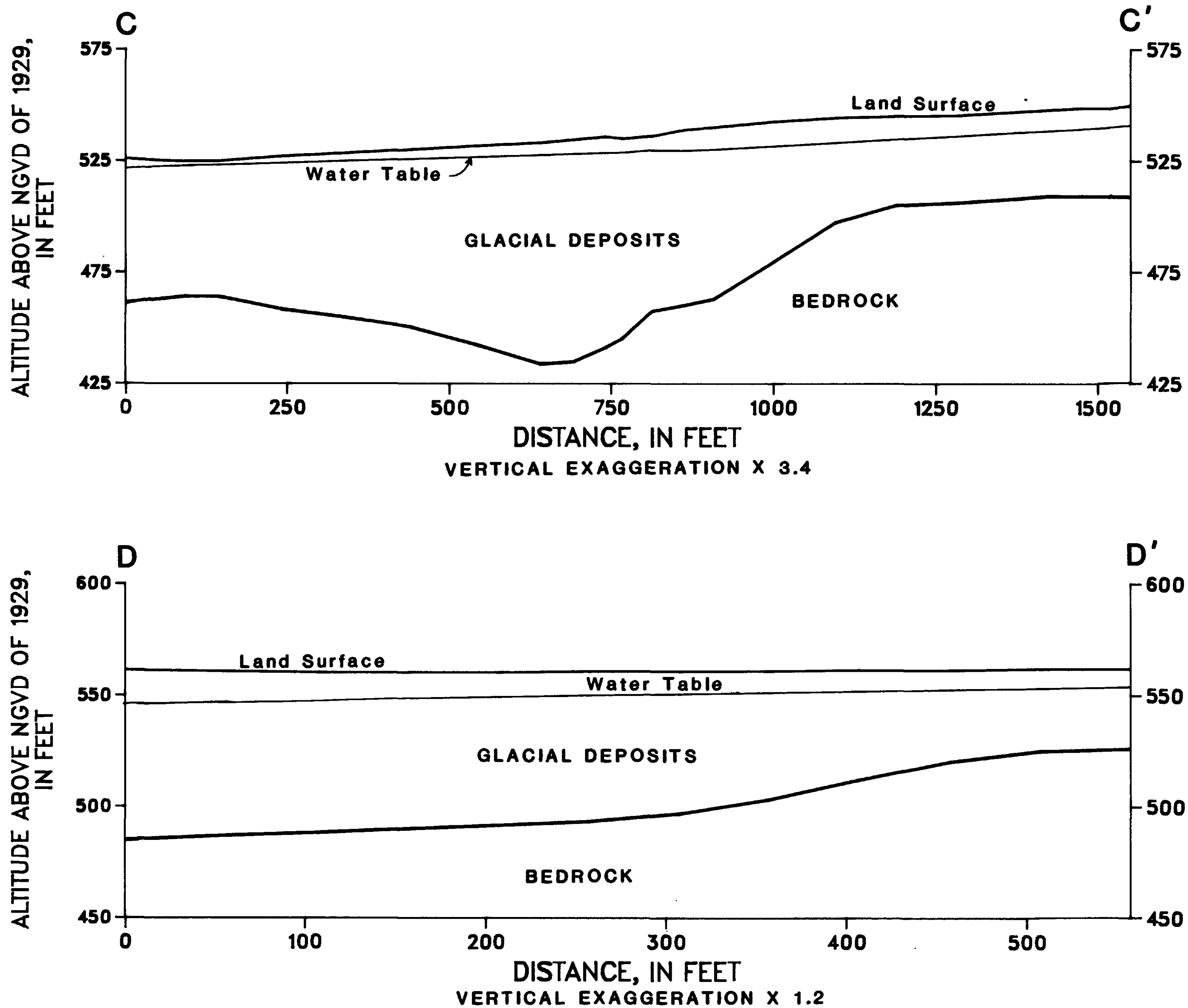


Figure 23.--Seismic-refraction profiles.

Hydrogeologic sections from seismic-refraction surveys conducted by the U.S. Geological Survey Locations of individual profiles are shown on plates 1, 2, and 3. Data interpretation is based on a computer-modeling program described by Scott and others (1972). The altitudes of the water table and bedrock surface have been shown with dashed lines where data were questionable near the ends of some profiles.



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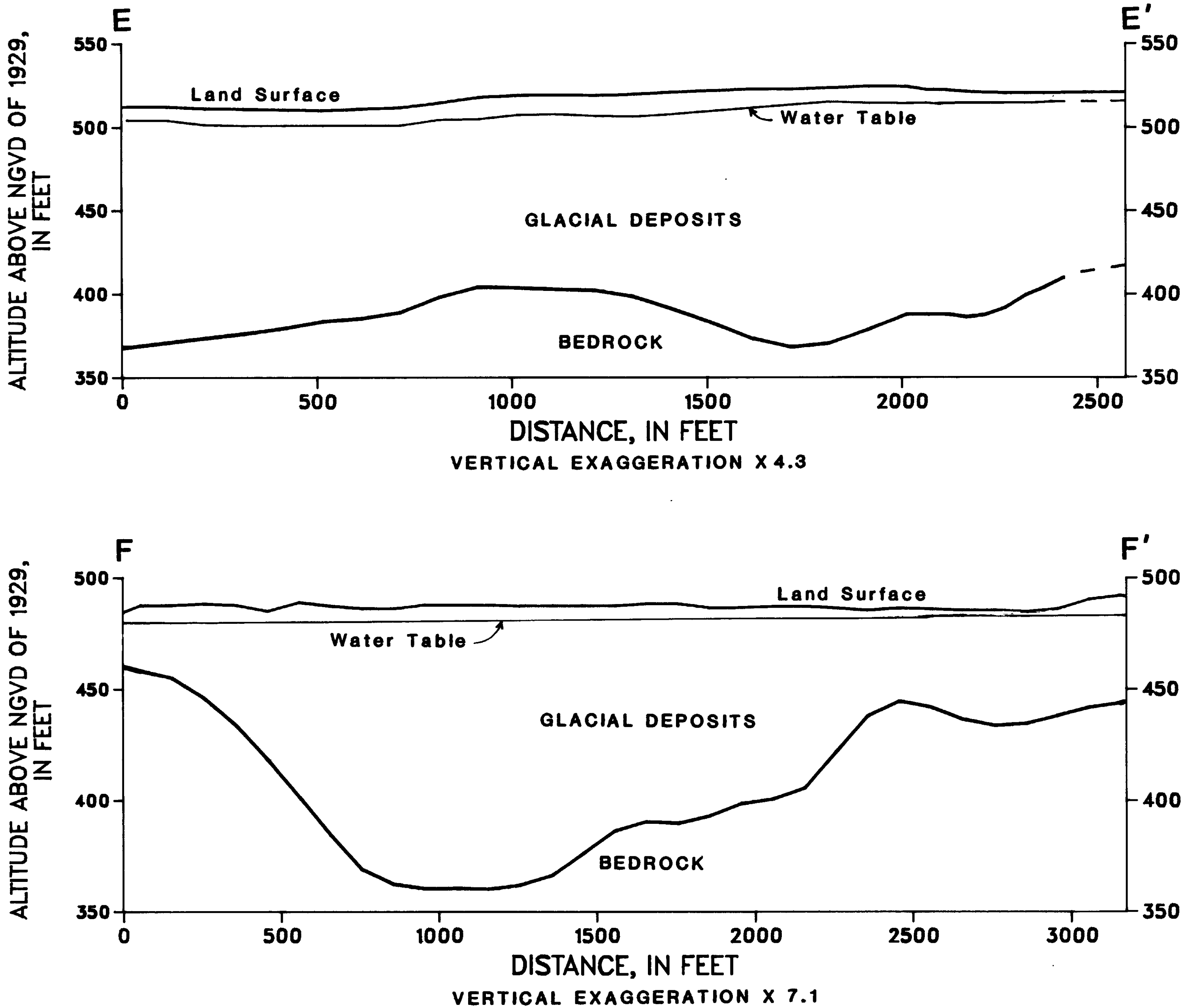

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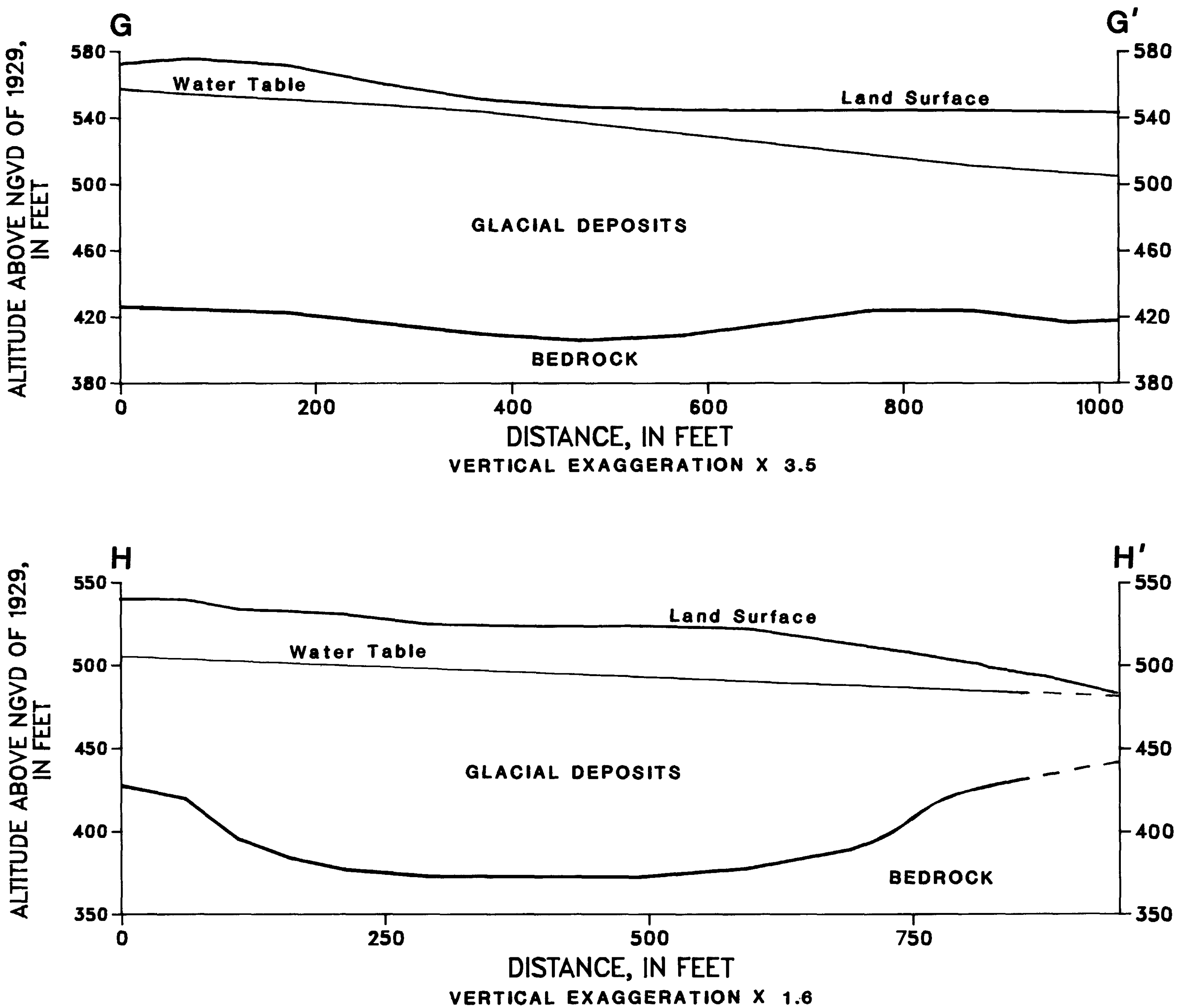

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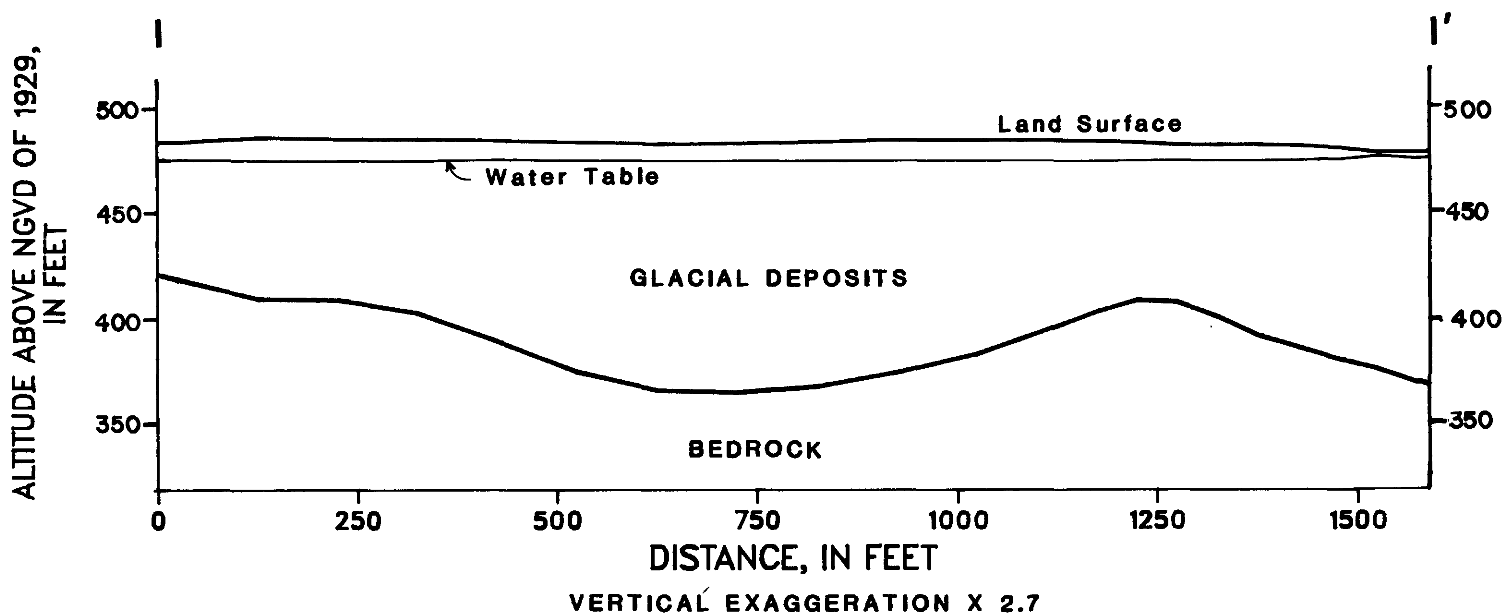

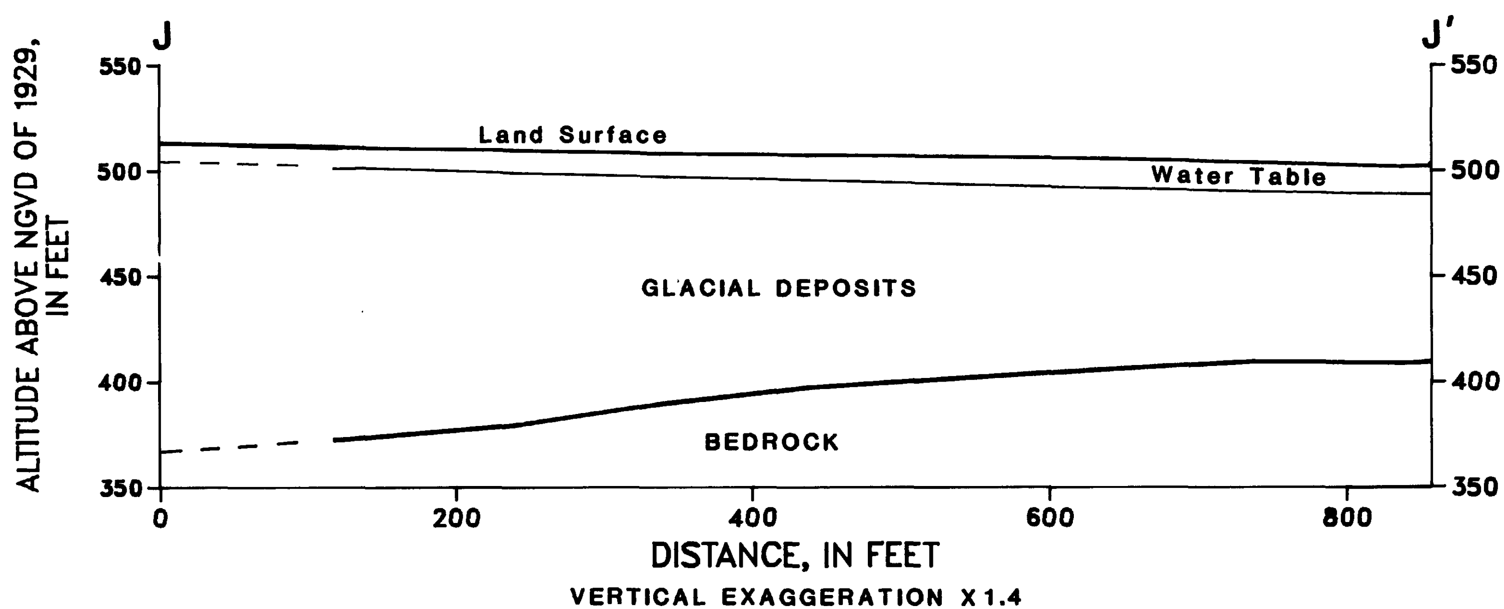

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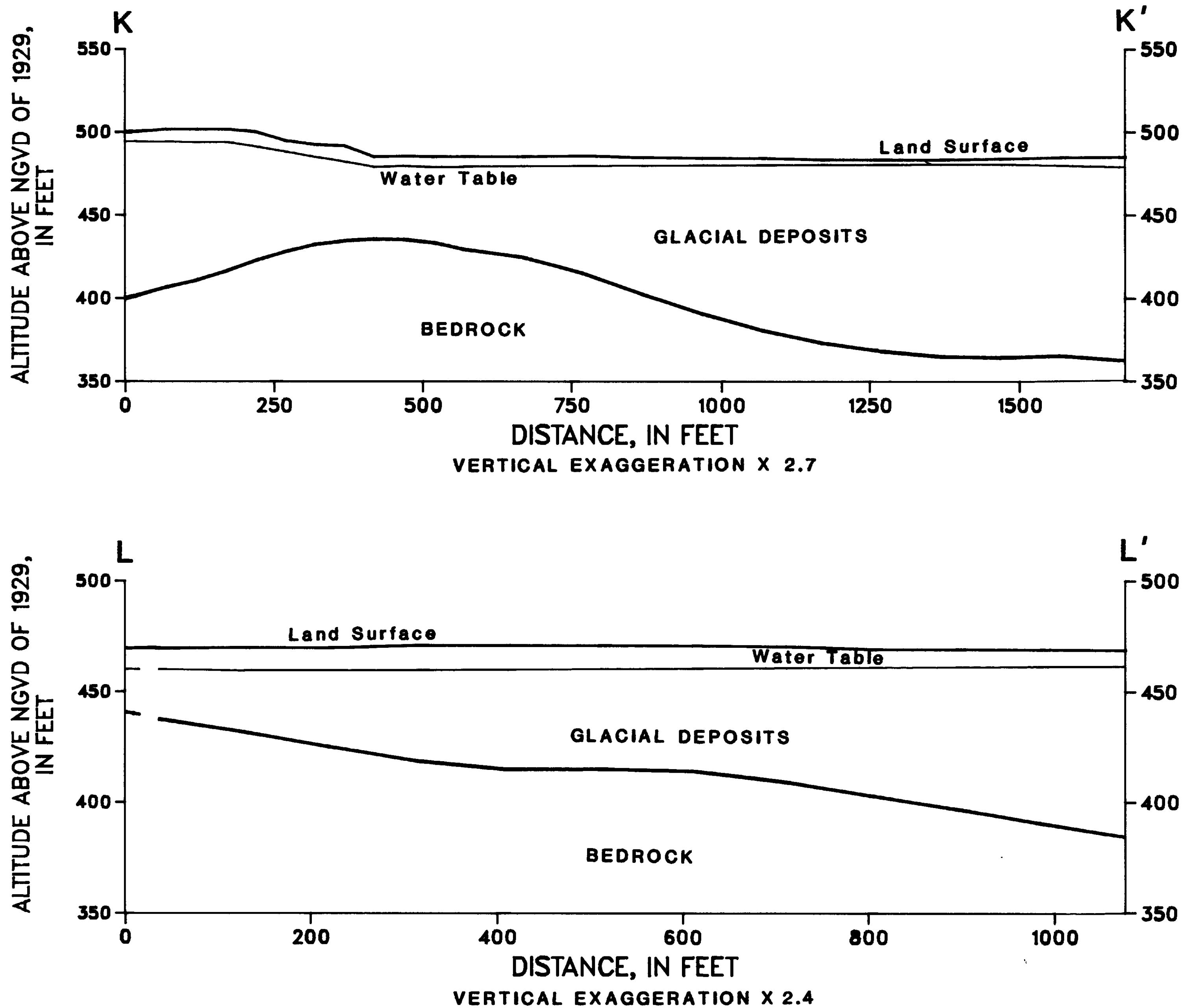

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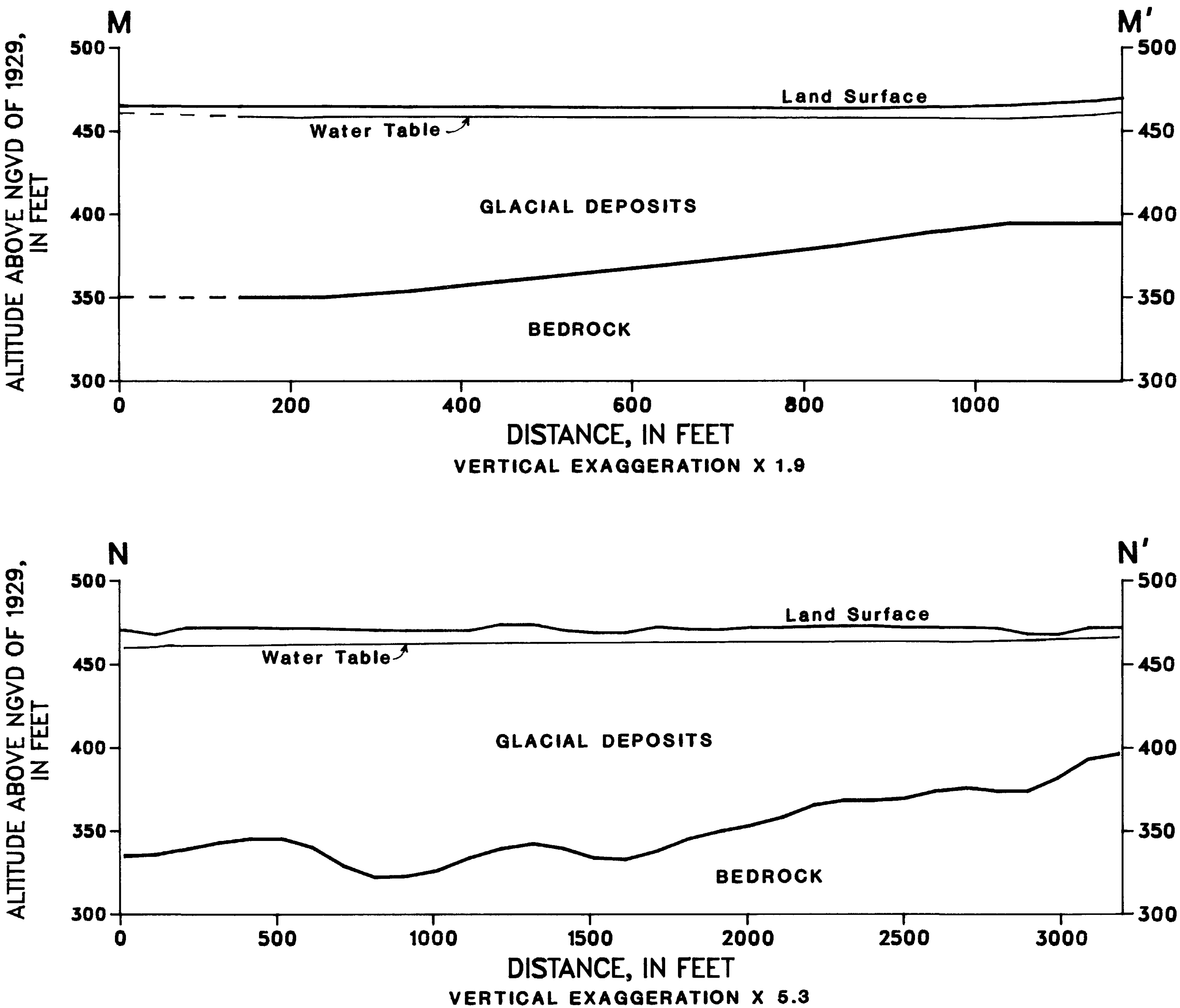

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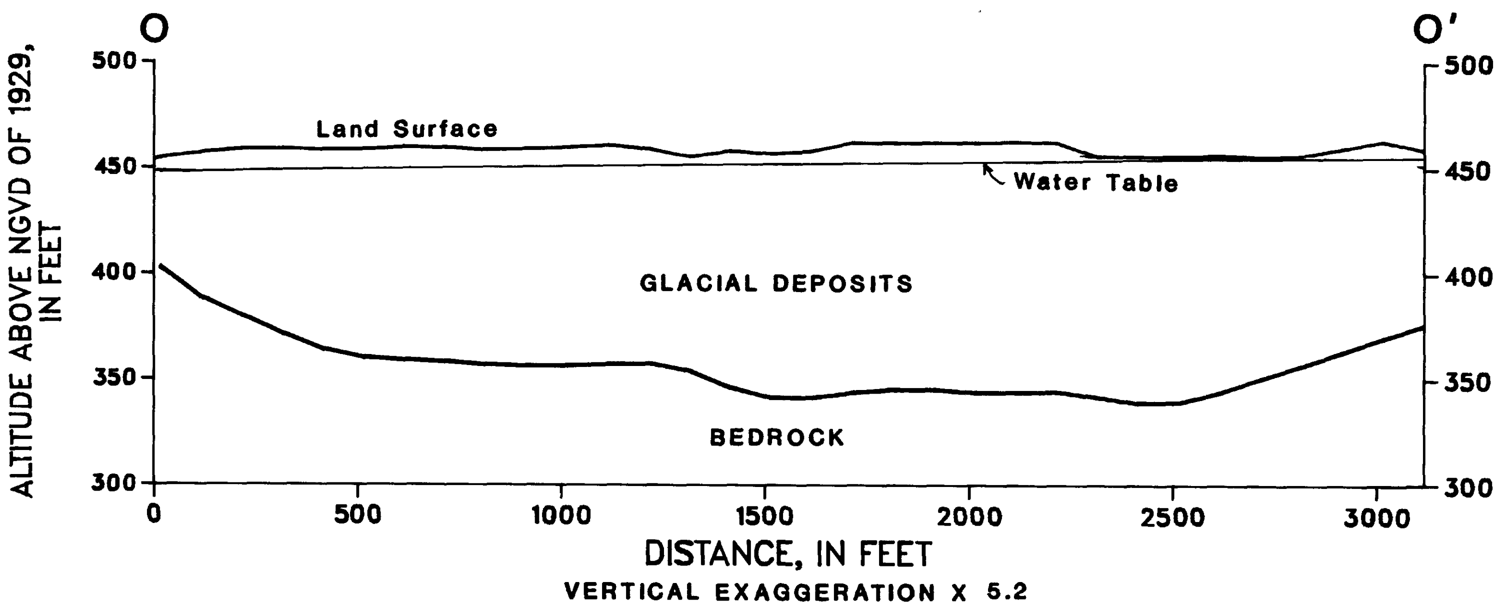

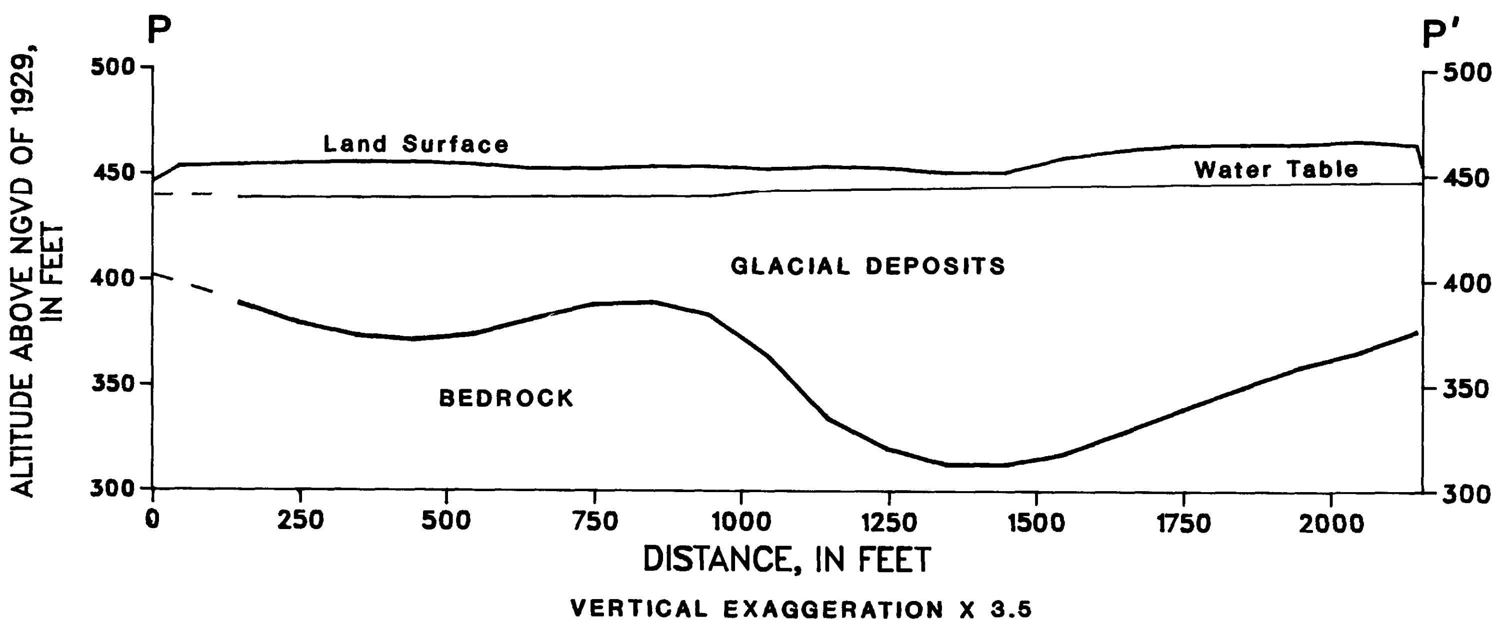

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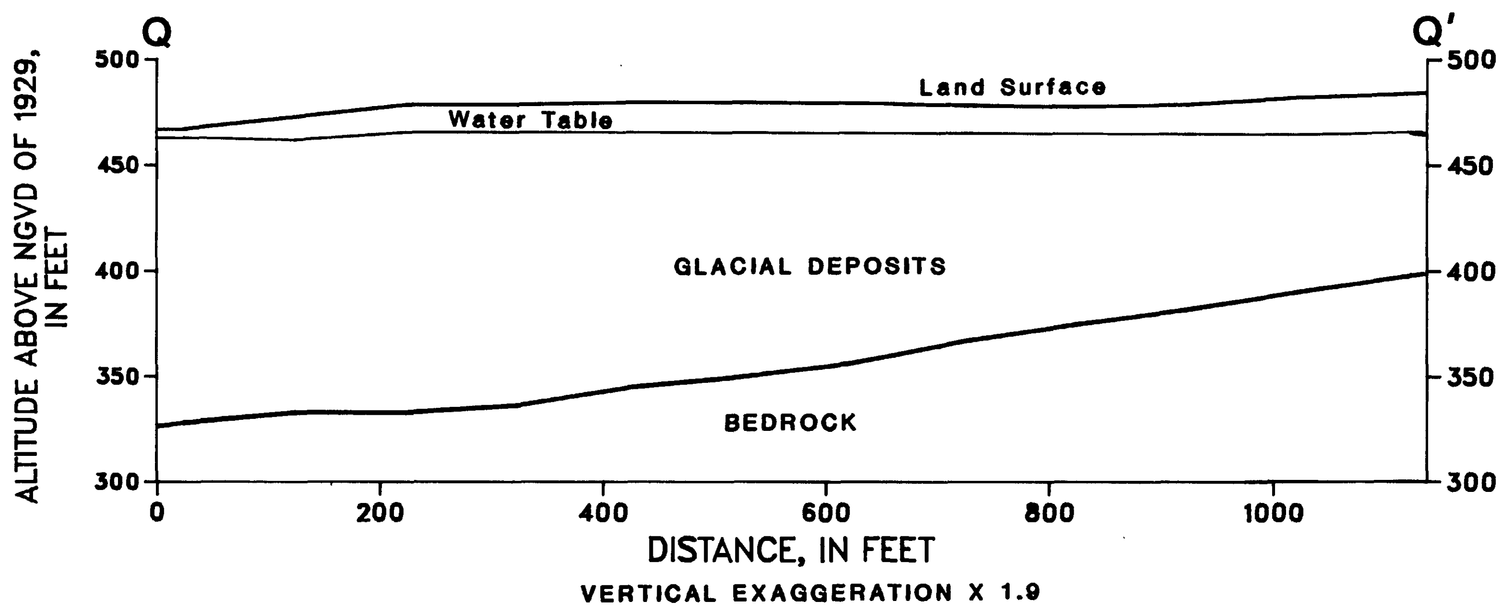


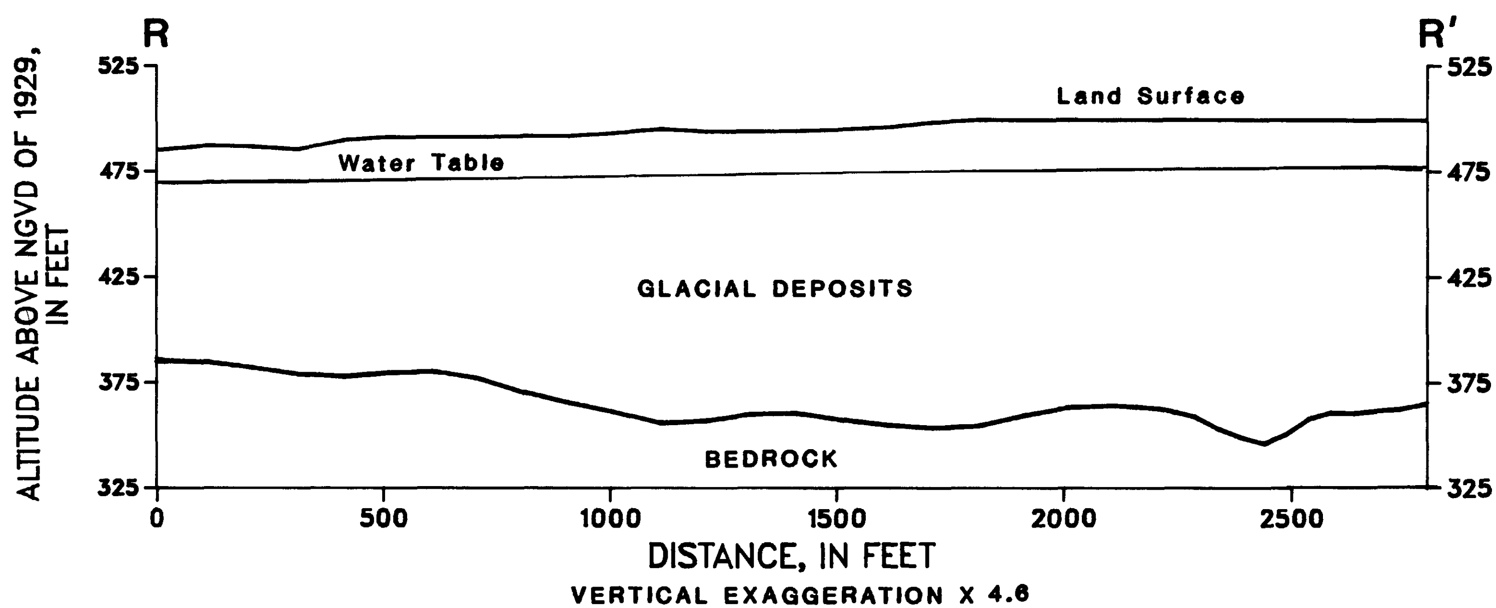
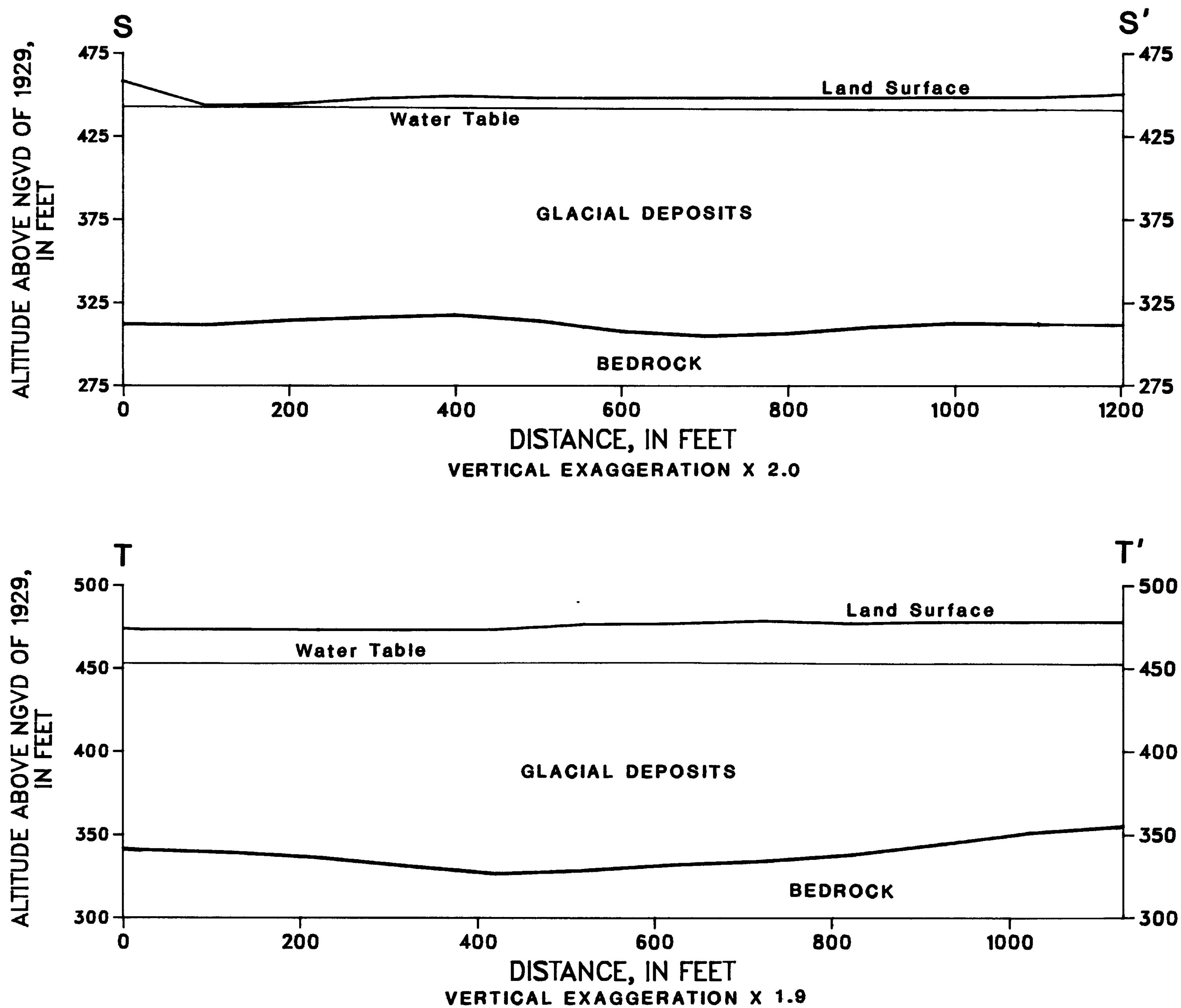


Figure 23.--Seismic-refraction profiles--Continued.



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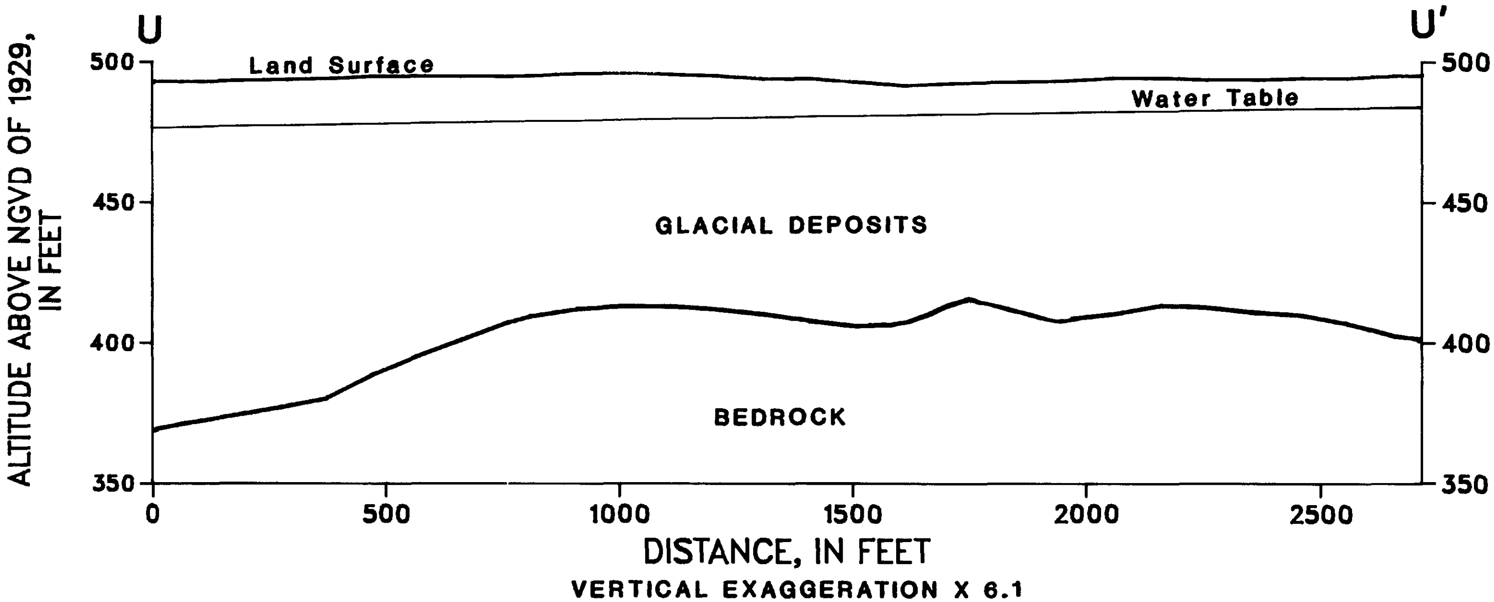

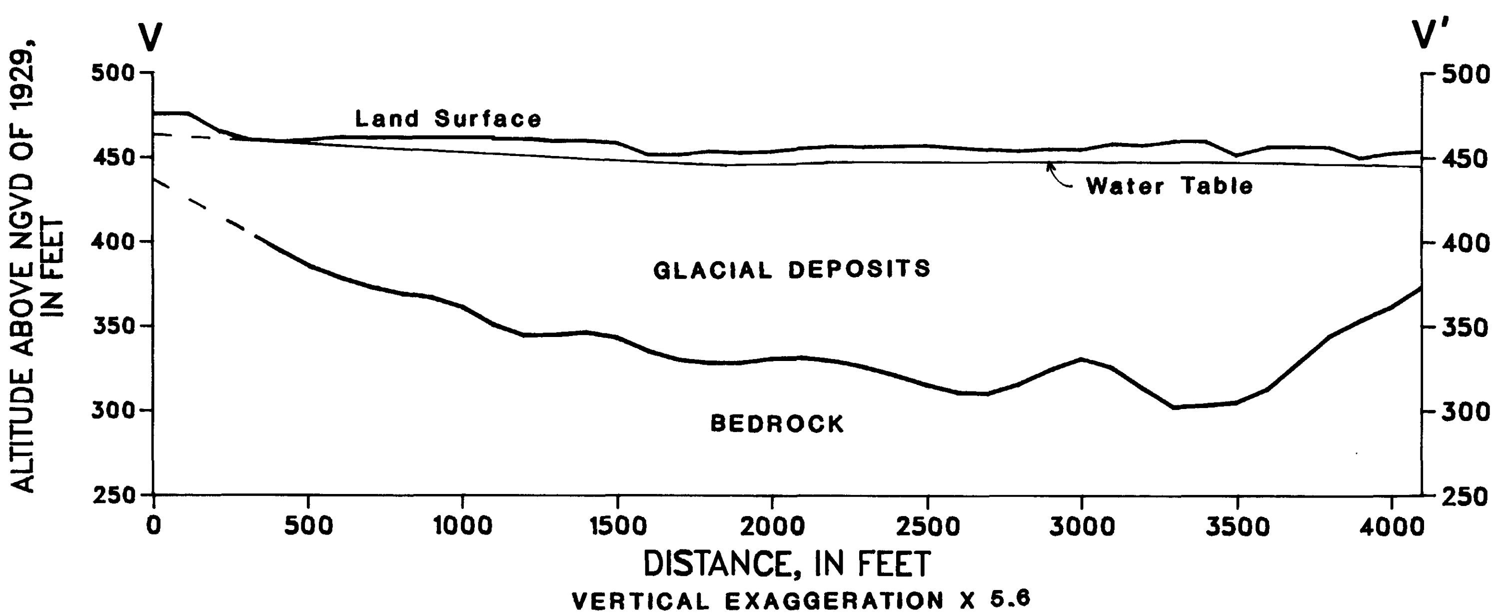

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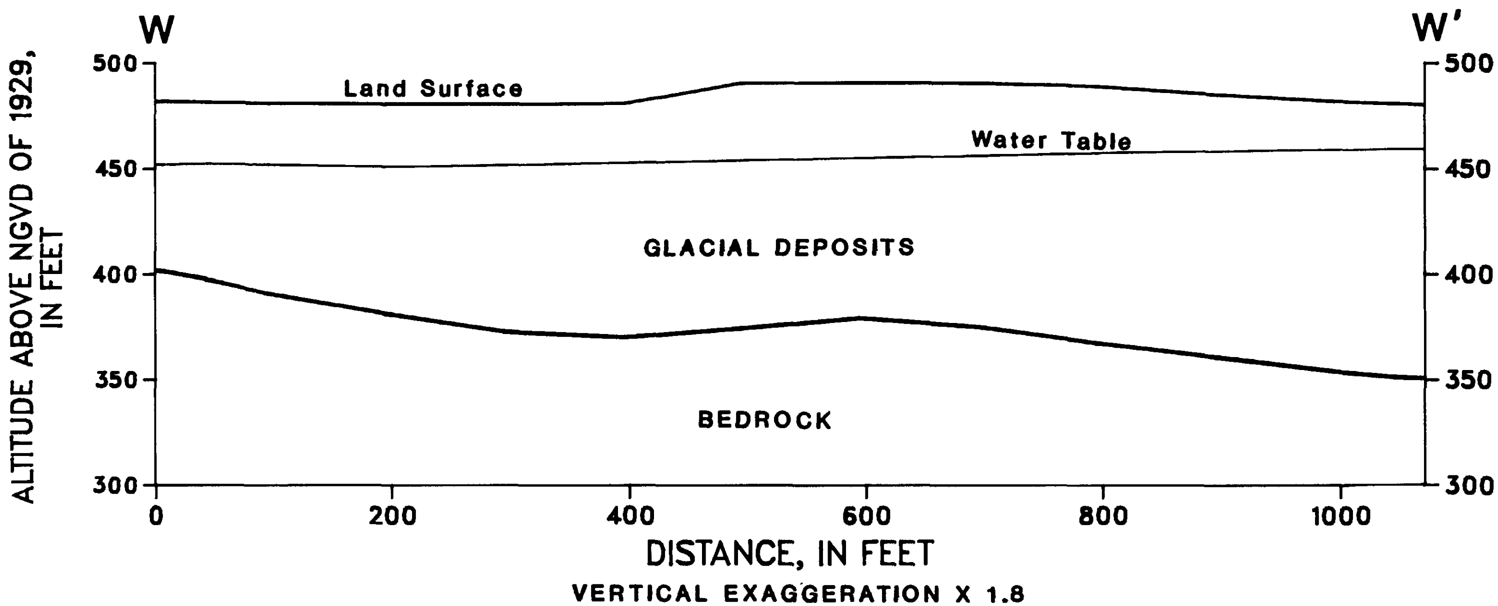

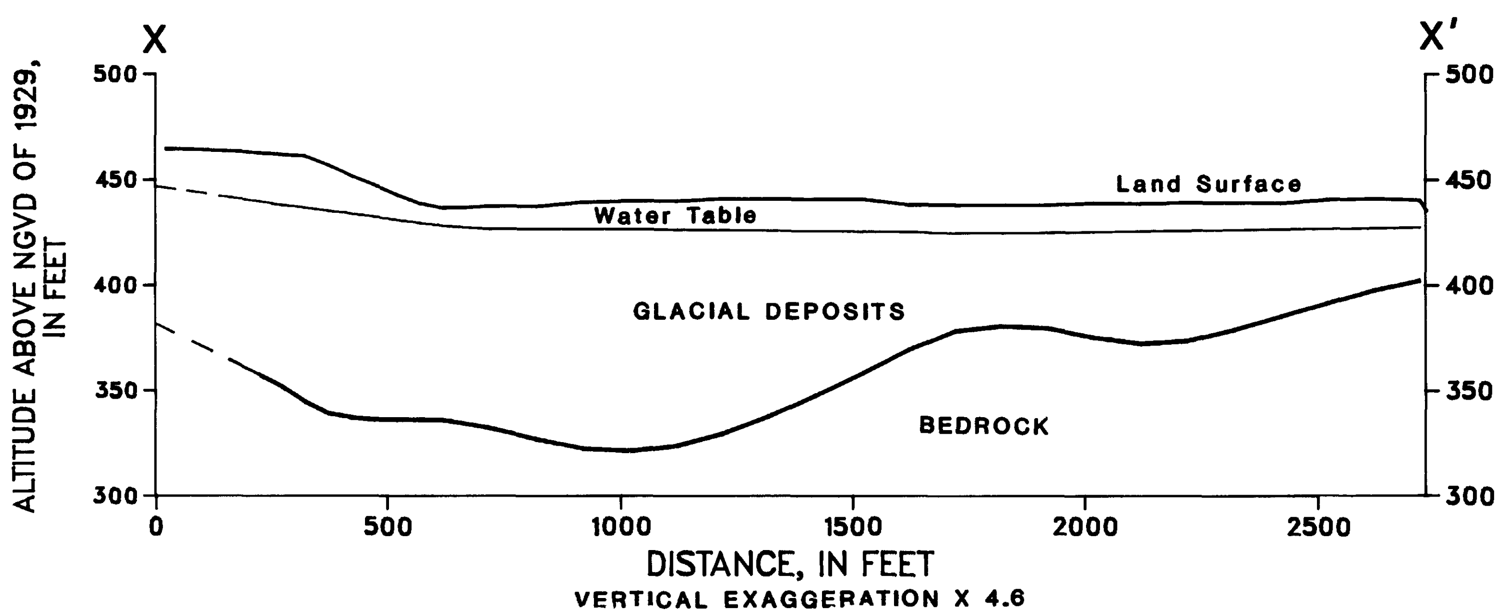

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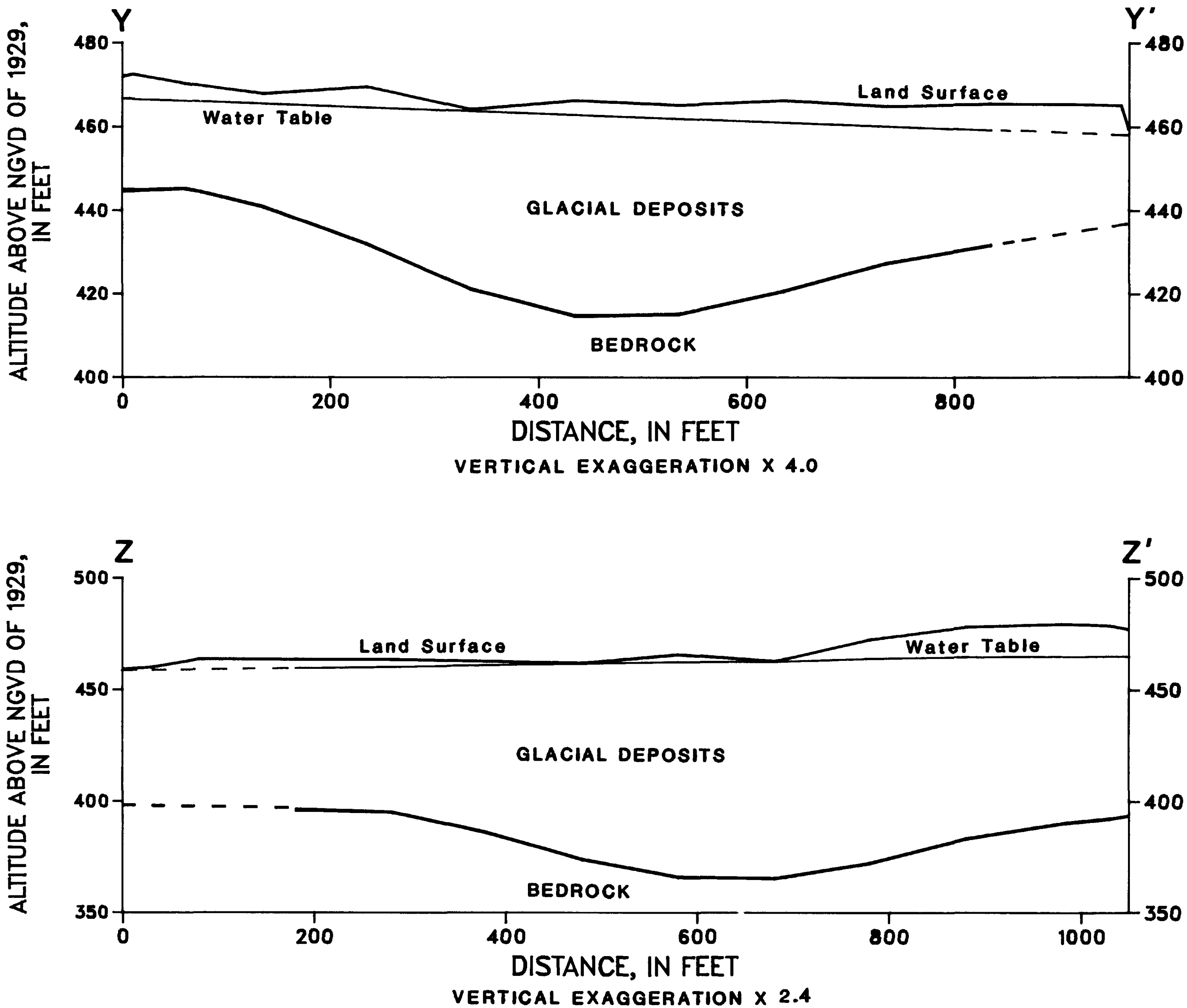

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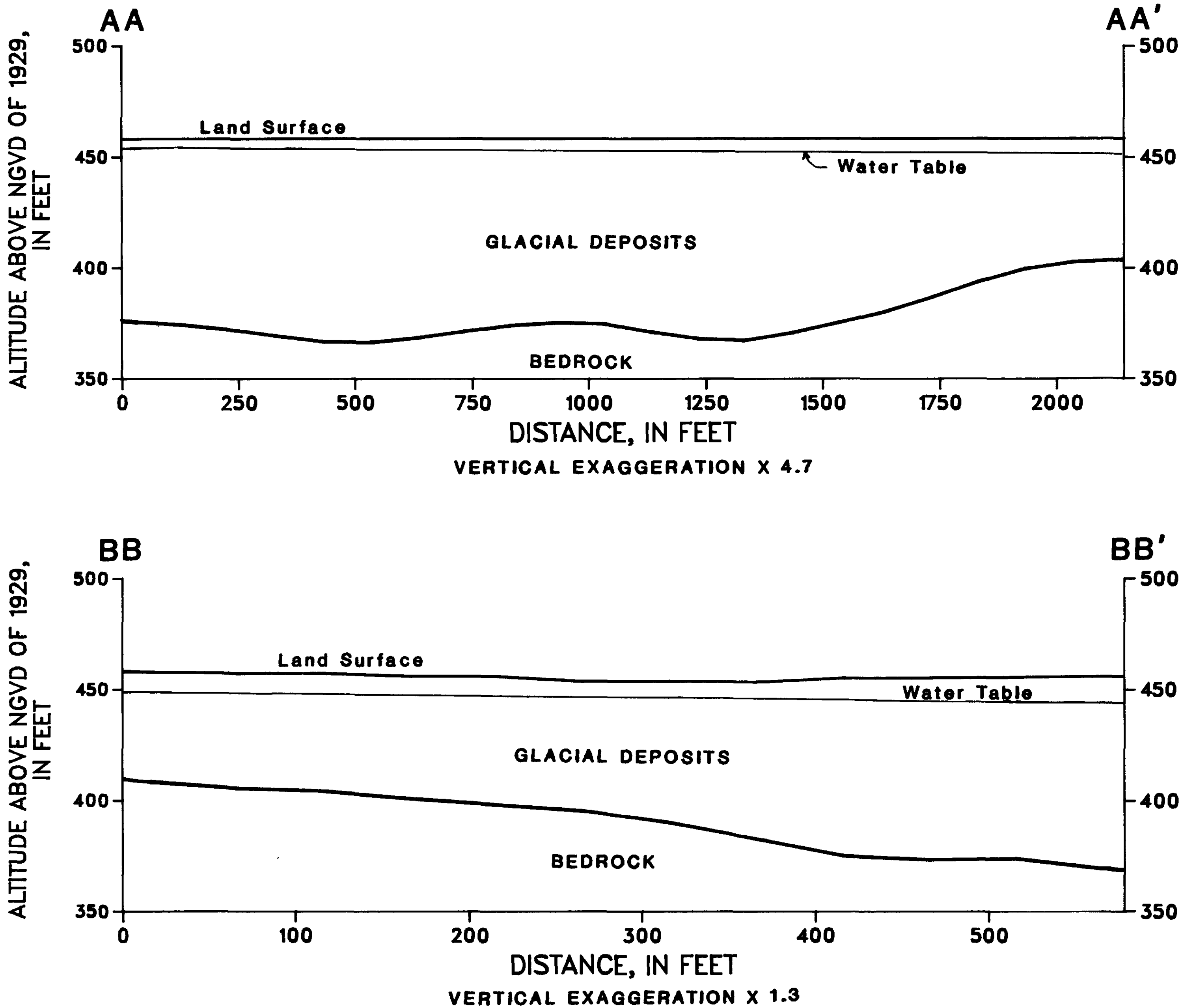

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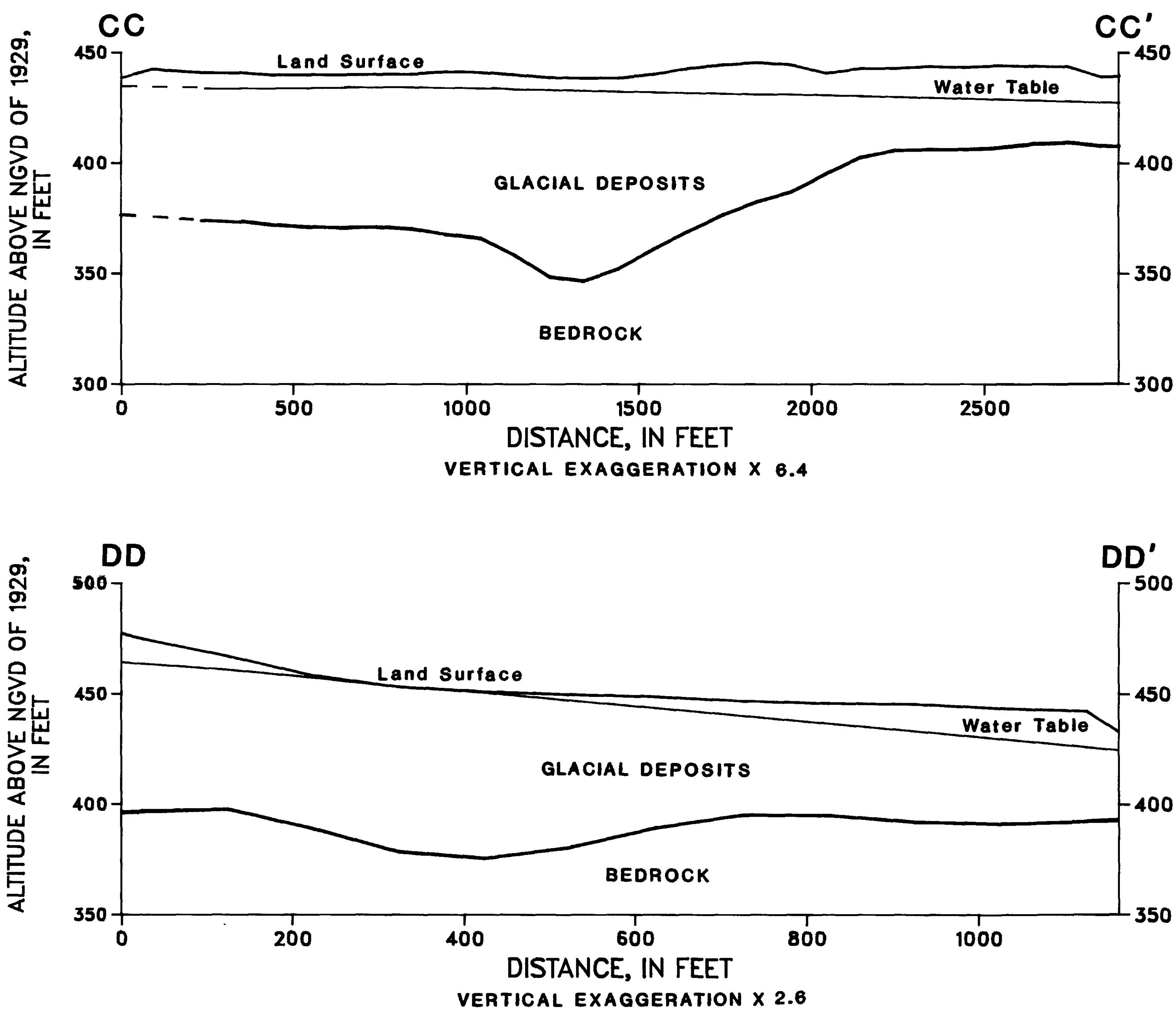

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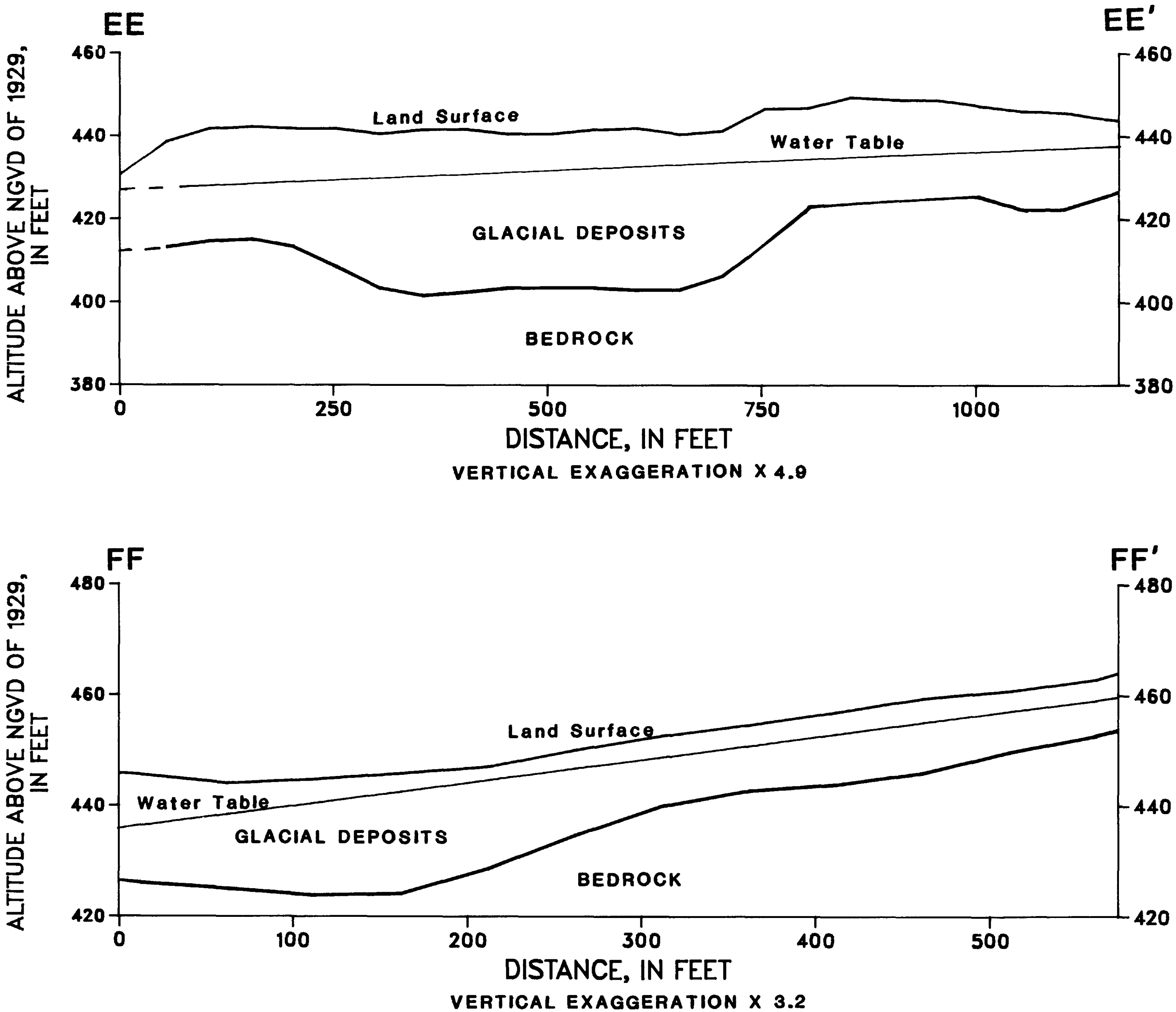

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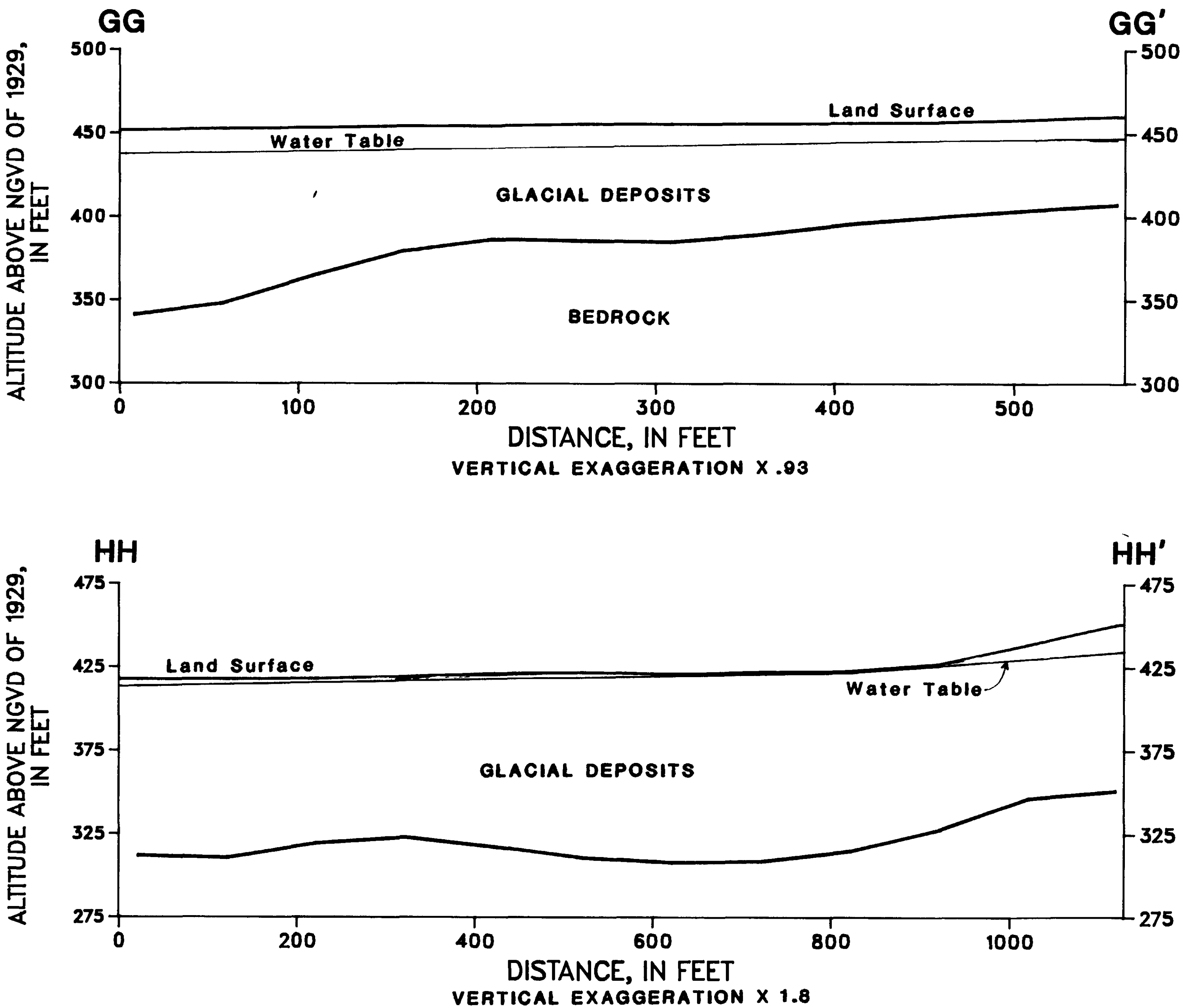

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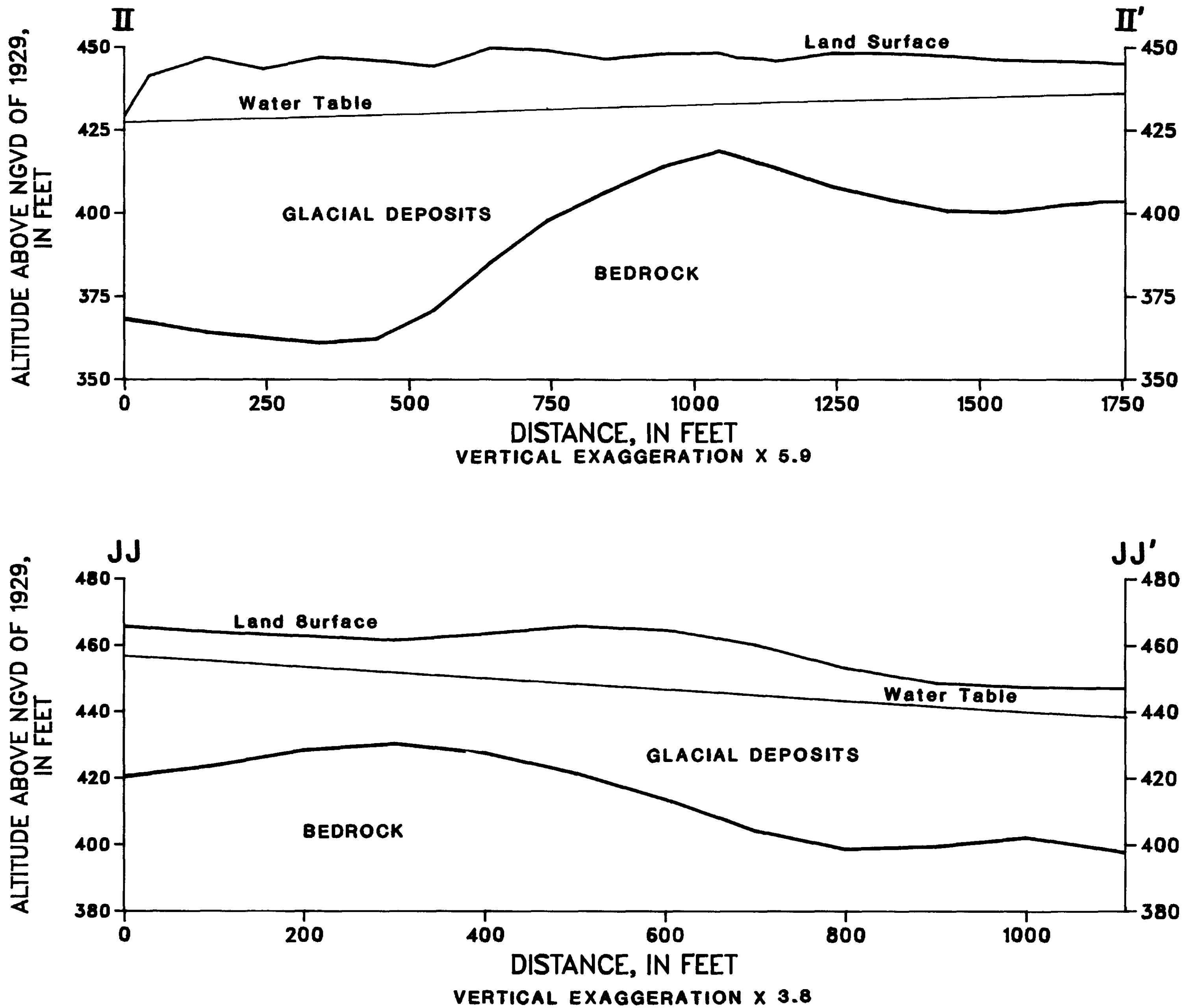

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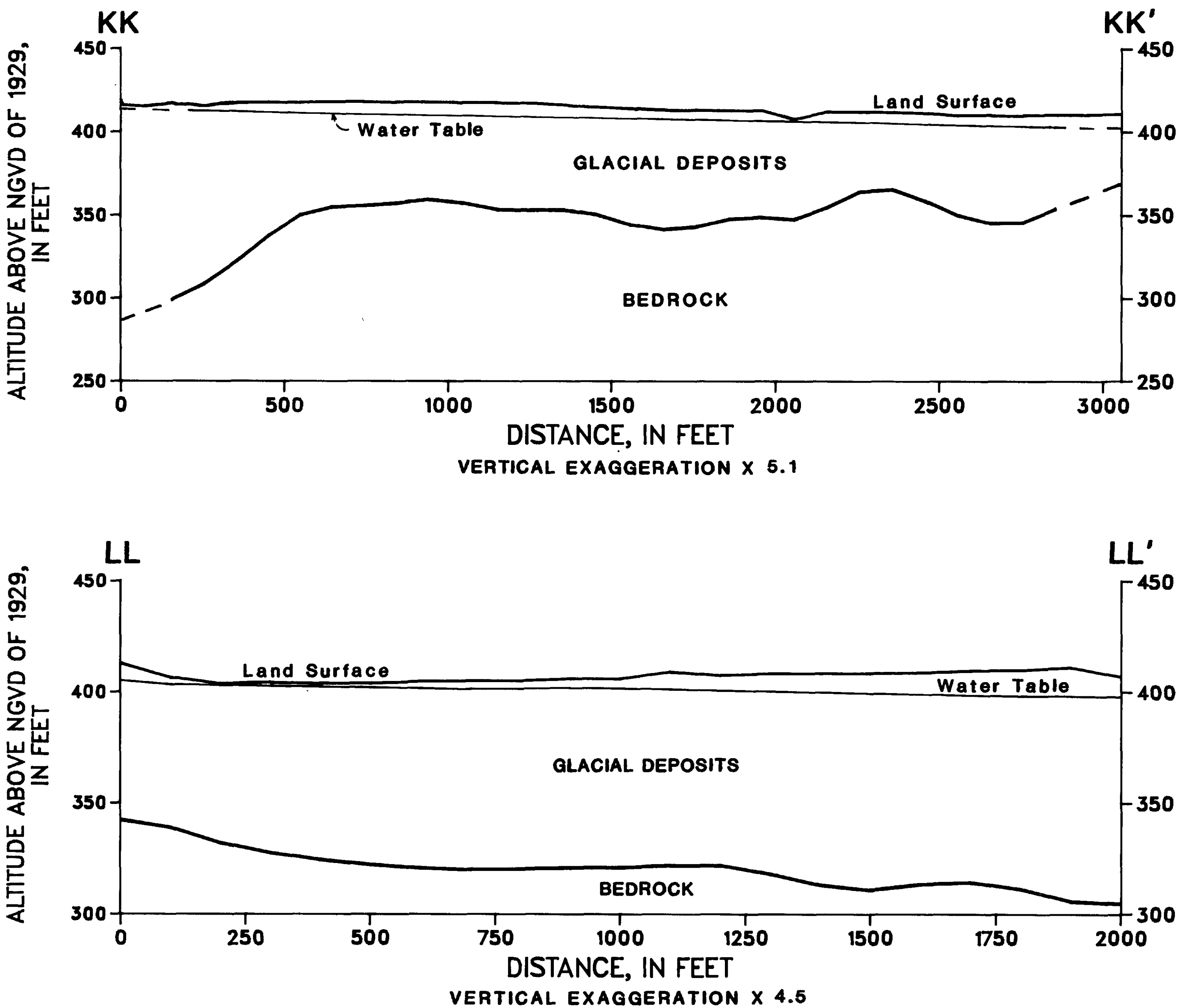

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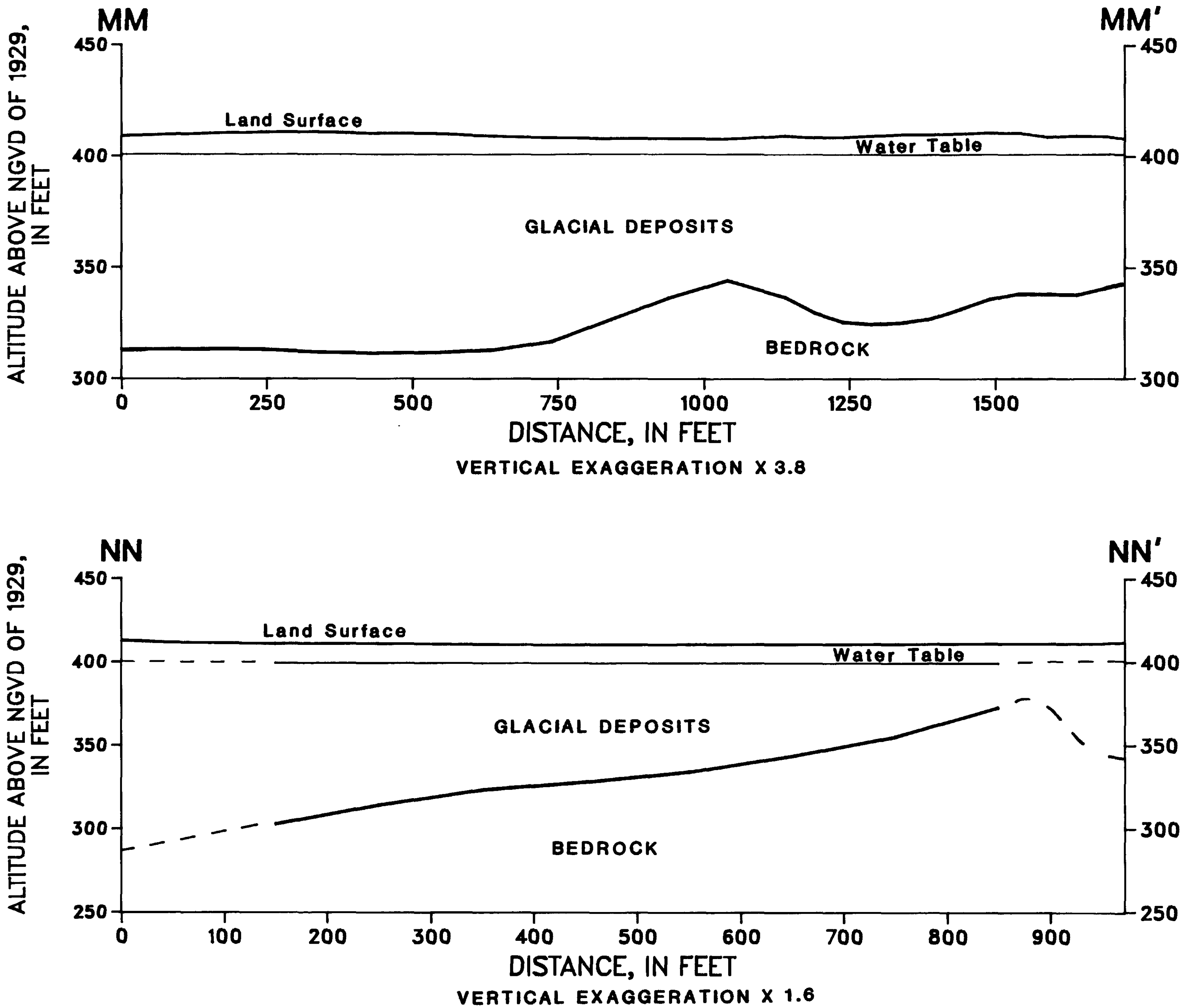

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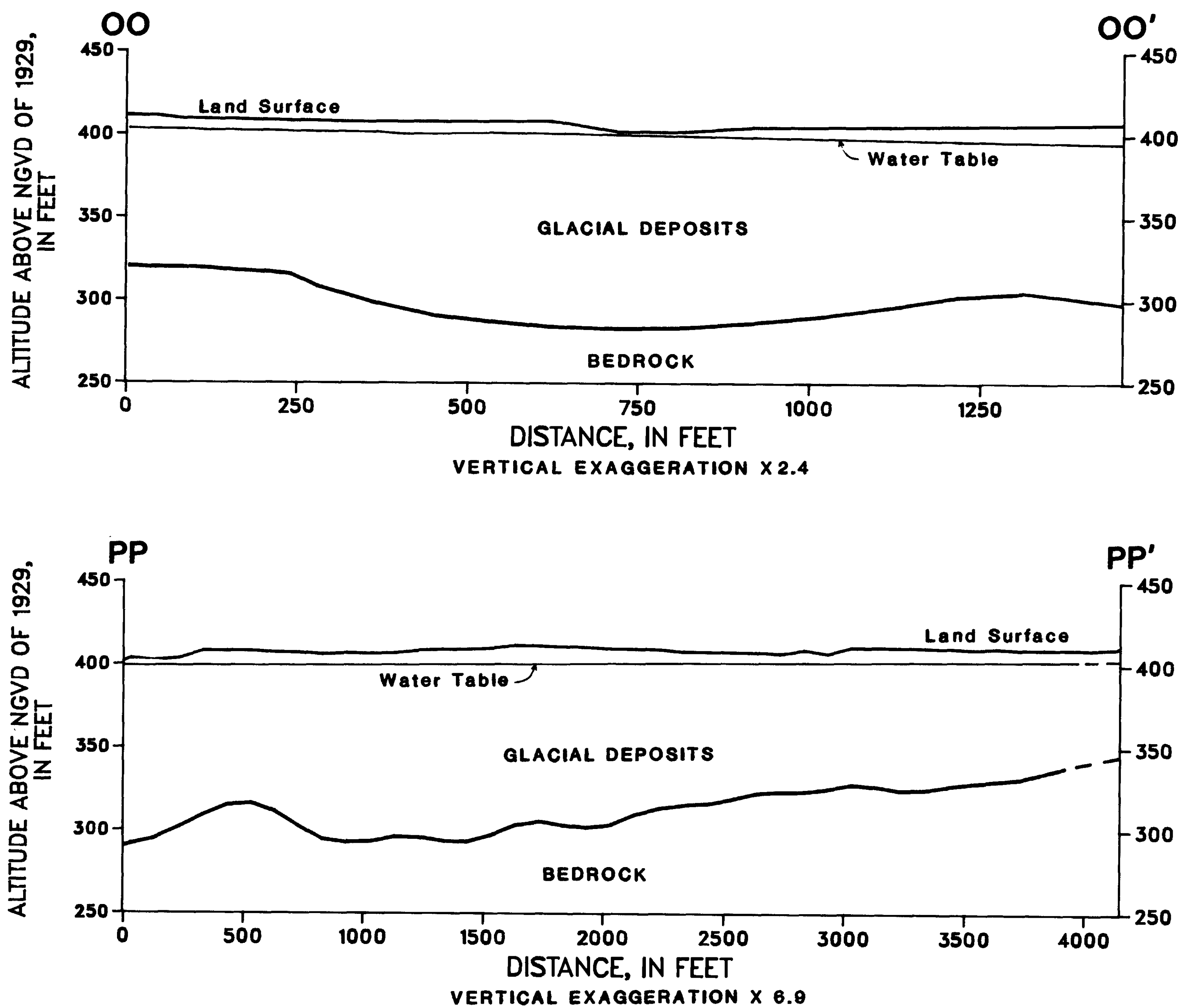

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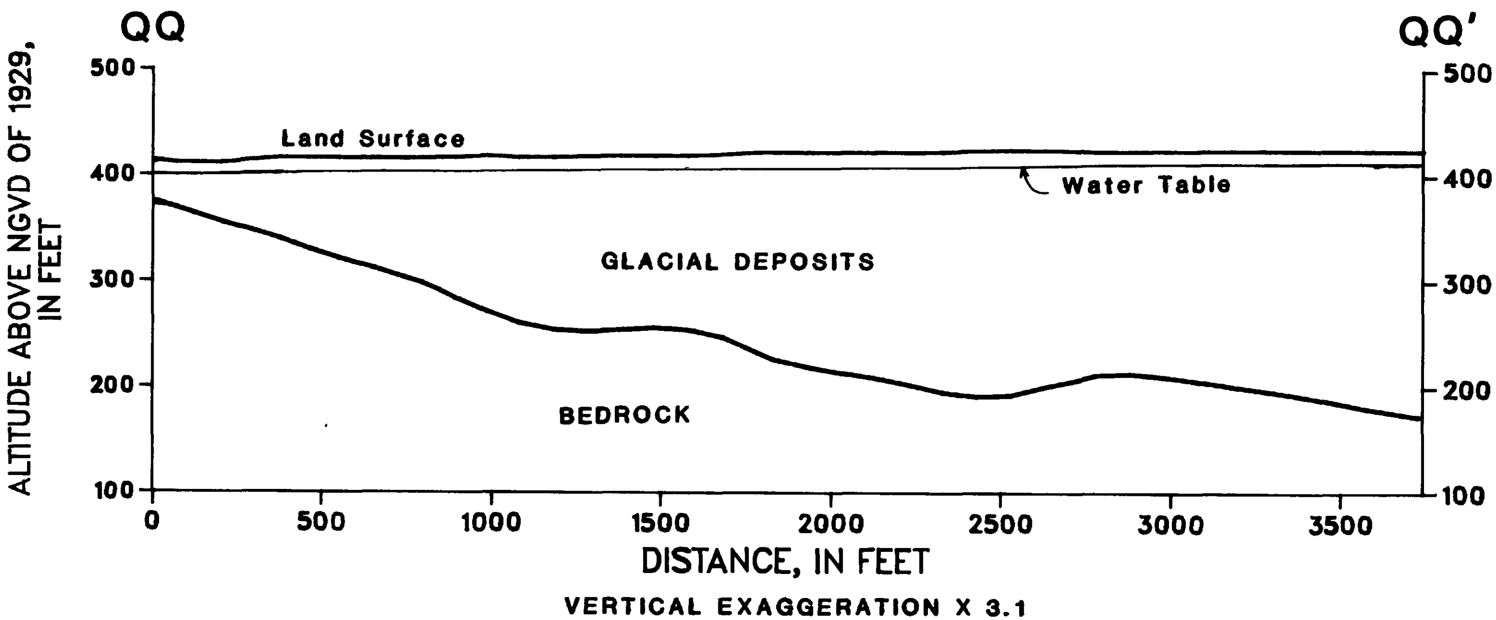

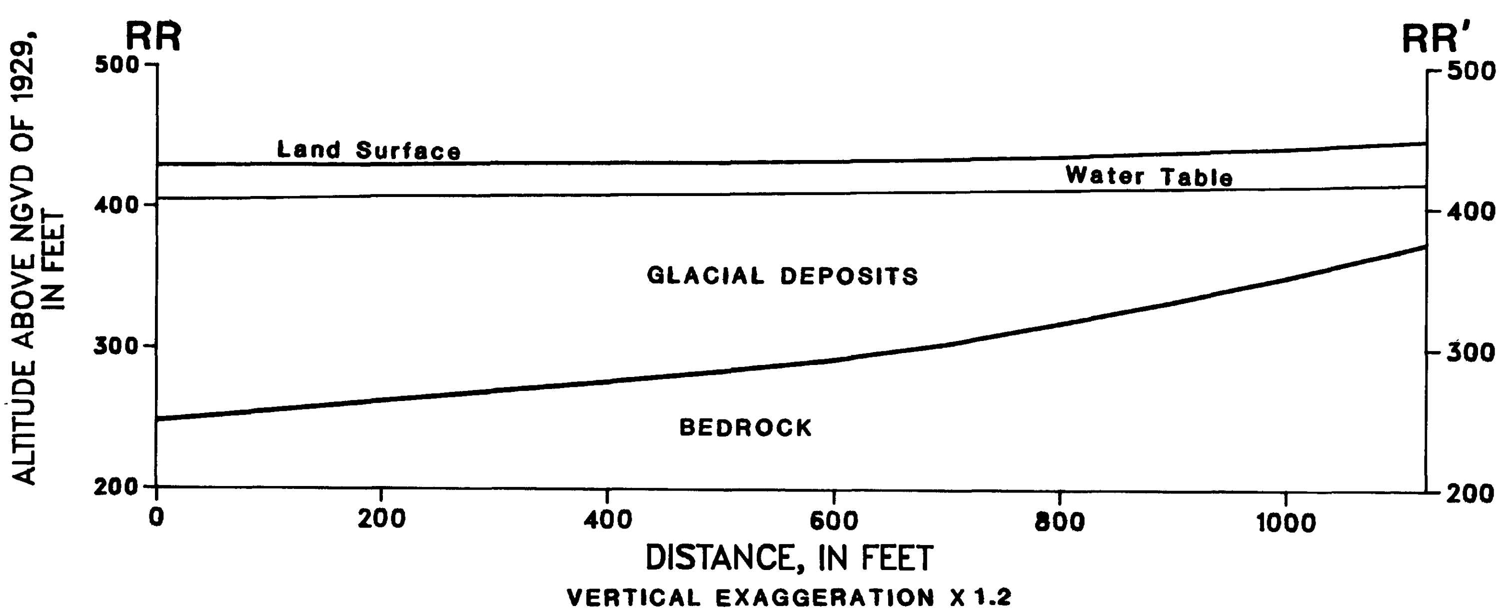

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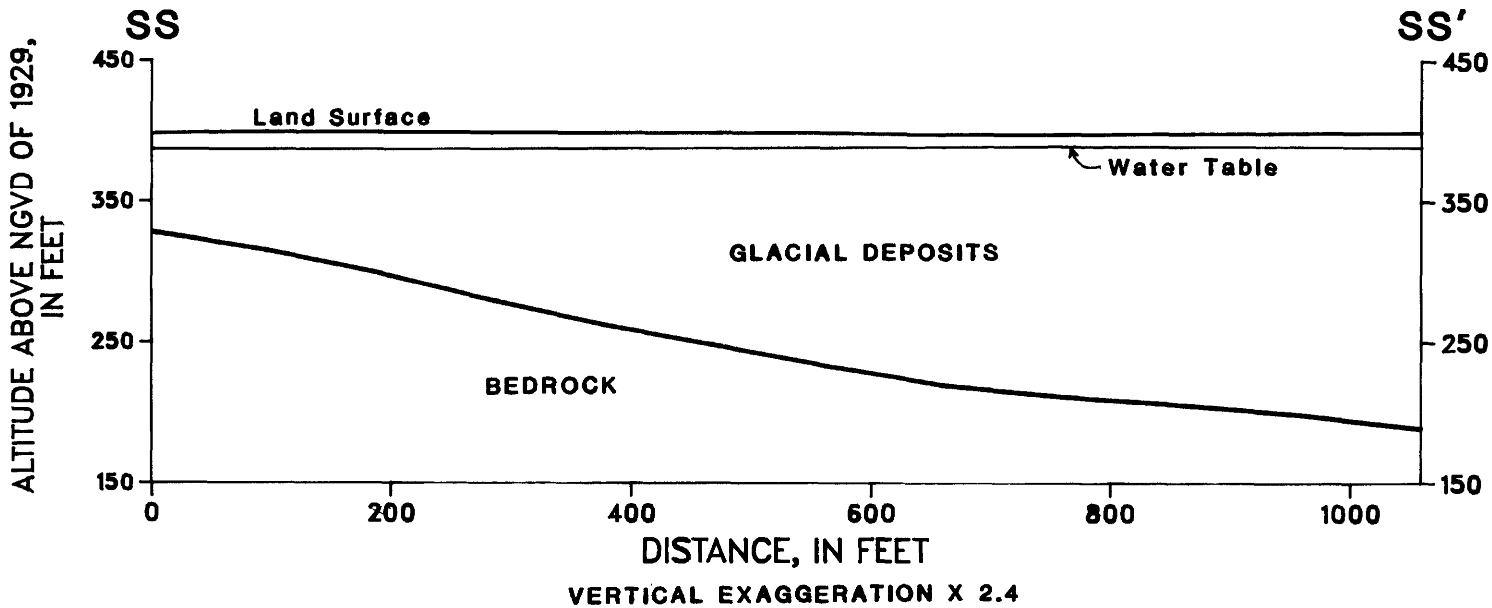

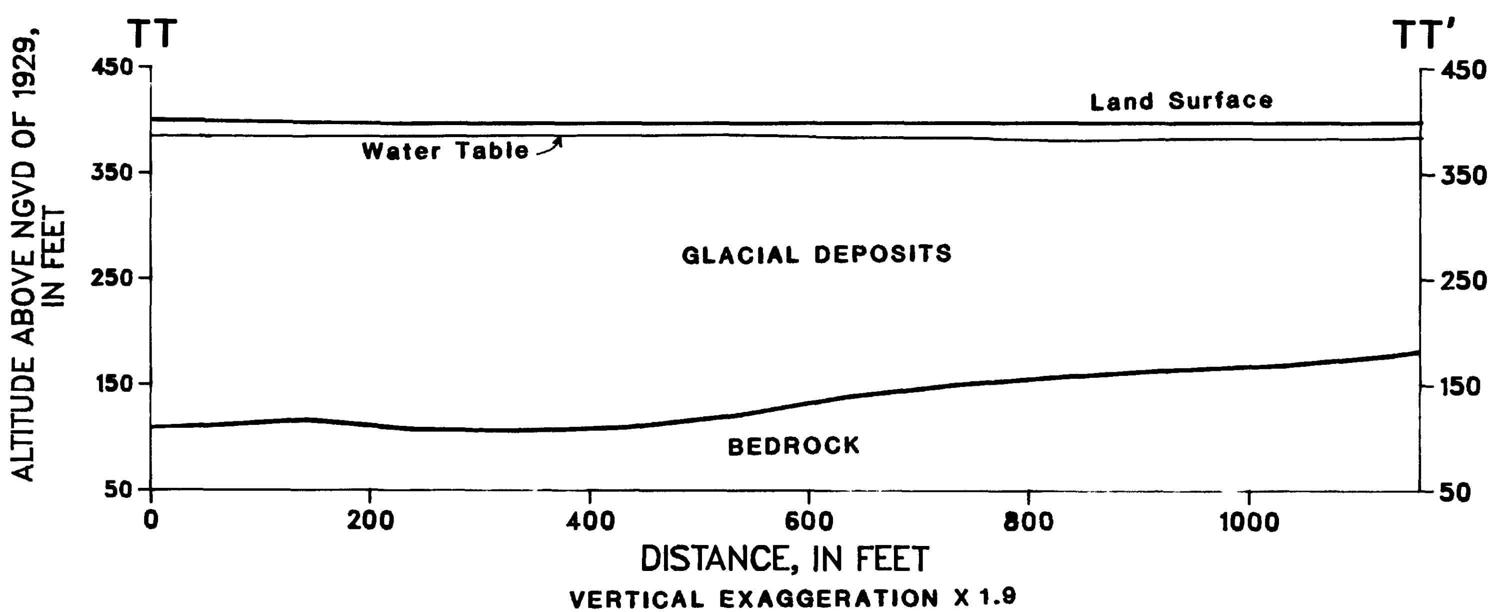

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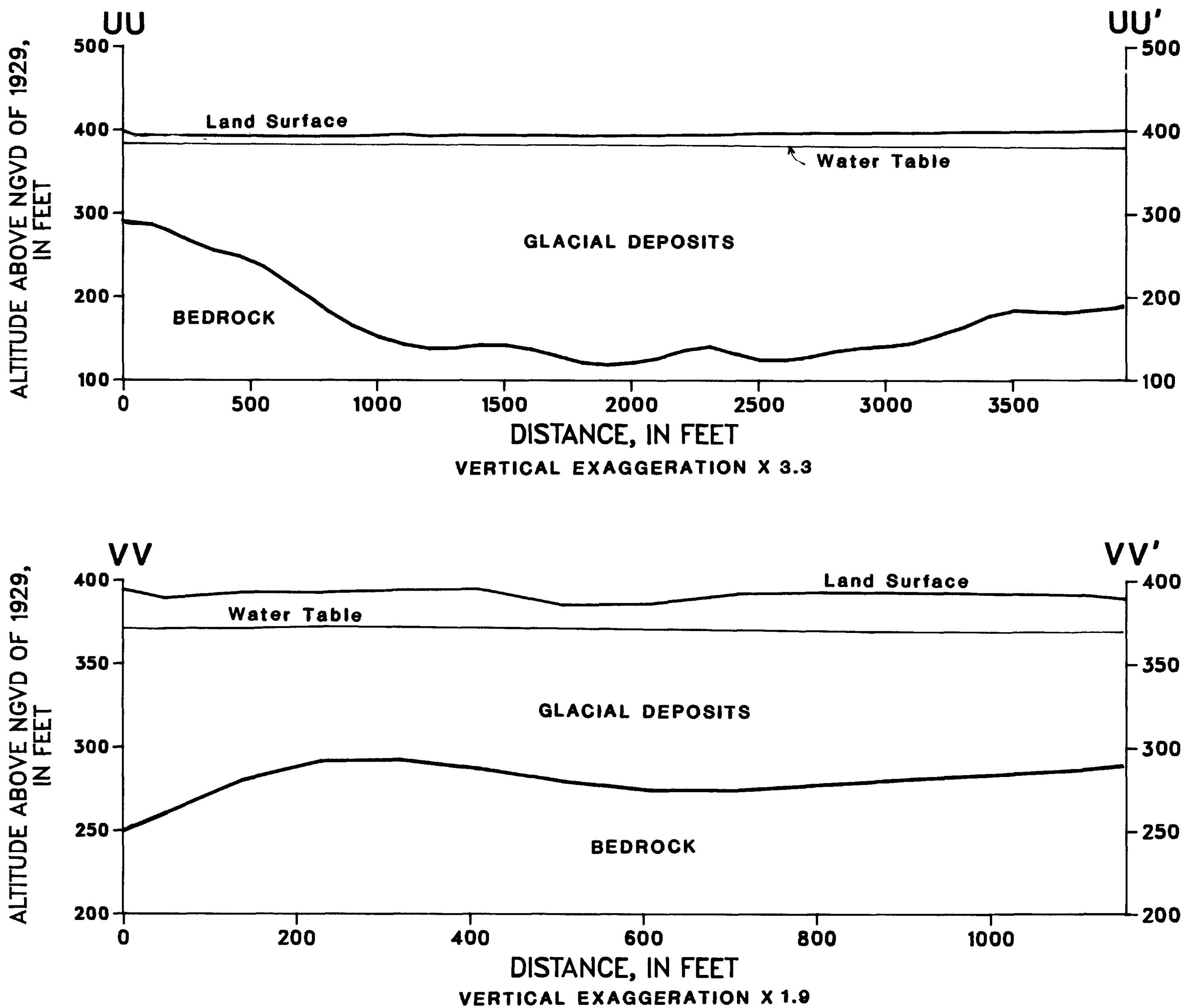

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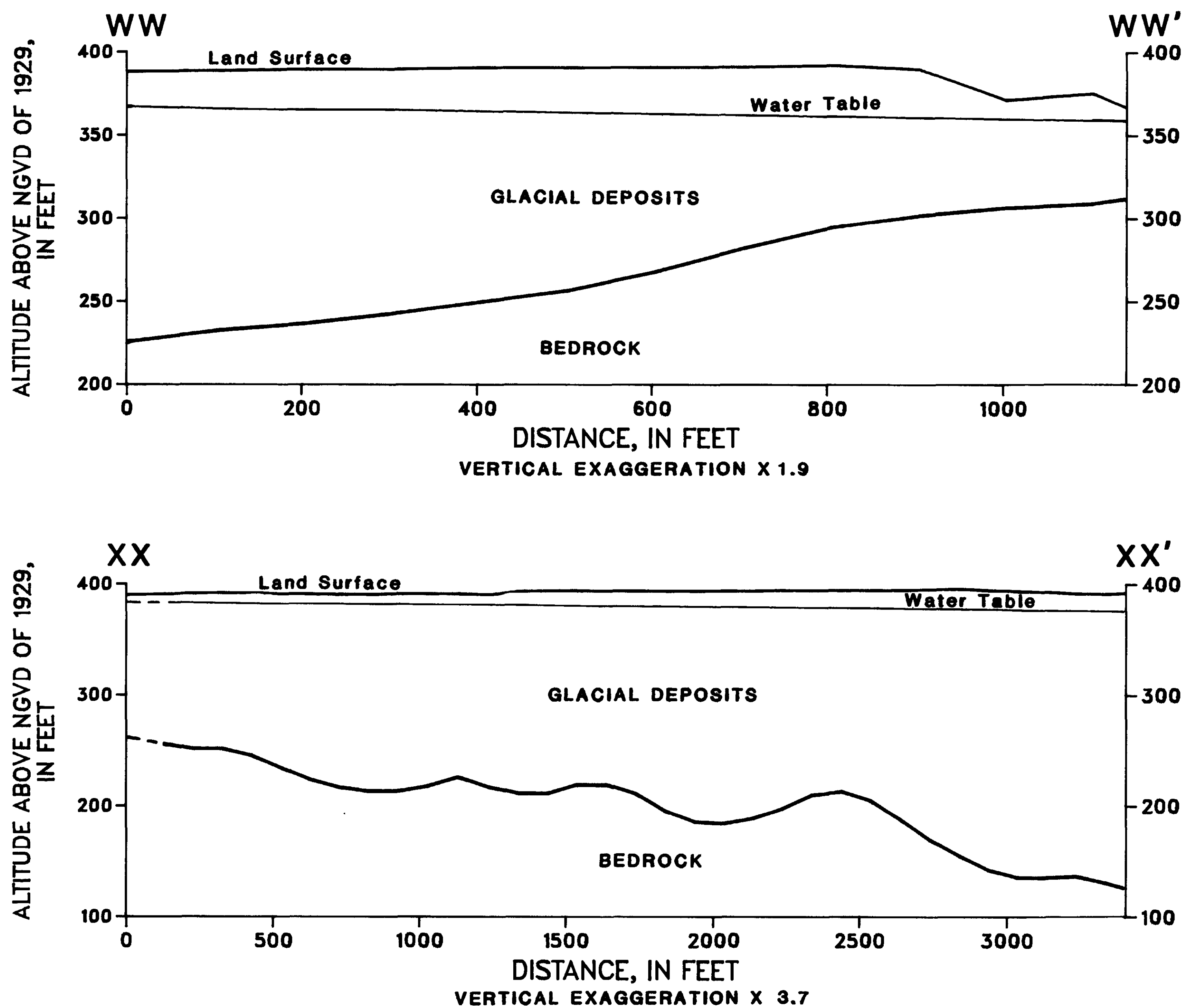

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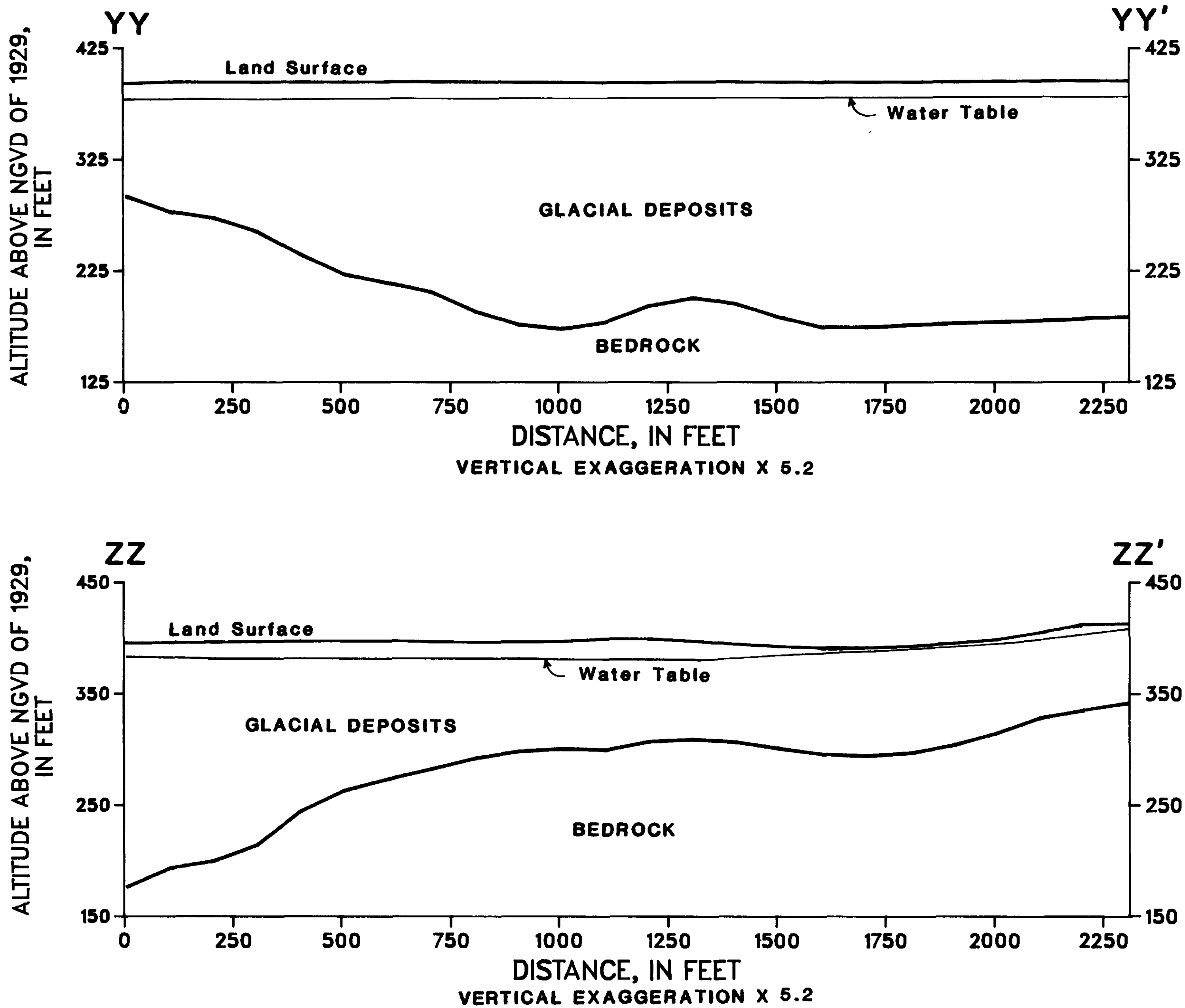

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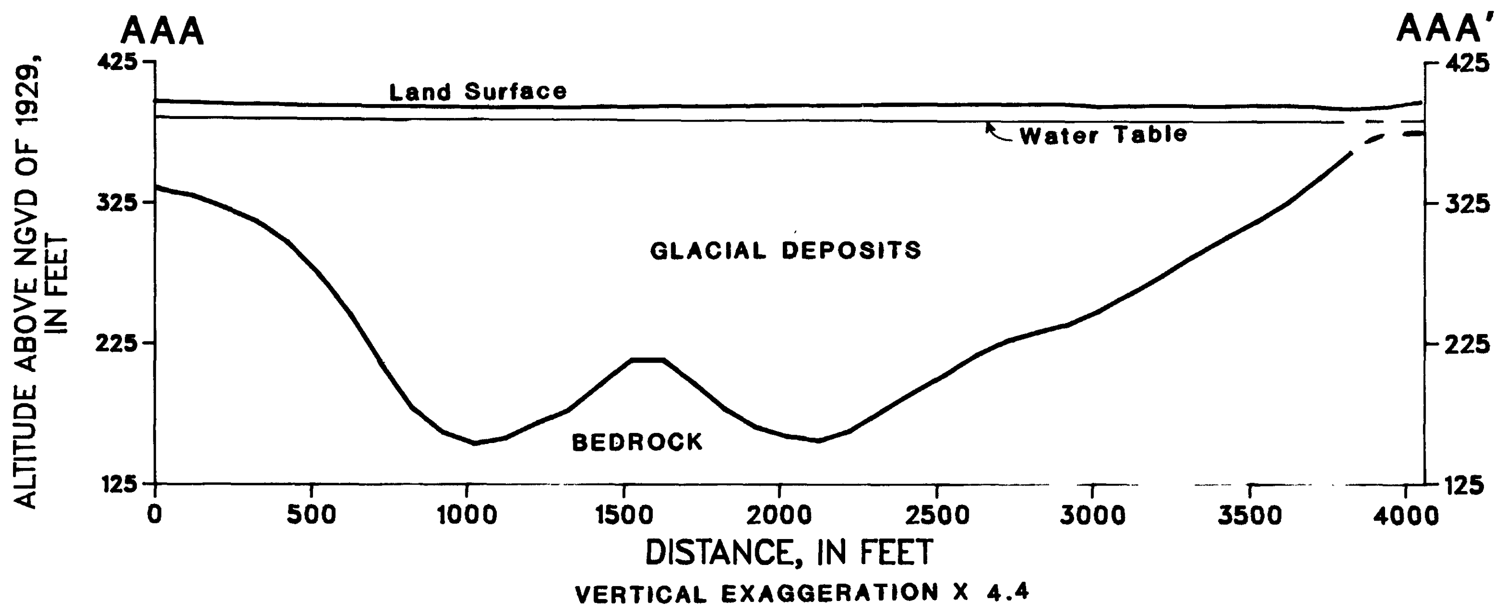

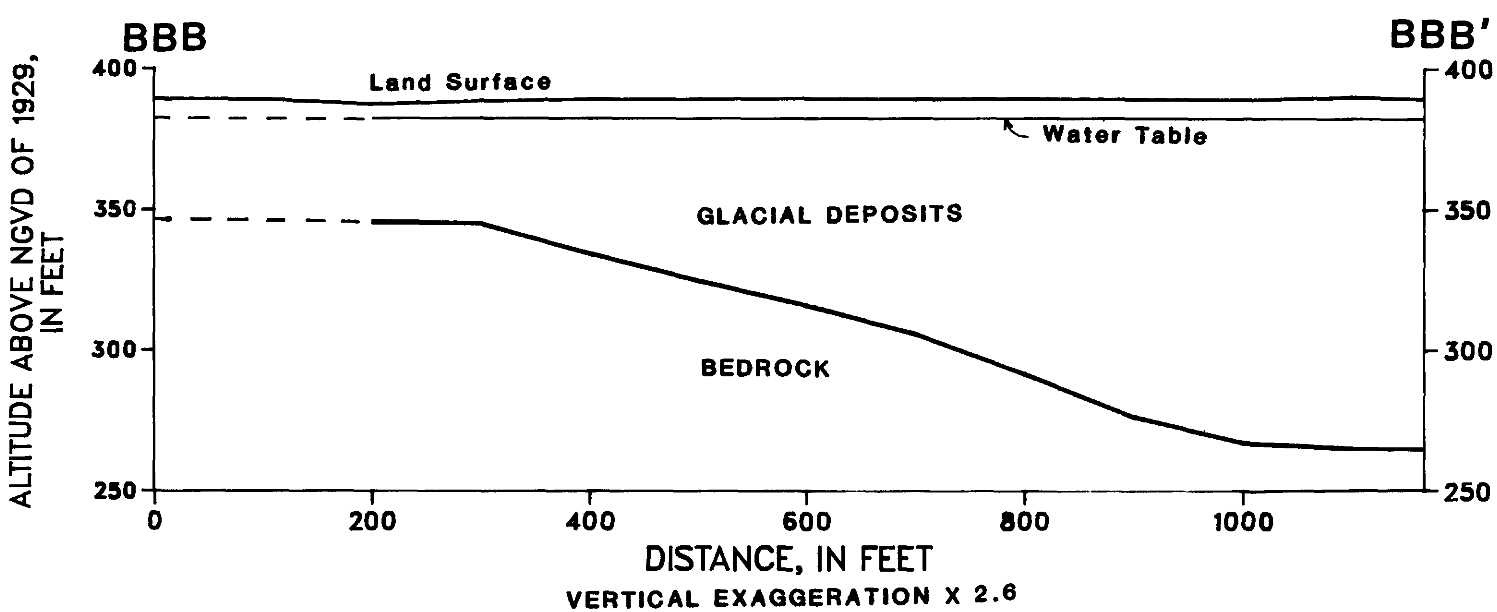

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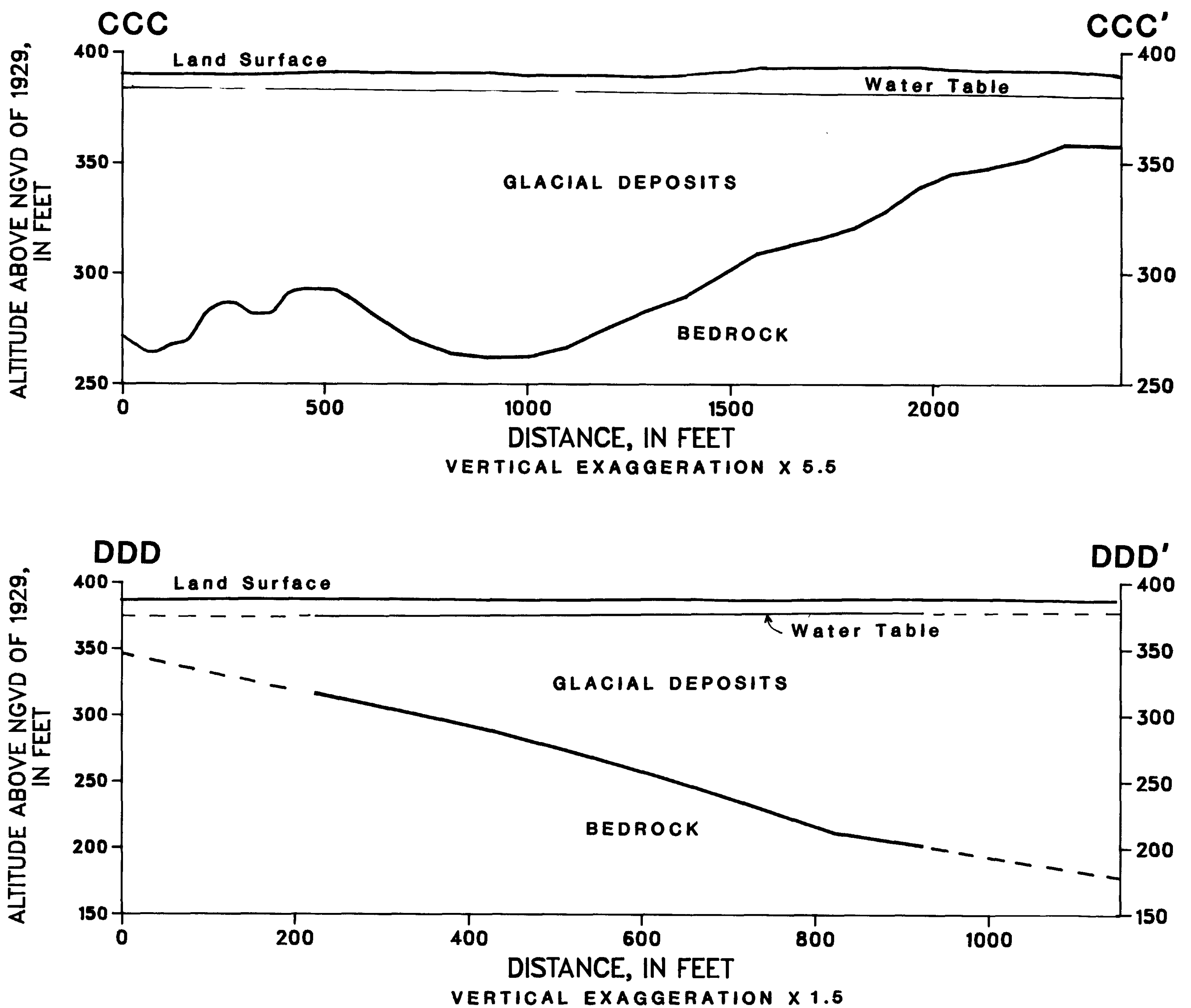

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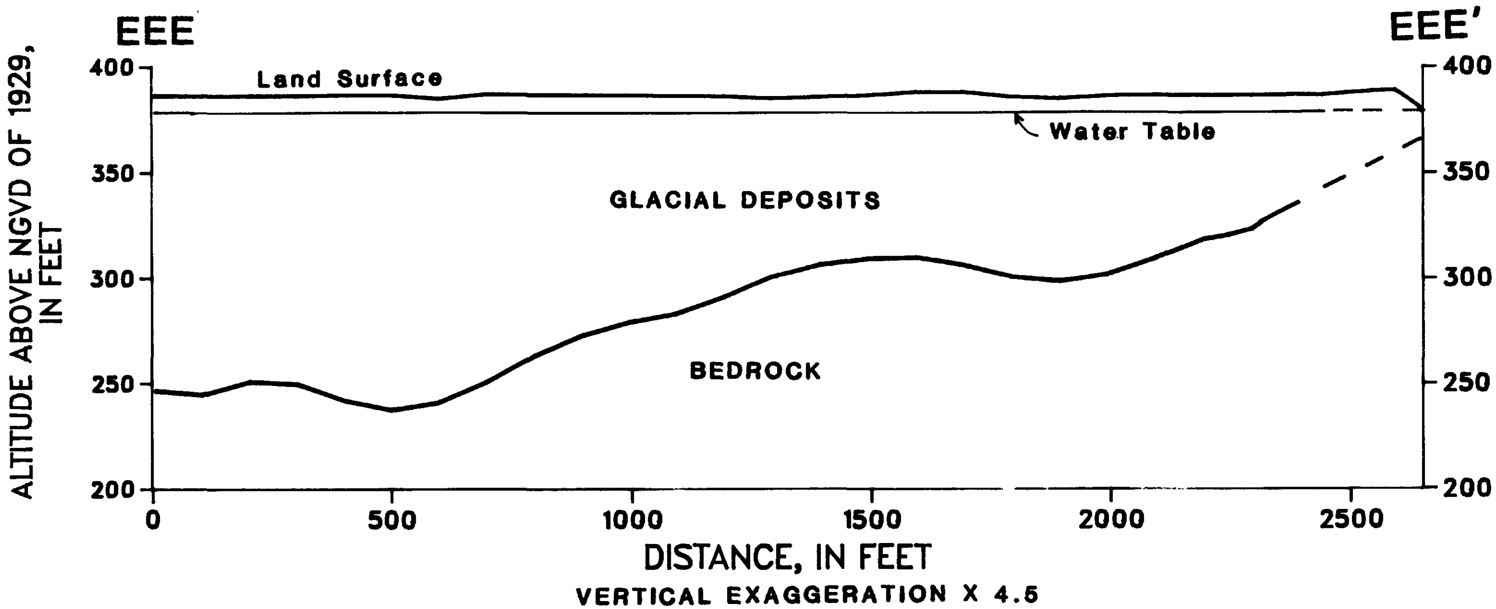

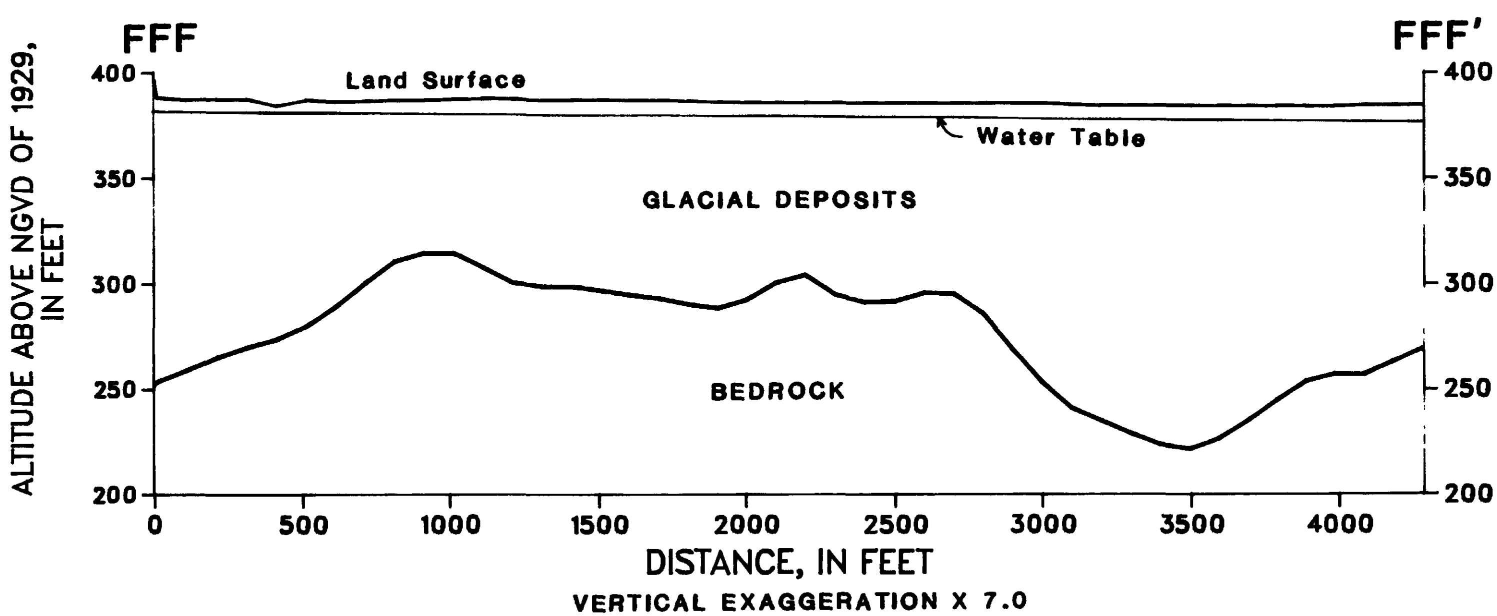

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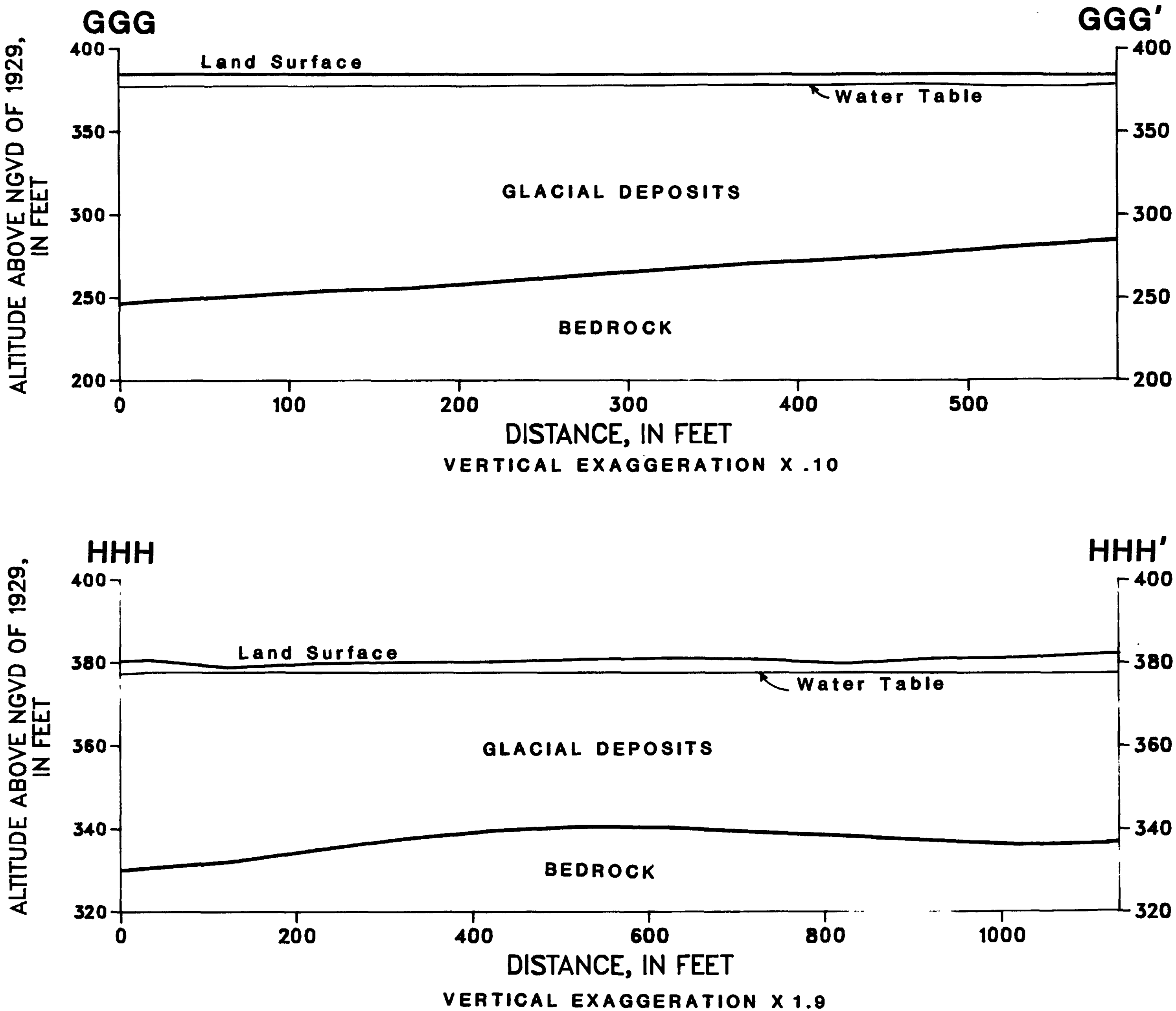

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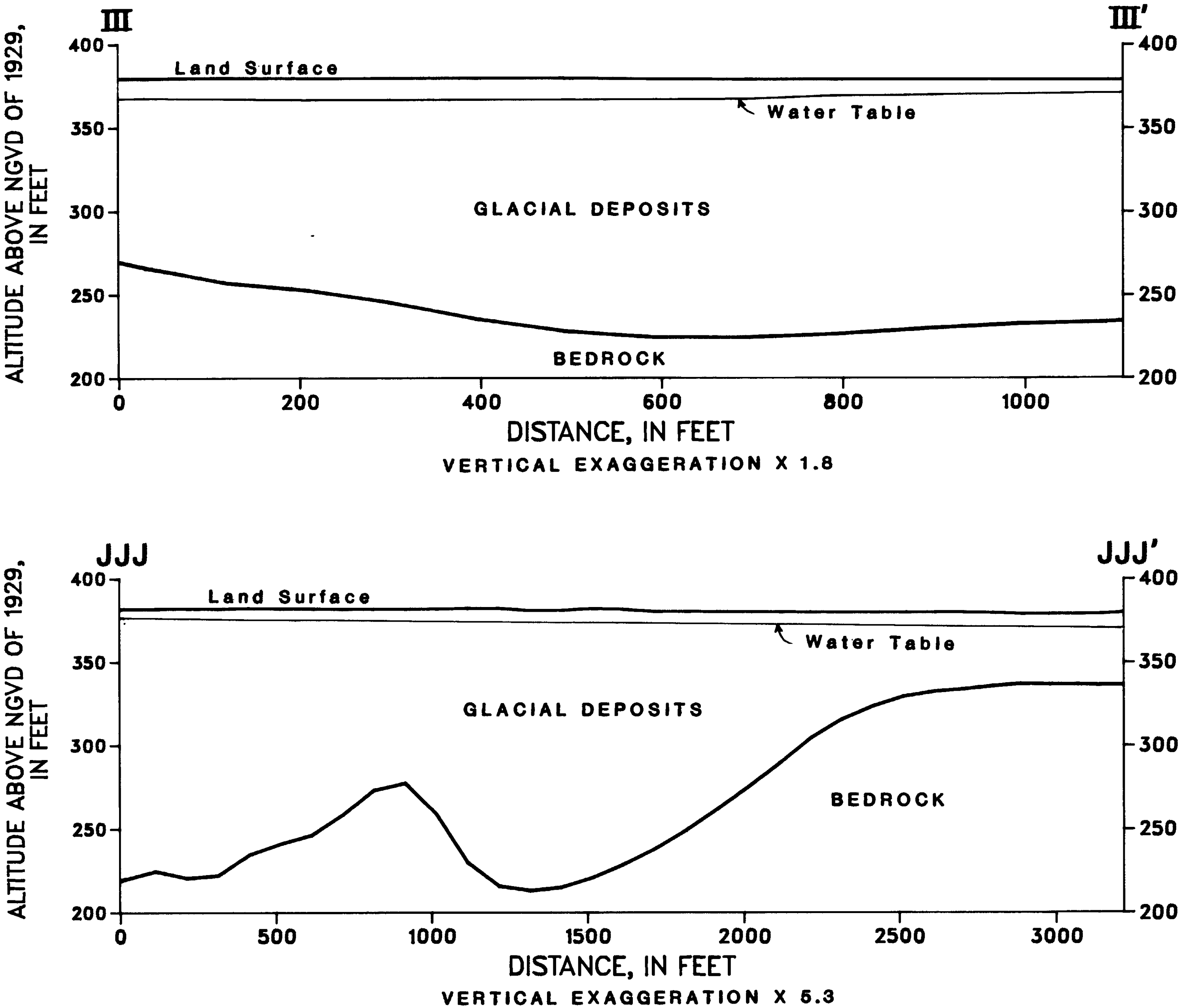

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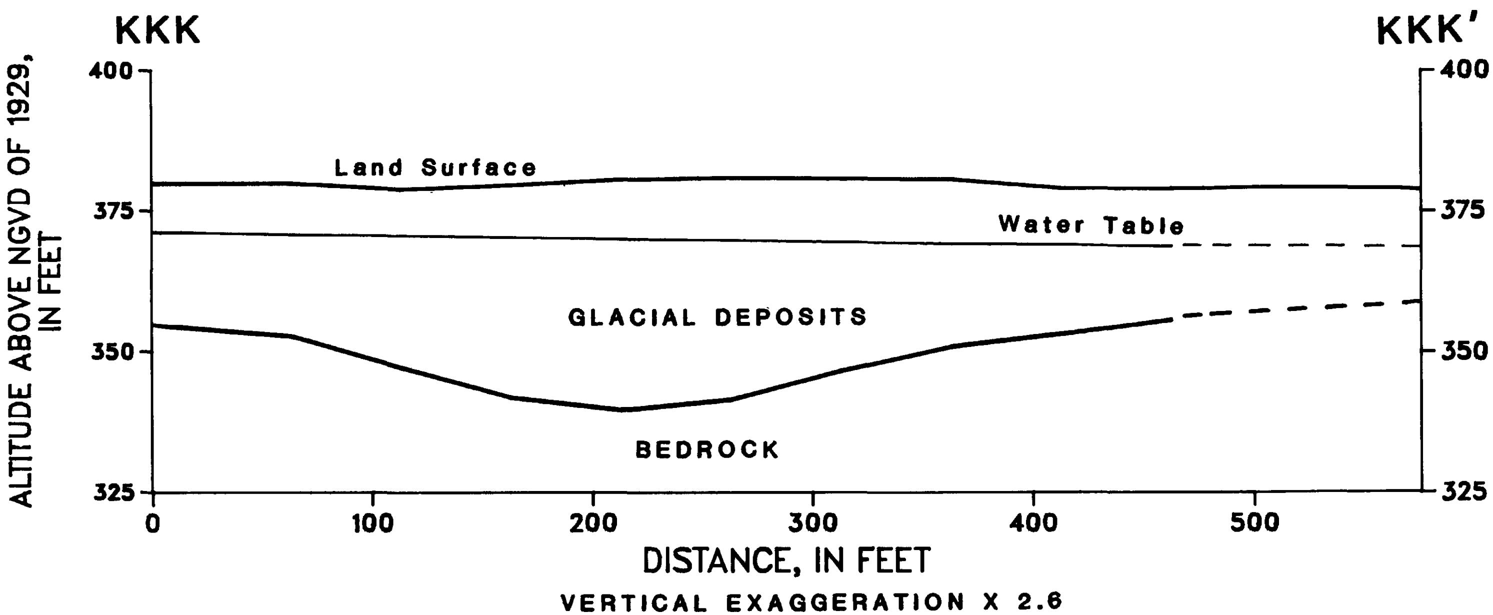

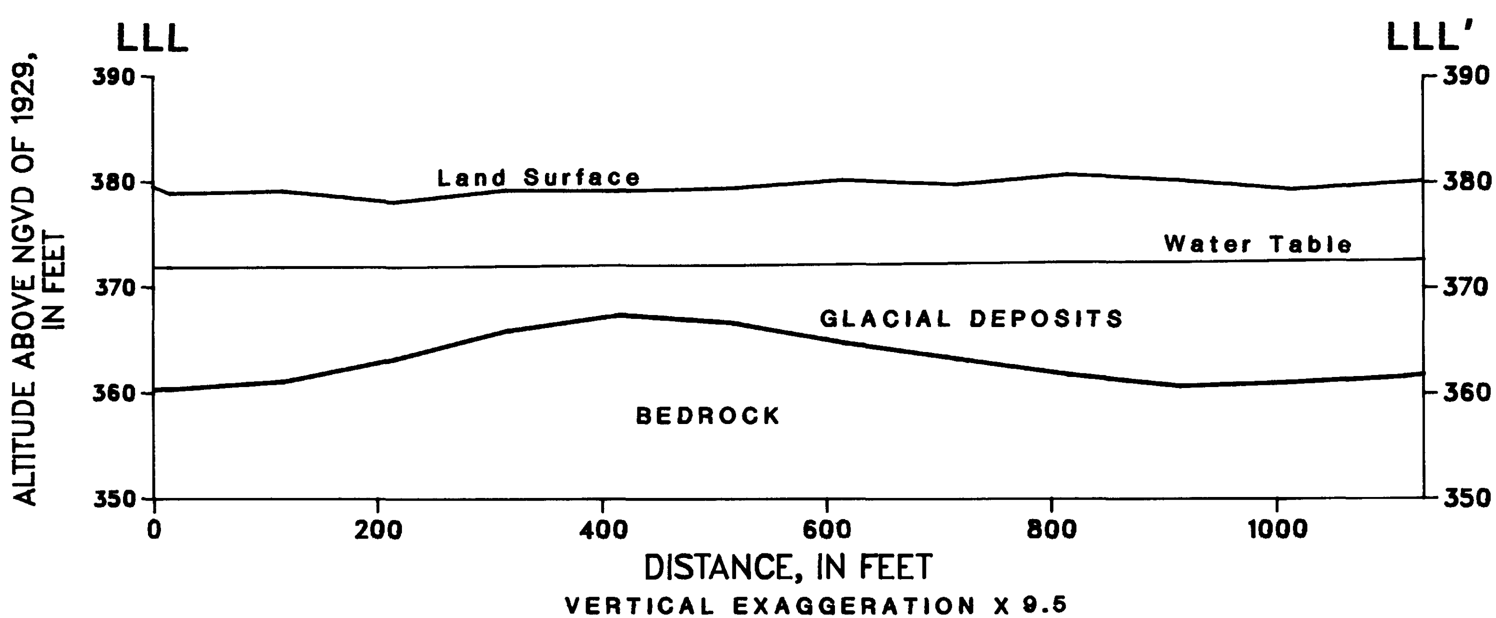

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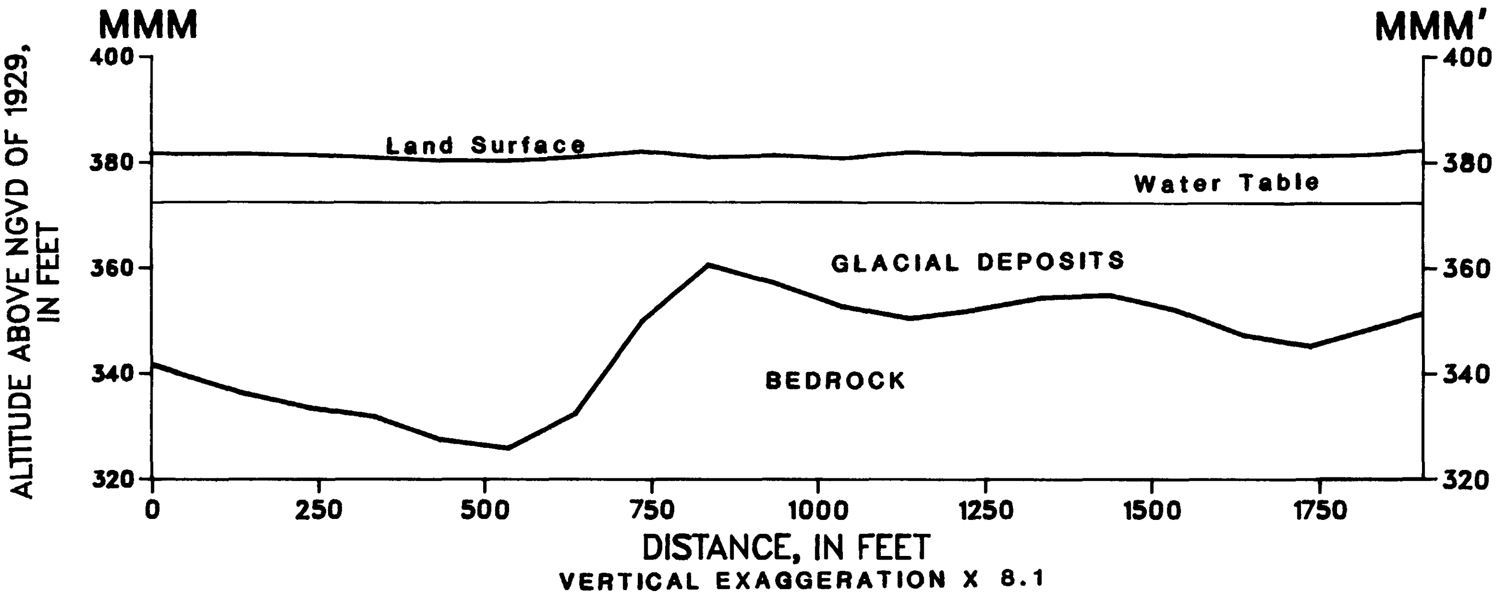

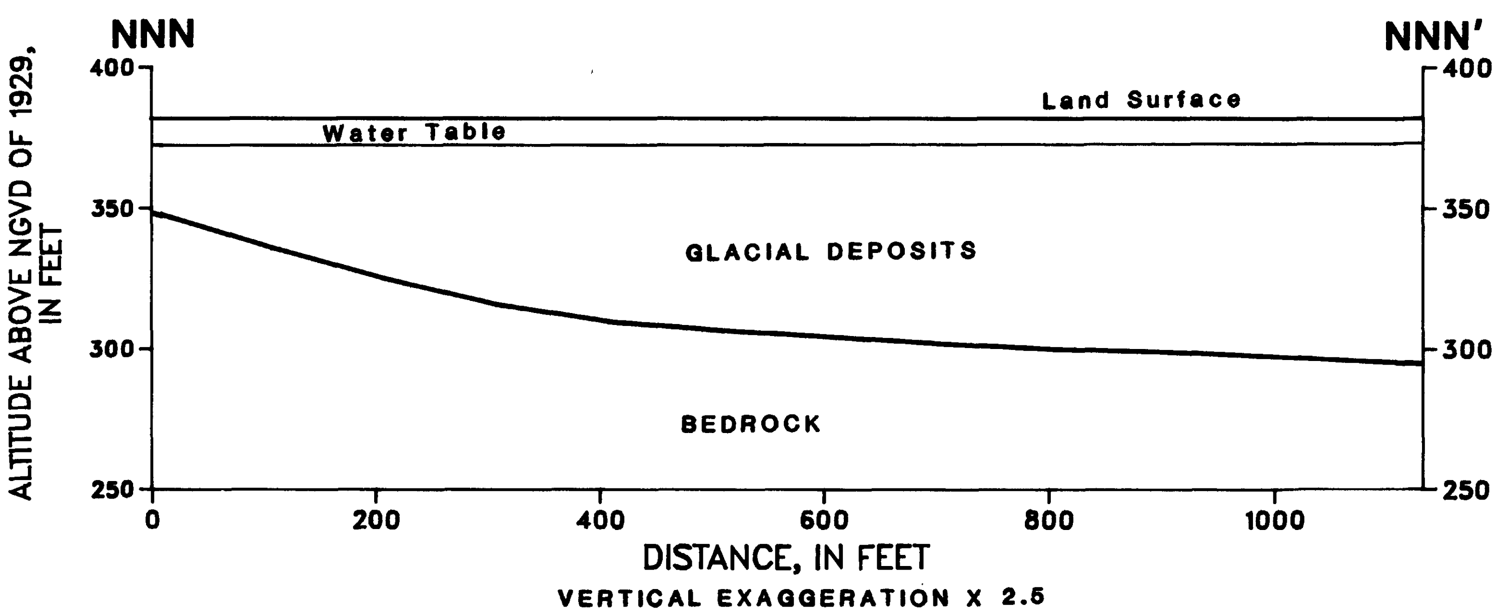

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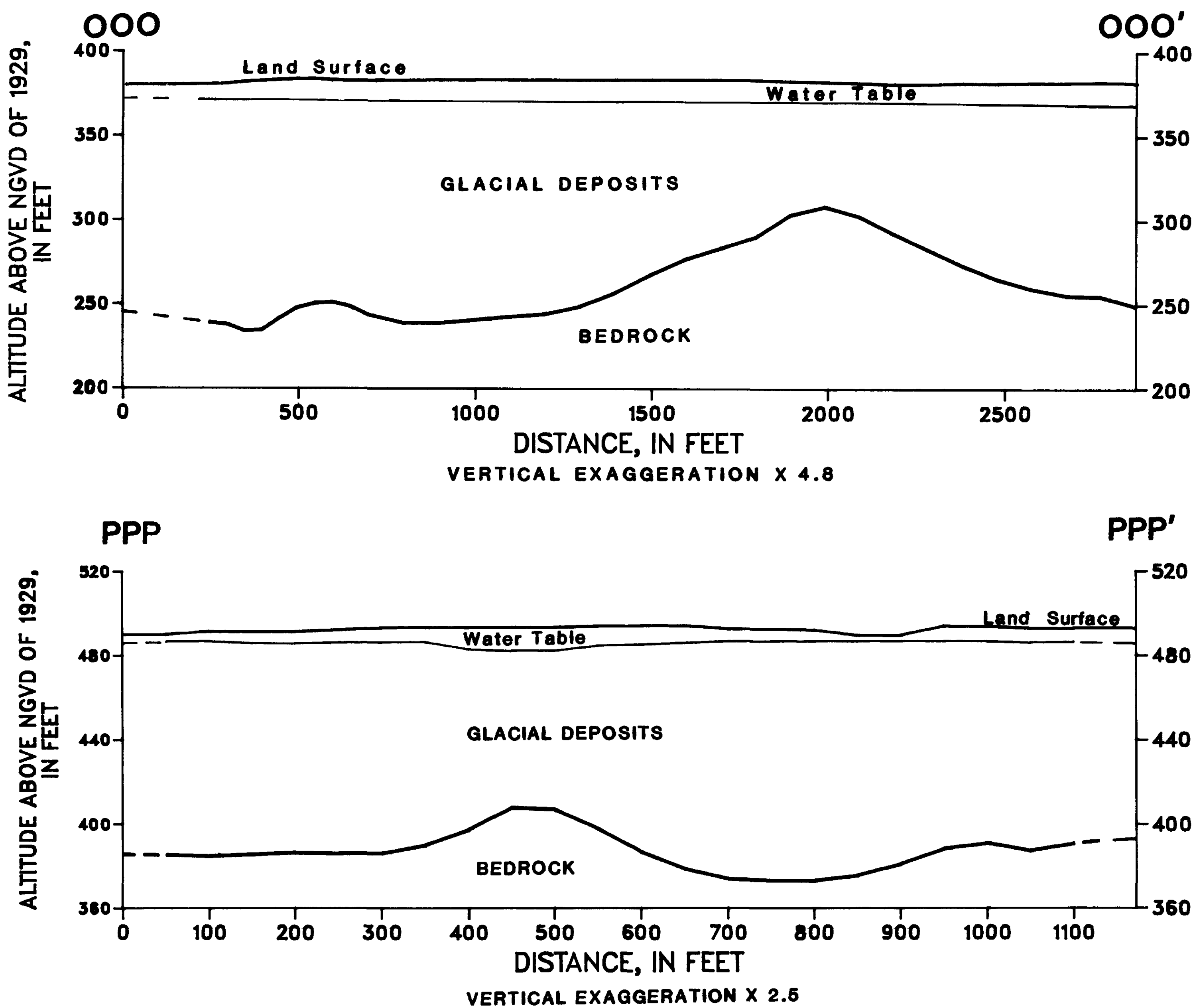

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