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Hydrogeology and Water Quality of Significant Sand and Gravel Aquifers

in parts of Piscataquis and Somerset Counties, Maine

by

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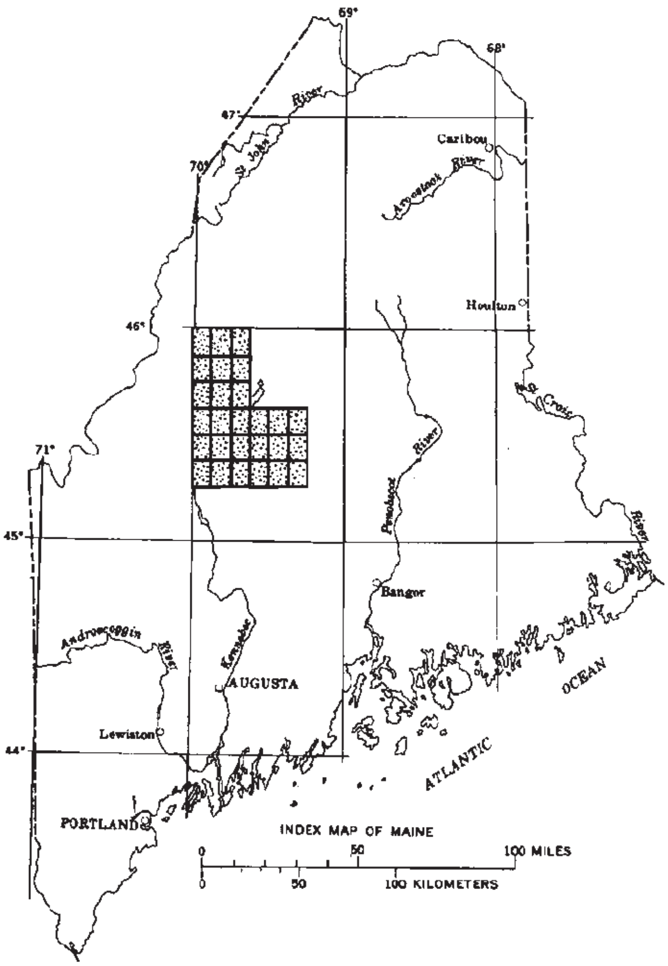

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DEPARTMENT OF CONSERVATION

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ASSOCIATED MAPS

(Available separately)

Significant sand and gravel aquifers maps and surficial materials maps associated with this report are available for the following quadrangles:

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CONVERSION FACTORS AND ABBREVIATIONS

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

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile(mi^2)	2.590	square kilometer (km^2)
	Velocity	
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
	Flow	
gallon per minute (gal/min)	0.06308	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

OTHER ABBREVIATIONS USED IN THIS REPORT

S/cm, microsiemens per centimeter at 25 degrees Celsius
mg/L, milligrams per liter
g/L, micrograms per liter
Temperatures in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows: °F = 1.8° C + 32

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 g/L (micrograms per liter) is equivalent to 1 mg/L (milligram per liter). For concentrations less than 7,000 mg/L, the numerical values are the same as concentrations in parts per million.

Specific-conductance data are reported in S/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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ABSTRACT

A reconnaissance-level hydrogeologic study was made of 1,412.4 square miles in Piscataquis and Somerset Counties in Maine to update maps 52, 53, and 58 of the Sand and Gravel Aquifer Map series previously published by the Maine Geological Survey. Those maps have been recompiled to include additional data and published as 1:24,000 scale maps of the Significant Sand and Gravel Aquifer Map series. Significant sand and gravel aquifers consist of glacial ice-contact, ice-stagnation, outwash, and alluvial deposits found primarily in the valleys of the major river systems and their tributaries and near other surface-water bodies. Significant aquifers are those capable of a sustained yield of more than 10 gallons per minute to a properly constructed well. Significant aquifers comprise approximately 15.7 square miles (1.1 percent) of the study area, but yields estimated to exceed 50 gallons per minute are believed to be available from only 0.1 square miles (less than 0.1 percent) of this area. Typically, the water table, as observed in project observation wells, is within 15 feet of land surface in significant sand and gravel aquifers. On the basis of well records, the greatest known depth to bedrock exceeds 122 feet in observation well OW 94-9 in Willimantic. According to seismic-refraction data, the greatest depth to bedrock is approximately 167 feet. The largest reported well yield is approximately 300 gallons per minute from a gravel-packed well in Little Squaw township that supplies the town of Greenville. The regional ground-water quality ranges from moderately acidic to moderately basic; calcium and sodium are the most abundant cations; bicarbonate is the most abundant anion; and the water ranges from soft to moderately hard. In some locations, concentrations of iron and manganese are high enough to limit the suitability of untreated water for some uses.

INTRODUCTION

The Maine State Legislature (38 MRSA Chapter 3, Section 403) defines a significant aquifer as one that is capable of producing 10 gal/min (gallons per minute) or more to a properly constructed well. Significant sand and gravel aquifers are a primary ground-water resource for supplying the needs of municipalities and industry throughout Maine. They also are a major source of water for domestic wells and may provide recharge to the underlying fractured bedrock aquifer. The term "aquifer" has varying connotations, but may best be defined as a "geologic deposit that yields useful quantities of ground water to wells and springs" (Caswell, 1987).

Recognizing the value of significant sand and gravel aquifers, the Maine State Legislature adopted a number of provisions that restrict the siting of activities that may discharge contaminants to the aquifers. Many local governments and planning boards have passed zoning ordinances to protect significant sand and gravel aquifers. To assist local and state governments in developing aquifer protection laws and ordinances, the Maine Geological Survey (MGS), in cooperation with the U.S. Geological Survey (USGS) and with financial cooperation from the Maine Department of Environmental Protection (MDEP), carried out preliminary investigations of sand and gravel aquifers throughout much of the state. These investigations, conducted from 1978 through 1980, resulted in the production of 59 maps at a scale of 1:50,000 that delineate approximate aquifer boundaries, potential well yields, and potential point sources of contamination.

The original Sand and Gravel Aquifer Maps provide a valuable source of information, but are limited in accuracy because of the large area mapped in a short period of time. Also, the maps contain little information on aquifer thickness and stratigraphy and no information on water quality. To correct these shortcomings, the Maine State Legislature directed the MDEP and MGS to update the sand and gravel aquifer maps to provide more information on depth to bedrock, depth to water table, stratigraphy, and water quality (38 MRSA Chapter 3, Section 403). In 1979, the Legislature instructed the MDEP and MGS to delineate all significant sand and gravel aquifers. These new maps are referred to as Significant Sand and Gravel Aquifer Maps.

A cooperative, reconnaissance aquifer-mapping project was initiated in June 1981 by the MGS, USGS, and the MDEP to satisfy the demand for more accurate, complete, and current hydrogeologic information concerning sand and gravel aquifers in Maine. The mapping was first conducted in densely populated and rapidly developing areas and has subsequently been extended to other areas of the state (Tolman and others, 1983; Tepper and others, 1985; Williams and others, 1987; Adamik and others, 1987; Weddle and others, 1988; Locke and others, 1989; Neil and others, 1992; Nichols and others, 1995; Foster and others, 1995; Locke and others, 1997; Neil and others, 1998; Nichols and others, 1998). The study area locations for the Significant Sand and Gravel Aquifer Mapping Project are shown in Figure 1. Significant Sand and Gravel Aquifer Maps for the 1981 through 1986 study areas were published at a scale of 1:50,000. Beginning with the 1987-88 study area and for subsequent years, Significant Sand and Gravel Aquifer Maps for the study areas designated on Figure 1 are published at a scale of 1:24,000. Beginning with the 1991-93 study area, data from the project are used to produce two series of maps; hydrogeologic data are shown on the Significant Sand and Gravel Aquifer Map while stratigraphic and materials data are shown on the Surficial Materials Map.

This report presents the results from the 1994 field season, the fourteenth year of the mapping project, and updates the Sand and Gravel Aquifer Map series for maps 52, 53, and 58. These maps have been modified locally on the basis of new data, are compiled onto 1:24,000 scale topographic base maps, and are available separately (MGS Open File No. 98-3 through 98-56). The maps can be used as a basis for detailed hydrogeological siting studies and planning. Furthermore, they provide a variety of information on aquifer favorability and vulnerability, as well as a preliminary estimate of well yield in certain areas.

Purpose and Scope

The purpose of this report is to describe the physical characteristics of sand and gravel aquifers in the area covered by Sand and Gravel Aquifer Maps 52, 53, and 58 in parts of Piscataquis and Somerset Counties, Maine. A secondary objective is to describe the water quality in the aquifers and compare it with water quality in other areas of the State.

The scope of the investigation included:

(1) surficial geologic mapping to define the boundaries and composition of glacial deposits

(2) presentation of supplemental information about the glacial geology of the area

(3) seismic-refraction investigations to determine the depth to water, depth to bedrock, and bedrock profile

(4) a well inventory to supplement existing data on depth to water, depth to bedrock, and well yields

(5) observation-well and test-boring drilling to determine aquifer stratigraphy, thickness, and grain size (used to estimate transmissivity and well yield)

(6) water-quality sampling and analysis to characterize the regional ground-water chemistry

(7) identification of potential sources of ground-water contamination, and

(8) location of municipal-well fields.

Previous Investigations

Reconnaissance surficial and bedrock geologic mapping conducted in the study area provided information on bedrock outcrops and the areal extent of sand and gravel deposits (Boucot and Heath, 1969; Brewer and Caldwell, 1976; Burroughs nd Marvinney, 1981; Caldwell and Hanson, 1976; Caldwell and others, 1986a; Caldwell and others, 1986b; Genes and others, 1976; Genes and others, 1986; Griffin, 1971; Hanson and Caldwell, 1986; Kaktins and Caldwell, 1976; Marvinney, 1994; Newberg, 1983; Osberg and others, 1985; Simmons, 1987;

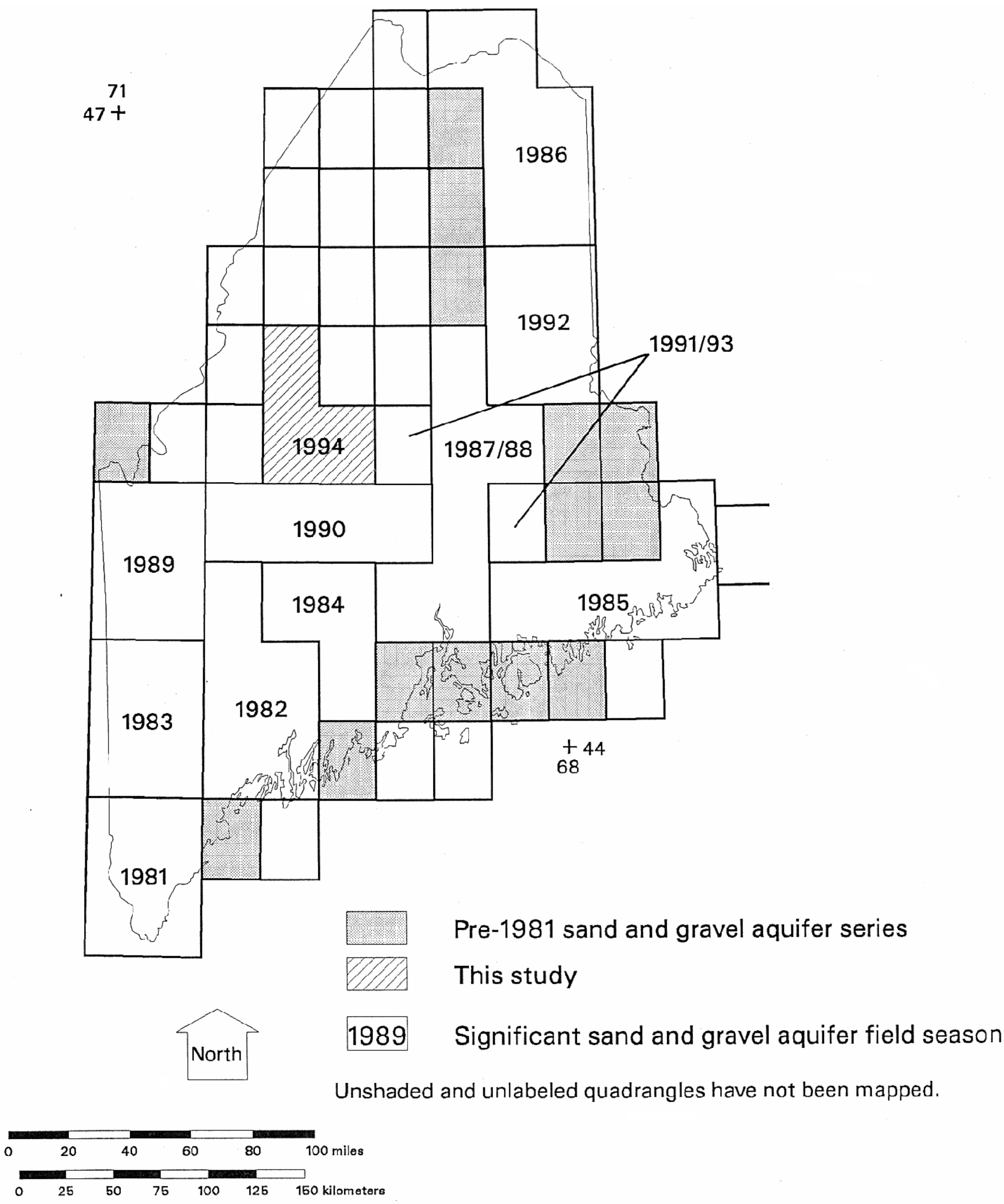

Figure 1. Location of study areas for the Significant Sand and Gravel Aquifer Mapping Project.

Thompson and Borns, 1985). The maps associated with this report update information from earlier aquifer mapping efforts (Tolman and Lanctot, 1981).

METHODS OF STUDY

Approach

The methodology of this investigation included:

(1) recompilation of existing hydrogeologic and surficial materials data from each 1:50,000-scale map onto 1:24,000-scale maps

(2) collection of information on existing domestic, municipal, and monitoring wells, boring logs, and test pits

(3) identification of potential ground-water contamination sites

(4) verification of the original sand and gravel aquifer map boundaries in the field by mapping surficial deposits

(5) seismic-refraction surveys

(6) test borings and observation-well installation

(7) well development and water-quality sampling

(8) monthly water-level measurements

(9) compilation of all data on 1:24,000-scale maps.

Details concerning several of these steps are given below.

Identification of Sites of Potential Ground-Water Contamination

Potential ground-water contamination sites located on or near significant aquifers are shown on the associated maps[1]. These sites were identified primarily from files of the MDEP Bureaus of Land and Water Quality, and Hazardous Materials and Solid Waste Control. The locations of State-owned salt and salt-sand storage lots were determined from Maine Department of Transportation and Maine Department of Environmental Protection records.

The sites shown on the maps include waste-disposal areas and salt-sand storage piles. Sources of potential ground-water contamination not shown include, but are not limited to: septic systems, road de-icing activities, fertilized fields, pesticide use areas, underground fuel storage tanks, small-quantity generators of hazardous wastes, and other agricultural, industrial, or commercial sites.

Surficial Mapping Techniques

The aquifers were mapped by field determination of boundaries between significant sand and gravel deposits and materials such as compact till or bedrock outcrops. All known borrow pits and other exposures of sand and gravel deposits were examined, with particular attention to the thickness and texture of the deposits, and to any water in the pit. Shallow, hand-dugshovel and auger holes were used to identify surficial materials in areas where exposures were lacking. Off-road areas were mapped by foot traverse and examination of aerial photographs.

Boundaries of the significant aquifers shown on the associated maps were delineated on the basis of known or inferred saturated thickness and confirmed where possible by well, boring, or seismic data. In some cases, interpreted land-surface contacts between aquifers and surrounding materials were shifted slightly into the aquifers to indicate that the tapering margins of some aquifers are unlikely to yield 10 gal/min or more. The boundaries of the significant aquifer deposits are shown as dashed lines indicating the interpretive nature of the boundary delineation.

Seismic-Refraction Surveys

Seismic-refraction techniques, following field procedures described by Haeni (1988), were used to obtain profiles showing the depth to water table, depth to bedrock, and topography of the bedrock surface. In seismic exploration, seismic waves are generated at the surface by a small explosion or hammer blows. These waves travel at different velocities through different materials—the denser the material, the faster the wave velocity. In this study, seismic refraction was used to distinguish between dry sand and gravel, saturated sand and gravel, and bedrock. To permit these distinctions, the seismic velocity must increase with depth and there must be a significant velocity contrast between layers.

A 12-channel, EG&G Geometrics ES-1225 seismograph[2] was used to determine saturated thickness and bedrock surface topography in the study area. Shot points and geophones were surveyed to determine their relative elevations. A computer program (Scott and others, 1972) was used to determine layer velocities and to generate a continuous profile of the water table and bedrock surface beneath each line. Wherever possible, data from any nearby private wells and project borings were used to verify seismic results. In total, 110 12-channel lines were run for a total of 25,250 ft. Fifty-five of these lines (12,650 ft) provided reliable data for interpretation.

In the study area, the seismic velocity in unsaturated overburden materials ranges from 730 to 2,227 ft/s (feet per second), with an average velocity of 1,264 ft/s. Saturated overburden materials have velocities of 4,605 to 6,947 ft/s with an average velocity of 5,646 ft/s. Bedrock seismic velocities in the study area vary from 11,205 to 19,042 ft/s with an average velocity of 15,002 ft/s.

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[1] The use of industrial firm or local town names in this report and on the maps is for location purposes only, and does not impute responsibility for any present or potential effects on natural resources.

[2] Use of trade names in this report is for descriptive purposes only and does not constitute endorsement by the MGS or the USGS.

Hydrogeologic sections from seismic-refraction surveys conducted with the 12-channel seismograph are presented in Appendix 1 (at end of report). The locations of the 55 12-channel seismic-refraction lines conducted throughout the study area are plotted to scale on the associated aquifer maps. The computer program used to interpret 12-channel seismic data generates a profile of the subsurface with depths at twelve locations along the line. The most reliable segment of the profile is the center where the most data went into the interpretation. Therefore, the depths to the water table and bedrock are reported only for the center of 12-channel seismic lines.

Drilling and Stratigraphic-Logging Methods

Twenty-seven borings were made to determine the thickness of deposits, to collect sediment samples, and to verify depth to water table and bedrock as determined from seismic data. For the purpose of this report, the term "test boring" (TB) refers to a boring that was backfilled after test information was obtained. The term "observation well" (OW) refers to a boring where a monitoring well was installed. Borings are identified first by the appropriate TB or OW designation, followed by a number corresponding to the year in which it was drilled, and concluding with a sequential number in the order in which the borings were drilled. The observation wells were used to obtain ground-water levels and water-quality samples during the period of investigation.

An auger drilling rig with 6-inch-diameter hollow-stem augers was used to drill 26 of the borings. Overburden material penetrated above the water table was brought to the surface by the rotation of the augers. Where detailed stratigraphic information was needed below the water table, a split-spoon sediment sampler was used to collect undisturbed sediment samples ahead of the drill stem. Samples were collected according to guidelines established by the Federal Interagency Work Group (1977, Chap. 2). One boring was completed using a hand auger and a stainless-steel drive point with galvanized steel casing. Twenty-five borings were drilled to refusal, which occurred when either bedrock, compact sediments, or sediments containing cobbles larger than 6-inches were encountered. Two borings were terminated before reaching refusal because the deposit was deeper than the capabilities of the rig. Stratigraphic logs and screened intervals of observation wells are presented in Appendix 2 (at end of report).

Observation-Well Installation and Development

Nine borings were cased with 2-inch-diameter, schedule 40 PVC (polyvinyl chloride) pipe to allow collection of water samples and water-level data. PVC screens with a slot width of 0.006 inch were used. Casing and screen sections were threaded and the well was advanced by screwing on additional lengths of casing. The casing and screen were placed inside the hollow stem auger and the boring wall was allowed to collapse around the casing as the drill stem was withdrawn. Bentonite pellets were used as backfill from 1 ft below ground surface to the ground surface to prevent water from infiltrating directly around the casing.

One boring was cased with 2-inch-diameter, galvanized steel pipe threaded onto a 2.5 ft stainless-steel drive point. The drive point had a 0.007-inch stainless steel mesh screen. A hand auger was used to drill to the water table. The drive point was placed in this boring and advanced below the water table with a sledgehammer.

At all well sites drilled with the auger rig, immediately after the casing was installed, water was pumped from or forced into the observation well to aid well development. This procedure removed the fine materials from the screen and developed the hydraulic connection with the aquifer.

Procedures for Water-Quality Sampling and Analysis

Ten observation wells, three springs, and a municipal well were sampled to determine water quality. To ensure that water samples were representative of the geochemical environment, the observation wells were pumped with an ISCO model 2600 bladder pump or bailed with a PVC bailer until the pH, temperature, and specific conductance measurements stabilized and at least three well volumes of water were removed. Field measurements of pH, alkalinity, dissolved oxygen, and specific conductance were made with portable meters (Leeds and Northrup model 7417 for pH and alkalinity, Fisher model 152 for specific conductance, YSI Model 54A for dissolved oxygen).

Unfiltered samples for nitrate, chloride, sulfate, and total organic carbon analyses were collected in plastic containers rinsed three times with sample water. Samples for dissolved metal analyses also were collected in rinsed plastic containers, but were filtered and then acidified with nitric acid. All samples were kept on ice and delivered to the USGS laboratory in Arvada, Colorado within 48 hours after collection.

Metals were analyzed by atomic-absorption spectrophotometry. Chloride was analyzed by the Argentometric Method (Standard Method 408A, American Public Health Association and others, 1976), nitrate-nitrite and sulfate by an automated Technicon method, and total organic carbon by a combustion-tube infrared technique (Standard Method 505, American Public Health Association and others, 1985).

SURFICIAL GEOLOGY

Glacial History

Maine was covered by continental glaciers several times during the Pleistocene Epoch, which occurred from approximately 2,000,000 to l0,000 years B.P. (before present). The last ice sheet, known as the Laurentide Ice Sheet, reached its maximum extent about 20,000 to 22,000 years B.P., in late Wisconsinan time. It flowed from Canada southeastward and eastward across Maine, beyond the present coastline, and into the Gulf of Maine.

After the peak of the late Wisconsinan glaciation, the margin of the Laurentide Ice Sheet began to retreat from its terminal position on the continental shelf. By about 14,000 years B.P., the ice margin was approximately at the present coast of Maine (Stuiver and Borns, 1975; Smith, 1985). The weight of the ice depressed the earth's crust enough to allow the sea to follow the retreating ice margin inland. The inland extent and elevation of the deposits laid down in the sea during this time mark what is known to geologists as the marine limit.

As deglaciation continued, glacial sediments were deposited, their mode of deposition recording the style and pattern of glacial retreat in Maine. Glacial deltas in eastern Maine formed close to the inland marine limit elevation (Thompson and Borns, 1985), where the ice retreat became slow enough for large volumes of sediment to accumulate. At elevations below the marine limit, other glacial deposits are associated with an extensive silt and clay unit, the Presumpscot Formation (Bloom, 1960). Radiocarbon-age dates, determined largely from marine mollusks recovered from the Presumpscot Formation, bracket Maine's marine deglacial history to between 13,200 and 11,000 years B.P. (Stuiver and Borns, 1975; Smith, 1985). When the ice retreated beyond the reach of the sea, vast amounts of meltwater reworked the glacial sediment and laid down stream deposits and shoreline sediments over the Presumpscot Formation.

In the study area, which is above the inland extent of the marine limit, the sand and gravel deposits consist primarily of ice-contact and glacial-stream deposits laid down at or near the glacier, glacial lake deposits, and stream deposits laid down after the ice retreated (Thompson and Borns, 1985).

The mode of deglaciation in the study area has been a controversial topic. As the ice margin retreated, marine waters removed much of the ice volume. In the Gulf of Maine, as the ice in contact with marine water retreated, a calving embayment developed (Hughes and others, 1985; Oldale and others, 1990; Belknap and others, 1992). In the Penobscot and Kennebec River valleys, the ice was grounded; however, its terminus was buoyed by the sea, allowing it to float and continue calving. There have been a number of theories proposed to explain how ice retreated up these valleys and beyond the marine limit. Recent workers (Borns and Calkin, 1977; Borns, 1985; and Stone and Borns, 1986) suggest that regional stagnation and downwasting of the Wisconsinan ice sheet occurred following thinning and separation of the ice mass along the Canada - U.S. international border (Boundary Mountains drainage divide). Others (Caldwell and others, 1985; Clinch and Weddle, 1989) have argued for active ice recession through and directly north of the study area. The style of deglaciation determines the types of surficial deposits found in the area.

Surficial Materials in the Study Area

As the glacier advanced, it eroded soil and rock debris and incorporated it into the ice. This material, deposited directly from the ice as a discontinuous layer on the bedrock surface, is called till. Till deposits in the State generally are not more than 10 ft thick. Till was deposited either at the base of the ice (lodgement or basal till) as the glacier advanced, or from melting ice (ablation till) as the glacier stagnated and retreated (Thompson, 1979). Till is a poorly sorted, usually nonstratified mixture of pebbles, cobbles, and boulders in a sandy silt or clayey silt matrix. It can be very compact to very loose, and usually is not a productive aquifer. Although till usually is a poor ground water producer, its hydraulic qualities and areal extent affect the amount of natural recharge to the region. A poorly sorted, compact, clayey till with low permeability will not have as rapid an infiltration rate as a more well-sorted, less compact, sandy till. However, large amounts of runoff from upland till areas can recharge adjacent stratified-drift deposits (Morrissey and others, 1988; Randall and others, 1988).

In some places in Maine, thick deposits of till occur as streamlined till or till-covered hills. The long axes of these hills trend northwest-southeast, parallel to the direction of flow of the last ice sheet that covered the region. An example of streamlined hills is found on the Moxie Pond quadrangle (Figure 2, Open-File No. 98-20). In places, linear ridges of sediment were deposited either in front of or beneath the ice at or near the terminus of the glacier. These ridges, termed moraines, are comprised predominantly of stratified sand and gravel interbedded with till. Few moraines have been recognized in the study area, but examples are found on the Number Four Mtn. quadrangle in a valley north of Horseshoe Pond where a series of moraines was deposited as the glacier receded to the north (Figure 3, Open-File No. 98-22).

As the ice margin retreated through the study area, meltwater streams transported and deposited large quantities of sand and gravel, mainly in the valleys. Coarse sediments transported by the streams accumulated in channels within or beneath the ice, between the ice and adjacent valley walls, or in glacial lakes at or near the glacier front. Typical "ice-contact" stratified-drift deposits include such features as eskers (long, sinuous ridges formed as tunnel fillings within the ice), crevasse fillings (ridges formed from sediments filling cracks on the ice surface), subaqueous fans (irregularly shaped hills formed by streams from ice tunnels entering a water body below the water surface), and deltas (flat-topped or irregularly shaped hills formed by streams entering a water body and building to the water surface). Sediments deposited by meltwater streams in valleys adjacent to or beyond the ice margin are termed fluvial outwash or outwash plain deposits, respectively, and commonly display pitted surfaces as a result of the burial and subsequent melting of blocks of ice.

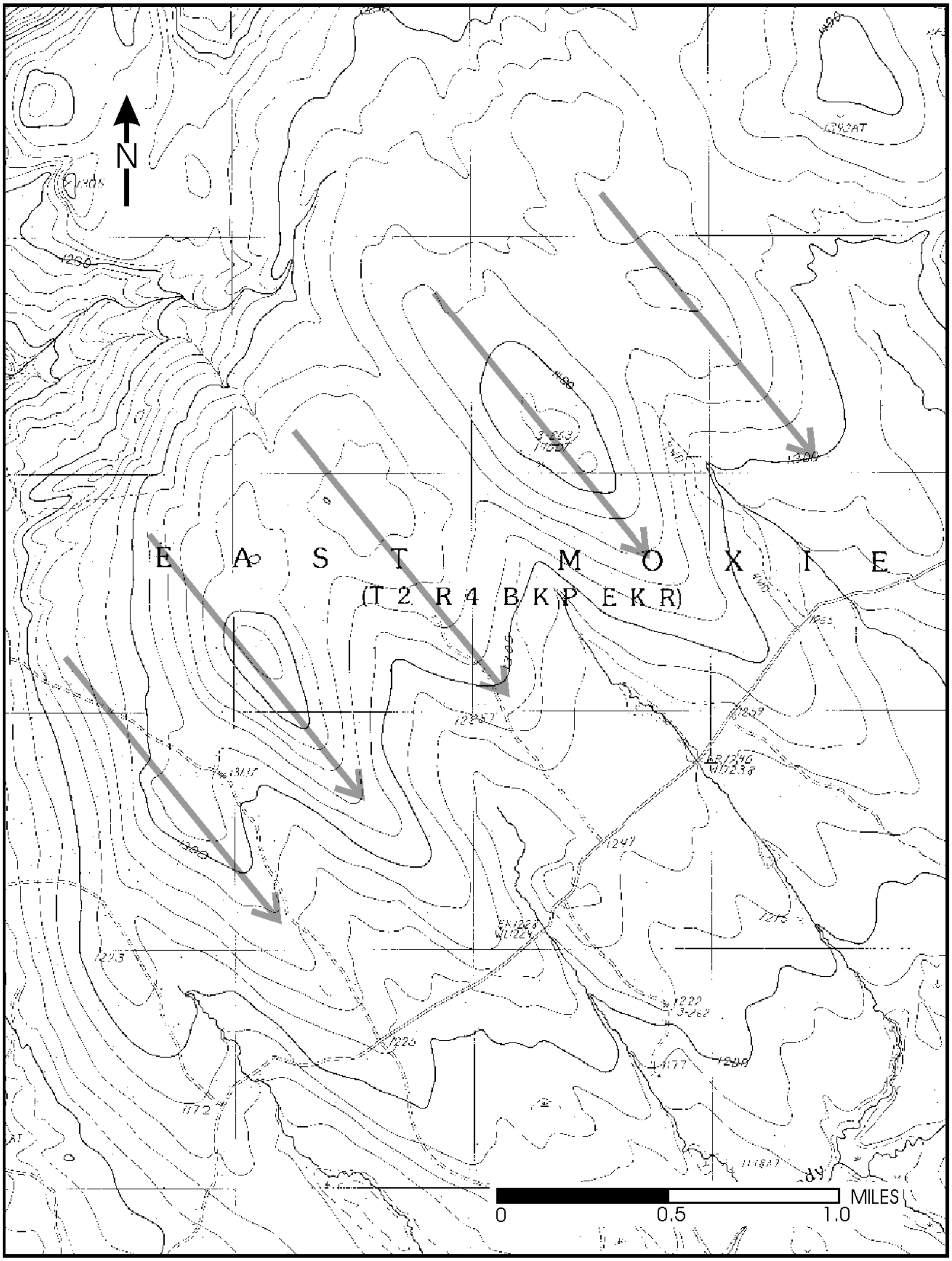


Figure 2. Examples of streamlined hills, Moxie Pond quadrangle.

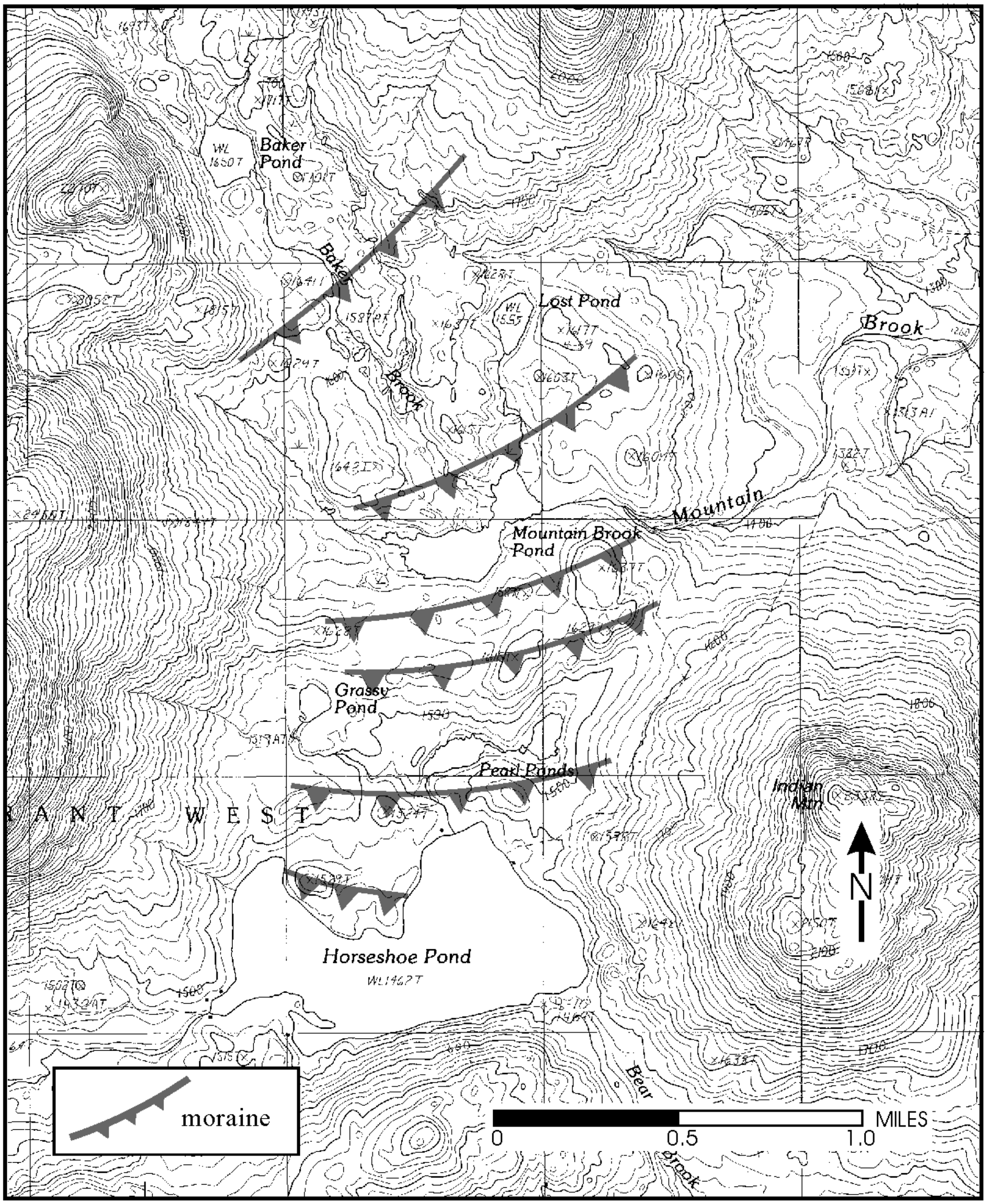


Figure 2. Examples of moraines, Number four Mtn. quadrangle.

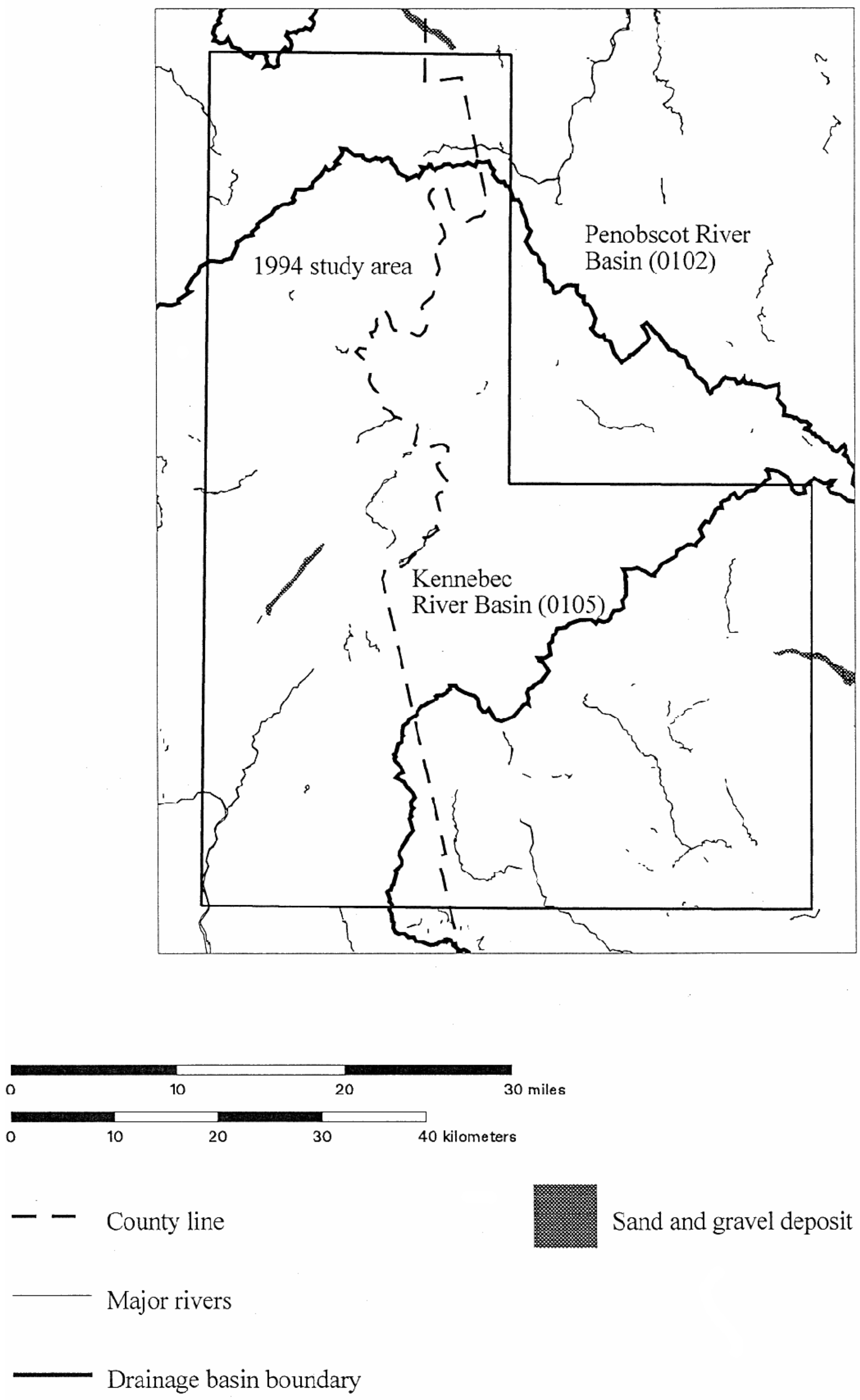


Figure 4. Glacial sand and gravel deposits of parts of the Penobscot River and Kennebec River drainage basins.

The study area lies within the Kennebec and Penobscot River drainage basins. Prominent deposits representing glacial drainage systems are shown on Figure 4 (Thompson and Borns, 1985). Esker systems are comprised of segments of esker-fed deltas or fans that were deposited at the ice marginal position at the time that the esker segment was forming (Clinch and Weddle, 1989; Ashley and others, 1991). Figure 5 shows an example of an esker in the west-central portion of the Seboomook Lake West quadrangle (Open-File No. 98-26).

Also shown on Figure 5 is a set of channels that resulted from glacial meltwater drainage between the ice front and the adjacent valley wall. Along with subglacial meltwater flow represented by the esker deposit, these channels supplied much of the sediment found further down the Seboomook Lake basin.

Deltas are formed where meltwater streams entered a body of water. Deltas formed at ice margins are termed ice-contact deltas; deltas formed distant from ice margins are termed outwash deltas. Well developed deltas with characteristic lobe-shaped form are not as common in the study area as they are in southwest and southeast Maine.

Associated with deltas are lake bottom deposits. The basin now occupied by Seboomook Lake is the site of a glacial lake termed glacial Lake Seboomook (Lowell and Crossen, 1983). The large flat-topped landform shown in Figure 5 was deposited into this glacial lake. Borings in this landform, TB 94-12 and 94-13, record as much as 75 ft of fine-grained glacial lake deposits. The upper few feet of these borings are fine to coarse sands with pebbles or cobbles that may be, in part, deltaic.

Outwash deposits are primarily found in the river valleys in the study area and are usually aquifers. An example of an outwash deposit is seen along the West Branch Piscataquis River near Blanchard (Figure 6, Open-File No. 98-17). Two seismic lines on this deposit, MSW-1 and MSW-2, indicate a saturated thickness of 70-80 ft (see Appendix 1).

Post-glacial sediments are also found in the study area. Wetland deposits, swamps, and bogs are typically underlain by till, fine-grained stratified deposits, or bedrock. Many of the wetlands are characterized by peat deposits. Though saturated, wetland deposits are usually not aquifers because of their low permeability. However, wetlands are often found adjacent to esker systems and may be hydraulically connected to the system.

Eolian deposits of fine-grained sand and silt occur in the study area, generally as a cap not more than a few feet thick over other glacial deposits. These wind-blown deposits are not permeable enough to be significant aquifers; however, they may overlie more coarse-grained, water-bearing strata.

Recent alluvial deposits, generally consisting of interbedded sand, gravel, silt, and cobble gravel, occupy much of the flood plain of the major rivers in the study area. Alluvial deposits of late glacial and early post-glacial age may be difficult to differentiate from glacial outwash; however, post-glacial alluvium is generally deposited at lower elevations than outwash.

Stratigraphy of Glacial Deposits

Figure 7 is a schematic diagram that shows the generalized regional stratigraphic relations of glacial deposits in Maine. Examples of all the depositional environments portrayed in Figure 7 can be found in the study area with the exception of marine environments. Not all of the units shown on this figure will necessarily be found in any one place.

Figure 7 indicates the relative positions of the deposits. Bedrock is overlain by till, which is overlain in places by clay, silt, sand, and gravel in the form of ice-contact stratified drift, glacial outwash, and glacial-lake sediments. The youngest surficial deposit, a thin veneer of sand and gravel overlying the glacial deposits, may represent late outwash deposit or alluvium.

HYDROLOGY OF THE SIGNIFICANT SAND AND GRAVEL AQUIFERS

Significant sand and gravel aquifers consist of coarse-grained glaciolacustrine and glaciomarine sediments; ice-contact, ice-stagnation, and glaciofluvial-outwash deposits; and Holocene stream alluvium. The largest yields available are from wells in coarse-grained ice-contact stratified drift or alluvial deposits near surface-water bodies that may serve as sources of induced recharge.

The most productive and highly developed aquifers are located in ice-contact and outwash deposits such as those near Greenville Junction (Big Squaw Pond quadrangle) and Willamantic (Monson East quadrangle). The largest reported single well yield, 300 gal/min, is from a gravel-packed well in Little Squaw township, drilled in an ice-contact esker deposit (Figure 8, Big Squaw Pond quadrangle, Open-File No. 98-7). This well serves as the water supply for the town of Greenville.

Significant sand and gravel aquifers are shown on the associated maps as areas with moderate to good potential water yield (greater than 10 gal/min to a properly constructed well) and areas with good to excellent potential water yield (greater than 50 gal/min to a properly constructed well). Areas with moderate to low or no potential water yield (generally less than 10 gal/min to a properly constructed well) are shown as surficial deposits with less favorable aquifer characteristics. These less favorable areas include regions underlain by surficial deposits such as till, alluvium, peat, and thin glacial sand and gravel deposits. Bedrock wells shown on these maps record only the depth to bedrock in the well as recorded in well driller records. Aquifer boundaries and estimated yield zones shown on the associated maps are based on available information and are subject to modification as additional data become available.

Major surface-water drainage-basin boundaries also are identified on the maps. In general, ground-water divides coincide with surface-water divides. The general direction of

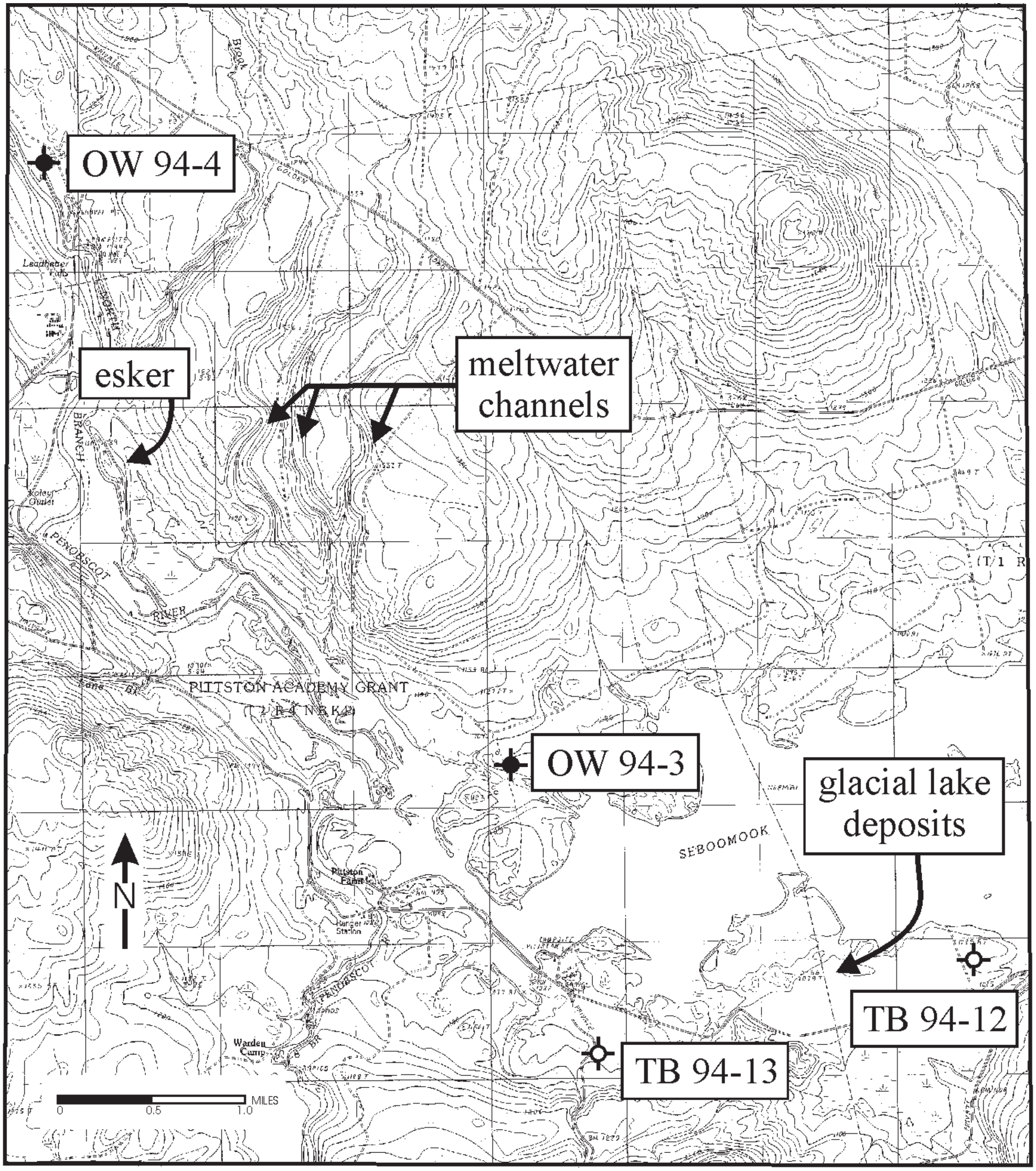


Figure 5. Example of an esker, meltwater channels, and glacial lake deposits, Seboomook Lake West quadrangle.

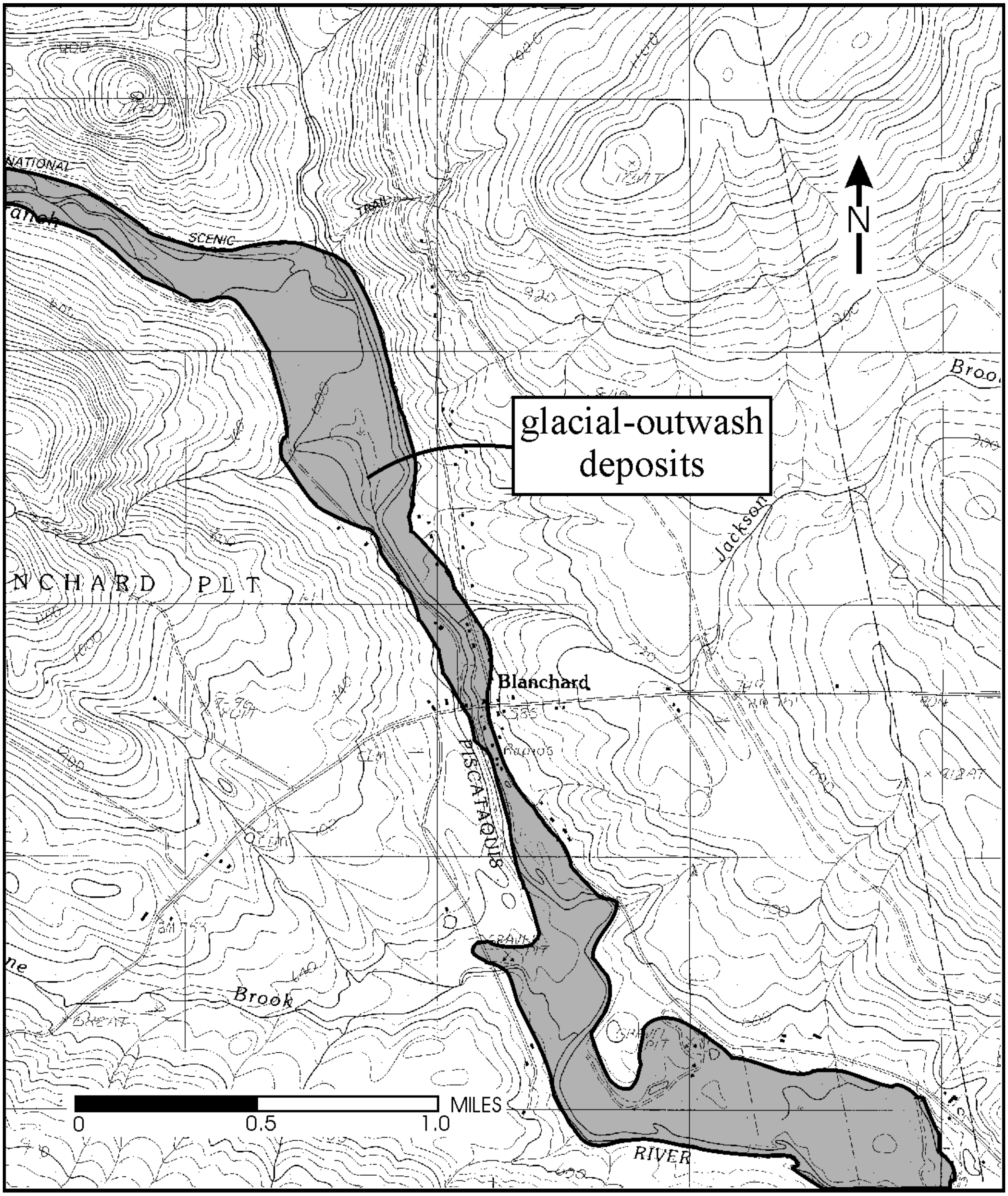


Figure 6. Example of glacial-outwash deposits, Monson West quadrangle.

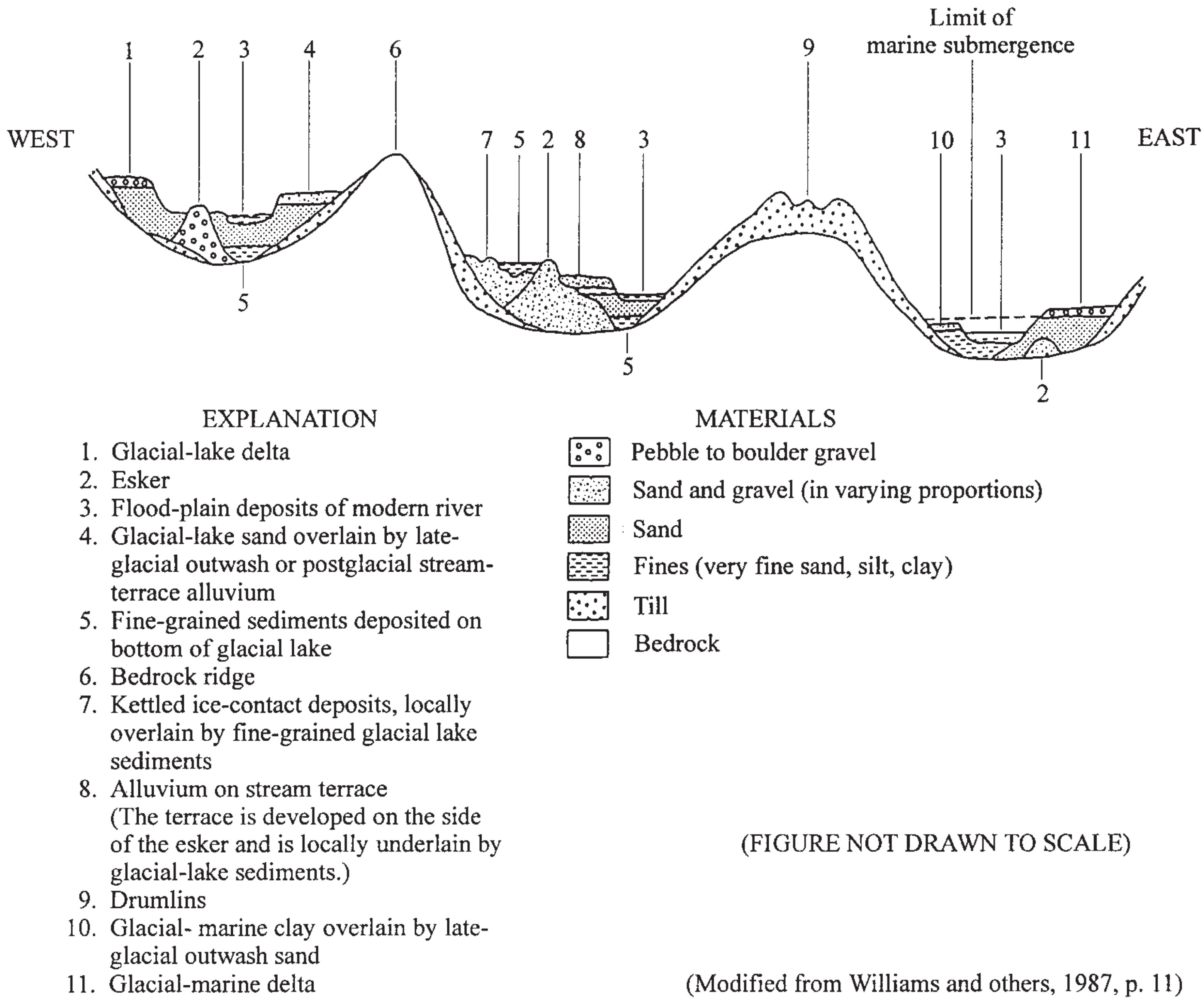


Figure 7. Generalized regional stratigraphic relation of glacial deposits.

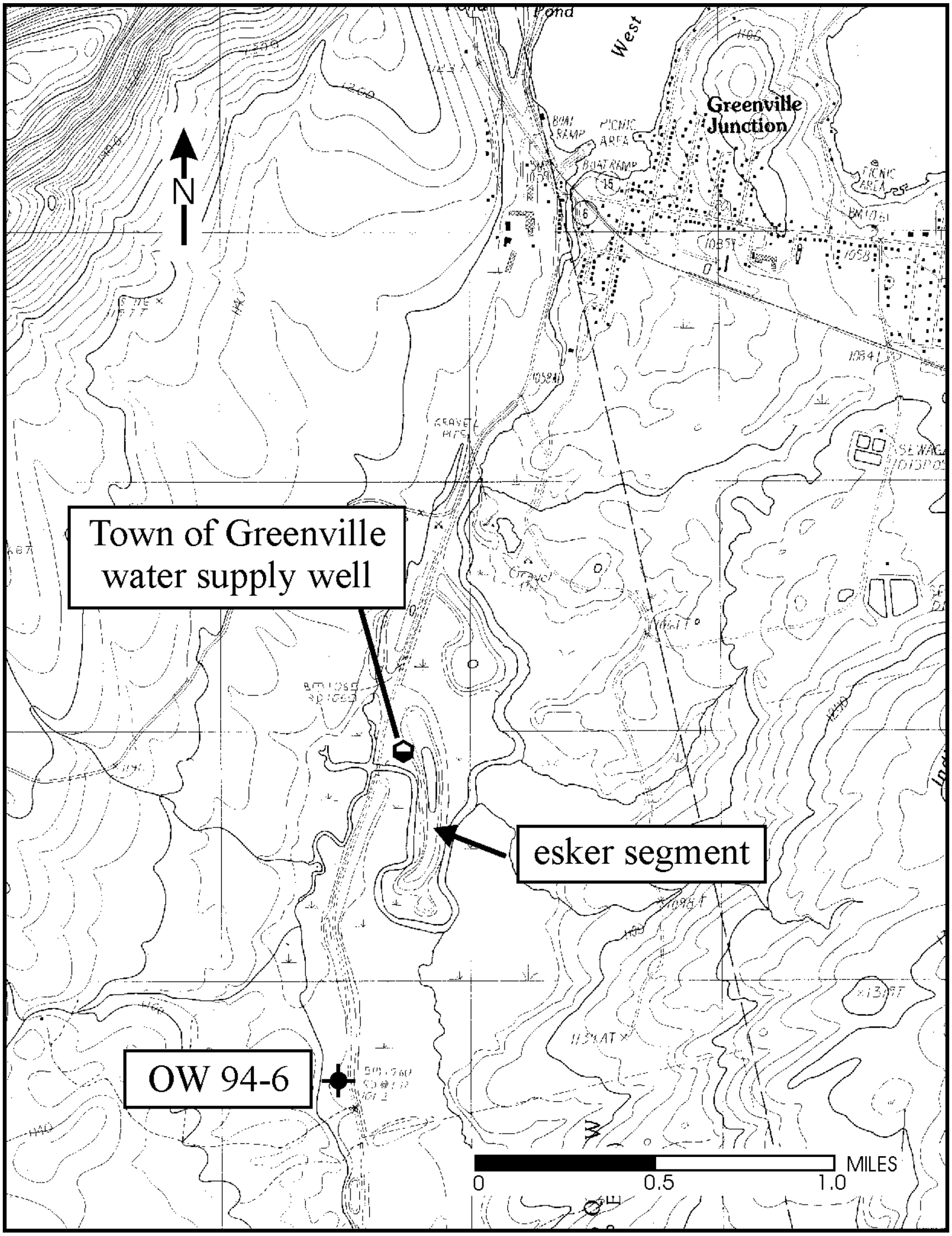


Figure 8. Location of the town of Greenville water supply well, Little Squaw township, Maine.

ground-water flow is away from surface-water divides and toward surface-water bodies.

Hydraulic Properties

Hydraulic Conductivity

Hydraulic conductivity is a measure of the rate at which water will flow through aquifer materials. It is dependent on a variety of physical factors, including porosity, particle size and distribution, shape of particles, and arrangement of particles (Todd, 1980). Hydraulic conductivity is usually the most important hydraulic property of sediments for assessing ground-water flow and well yield (Caswell, 1987).

Hydraulic conductivity is best measured directly in the field on an undisturbed section of aquifer. When field measurements are impractical, hydraulic conductivity can be estimated in the laboratory. For this study, the median particle diameter (in millimeters) and the degree of sorting of representative sediment samples were determined by grain-size analyses. These analyses were performed at the USGS laboratory in Harrisburg, Pennsylvania, using a dry sieve method (Folk, 1974). The results of these analyses were used to estimate hydraulic conductivity using the method of Zamarin, as described by Vukovic and Soro (1972). This method relates porosity and effective grain diameter to hydraulic conductivity (Table 1). A typical range of hydraulic conductivities suggested by Freeze and Cherry (1979), expressed in ft/d (feet per day), is 10^{-6} to 10^{-3} for marine or lacustrine clay, 10^{-7} to 10^{-2} for till, 10^{-3} to 10^{1} for silt, 10^{-1} to 10^{2} for silty sand, and 10^{0} to 10^{3} for clean sand. The hydraulic conductivities estimated for selected aquifer materials sampled in this study have much less variation, from <0.1 ft/d to 258 ft/d (Table 1).

In the 1981 through 1990 reports of this study, hydraulic conductivity was estimated using the method of Masch and Denny (1966). That method uses a nomograph with a series of curves that represent the sorting of the sediment sample by the number of standard deviations, from 0.0 to 2.0, from the mean sediment size. Because forty-seven percent of the sediment samples from this field season had standard deviations greater than 2.0, the hydraulic conductivity could not be estimated reliably using the method of Masch and Denny.

Transmissivity

Transmissivity is a measure of the rate at which water is transmitted through an aquifer or confining bed. It is a function of properties of the liquid and the porous media and the saturated thickness of the porous media (Fetter, 1988). Transmissivity is equal to the average hydraulic conductivity multiplied by the saturated thickness. Driscoll (1986) suggests that aquifers with transmissivities less than 130 ft^2/d (feet squared per day) can only supply enough water for domestic wells or other low yield uses. Aquifers with transmissivities of 1,700 ft^2/d or greater are capable of transmitting adequate quantities of water for industrial, municipal, or irrigation purposes.

Approximate transmissivity values were estimated for 10 sites on the basis of stratigraphic logs of observation wells. Sediment from each interval in the saturated part of the exploration boring (Appendix 2, at end of report) was assigned a hydraulic conductivity based on sample descriptions, grain size, and sorting (Table 1). This hydraulic conductivity was multiplied by the interval thickness to obtain an interval transmissivity. The interval transmissivity values were then summed to give a total transmissivity for that part of the aquifer penetrated by the exploration boring. The transmissivities estimated by this method range from 24 to 3,721 ft^2/d and are presented in Table 2.

Estimated Well Yields

Significant sand and gravel aquifers consist of deposits that have sufficient areal extent, hydraulic conductivity, and saturated thickness to sustain a yield of 10 gal/min or more to a properly installed well. Yields available from wells constructed in the aquifers were obtained from yields reported by well drillers, well owners, and previously published studies, and from estimates based on saturated thickness, transmissivity, and areal extent of the aquifers. Sustained yield values determined through aquifer tests were not within the scope of this study. Therefore, a method developed by Mazzaferro (1980) was used to estimate well yields in a water-table aquifer. This method is based on transmissivity (T), in ft^2/d, and saturated thickness (B), in ft, where $(T \times B)/750$ = well yield in gallons per minute. Yields calculated for project observation wells range from 1 to 218 gal/min (Table 3). Areas where wells are estimated to yield more than 10 gal/min and more than 50 gal/min are shown in separate shading patterns on the associated maps. Areas where wells may yield less than 10 gal/min constitute the remaining unshaded portion of the map.

Although the total study area covers 1,412.4 mi^2 (square miles), areas mapped as significant sand and gravel aquifers include only about 15.7 mi^2 (1.1 percent) of this area. Yields exceeding 50 gal/min are estimated to be obtainable in only 0.1 mi^2 (less than 0.1 percent) of the study area.

The greatest yields are obtainable in areas where the deposits are coarse grained, have a thick saturated zone, or are hydraulically connected to an adjacent body of surface water that is a source of induced recharge. The largest reported well yield in the sand and gravel deposits is 300 gal/min from a gravel-packed well drilled in an esker in Little Squaw township that supplies the town of Greenville (Big Squaw Pond quadrangle). Other large well yields in the area include >50 gal/min from a contaminant recovery well in The Forks that is screened in outwash/alluvium

Table 1. Grain-size analysis, sorting, and estimated hydraulic conductivity of aquifer material.

Sample description (field)	Observation well or test boring number	Depth of interval sampled (feet)	Median diameter (phi)[1]	Degree of sorting[2]	Estimated hydraulic conductivity (feet per day)[3]
Silt-very fine sand					
Fine sand,silt, clay	OW 94-8	17-19	6.9	Poor - 2.4	<0.1
Silt	OW 94-1	12-14	5.2	Poor - 1.2	0.3
Fine-medium sand	OW 94-5	7-9	3.6	Poor - 1.7	0.8
Very fine-fine sand	OW 94-1	22-24	3.4	Poor - 1.3	1.1
Fine sand-medium sand					
Fine-medium sand	OW 94-9	47-49	2.9	Poor - 1.3	2.1
Fine-medium sand	OW 94-9	37-39	2.8	Moderate - 1.0	5.0
Fine-medium sand	OW 94-9	22-24	2.7	Moderate - 1.0	15.6
Fine sand	OW 94-1	32-34	2.2	Poor - 1.2	7.8
Fine-coarse sand, pebbles, silt	OW 94-2	27-29	2.2	Poor - 4.0	0.4
Fine-medium sand	OW 94-1	42-44	1.6	Moderate - 0.8	59.5
Coarse-very coarse sand					
Coarse-very coarse sand, pebble gravel	OW 94-10	5-6	0.1	Poor - 1.6	258.0
Pebble gravel, silt, fine sand	OW 94-5	27-29	0.1	Poor - 3.8	0.4
Fine-coarse sand, pebble gravel	OW 94-2	7-9	-0.1	Poor - 1.8	185.1
Very fine-fine sand, silt, gravel	OW 94-4	47-49	-0.6	Poor - 3.9	0.3
Medium-coarse sand, pebble gravel	OW 94-8	12-14	-0.7	Poor - 3.7	0.3
Very fine-fine sand, silt, gravel	OW 94-4	27-29	-0.8	Poor - 3.6	0.3
Gravel					
Fine-coarse sand, pebble gravel, silt	OW 94-2	17-19	-1.3	Poor - 1.5	25.3
Very fine-fine sand, silt, gravel	OW 94-4	37-39	-1.4	Poor - 3.7	0.5
Sandy till	OW 94-2	37-39	-1.6	Poor - 2.7	34.9
Cobbles, fine sand	OW 94-6	17-19	-1.7	Poor - 3.1	15.4
Pebble gravel, sand, some silt	OW 94-5	17-19	-1.7	Poor - 2.4	24.4
Fine-coarse sand, silt, gravel	OW 94-3	17-19	-3.5	Poor - 2.6	84.2

[1] Phi is the negative log (base 2) of the particle diameter in millimeters

[3] Vukovic and Soro (1972)

[2] Sorting classified by Inclusive Graphic Standard Deviation:
greater than 1.0 - poor
0.75 - 1.00 - moderate
0.51 - 0.74 - moderately well
less than or equal to 0.50 - well

Table 2. Estimated transmissivity values of aquifers based on stratigraphic logs of observation wells.

Aquifer quadrangle	Observation well number	Estimated transmissivity, in feet squared per day
Misery Knob	OW 94-1	549
Socatean Bay	OW 94-2	3,721
Seboomook Lake West	OW 94-3	231
Seboomook Lake West	OW 94-4	89
Greenville	OW 94-5	305
Big Squaw Pond	OW 94-6	123
Bald Mtn. Pond	OW 94-7	70
Monson East	OW 94-8	24
Monson East	OW 94-9	>352
Sebec Lake West	OW 94-10	>1,032

Table 3. Estimated well yields for observation wells.

Aquifer quadrangle	Observation well number	Estimated well yield, (gallons per minute)[1]
Misery Knob	OW 94-1	40
Socatean Bay	OW 94-2	218
Seboomook Lake West	OW 94-3	10
Seboomook Lake West	OW 94-4	6
Greenville	OW 94-5	13
Big Squaw Pond	OW 94-6	1
Bald Mtn. Pond	OW 94-7	1
Monson East	OW 94-8	1
Monson East	OW 94-9	>47
Sebec Lake West	OW 94-10	>6

[1] Yields calculated from methodology of Mazzaferro (1980), where yield (gallons per minute) = transmissivity (T) x saturated thickness (B) / 750.

adjacent to the Kennebec and Dead Rivers (The Forks quadrangle) and high yields reported from wells drilled in a glaciolacustrine delta in Willimantic (Monson East quadrangle).

Depths to the Water Table and Bedrock Surface

Depths to the water table and bedrock surface in the significant sand and gravel aquifers were determined from seismic-refraction surveys, water-level measurements, well inventory, test drilling, mapping of bedrock outcrops, and previous investigations. In the significant sand and gravel aquifers, the depth to the water table differs considerably areally, but typically is within 15 ft of the land surface. The greatest depth to bedrock determined by seismic-refraction is approximately 167 ft, along seismic line MSE-1 (Monson East quadrangle). Project observation-well records indicate that bedrock is at a depth of at least 122 ft at OW 94-9, also located on the Monson East quadrangle.

Determinations of depths to the water table and bedrock surface are necessary to provide a three-dimensional picture of aquifer geometry. Saturated thickness at selected points can be determined by subtracting the depth to water table from the depth to bedrock. Depth to bedrock data and bedrock surface profiles can be used to estimate the amount of casing required in overburden for bedrock well construction and to locate buried valleys, that may contain water-bearing sediments.

Water-Level Fluctuations

Monthly water-level measurements at 10 observation wells in the study area are shown in Table 4. Water-level measure-ments were made once a month from October 1994 through September 1995. Water levels in all observation wells fluctuated within a range of 1.61 to 5.59 ft during this period (Table 5). The mean depth to the water table in the 10 wells ranged from 2.28 to 23.61 ft below land surface. In the majority of wells, the water table is less than 15 ft from land surface. This thin unsaturated zone renders the ground water vulnerable to potential contamination originating at the land surface.

Hydrographs from selected observation wells are shown in Figure 9. For comparison, monthly precipitation in the study area is shown, estimated by averaging monthly precipitation from the National Oceanic and Atmospheric Administration Stations at Brassua Dam, Comstock, and Sebec Lake. Regional recharge generally occurs in the late fall and early spring months, when the ground is not frozen and there is little plant growth to intercept precipitation as it infiltrates the aquifer. Most water levels decline slowly but steadily between these recharge periods.

GROUND-WATER QUALITY

Factors Influencing Water Quality

The chemical quality of water in sand and gravel aquifers is determined by a number of factors. The primary control is the mineralogy of the sand and gravel. Most sand and gravel in the study area is derived from granitic rocks and medium to high grade metamorphic rocks (slates, quartzites, gneisses, and schists). The metamorphic grade of the bedrock from which stratified drift is derived has a strong influence on the chemical quality of water from that aquifer (Weddle and Loiselle, 1996). Chemical reactions that occur as water passes through the soil zone also can affect ground-water chemistry. Where the flow path of water from the recharge zone to the discharge zone is long, more time is available for the dissolution of soluble material in the aquifer (Hem, 1985).

Residence time depends on hydraulic conductivity, hydraulic gradient, and the porosity of the unconsolidated deposits. For a given flow path, the higher the hydraulic conductivity and hydraulic gradient of the deposit, the shorter the residence time of the ground water. Conversely, for a given flow path, high porosity may lead to a long residence time if the material is fine-grained, such as silt or clay or to a short residence time if the material is coarse-grained, such as well- sorted sand or gravel.

Contamination by human activities may introduce elevated concentrations of many compounds into ground water. Activities that may significantly alter the quality of ground water include the following:

(1) Landfill disposal of household and industrial wastes, which may include petroleum derivatives and other hazardous material.

(2) Road salt application and storage. An investigation conducted in the Province of New Brunswick, Canada, indicated that as much as 57 percent of the salt in an uncovered salt-sand storage pile may leach in a year (Environment New Brunswick, 1978).

(3) Human wastes introduced into ground water through septic tanks, disposal of septic wastes, or by spreading or landfilling of sludge from municipal sewage treatment systems. Studies indicate that the density of housing units that use individual septic disposal systems is a controlling factor in the likelihood of nitrate contamination of ground water (Wehrmann,1983; Pinette and others, in prep).

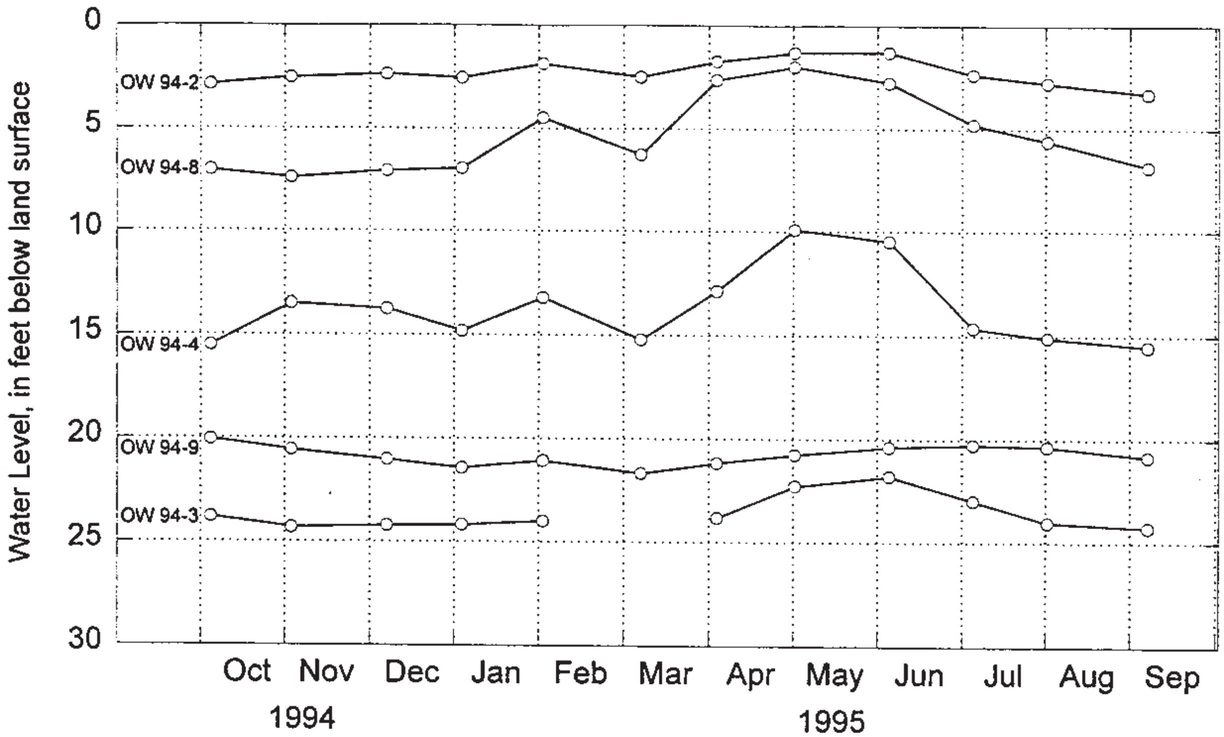
(4) Agricultural activities, which include stockpiling and spreading of manure, applying commercial fertilizers, and spraying pesticides. From 1985 to 1988, the Maine Geological Survey collected samples from 47 overburden wells within agricultural areas underlain by sand and gravel; eight of these wells had detectable concentrations of pesticides. Furthermore, seven of these wells had nitrate concentrations exceeding the State

Table 4. Water-level data for observation wells in the study area, October 1994 through September 1995.
[Depth to water, in feet below land surface; —, no water level measured during this period]

Observation Well Number	Town	Oct. 5	Nov. 3	Dec. 7	Jan. 3 - 4	Feb. 1\31-2\3	Mar 8 - 9	Apr. 4 - 5	May 2	Jun. 5	Jul. 5	Aug. 1	Sep. 6
OW 94-1	Misery Twp.	14.49	14.25	13.86	14.08	13.59	14.43	13.38	13.18	12.80	14.07	13.72	14.57
OW 94-2	West Middlesex Canal Grant	2.87	2.53	2.37	2.55	1.86	2.50	1.73	1.30	1.29	2.36	2.76	3.28
OW 94-3	Pittston Academy Grant	23.83	24.33	24.23	24.19	24.01	—	23.83	22.28	21.79	22.98	24.03	24.26
OW 94-4	Comstock Twp.	15.51	13.51	13.77	14.81	13.22	15.21	12.88	9.92	10.49	14.63	15.09	15.51
OW 94-5	Little Squaw Twp.	5.09	2.38	2.34	2.98	2.78	3.08	2.39	2.82	2.55	3.45	2.80	3.70
OW 94-6	Little Squaw Twp.	10.89	10.77	10.53	10.76	10.37	11.41	10.52	10.17	9.92	11.25	10.51	11.68
OW 94-7	Blanchard Twp.	13.51	13.48	12.71	12.78	11.33	13.25	11.13	10.69	10.10	13.17	14.31	15.04
OW 94-8	Willimantic	7.04	7.41	7.08	6.95	4.48	6.27	2.63	1.98	2.75	4.77	5.58	6.84
OW 94-9	Willimantic	20.07	20.57	21.04	21.43	21.08	21.68	21.18	20.76	20.37	20.26	20.35	20.83
OW 94-10	Willimantic	6.39	8.35	6.88	6.37	5.32	—	6.86	6.31	5.19	5.96	5.91	6.45

Table 5. Statistical analysis of water-level data for observation wells in the study area, October 1994 through September 1995.

Observation Well Number	Town	Number of Measurements	Mean depth to water (in feet below land surface)	Standard Deviation	Maximum depth to water (in feet below land surface)	Minimum depth to water (in feet below land surface)	Range of values (feet)
OW 94-1	Misery Twp.	12	13.87	0.55	14.57	12.80	1.77
OW 94-2	West Middlesex Canal Grant	12	2.28	0.62	3.28	1.29	1.99
OW 94-3	Pittston Academy Grant	11	23.61	0.87	24.33	21.79	2.54
OW 94-4	Comstock Twp.	12	13.71	1.87	15.51	9.92	5.59
OW 94-5	Little Squaw Twp.	12	3.03	0.77	5.09	2.34	2.72
OW 94-6	Little Squaw Twp.	12	10.73	0.51	11.68	9.92	1.76
OW 94-7	Blanchard Twp.	12	12.62	1.51	15.04	10.10	4.94
OW 94-8	Willimantic	12	5.32	1.96	7.41	1.98	5.43
OW 94-9	Willimantic	12	20.80	0.50	21.68	20.07	1.61
OW 94-10	Willimantic	11	6.36	0.85	8.35	5.19	3.16



B. Average monthly precipitation data from the Brassua Dam, Comstock, and Sebec Lake National Oceanic and Atmospheric Administration stations.

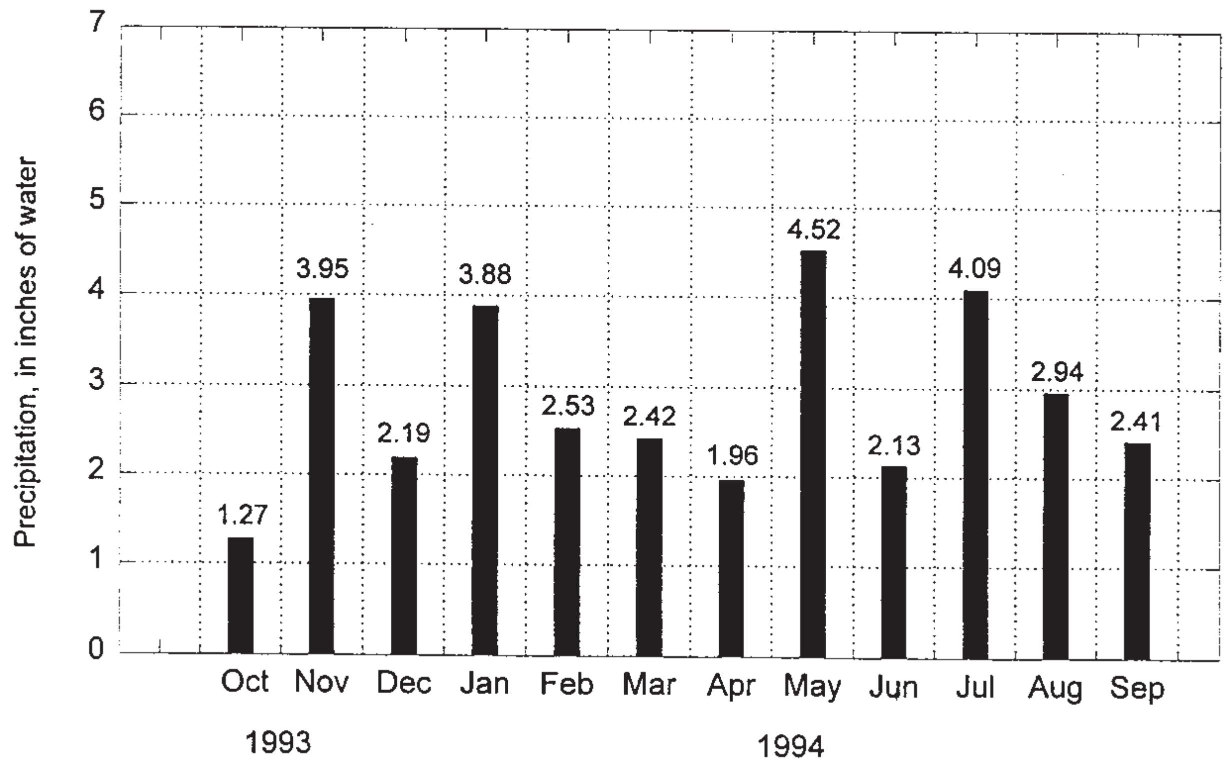


Figure 9. Ground-water levels in selected observation wells (A) and average monthly precipitation (B), October 1994 through September 1995.

drinking water standard of 10 mg/L (milligrams per liter) (Neil and others, 1989). More than 100 wells in Aroostook County contaminated by aldicarb (Temik), an agricultural chemical used extensively for potato farming, also have been documented (unpublished data, Rhone-Poulenc Agricultural Products Company)

(5) Leaking waste-storage or disposal lagoons. MDEP Bureau of Remediation and Waste Management records indicate 8 sites statewide where industrial waste storage or disposal lagoons were closed under the federal Resource Conservation Recovery Act (RCRA).

(6) Leaking fuel- or chemical-storage tanks. The MDEP Bureau of Remediation and Waste Management has documented concentrations of gasoline as high as 600,000 parts per billion in a well installed in a sand and gravel aquifer (Garrett and others, 1986). Underground petroleum tank leaks were documented at 158 locations in Maine from 1979-83. In total, 76 wells were found to be contaminated statewide, most commonly by gasoline that leaked from buried tanks and connecting pipes at retail and nonretail commercial establishments (Caswell, 1987). For 1993 alone, MDEP files show 15 wells contaminated and another 69 wells at high risk statewide as a result of leaking underground petroleum storage tanks.

(7) Toxic or hazardous-material spills along transportation routes. During 1991, the latest year for which summary statistics are available, 304 incidents of toxic or hazardous-material spills along transportation routes were reported statewide to the MDEP.

(8) Contaminants in precipitation. In the northeastern United States, "acid rain" has been reported to cause a lowering of pH and subsequent increase in aluminum and trace metal concentrations in ground water in New Hampshire and New York (Bridge and Fairchild, 1981). Continued research has failed to conclusively document this finding (Steve Kahl, University of Maine, personal communication, April 26, 1990).

A USGS study (Goolsby and others, 1991) has documented quantifiable levels of several herbicides in rainwater samples from a 23 state area mostly in the midwest and northeast.

Common indicators of ground-water contamination are elevated levels of nitrate, a contaminant derived from sewage, animal waste, fertilizer, and landfill waste; chloride, a contaminant introduced by road salt, saltwater intrusion, fertilizer, and landfill wastes; and specific conductance, which indicates the presence of dissolved ionic compounds.

Background Water Quality

The six major drainage basins in Maine, as mapped by the U.S. Geological Survey (1974) are the St. John/Aroostook River, the Penobscot River, the Kennebec River, the Androscoggin River, Eastern and Central Coastal Maine, and the Saco River. The Eastern and Central Coastal basins are a number of medium to small drainage basins that discharge directly into the Gulf of Maine. These six major drainage basins with their corresponding Hydrologic Unit Code (HUC) number are shown in Figure 10. Also shown on Figure 10 is an outline of the study area and the location of all sand and gravel observation wells from this and previous study areas.

The 10 wells installed for this study are within the drainage basins of the Penobscot and Kennebec Rivers. Characteristics of these wells are given in Table 6. Water-quality analyses of samples from 8 of the 10 wells, a gravel-packed municipal well near Greenville (well GVWD), and a spring (T-NR) are provided in Table 7 and are summarized for the study area as a whole and by the individual drainage basins in which they lie. Two other springs(FWB and TF) indicated on Table 7 are located in glacial till. The water- quality data from the springs in till are shown for comparison, but are not included in the summary statistics. Table 8 presents the background water-quality data from the statewide Significant Sand and Gravel Aquifer Mapping Program to date grouped by the major drainage basins. Data for all properties are reported in standard metric units used for these analyses.

Comparisons of water-quality constituents or parameters between drainage basins are made using median concentrations rather than mean concentrations. Because water quality concentrations do not represent a normal distribution, the median concentration for a constituent or parameter is a more representative indicator of water quality in a drainage basin than mean concentration.

The study area lies within both the Kennebec and Penobscot River basins. Both basins are underlain by medium grade metamorphic and intrusive rocks, and have been subjected to the same glacial processes that left behind similar surficial deposits.

The similarity in geologic setting between the Kennebec and Penobscot River basins within the field area is reflected in the ground-water chemistry. The mean, median, and range of values for all parameters are very similar within each basin and between the two basins. Where significant differences in statistical values for a parameter do occur, for example, iron concentrations, they usually can be attributed to an anomalous value from one well. Comparisons of water quality between drainage basins within the study area and between the various drainage basins around the State can be reviewed in Tables 7 and 8.

The wells installed for the Significant Sand and Gravel Aquifer Mapping Project were sited to minimize any influence by human activities, particularly contamination. Variations in water quality are attributed to natural geologic and geochemical factors and to the influence of agricultural practices on ground water. Volatile organic compounds were analyzed in early project field seasons (1981-84) but were not detected. Therefore, volatile organic compound analyses were dicontinued for all subsequent field seasons.

Graphic summaries of selected water-quality properties and constituents are presented as box plots in Figures 11 and 12. The summaries are based on analyses of water samples collected

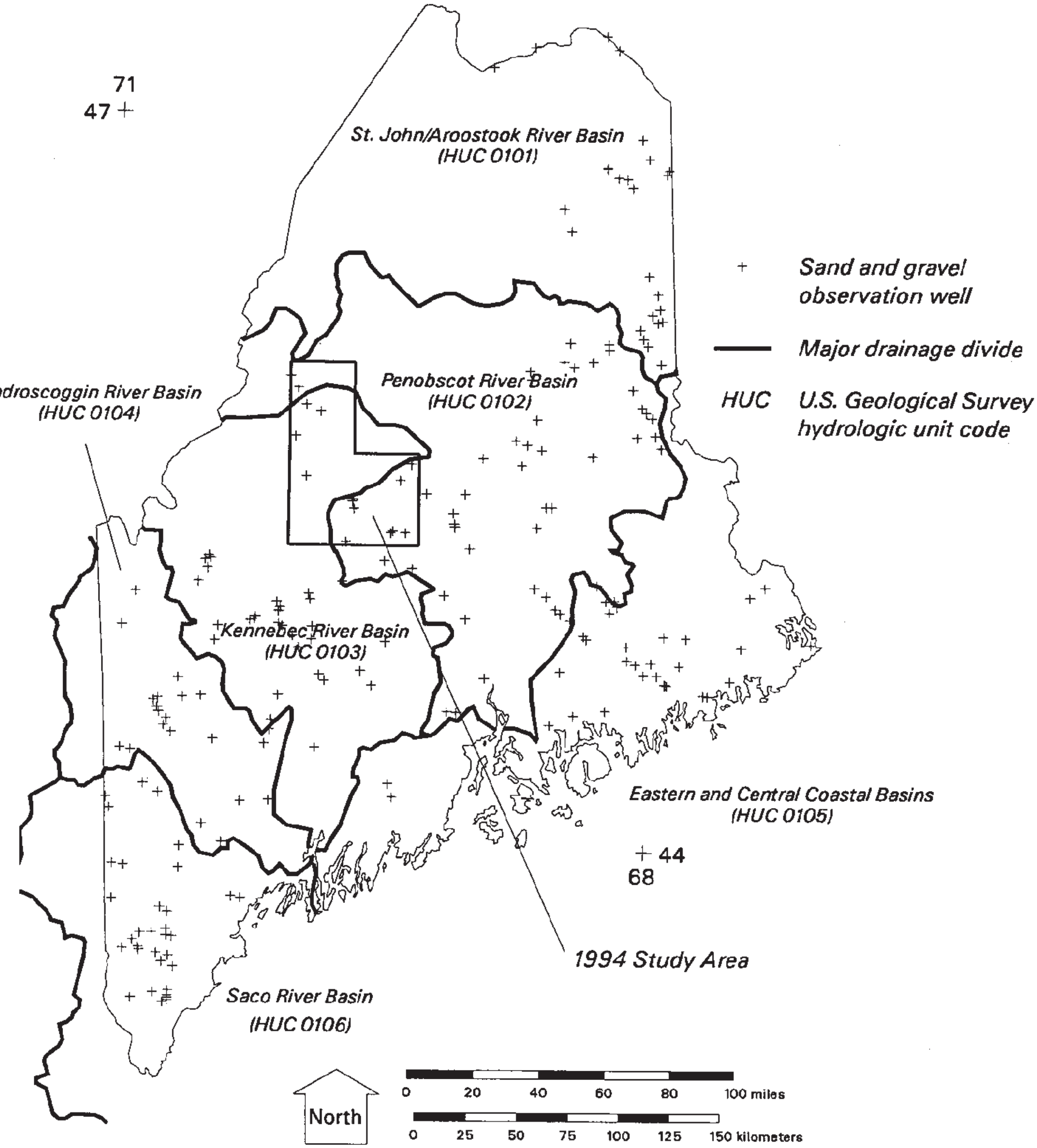


Figure 10. Major drainage basins, the study area, and sand and gravel observation wells.

Table 6. Characteristics of observation wells in the study area.

Observation Well Number	Town	Drainage Basin (HUC)	Latitude	Longitude	Altitude (feet)	Depth (feet)	Predominant Land Type Around Well
OW 94-1	Misery Twp.	0103	45°31’55"N	68°54’01"W	1130	46.0	Gravel Pit/Forest
OW 94-2	West Middlesex Canal Grant	0103	45°47’57"N	69°49’11"W	1050	17.5	Gravel Pit
OW 94-3	Pittston Academy Grant	0102	45°53’58"N	69o57’04"W	1090	45.0	Forest
OW 94-4	Comstock Twp.	0102	45°56’30"N	69°59’49"W	1110	56.0	Gravel Pit
OW 94-5	Little Squaw Twp.	0102	45°24’01"N	69°37’28"W	1050	23.0	Gravel Pit
OW 94-6	Little Squaw Twp.	0103	45°25’48"N	69°37’59"W	1070	14.0	Forest
OW 94-7	Blanchard Twp.	0102	45°15’56"N	69°40’12"W	1060	20.0	Gravel Pit/Forest
OW 94-8	Willimantic	0102	45°18’36"N	69°23’57"W	370	15.0	Gravel Pit/Forest
OW 94-9	Willimantic	0102	45°18’10"N	69°24’40"W	430	75.0	Field
OW 94-10	Willimantic	0102	45°18’11"N	69°19’37"W	330	13.5	Forest

Table 7. Background water quality in sand and gravel aquifers in the study area.
All values in milligrams per liter (mg/L) except as noted; uS/cm, microsiemens per centimeter at 25^{o} Celsius;
—, value not determined.

OBSERVATION WELL NUMBER	HUC	DATE	SPECIFIC CONDUCTANCE (uS/cm)	pH (STANDARD UNITS)	TEMPERATURE WATER (DEG C)	OXYGEN DISSOLVED (mg/L)	HARDNESS TOTAL (mg/L as $CaCO_3$)	CALCIUM DISSOLVED (mg/L as Ca)	MAGNESIUM DISSOLVED (mg/L as Mg)	SODIUM DISSOLVED (mg/L as Na)
94-1	0103	08-30-94	40	5.6	7.5	1.30	11	2.9	1.00	2.3
94-2	0103	08-31-94	180	8.2	7.5	1.60	88	29.0	3.70	1.8
94-3	0102	08-30-94	152	7.2	6.0	4.00	74	25.0	2.80	2.7
94-4	0102	08-30-94	128	6.7	6.5	2.20	54	17.0	2.90	2.9
94-5	0102	08-31-94	60	6.1	8.5	1.50	20	5.1	1.80	2.5
94-6	0102	—	—	—	—	—	—	—	—	—
94-7	0102	—	—	—	—	—	—	—	—	—
94-8	0102	08-29-94	59	6.6	11.0	8.30	25	7.1	1.80	60.0
94-9	0102	09-01-94	131	8.2	8.5	1.20	55	15.0	4.20	2.8
94-10	0102	09-01-94	26	6.3	9.5	9.50	8	2.4	0.47	1.0
GVWD[1]	0103	09-02-94	86	6.7	7.0	4.60	40	11.0	3.00	1.4
T-NR[1]	0103	08-31-94	61	5.9	10.0	3.60	21	6.7	1.10	2.0
FWB[2]	0102	09-01-94	54	6.2	8.0	8.80	20	5.4	1.50	2.3
TF[2]	0103	08-31-94	50	6.2	7.0	8.20	19	5.3	1.50	1.9
		MINIMUM	26	5.6	6.0	1.20	8	2.4	0.47	1.0
		MAXIMUM	180	8.2	11.0	9.50	88	29.0	4.20	60.0
		MEDIAN	74	6.6	8.0	2.90	32	9.0	2.30	2.4
		MEAN	92	6.8	8.2	3.78	40	12.1	2.28	7.9
		STD. DEVIATION	52	0.9	1.6	2.97	27	9.2	1.23	18.3

HUC 0102 Penobscot River Basin

NUMBER	6	6	6	6	6	6	6	6
MINIMUM	26	6.1	6.0	1.20	8	2.4	0.47	1.0
MAXIMUM	152	8.2	11.0	9.50	74	25.0	4.20	60.0
MEDIAN	94	6.6	8.5	3.10	40	11.0	2.30	2.8
MEAN	93	6.8	8.3	4.45	39	11.9	2.33	12.0
STD. DEVIATION	51	0.8	1.9	3.60	25	8.6	1.27	23.5

HUC 0103 Kennebec River Basin

NUMBER	4	4	4	4	4	4	4	4
MINIMUM	40	5.6	7.0	1.30	11	2.9	1.00	1.4
MAXIMUM	180	8.2	10.0	4.60	88	29.0	3.70	2.3
MEDIAN	74	6.3	7.5	2.60	30	8.8	2.05	1.9
MEAN	92	6.6	8.0	2.78	40	12.4	2.20	1.9
STD. DEVIATION	62	1.2	1.4	1.59	34	11.6	1.36	0.4

1. Non-project well or spring located on an aquifer; water-quality results included in statistical analysis.
2. Non-project well or spring not located on an aquifer; water-quality results not included in statistical analysis.

Table 7. Background water quality in sand and gravel aquifers in the study area.
All values in milligrams per liter (mg/L) except as noted; uS/cm, microsiemens per centimeter at 25° Celsius;
—, value not determined.

OBSERVATION WELL NUMBER	POTASSIUM DISSOLVED (mg/L as K)	CARBONATE WATER DIS IT[3] FIELD (mg/L as $CACO_3$)	BICARBONATE WATER DIS IT[3] FIELD (mg/L as HCO_3)	ALKALINITY WAT WH TOT FET[4] FIELD (mg/L as $CaCO_3$)	ALKALINITY WAT DIS TOT IT[5] FIELD (mg/L as $CaCO_3$)	SULFATE DISSOLVED (mg/L as SO_4)	CHLORIDE DISSOLVED (mg/L as Cl)	FLUORIDE DISSOLVED (mg/L as F)	SILICA DISSOLVED (mg/L as SiO_2)
94-1	0.70	0	13	11	—	5.4	1.3	<0.10	11.0
94-2	0.40	0	93	76	—	9.5	0.7	<0.10	9.5
94-3	0.40	0	90	73	—	4.1	0.3	<0.10	9.5
94-4	0.80	0	52	43	—	5.5	9.9	<0.10	12.0
94-5	0.40	0	29	24	—	2.5	1.9	<0.10	16.0
94-6	—	—	—	—	—	—	—	—	—
94-7	—	—	—	—	—	—	—	—	—
94-8	0.40	0	27	22	—	4.7	0.8	<0.10	9.2
94-9	1.20	0	67	55	—	6.9	0.8	<0.10	12.0
94-10	0.30	0	8	7	—	2.8	0.7	<0.10	7.3
GVWD[1]	0.50	0	43	36	—	4.8	0.9	<0.10	12.0
T-NR[1]	0.10	0	15	13	—	3.0	7.7	<0.10	5.3
FWB[2]	0.90	0	23	20	—	3.2	0.8	<0.10	13.0
TF[2]	0.10	0	21	17	—	4.7	0.3	<0.10	9.9
MINIMUM	0.10	0	8	7	—	2.5	0.3	<0.10	5.3
MAXIMUM	1.20	0	93	76	—	9.5	9.9	<0.10	16.0
MEDIAN	0.40	0	36	30	—	4.8	0.8	<0.10	10.2
MEAN	0.52	0	44	36	—	4.9	2.5	<0.10	10.4
STD. DEVIATION	0.31	0	31	25	—	2.1	3.4	0	2.9

HUC 0102 Penobscot River Basin

NUMBER	6	6	6	6	0	6	6	6	6
MINIMUM	0.30	0	8	7	—	2.5	0.3	<0.10	7.3
MAXIMUM	1.20	0	90	73	—	6.9	9.9	<0.10	16.0
MEDIAN	0.40	0	40	34	—	4.4	0.8	<0.10	10.8
MEAN	0.58	0	46	37	—	4.4	2.4	<0.10	11.0
STD. DEVIATION	0.35	0	30	24	—	1.7	3.7	0	3.0

HUC 0103 Kennebec River Basin

NUMBER	4	4	4	4	0	4	4	4	4
MINIMUM	0.10	0	13	11	—	3.0	0.7	<0.10	5.3
MAXIMUM	0.70	0	93	76	—	9.5	7.7	<0.10	12.0
MEDIAN	0.45	0	29	24	—	5.1	1.1	<0.10	10.2
MEAN	0.42	0	40	34	—	5.7	2.6	<0.10	9.4
STD. DEVIATION	0.25	0	37	30	—	2.7	3.4	0	3.0

1. Non-project well or spring located on an aquifer; water-quality results included in statistical analysis.
2. Non-project well or spring not located on an aquifer; water-quality results not included in statistical analysis.
3. WATER DIS IT - Water dissolved incremental titration.
4. WAT WH TOT FT - Water whole total fixed end point titration (unfiltered sample).
5. WAT DIS TOT IT - Water dissolved incremental titration (filtered sample).

Table 7. Background water quality in sand and gravel aquifers in the study area. All values in milligrams per liter (mg/L) except as noted; uS/cm, microsiemens per centimeter at 25° Celsius; —, value not determined.

OBSERVATION WELL NUMBER	SOLIDS, RESIDUE AT 180°C DISSOLVED (mg/L)	SOLIDS, SUM OF CONSTITUENTS DISSOLVED (mg/L)	NITROGEN, $NO_2 + NO_3$ TOTAL (mg/L as N)	PHOSPHORUS TOTAL (mg/L as P)	IRON, TOTAL RECOVERABLE (mg/L as FE)	IRON DISSOLVED (mg/L as FE)	MANGANESE TOTAL RECOVERABLE (mg/L as MN)	MANGANESE DISSOLVED (mg/L as MN)	CARBON, ORGANIC TOTAL (mg/L as C)
94-1	33	34	0.180	0.47	73.00	1.200	1.90	0.630	10.0
94-2	96	101	0.077	0.07	9.90	0.018	0.32	0.010	0.7
94-3	105	90	0.130	0.14	28.00	0.065	1.30	0.560	4.6
94-4	84	81	0.063	0.10	60.00	2.400	2.30	1.300	7.7
94-5	42	47	0.086	0.24	8.30	0.990	1.20	1.100	2.4
94-6	—	—	—	—	—	—	—	—	—
94-7	—	—	—	—	—	—	—	—	—
94-8	41	97	<0.050	0.22	7.00	0.065	0.17	0.008	0.8
94-9	81	76	0.054	0.05	53.00	0.017	1.40	0.170	2.0
94-10	20	19	<0.050	<0.01	0.07	<0.003	0.02	0.021	0.4
GVWD[1]	52	55	<0.050	0.24	29.00	0.580	0.12	0.043	1.0
T-NR[1]	39	34	0.170	<0.01	0.02	0.006	<0.01	<0.001	1.3
FWB[2]	42	40	0.450	<0.01	<0.01	<0.003	<0.01	<0.001	0.4
TF[2]	31	36	0.350	<0.01	0.03	0.008	<0.01	0.001	0.9
MINIMUM	20	19	<0.050	<0.01	0.02	<0.003	<0.01	<0.001	0.4
MAXIMUM	105	101	0.180	0.47	73.00	2.400	2.30	1.300	10.0
MEDIAN	47	66	0.070	0.12	18.95	0.065	0.76	0.106	1.6
MEAN	59	63	0.084	0.15	26.83	0.534	0.87	0.384	3.1
STD. DEVIATION	30	29	0.058	0.14	26.63	0.794	0.85	0.490	3.3

HUC 0102 Penobscot River Basin

NUMBER	6	6	6	6	6	6	6	6	6
MINIMUM	20	19	<0.050	<0.01	0.07	<0.003	0.02	0.008	0.4
MAXIMUM	105	97	0.130	0.24	53.00	2.400	2.30	1.300	7.7
MEDIAN	62	78	0.058	0.12	18.15	0.065	1.25	0.365	2.2
MEAN	62	68	0.064	0.13	26.06	0.590	1.06	0.526	3.0
STD. DEVIATION	33	30	0.040	0.09	25.44	0.966	0.85	0.562	2.7

HUC 0103 Kennebec River Basin

NUMBER	4	4	4	4	4	4	4	4	4
MINIMUM	33	34	<0.050	<0.01	0.02	0.006	<0.01	<0.001	0.7
MAXIMUM	96	101	0.180	0.47	73.00	1.200	1.90	0.630	10.0
MEDIAN	46	44	0.124	0.16	19.45	0.299	0.22	0.026	1.2
MEAN	55	56	0.113	0.20	28.00	0.451	0.59	0.171	3.2
STD. DEVIATION	28	32	0.075	0.21	32.33	0.567	0.88	0.307	4.5

1. Non-project well or spring located on an aquifer; water-quality results included in statistical analysis.
2. Non-project well or spring not located on an aquifer; water-quality results not included in statistical analysis.

Table 8.—Background water quality in sand and gravel aquifers in previous and ongoing study areas, by drainage basin. (All values in milligrams per liter except as noted)

HUC 0101: St. John / Aroostook River Basin

	Conductivity (microsie-mens / cm)	pH	Tempera-ture (°C)	Hardness as $CaCO_3$	Calcium dissolved	Magnesium dissolved	Sodium dissolved	Potassium dissolved	Alkalinity as $CaCO_3$	Sulfate dissolved	Chloride dissolved	Nitrate + Nitrite as N	Iron dissolved	Manganese dissolved	Total Organic Carbon
Number	25	25	25	25	25	25	25	25	21	25	25	23	25	25	25
Minimum	110	5.8	6.0	38.0	10.0	1.30	1.4	0.4	41	5.0	<0.5	0.02	0.004	0.003	0.4
Maximum	530	8.1	13.5	260.0	85.0	18.00	29.0	3.2	202	54.0	20.0	5.30	42.000	3.100	62.0
Median	250	7.2	7.5	120.0	42.0	3.60	3.9	1.0	112	12.0	5.6	0.95	0.050	0.170	4.0
Mean	273	—	8.2	137.6	46.8	5.13	5.7	1.1	123	17.5	7.1	1.57	2.194	0.504	8.3
Standard Deviation	98	—	1.9	60.5	20.0	3.96	5.7	0.7	49	13.5	5.5	1.78	8.363	0.800	14.0

HUC 0102: Penobscot River Basin

	Conductivity (microsie-mens / cm)	pH	Tempera-ture (°C)	Hardness as $CaCO_3$	Calcium dissolved	Magnesium dissolved	Sodium dissolved	Potassium dissolved	Alkalinity as $CaCO_3$	Sulfate dissolved	Chloride dissolved	Nitrate + Nitrite as N	Iron dissolved	Manganese dissolved	Total Organic Carbon
Number	44	45	45	45	45	45	45	45	44	45	45	45	35	35	42
Minimum	24	5.8	6.0	7.0	2.0	0.07	1.2	0.3	4	<0.1	0.4	0.05	0.007	<0.001	0.3
Maximum	310	9.2	16.5	150.0	44.0	10.00	37.0	3.0	150	27.0	67.0	7.30	13.000	9.800	6.1
Median	126	7.0	7.5	43.0	13.0	2.20	2.6	0.8	46	5.3	1.7	0.10	0.060	0.059	1.3
Mean	133	—	8.0	53.5	16.8	2.70	5.3	1.0	55	6.3	6.4	0.38	1.301	0.829	1.8
Standard Deviation	74	—	1.9	35.1	11.5	2.00	7.4	0.6	36	4.6	13.5	1.10	3.104	1.847	1.4

Table 8.—Background water quality in sand and gravel aquifers in previous and ongoing study areas, by drainage basin.
(All values in milligrams per liter except as noted)

HUC 0103: Kennebec River Basin

	Conductivity (microsie-mens / cm)	pH	Tempera-ture (°C)	Hardness as $CaCO_3$	Calcium dissolved	Magnesium dissolved	Sodium dissolved	Potassium dissolved	Alkalinity as $CaCO_3$	Sulfate dissolved	Chloride dissolved	Nitrate + Nitrite as N	Iron dissolved	Manganese dissolved	Total Organic Carbon
Number	33	33	33	33	33	33	33	33	33	33	33	32	33	33	30
Minimum	28	6.0	6.0	8.3	2.2	0.60	1.2	0.5	5	<1.0	<0.4	<0.01	<0.020	<0.005	<1.0
Maximum	347	8.8	12.1	158.0	45.0	14.00	15.0	3.2	150	49.0	24.0	5.00	3.700	2.100	7.5
Median	103	7.2	8.5	37.0	12.0	3.00	3.3	1.8	35	6.0	2.4	0.10	0.040	0.150	1.6
Mean	125	—	8.6	52.1	14.8	3.66	4.6	1.9	43	8.5	5.5	0.51	0.405	0.272	2.1
Standard Deviation	78	—	1.3	36.9	10.1	3.19	3.3	0.7	33	10.6	6.1	1.04	0.799	0.421	2.0

HUC 0104: Androscoggin River Basin

	Conductivity (microsie-mens / cm)	pH	Tempera-ture (°C)	Hardness as $CaCO_3$	Calcium dissolved	Magnesium dissolved	Sodium dissolved	Potassium dissolved	Alkalinity as $CaCO_3$	Sulfate dissolved	Chloride dissolved	Nitrate + Nitrite as N	Iron dissolved	Manganese dissolved	Total Organic Carbon
Number	22	22	22	22	22	22	22	22	22	22	22	22	22	21	20
Minimum	34	5.6	6.0	8.0	2.2	0.80	1.5	0.4	4	<3.0	<0.5	<0.01	<0.020	<0.005	<1.0
Maximum	191	8.5	10.5	77.0	17.0	8.90	11.0	7.1	70	14.0	16.0	0.80	3.200	1.200	30.0
Median	82	6.6	8.5	21.0	5.8	1.45	4.2	1.3	18	7.0	1.5	0.12	0.070	0.100	1.7
Mean	89	—	8.4	29.3	8.5	1.94	4.8	2.0	24	6.9	3.6	0.23	0.023	0.190	4.4
Standard Deviation	38	—	1.0	17.8	5.1	1.73	2.7	1.6	16	3.3	3.8	0.24	0.670	0.270	7.3

Table 8.—Background water quality in sand and gravel aquifers in previous and ongoing study areas, by drainage basin.
(All values in milligrams per liter except as noted)

HUC 0105: Eastern and Central Coastal Basins

	Conductivity (microsiemens / cm)	pH	Temperature (°C)	Hardness as $CaCO_3$	Calcium dissolved	Magnesium dissolved	Sodium dissolved	Potassium dissolved	Alkalinity as $CaCO_3$	Sulfate dissolved	Chloride dissolved	Nitrate + Nitrite as N	Iron dissolved	Manganese dissolved	Total Organic Carbon
Number	32	32	32	32	32	32	32	32	32	32	32	32	28	28	31
Minimum	20	5.7	6.0	1.0	0.2	0.08	1.8	0.3	5	1.3	0.5	<0.01	<0.030	0.005	<1.0
Maximum	460	8.5	12.0	200.0	63.0	11.00	39.0	4.4	450	28.0	63.0	0.51	4.700	0.820	83.0
Median	46	6.7	9.0	12.5	3.6	0.90	3.8	1.0	15	2.5	2.0	0.09	0.070	0.034	0.5
Mean	78	—	9.4	25.1	7.5	1.57	6.9	1.3	36	4.4	4.5	0.13	0.420	0.111	8.6
Standard Deviation	85	—	1.7	36.4	11.6	1.97	7.6	1.0	78	4.8	11.0	0.14	0.927	0.196	19.7

HUC 0106: Saco River Basin

	Conductivity (microsiemens / cm)	pH	Temperature (°C)	Hardness as $CaCO_3$	Calcium dissolved	Magnesium dissolved	Sodium dissolved	Potassium dissolved	Alkalinity as $CaCO_3$	Sulfate dissolved	Chloride dissolved	Nitrate + Nitrite as N	Iron dissolved	Manganese dissolved	Total Organic Carbon
Number	36	35	36	36	36	36	36	36	35	35	35	35	36	36	13
Minimum	17	5.3	6.5	3.9	1.2	0.21	1.4	0.4	3	<3.0	<0.5	<0.01	<0.030	<0.005	<1.0
Maximum	214	7.3	15.0	92.0	29.0	4.80	52.0	4.8	82	18.0	42.0	8.00	10.000	1.500	17.0
Median	58	6.3	8.5	20.5	5.3	1.10	4.8	1.4	13	5.0	3.0	0.05	0.115	0.135	2.0
Mean	70	—	8.9	25.7	6.7	1.51	7.0	1.7	18	6.5	5.6	0.52	0.850	0.294	5.0
Standard Deviation	42	—	1.8	19.0	5.2	1.11	8.5	1.1	16	4.5	7.7	1.46	2.173	0.381	5.5

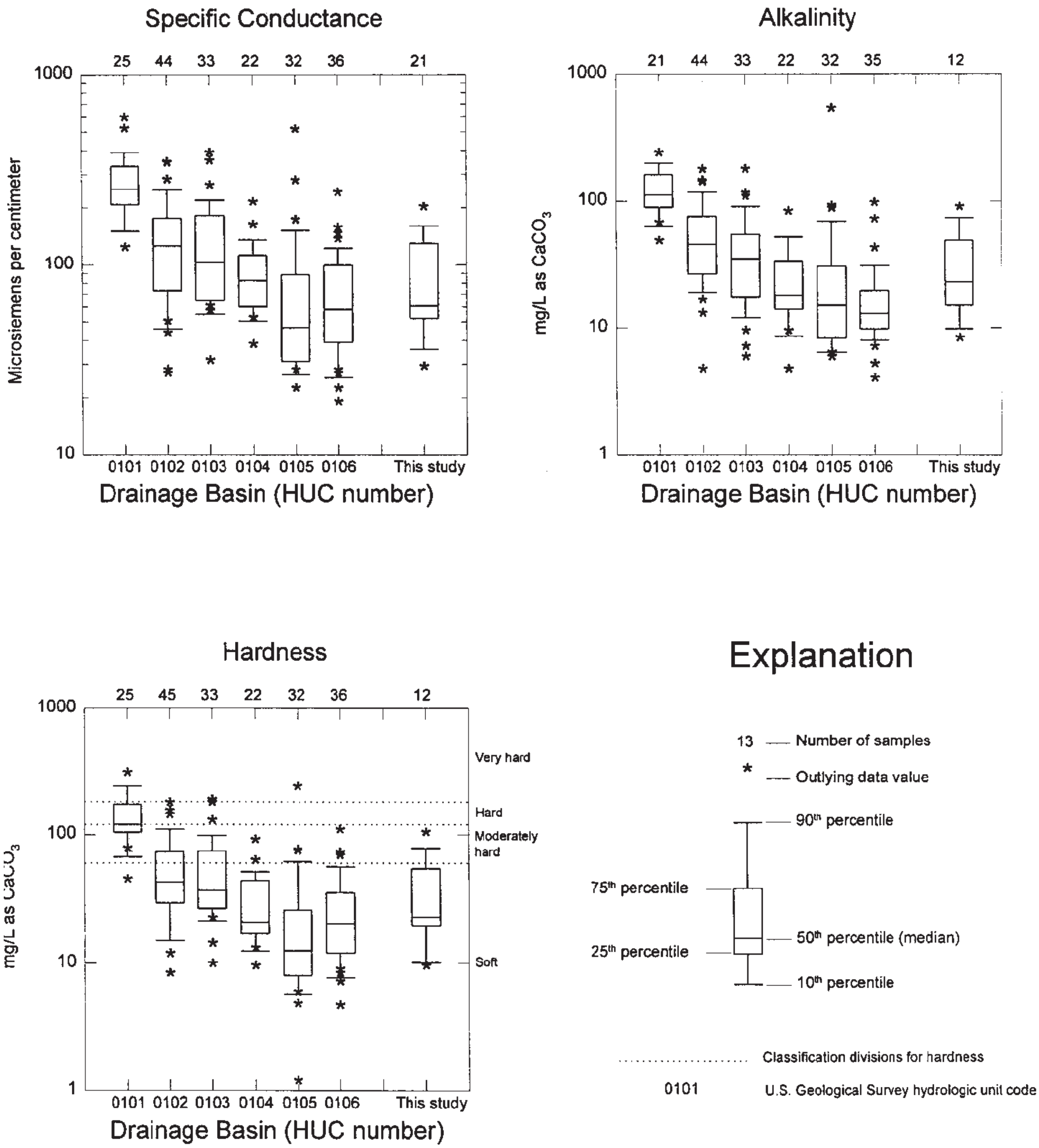


Figure 11. Boxplots of selected water-quality properties by drainage basin.

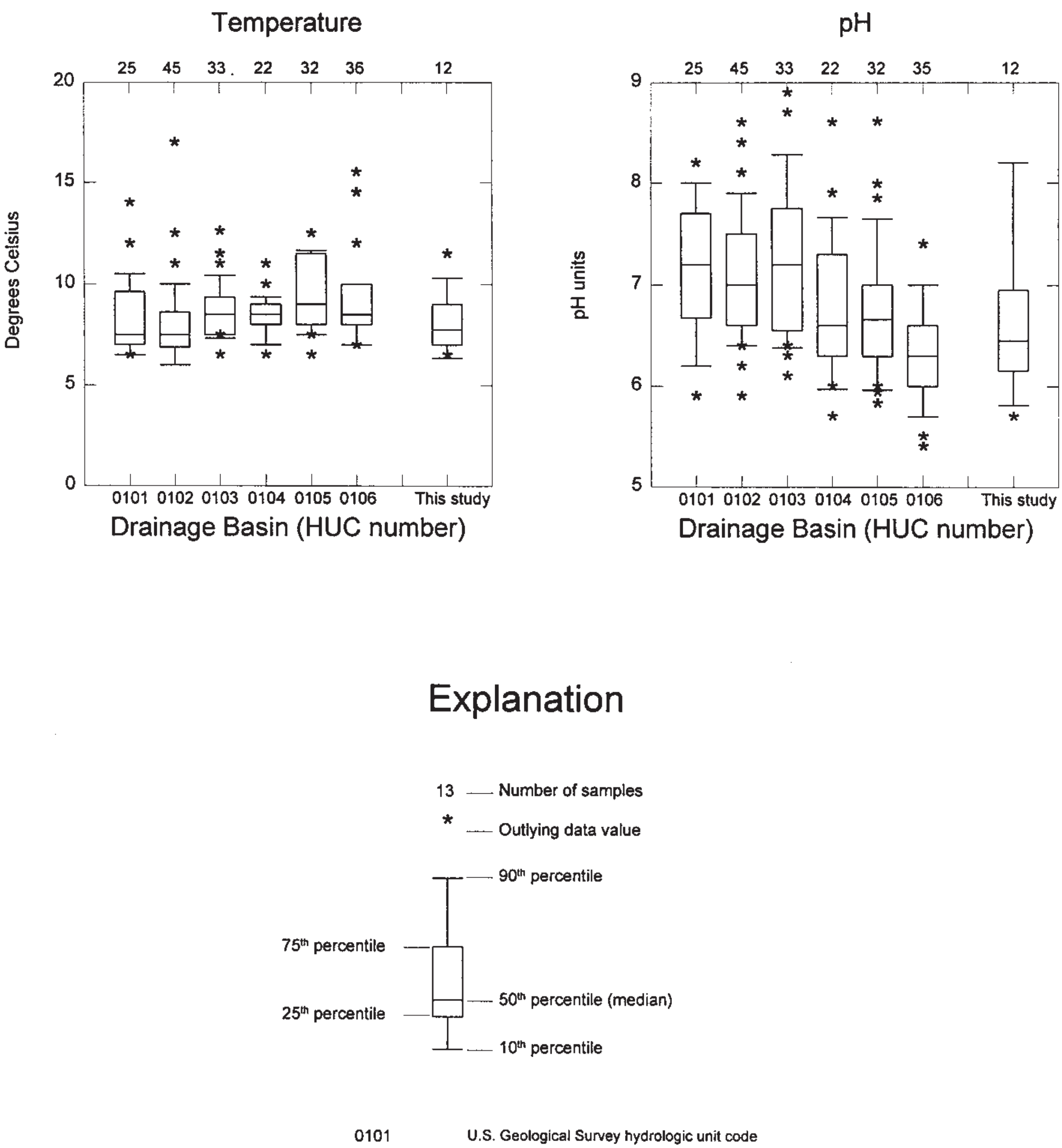


Figure 11. Boxplots of selected water-quality properties by drainage basin, continued.

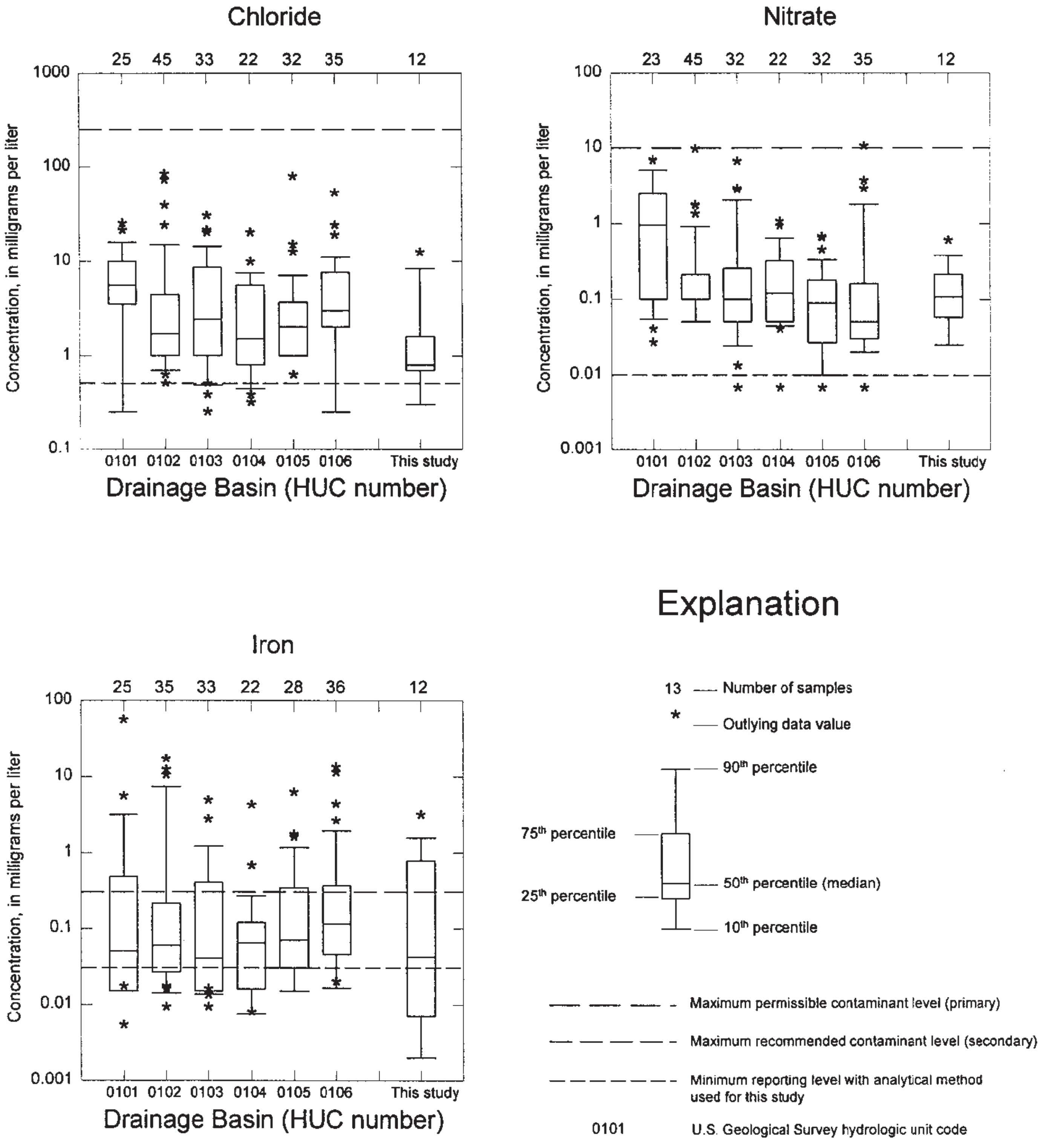


Figure 12. Boxplots of selected water-quality constituents by drainage basin with U.S. Environmental Protection Agency and Maine Department of Human Services drinking-water standards.

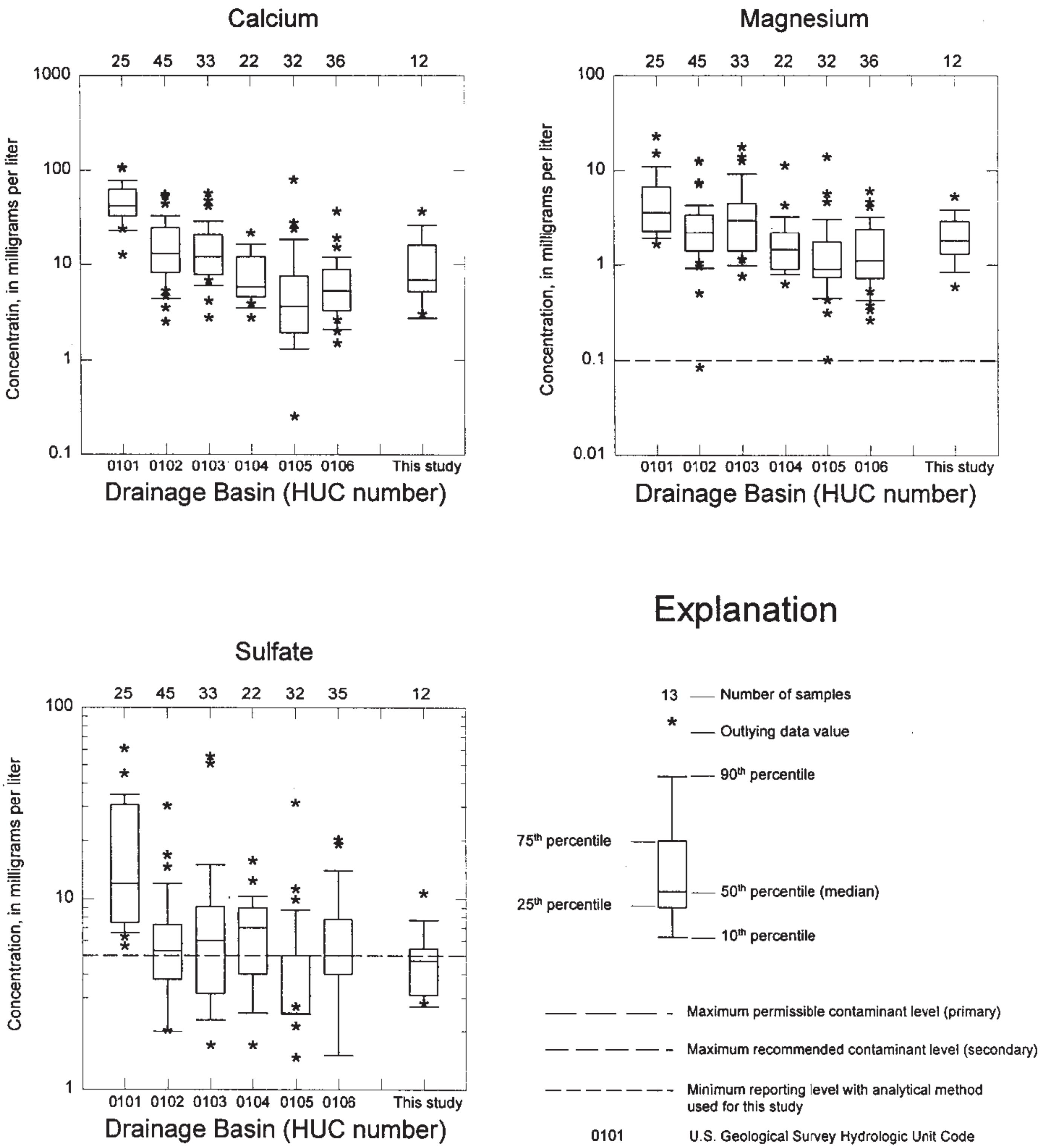


Figure 12. Boxplots of selected water-quality constituents by drainage basin with U.S. Environmental Protection Agency and Maine Department of Human Services drinking-water standards, continued.

from all study areas of the statewide Significant Sand and Gravel Aquifer Mapping Program. Percentiles of some of the constituents are compared to the U.S. Environmental Protection Agency (USEPA), (1986) and Maine Department of Human Services (MDHS) drinking-water standards (1983) in Figure 12. The maximum contaminant levels (MCL) are health related and are legally enforceable. The secondary maximum contaminant levels (SMCL) apply to aesthetic qualities and are recommended guidelines. The minimum reporting level shown on Figure 12 is the value presently in use at the USGS laboratory in Arvada, Colorado. That value has changed with time and with the particular laboratory used for the analyses. Data points on Figure 12 below the minimum reporting level are from earlier study areas when the minimum reporting level was lower or from a laboratory that claimed a lower reporting level.

Specific Conductance

The specific conductance (conductivity) of water is a measure of its capacity to conduct an electrical current. The presence of charged ions makes water conductive; as the ion concentration increases, so does the specific conductance. Dissolved inorganic salts are the source of most ionic species and make up a large part of the total dissolved solids in most natural waters.

Although there is no drinking-water standard for specific conductance, the U.S. Department of Health, Education and Welfare (1962) has recommended a maximum concentration of 500 mg/L for dissolved solids in drinking water. The concentration of dissolved solids, in milligrams per liter, can be estimated by multiplying the specific conductance value, in S/cm (microsiemens per centimeter at 25 degrees Celsius), by a factor that depends on the chemical character of the sample and usually ranges from 0.55 to 0.75 (Hem, 1985).

Specific conductance of the water-quality samples from the study area ranges from 26 to 180 S/cm, with a median of 74 S/cm (Table 7, Figure 11). Converting to dissolved solids (using the high-end factor of 0.75 for a worst-case estimate), a range of 20 to 135 mg/L and median of 56 mg/L is estimated for dissolved-solids concentration. The estimated dissolved-solid concentrations in the study area are therefore below the recommended maximum concentration of 500 mg/L.

pH

The pH of water is a measure of hydrogen-ion activity (concentration). Specifically, the abbreviation “pH” represents the negative base-10 log of the hydrogen ion activity in moles per liter. Each unit increase in the pH scale represents a tenfold decrease in hydrogen-ion activity. A pH of 7 is considered neutral, less than 7 is acidic, and greater than 7 is alkaline. In Tables 7 and 8, mean and standard deviation values are not given for pH because those statistics are not valid for values from an exponential scale. The primary control on pH in ground water involves interaction of soil and rocks with gaseous carbon dioxide, bicarbonate, and carbonate ions. The pH in the background water-quality samples from the study area ranges from 5.6 to 8.2, with a median of 6.6 (Table 7, Figure 11). The USEPA (1986) has set a recommended pH range for drinking water of from 5 to 9.

Temperature

The temperature of ground water normally has a small seasonal fluctuation and remains within a few degrees of the mean annual air temperature in a given area. In Maine, ground-water temperatures are typically between 4.4^{o}C and 10.0^{o}C (Caswell, 1987). The temperature of ground water in the study area varies from 6.0^{o} C to 11.0^{o} C, with a median of 8.0^{o} C (Table 7, Figure 11).

Calcium, Magnesium, and Hardness

Because calcium is widely distributed in the common minerals of rocks and soil, it is the principal cation in most freshwater (Hem, 1985). Magnesium is also a common cation in ground water. The Maine Department of Human Services (1983) has not recommended any maximum limits for calcium, magnesium, or hardness in drinking water.

Concentrations of calcium, the principal cation in the background water-quality samples, range from 2.4 to 29.0 mg/L in the study area, with a median of 9.0 mg/L (Table 7, Figure 12).

Magnesium concentrations in the study area range from 0.47 to 4.20 mg/L, with a median of 2.30 mg/L (Table 7, Figure 12).

Hardness is a measure of the abundance of cations, mainly calcium and magnesium, that react with soap to form insoluble compounds or precipitate from heated water to form encrustations (Hem, 1985). Other divalent cations, including strontium, iron, and manganese, also can contribute to hardness. Hard water requires considerable amounts of soap to produce a foam or lather and is the cause of scale in hot-water pipes, heaters, boilers, and other units that use hot water.

Hardness in study-area samples was calculated by Standard Method 314A (American Public Health Association and others, 1985) and is expressed in terms of an equivalent concentration of calcium carbonate. Water is considered soft if it contains 0 to 60 mg/L of hardness, moderately hard if it contains 61 to 120 mg/L, hard if it contains 121 to 180 mg/L, and very hard if it contains more than 180 mg/L (Hem, 1985). Ground-water samples from the study area have hardness ranging from 8 to 88 mg/L, with a median of 32 mg/L (Table 7, Figure 11). This indicates that hardness of water in the region is soft to moderately hard.

Sodium and Potassium

Sodium and potassium are among the major cations in ground water in Maine. For sodium, a drinking water standard of 20 mg/L has been set by the Maine Department of Human Services (1983) to protect individuals on restricted sodium diets. These diets usually are recommended for people with heart, hypertension, or kidney problems. No maximum limit has been set for potassium in drinking water.

Concentrations of sodium in the background water-quality samples from the study area range from 1.0 to 60.0 mg/L, with a median of 2.4 mg/L. Concentrations of potassium in the study area range from 0.10 to 1.20 mg/L, with a median of 0.40 mg/L (Table 7).

Alkalinity

Alkalinity is a measure of the capacity of a solution to neutralize acid. This capacity depends on the concentrations of carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), and hydroxyl (OH^-). Under equilibrium conditions, pH can be used to indicate the distribution of the different carbonate species (Hem, 1985). Bicarbonate is the dominant anion in ground water in the study area. Alkalinity is reported in terms of equivalent calcium carbonate ($CaCO_3$) concentration. Alkalinity concentrations in the study area range from 7 to 76 mg/L, with a median of 30 mg/L (Table 7, Figure 11).

Sulfate

Sulfate is one of the major anions in natural waters. Sulfate can be reduced under anaerobic conditions to hydrogen-sulfide gas (H_2S). The rotten-egg odor of this gas can be detected in water at levels as low as a few tenths of a milligram per liter. The USEPA (1989) has set a SMCL for sulfate of 250 mg/L in drinking water; at levels above this, sulfate can have a laxative effect. Sulfate concentrations in the background water-quality samples from the study area range from 2.5 to 9.5 mg/L, with a median of 4.8 mg/L (Table 7, Figure 12).

Chloride

Because chloride is a highly mobile ion and is not readily sorbed, it can be used to trace contamination from road salt, salt-sand storage piles, landfills, and septic tanks. The USEPA (1989) has set a SMCL of 250 mg/L for chloride. High chloride concentrations in water will contribute to the deterioration of plumbing, water heaters, and water works equipment. High chloride concentrations in water also may be associated with high sodium concentrations. Chloride concentrations in the background water-quality samples from the study area range from 0.3 to 9.9 mg/L, with a median concentration of 0.8 mg/L (Table 7, Figure 12).

Nitrate Plus Nitrite

Nitrate and nitrite commonly are derived from plant and animal materials, but also can be contributed by fertilizers. Nitrate is the most common nitrogen compound in ground water. Because nitrate is weakly adsorbed by soil, it is a good indicator of contamination from septic systems and waste-disposal sites. Nitrate can be converted to nitrite in the stomach; this may lead to the onset of methemoglobinemia in infants, a potentially lethal disease (National Research Council, 1977). Because of this, the USEPA (1986) established a MCL of 10 mg/L nitrate-nitrogen (NO3-N) in drinking water. High nitrate levels are also potentially lethal to cattle and other ruminants.

Nitrate plus nitrite concentrations in the background water-quality samples from the study area range from <0.050 to 0.180 mg/L, with a median of 0.070 mg/L (Table 7, Figure 12). Values at or below the detection limit of 0.050 mg/L were reported as less than 0.050 mg/L.

Iron and Manganese

Elevated iron and manganese concentrations may cause some problems for municipal water systems and individual well owners in the study area. Humans are not known to suffer any harmful effects from drinking water that contains excessive iron; however, concentrations of only a few tenths of a milligram per liter of iron and a few hundredths of a milligram per liter of manganese can make water unsuitable for some uses. Both iron and manganese may stain clothes and plumbing fixtures and can cause problems in distribution systems by supporting growth of iron bacteria. Even at very low concentrations, iron in water can impart an objectionable taste, which is often described as rusty or metallic. When exposed to the air, water that contains dissolved iron and manganese may become turbid because of the formation of colloidal precipitates.

Dissolved iron concentrations in the study area samples vary from <0.003 mg/L to 2.400 mg/L, with a median of 0.065mg/L (Table 7, Figure 12). The median values for iron in all the drainage basins are within the recommended limit of 0.3 mg/L for drinking water set by the USEPA (1989).

Dissolved manganese concentrations in the project area range from <0.001 mg/L to 1.300 mg/L, with a median of 0.106 mg/L (Table 7). The median dissolved manganese concentration exceeds the recommended drinking limit of 0.050 mg/L set by the USEPA (1989).

Filtration units can be installed by individual well owners to remove objectionable levels of iron and manganese. Treatment might be necessary to remove iron and manganese from public ground-water supplies in some localities in the study area.

Total Organic Carbon

TOC (total organic carbon) is a bulk indicator of all organic chemicals present in water. The TOC-measurement technique does not distinguish between toxic and nontoxic organic species. Natural organic species derived from soils can cause anomalously high TOC concentrations. The TOC concentrations in the background water-quality samples from the study area range from 0.4 to 10.0 mg/L, with a median of 1.6 mg/L (Table 7).

Discussion

Several studies have indicated that the composition of stratified drift in an area mirrors the local bedrock lithology (Trefethen and Trefethen, 1944; Flint, 1971; Van Beever, 1971; Legget, 1976; Bolduc and others, 1987; Evenson and Clinch, 1987). This is reflected in the water quality from wells installed in the stratified drift when compared by drainage basin.

The median values of selected chemical and physical parameters in Figures 11 and 12 and Table 8 show a consistent trend between major drainage basins. Median values for conductivity, alkalinity, sulfate, calcium, magnesium, and hardness consistently decrease from north to south. The highest parameter values are found in the St. John/Aroostook River basin (HUC 0101), with progressively decreasing values found in the Penobscot River basin (HUC 0102), the Kennebec River basin (HUC 0103), the Androscoggin River basin (HUC 0104), the Eastern and Central Coastal Basins (HUC 0105), and the Saco River basin (HUC 0106) respectively. While there may be a wide range of values for a particular parameter within each drainage basin, the consistent trend of the median values is noteworthy.

A geologic feature that varies from north to south in Maine is metamorphic grade (Figure 13). Using all ground water quality data collected for the Significant Sand and Gravel Aquifer Mapping Program through the 1994 study area, Figure 14 shows, both graphically and in tabular form, median values of conductivity, alkalinity, and hardness for each major drainage basin versus the percent of each basin underlain by "weakly metamorphosed" bedrock. Weakly metamorphosed in this case is taken from the Generalized Map of Metamorphic Facies in Osberg and others (1985), and corresponds roughly to sub-greenschist grade. A best fit regression line for each parameter is also shown on Figure 14. The correlations between conductivity, alkalinity, and hardness and percent weakly metamorphosed bedrock in each basin is good, with r^2 values greater than 0.92 in all cases.

The evidence suggests that the variation in water quality, and the inferred variation in total dissolved solids, is primarily a function of the solubility of the stratified drift in each basin. Water quality is a function of several factors, including the mineralogy of the aquifer material, the pH of the recharge to the aquifer, temperature, and residence time. However, drainage basins underlain by predominantly low-grade metamorphic rocks have higher values of many chemical and physical parameters as measured in background water quality than do basins underlain by abundant high-grade metamorphic rocks and felsic plutons (Weddle and Loiselle, 1996).

SUMMARY

The significant sand and gravel aquifers in the study area consist of glacial ice-contact, ice-stagnation, outwash, and stream-alluvium deposits. These deposits primarily occur in the valleys of the major river systems and their tributaries, or are associated with other surface-water bodies.

Although the study area includes 1,412.4 mi^2, areas mapped as significant aquifers cover only 15.7 mi^2. Yields exceeding 50 gal/min are estimated to be available in only 0.1 mi^2 of these significant aquifers. The highest yields are obtainable in areas of thick, coarse-grained, saturated deposits that are hydraulically connected to an adjacent body of surface water as a source of induced recharge. The greatest known well yield is approximately 300 gallons per minute from a gravel-packed well in Little Squaw township that supplies the town of Greenville.

The water table in the significant sand and gravel aquifers typically is within 15 ft of land surface. Based on well-record data, the greatest known depth to bedrock exceeds 122 feet in observation well OW 94-9 in Willimantic.

On the basis of field relations, logs of observation wells, and interpretation of the geologic history, the following generalized stratigraphic relations have been determined: bedrock is overlain by till, which locally is overlain by ice-contact and outwash deposits, which may be overlain by and locally interbedded with glaciolacustrine deposits. These deposits, in turn, may be overlain by sand and gravel deposits of mixed origin. The thickness of the deposits and stratigraphic units varies considerably, depending on landform and local depositional controls during deglaciation and postglaciation.

The background water quality in sand and gravel aquifers in the study area has the following characteristics: the median pH is 6.6, calcium and sodium are the most abundant cations, bicarbonate is the dominant anion, and the water is soft to moderately hard. According to water-quality data for the study area and the prescribed drinking water standards, the regional water quality generally is suitable for drinking and most other uses. However, in some localities, concentrations of iron and manganese may limit the use of untreated water.

Solid-waste facilities and salt-sand storage areas are the most common potential sources of ground-water contamination identified on or near sand and gravel aquifers in the study area. No municipal water-supply wells in the study area are known to have been contaminated by these sources.

Comparison of background water quality between the major drainage basins of the state reveals a consistent decrease in median values of selected parameters from north to south. This

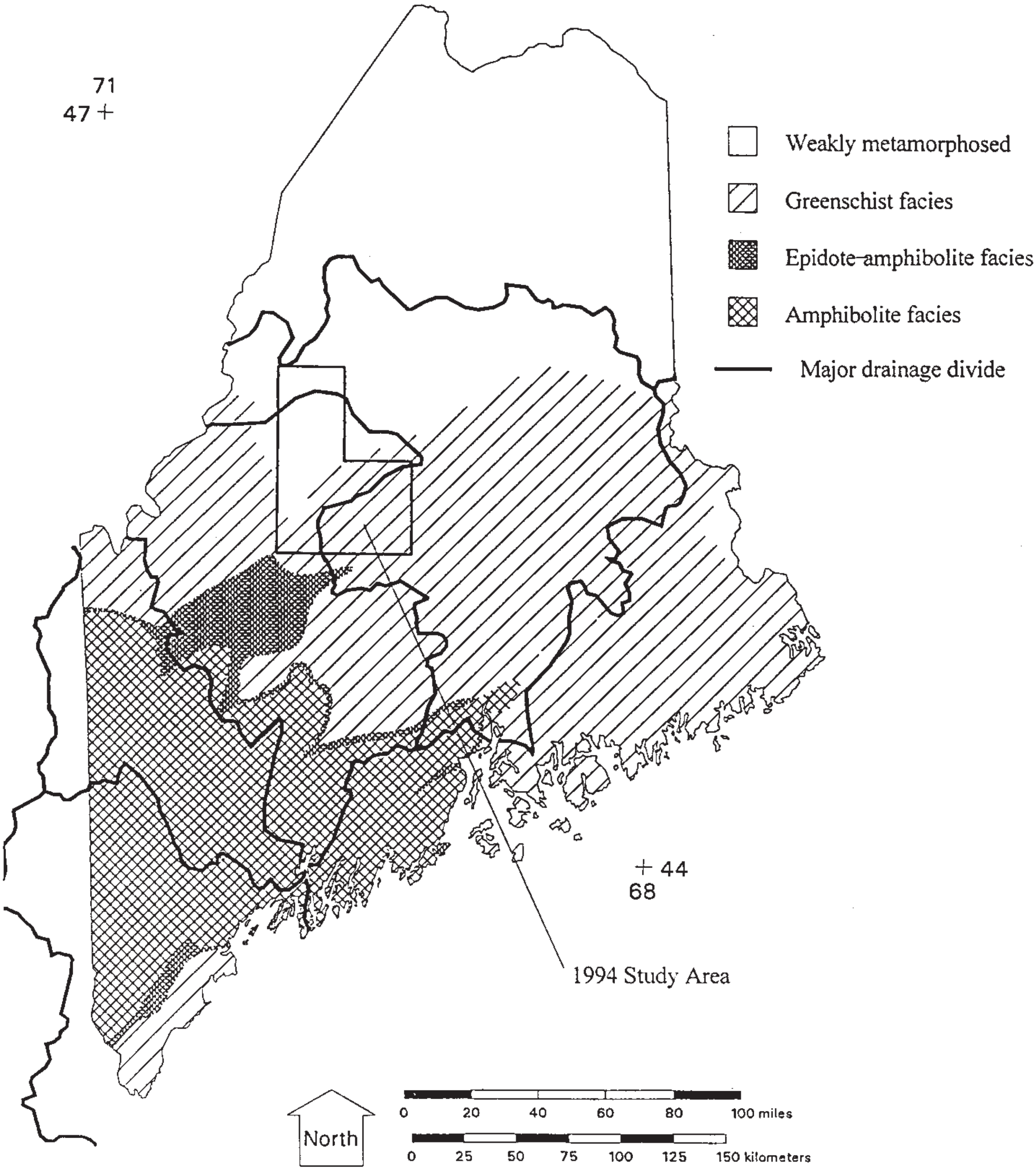
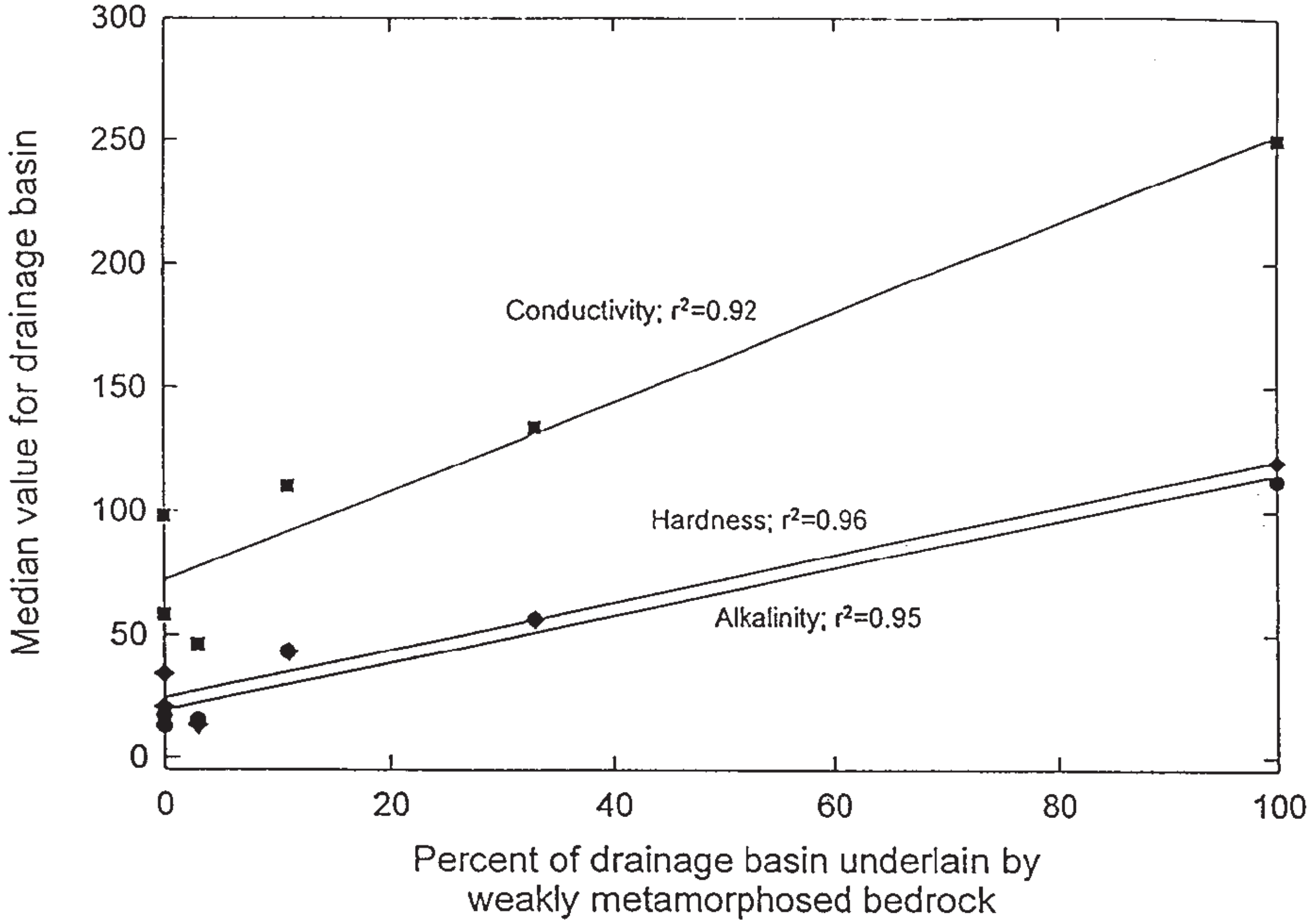


Figure 13. Major drainage basins, the study area, and metamorphic zones (modified vrom Osberg and others, 1985).



	PERCENT AREA	COND ■	ALK ●	HARD ♦
HUC 0101	100	250.0	112.0	120.0
HUC 0102	33	134.0	56.0	56.0
HUC 0103	11	110.0	43.0	43.0
HUC 0104	0	98.0	17.0	34.0
HUC 0105	3	46.0	15.0	13.5
HUC 0106	0	58.0	13.0	20.5

HUC - U.S. Geological Survey hydrologic unit code
PERCENT AREA - percentage of HUC underlain by weakly metamorphosed bedrock.
COND - conductivity, in microsiemens/cm.
ALK - alkalinity, in mg/L, as $CaCO_3$.
HARD - hardness, in mg/L, as $CaCO_3$.

Figure 14. Median conductivity, alkalinity, and hardness for the major drainage basins vs. percent of each basin underlain by weakly metamorphosed bedrock.

decrease correlates well with the percentage of the basin that is underlain by "weakly metamorphosed" bedrock. Numerous other factors (pH, temperature, residence time) may influence water quality but the evidence suggests these factors are minor relative to the composition of the aquifer material, which is controlled primarily by the basin bedrock geology and metamorphic grade.

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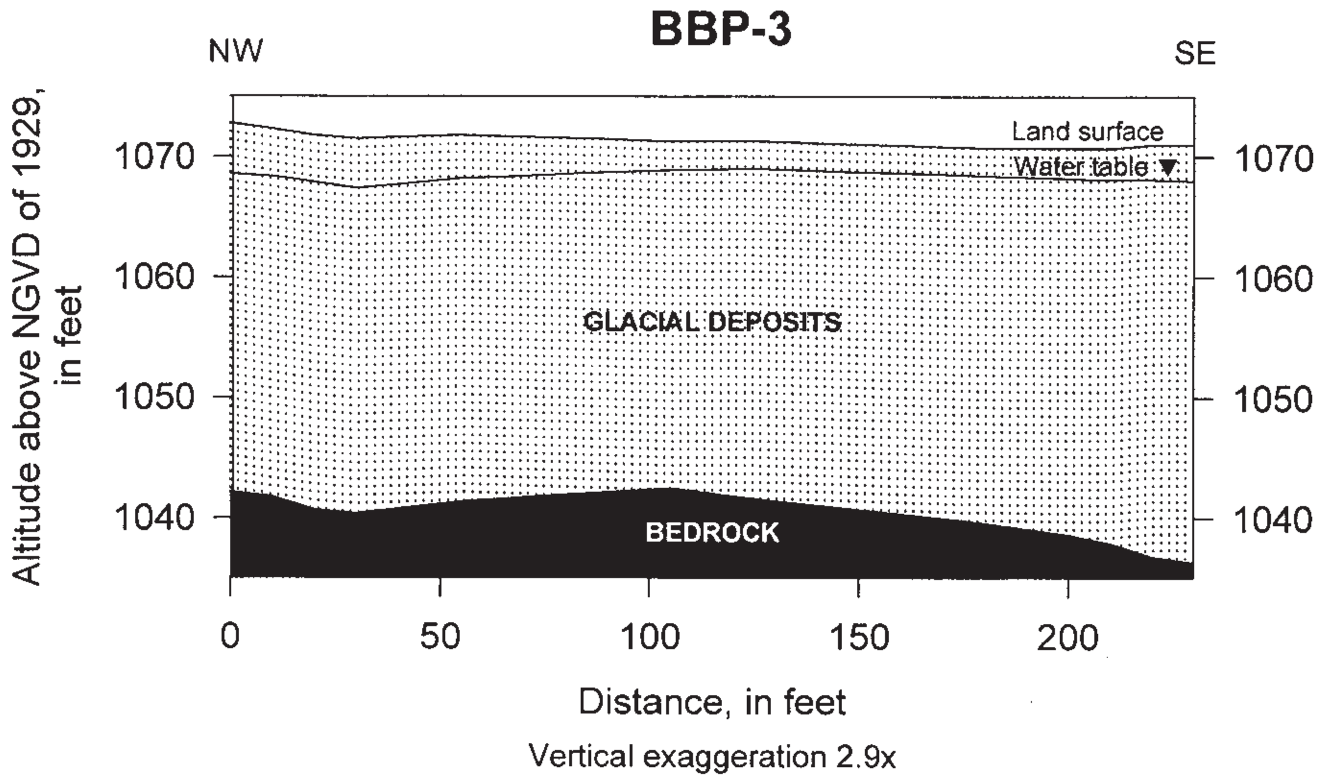
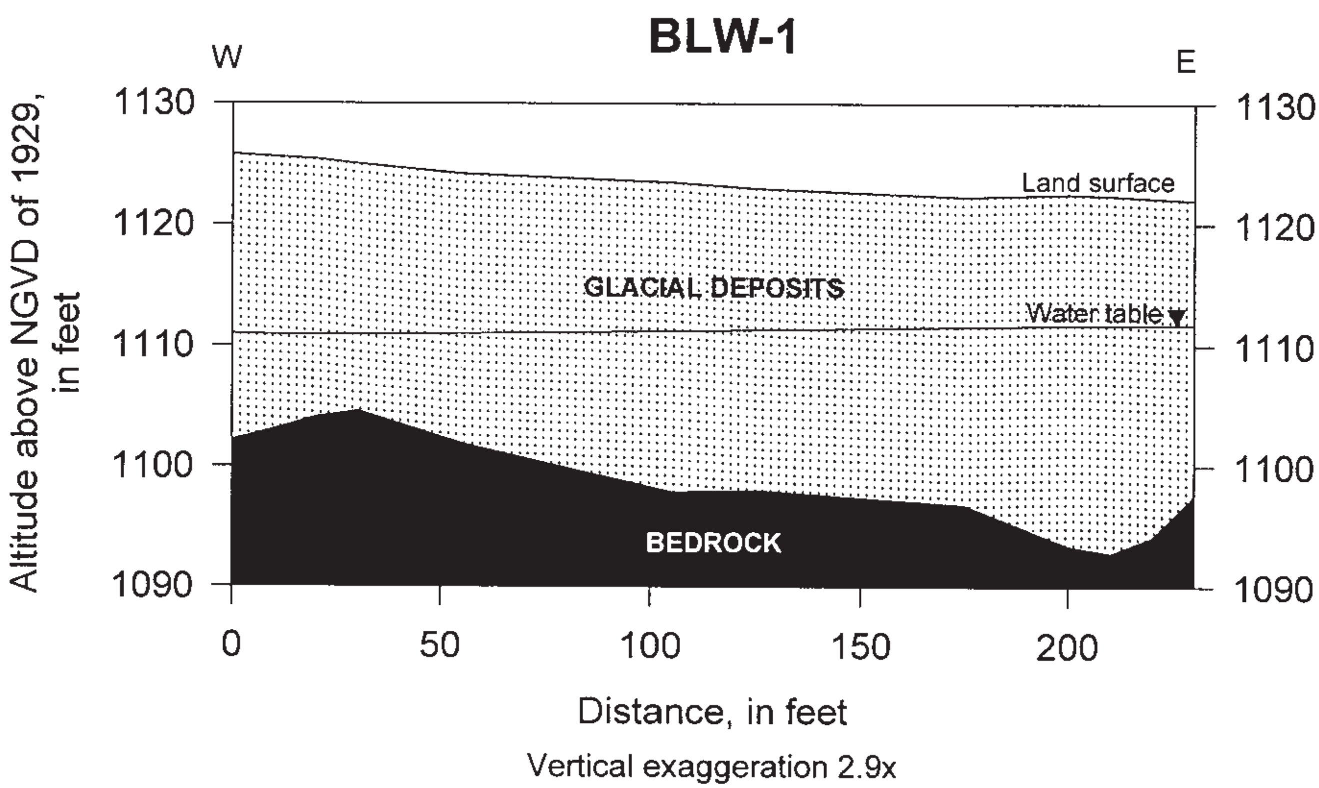
Appendix 1

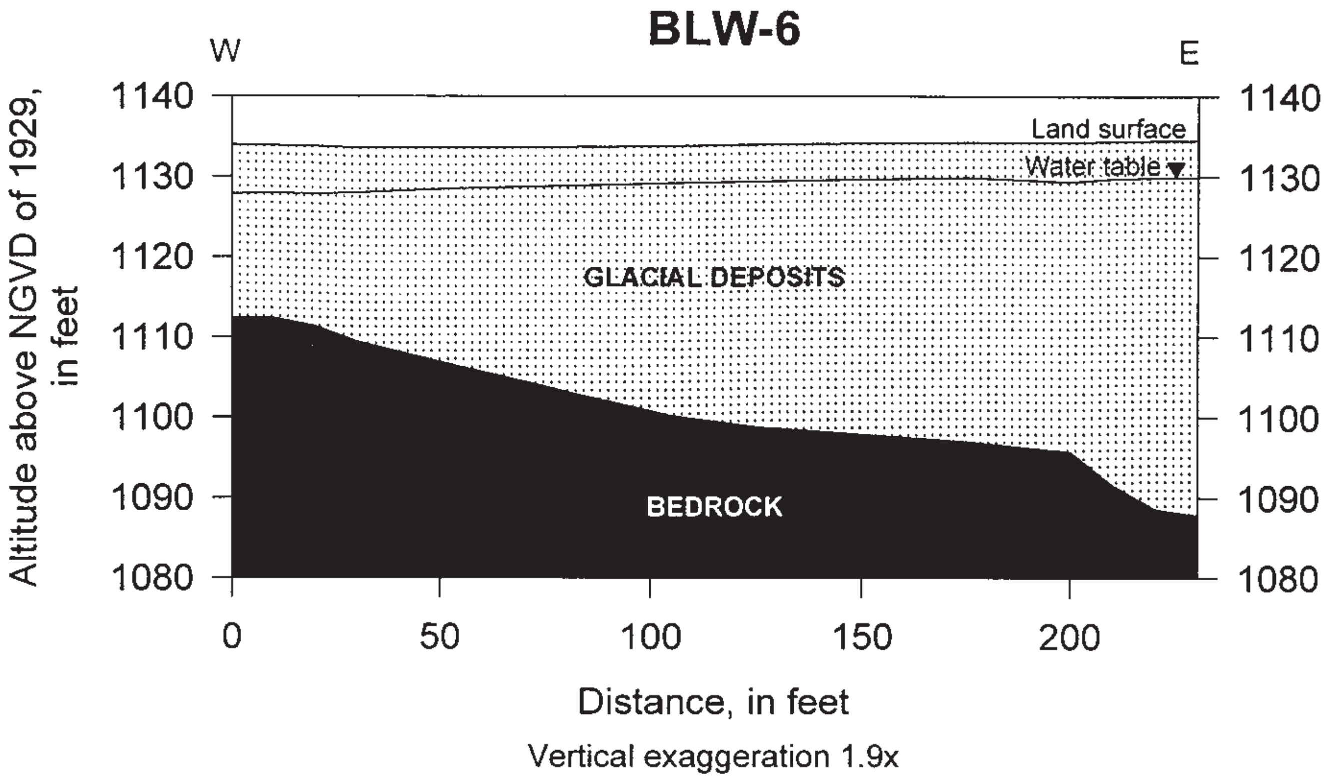
Twelve-Channel Seismic-Refraction Profiles

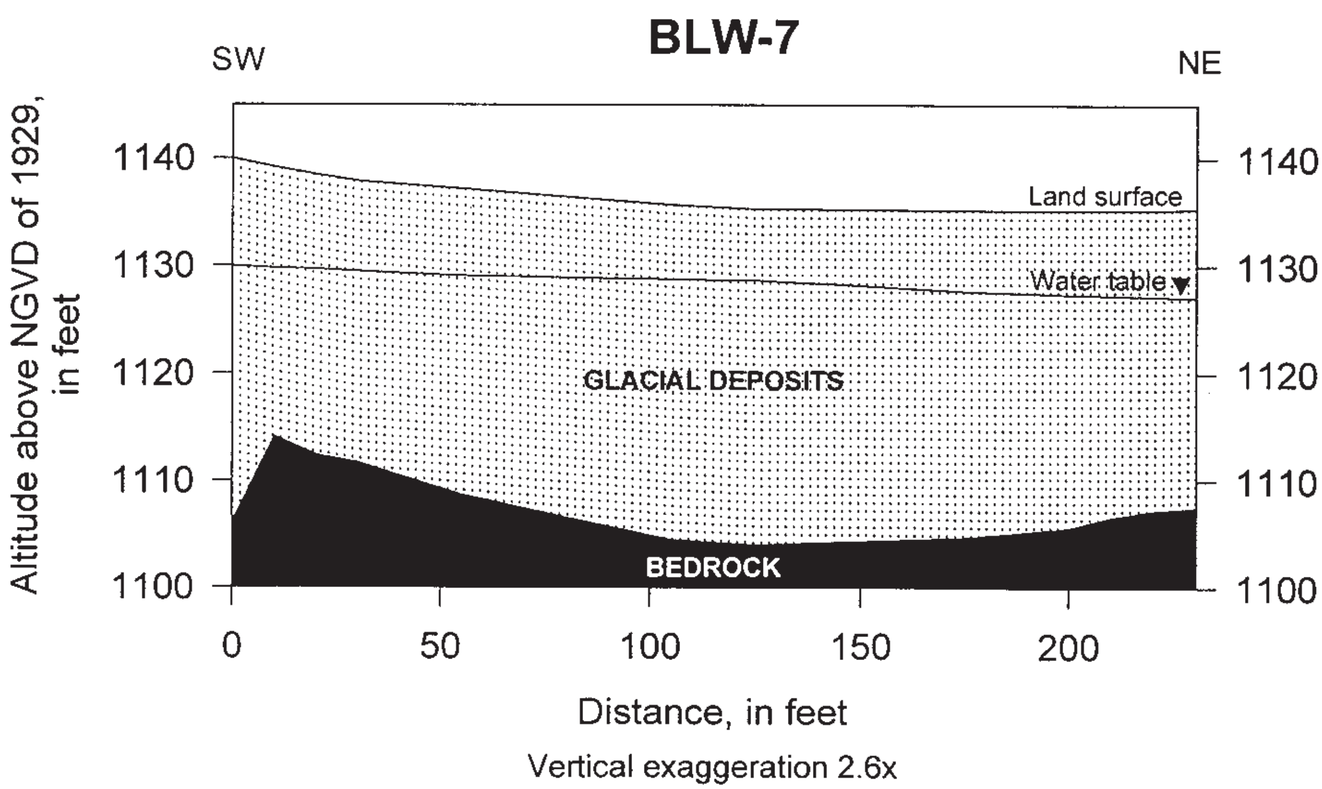
The following are hydrogeologic cross sections interpreted from 12-channel seismic-refraction surveys conducted by the Maine Geological Survey during 1994. Data interpretation is based on a computer modeling program described by Scott and others (1972). Distances shown on the x-axes are measured from geophone number 1. Because there is a greater concentration of redundant bedrock data in the center of lines than at the ends, the bedrock surfaces depicted in the central portions of the lines are believed to better reflect actual subsurface conditions than do the ends of the lines. Abrupt changes in the interpreted bedrock surface at the extreme ends of the lines might not reflect actual bedrock topography. Locations of individual profiles are shown on the quadrangle indicated by the three letter quadrangle code identifying the seismic line. A list of these quadrangle codes is given below.

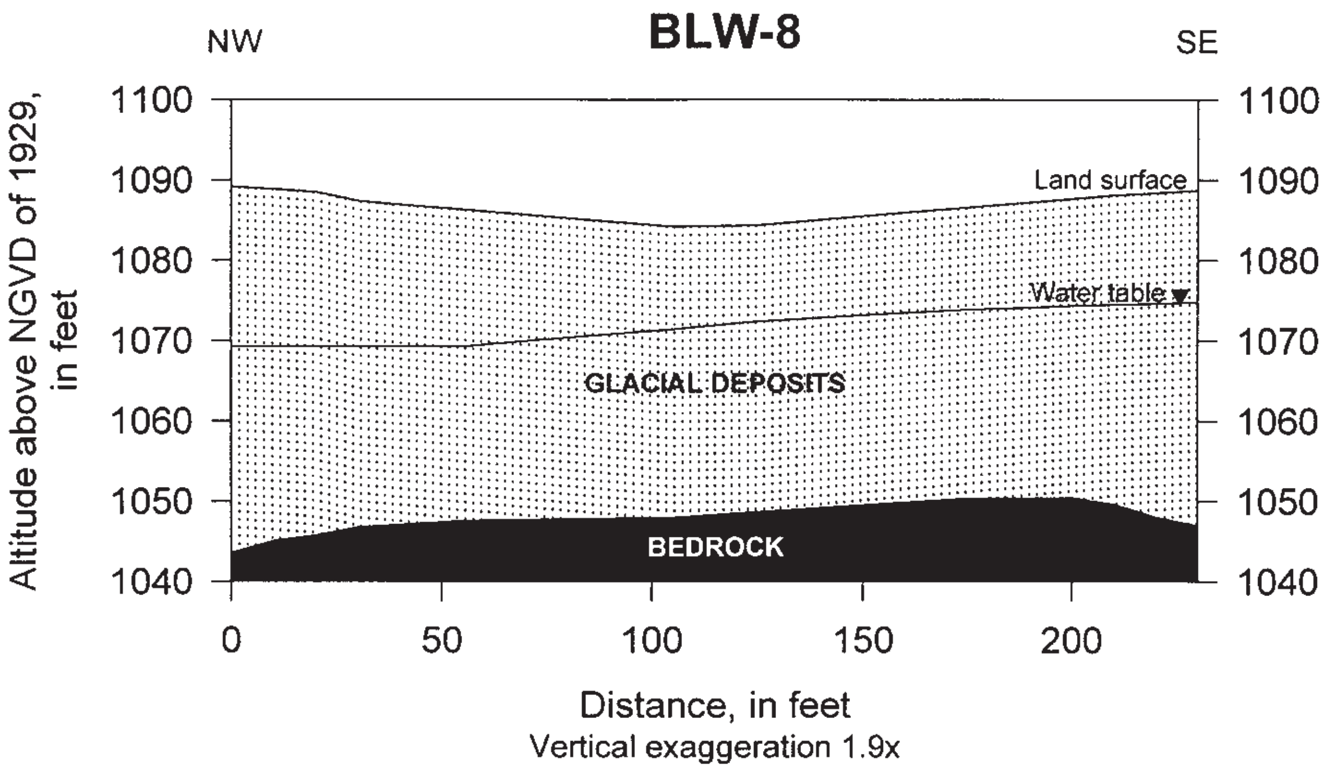
CODE	QUADRANGLE	CODE	QUADRANGLE
BBP	Black Brook Pond	MSW	Monson West
BLW	Brassua Lake West	MXP	Moxie Pond
BMP	Bald Mtn. Pond	MYK	Misery Knob
BMW	Barren Mountain West	SBW	Sebec LakeWest
BSP	Big Squaw Pond	SBY	Socatean Bay
GVL	Greenville	SET	Seboomook Lake East
HYM	Hay Mountain	SMK	Seboomook
IPN	Indian Pond North	SWT	Seboomook Lake West
LBY	Lily Bay	TFK	The Forks
MSE	Monson East		

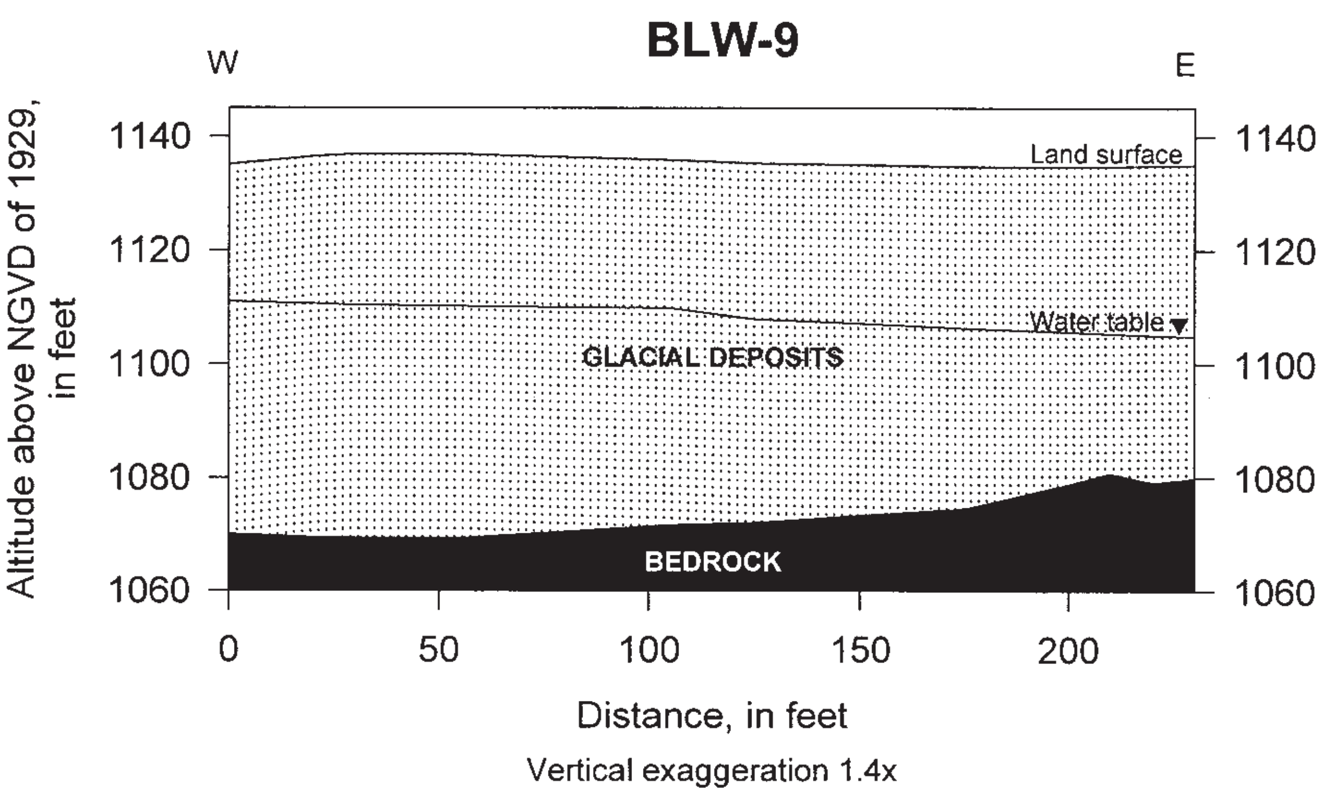

BBP-3
NW
SE
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
1070
1060
1050
1040
0
50
100
150
200
Distance, in feet
Vertical exaggeration 2.9x

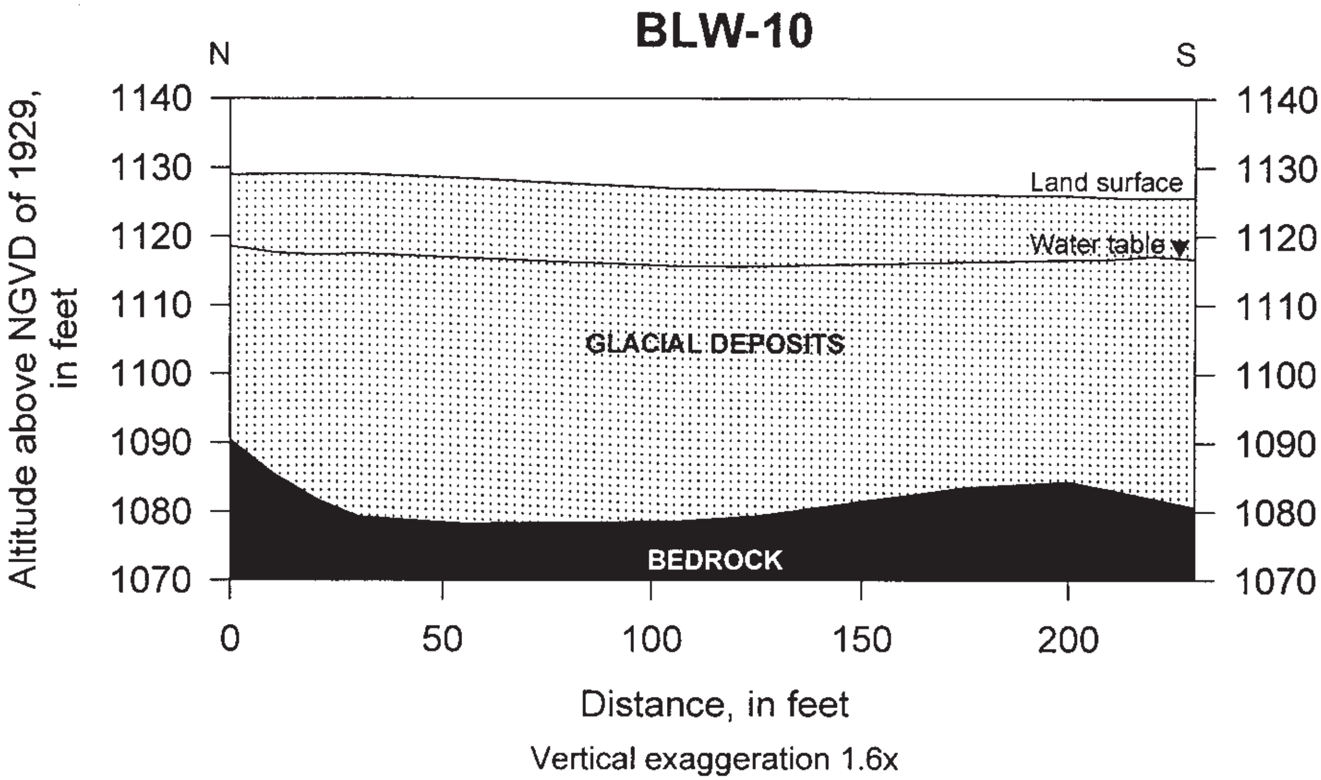

BLW-1
W
E
Land surface
GLACIAL DEPOSITS
Water table
BEDROCK
Altitude above NGVD of 1929, in feet
1130
1120
1110
1100
1090
0
50
100
150
200
Distance, in feet
Vertical exaggeration 2.9x

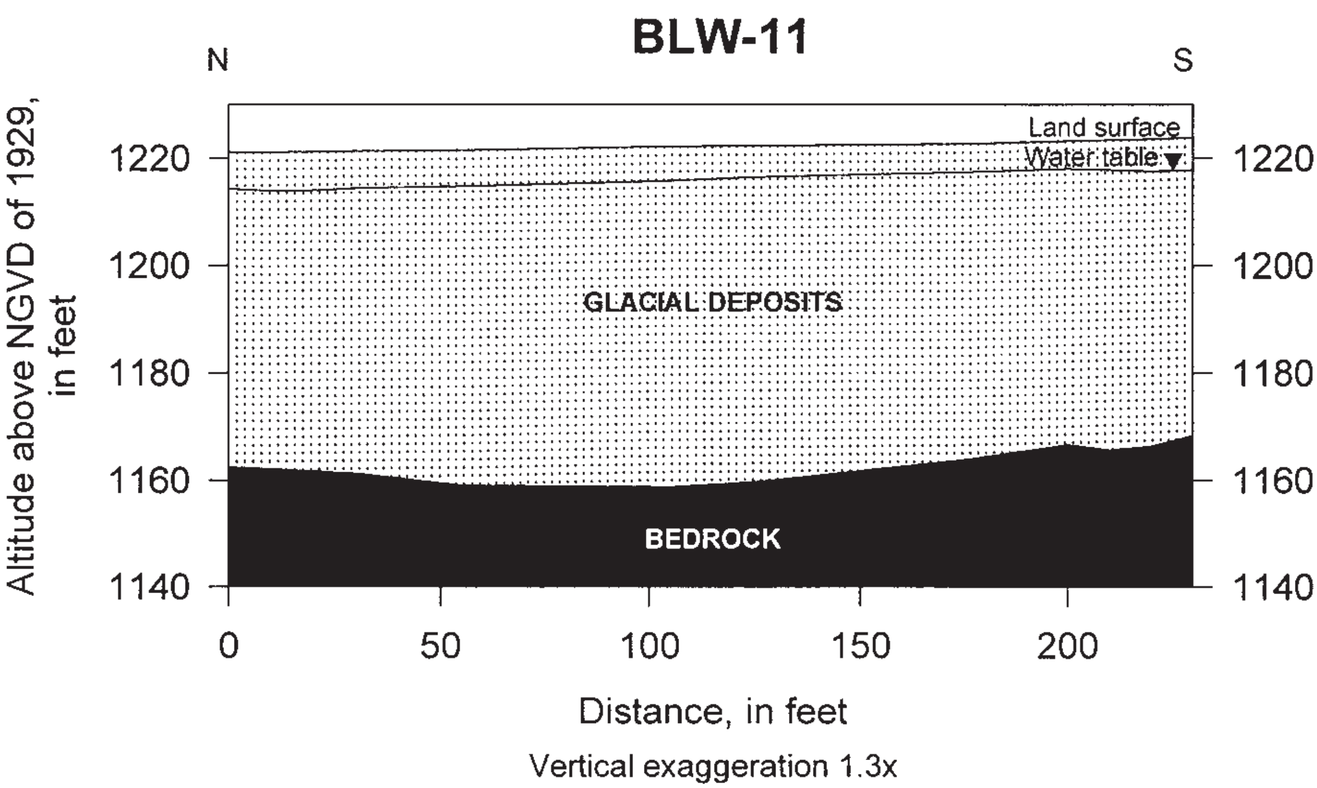

BLW-6
W
E
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
1140
1130
1120
1110
1100
1090
1080
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.9x

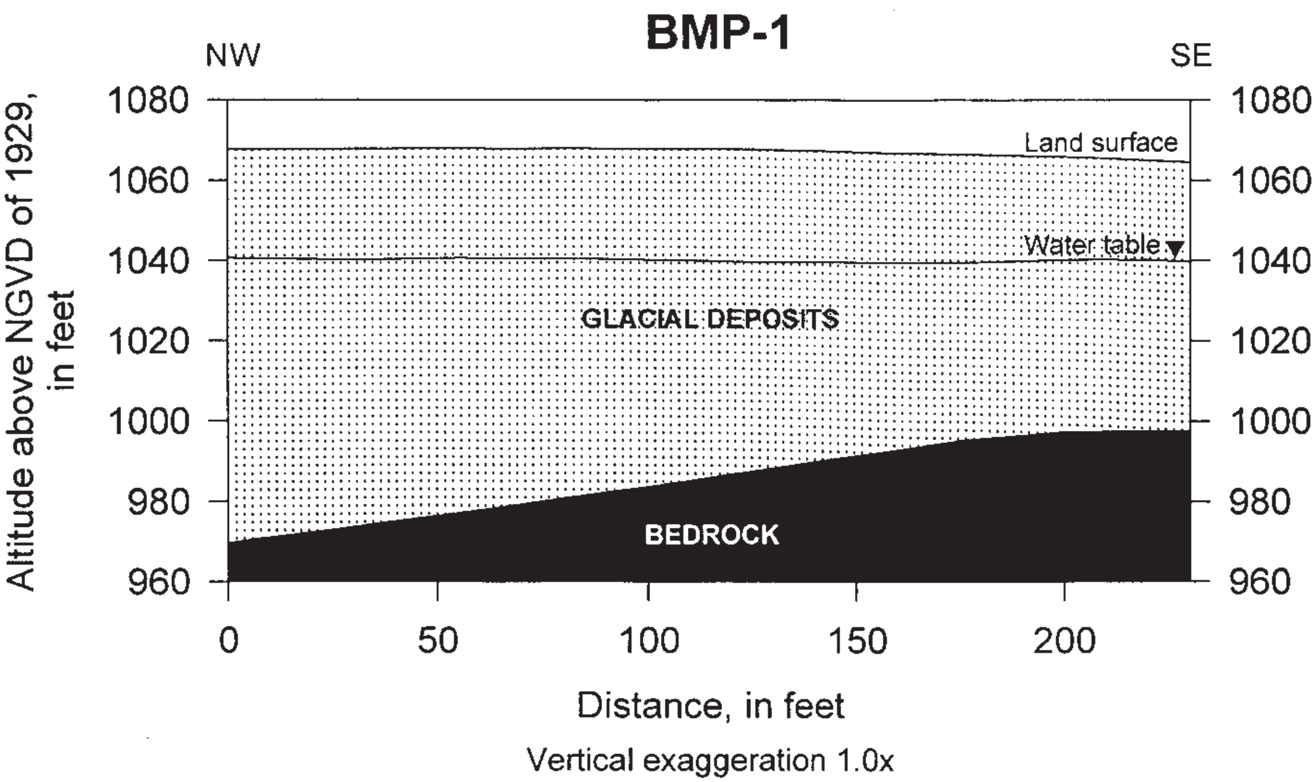

BLW-7
SW
NE
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
1140
1130
1120
1110
1100
0
50
100
150
200
Distance, in feet
Vertical exaggeration 2.6x

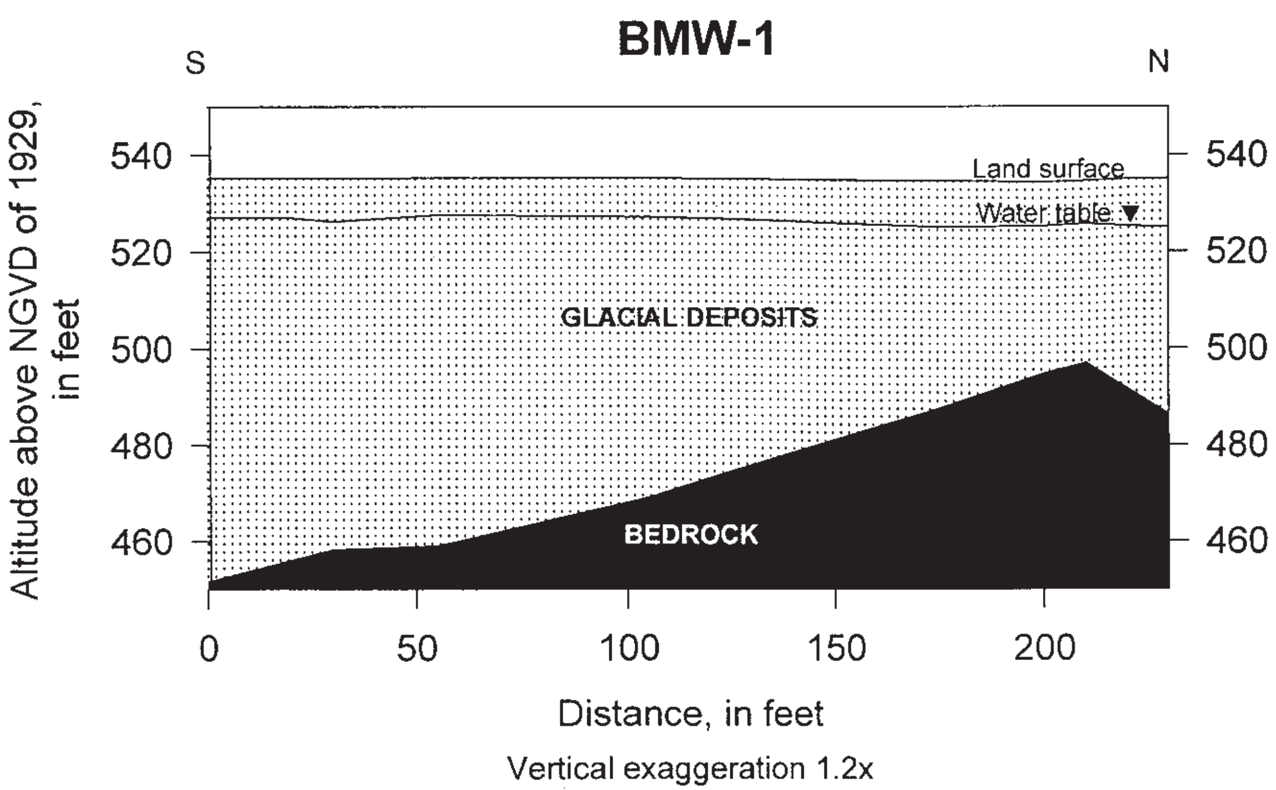

BLW-8
NW
SE
Altitude above NGVD of 1929, in feet
1100
1090
1080
1070
1060
1050
1040
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.9x

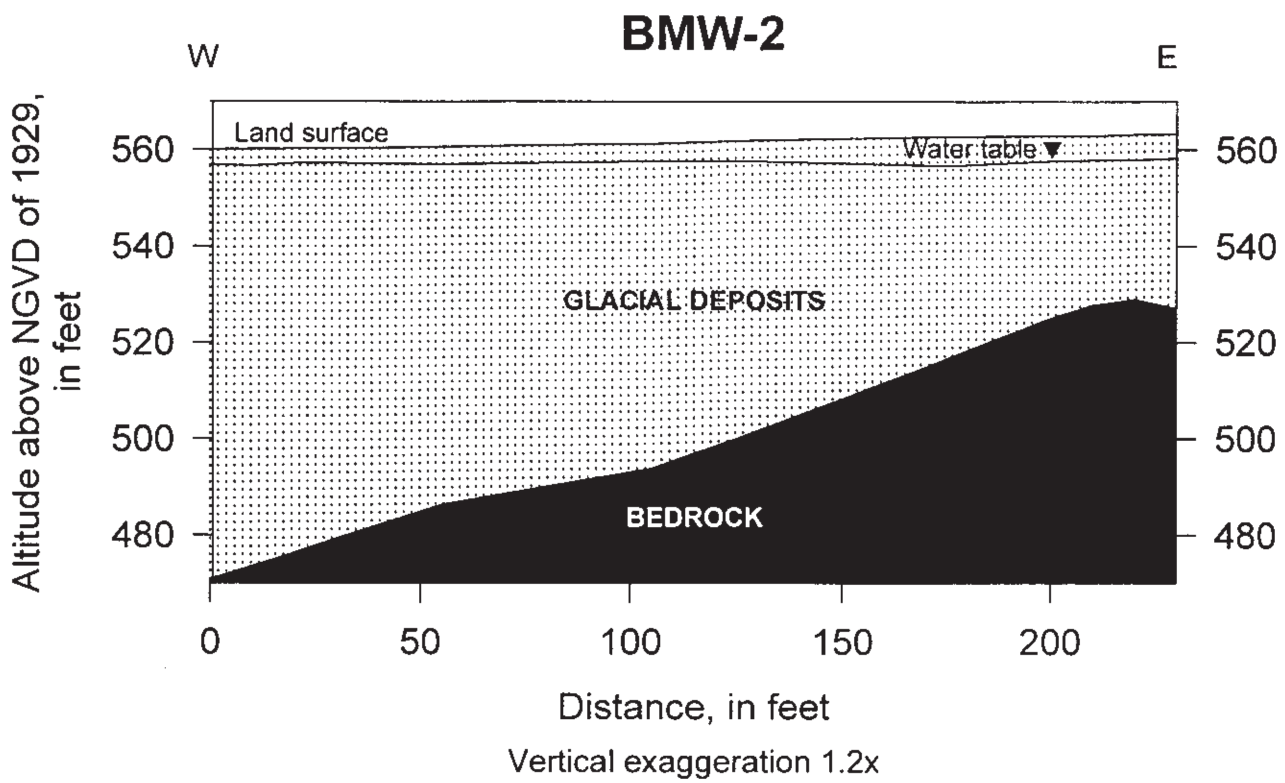

BLW-9
W
E
Altitude above NGVD of 1929, in feet
1140
1120
1100
1080
1060
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.4x

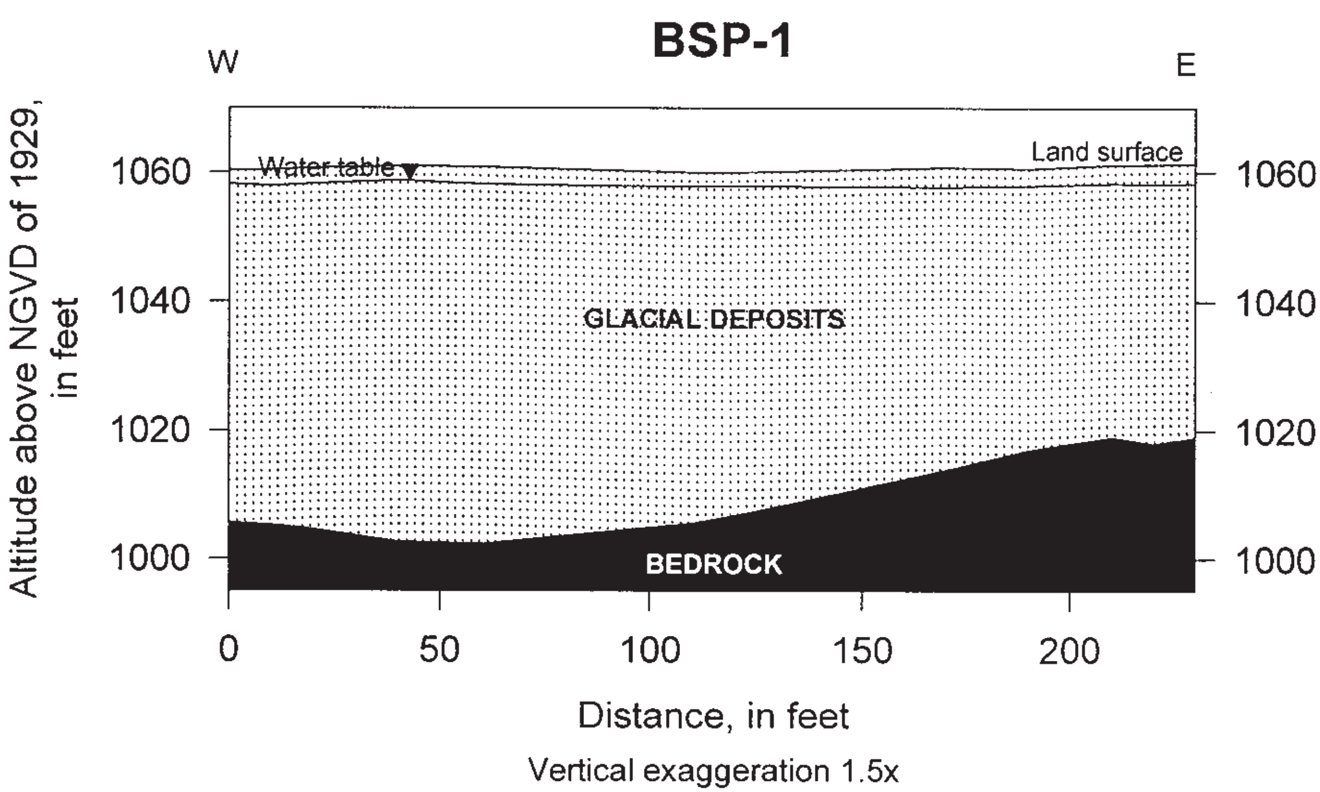

BLW-10
N
S
Altitude above NGVD of 1929, in feet
1140
1130
1120
1110
1100
1090
1080
1070
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.6x

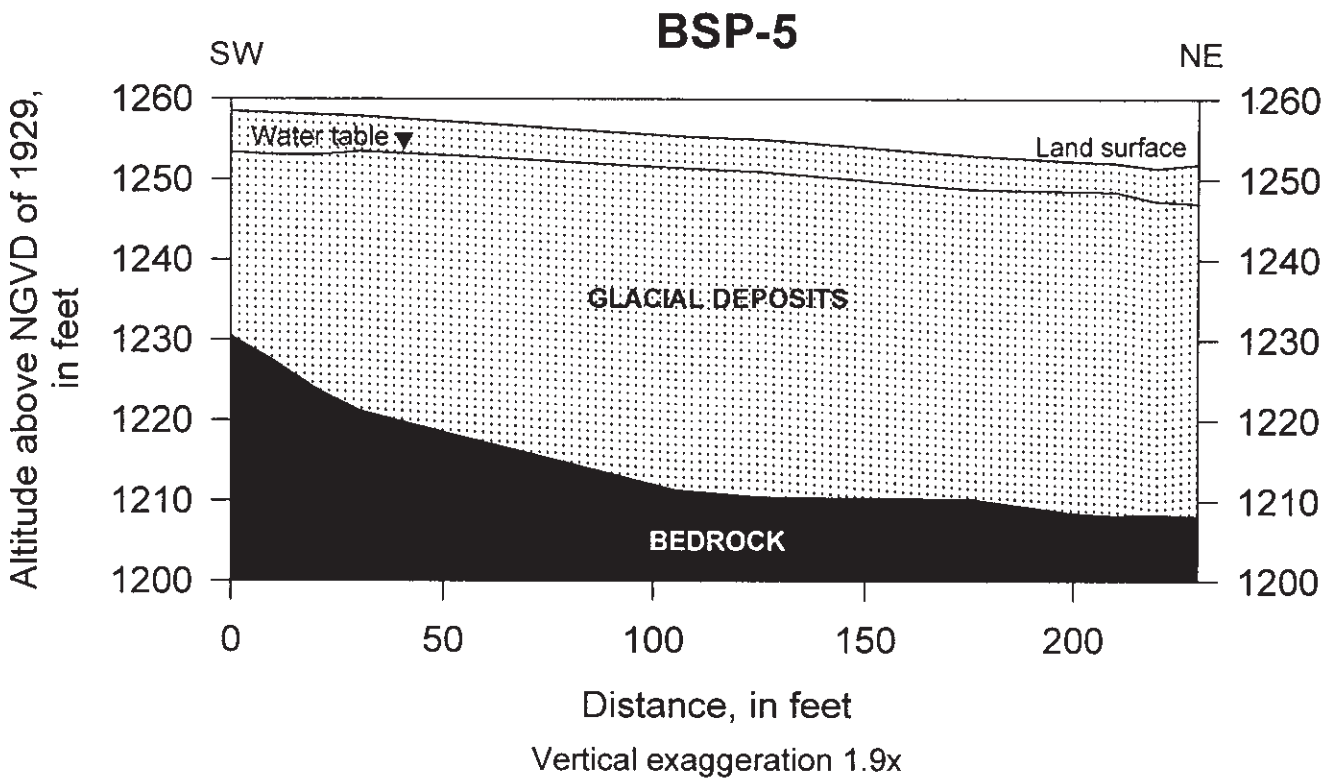

BLW-11
N
S
Altitude above NGVD of 1929, in feet
1220
1200
1180
1160
1140
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.3x

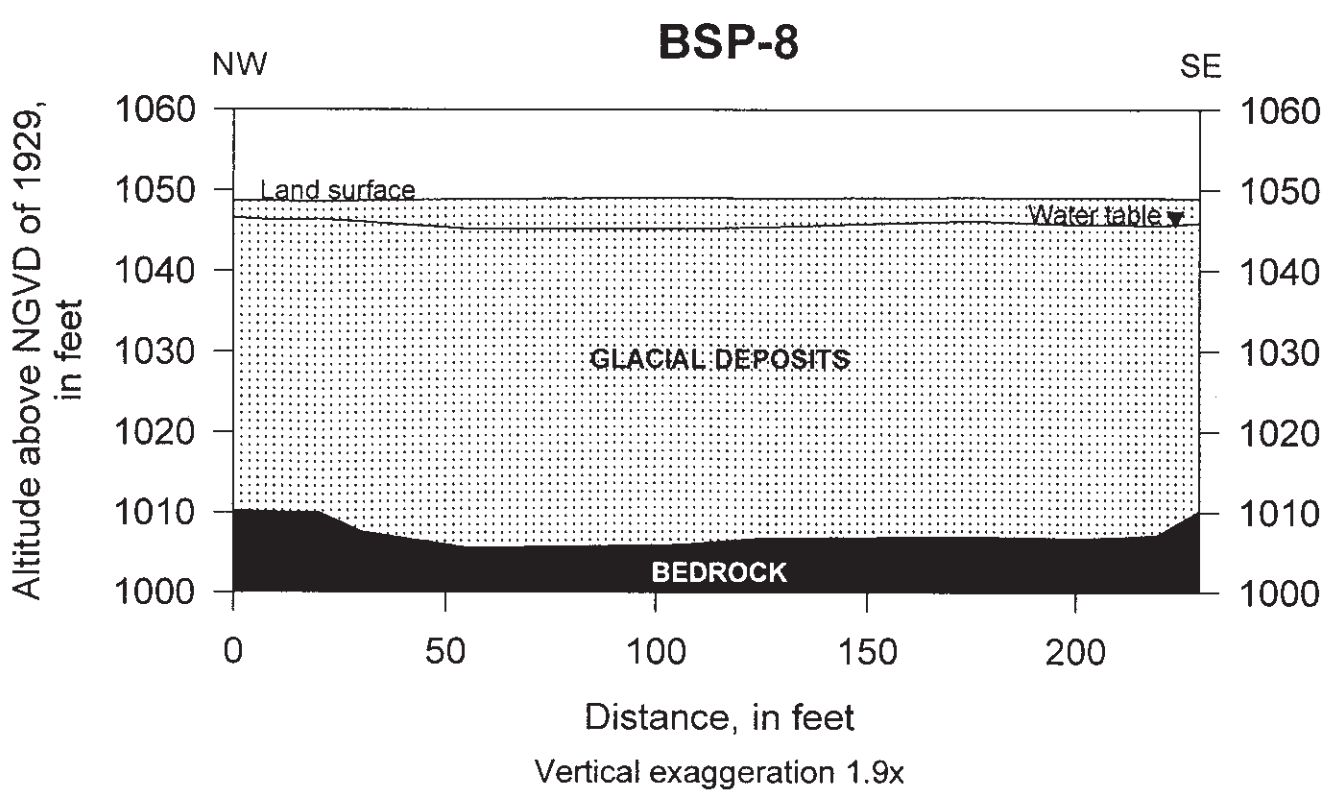

BMP-1
NW
SE
Altitude above NGVD of 1929, in feet
1080
1060
1040
1020
1000
980
960
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.0x

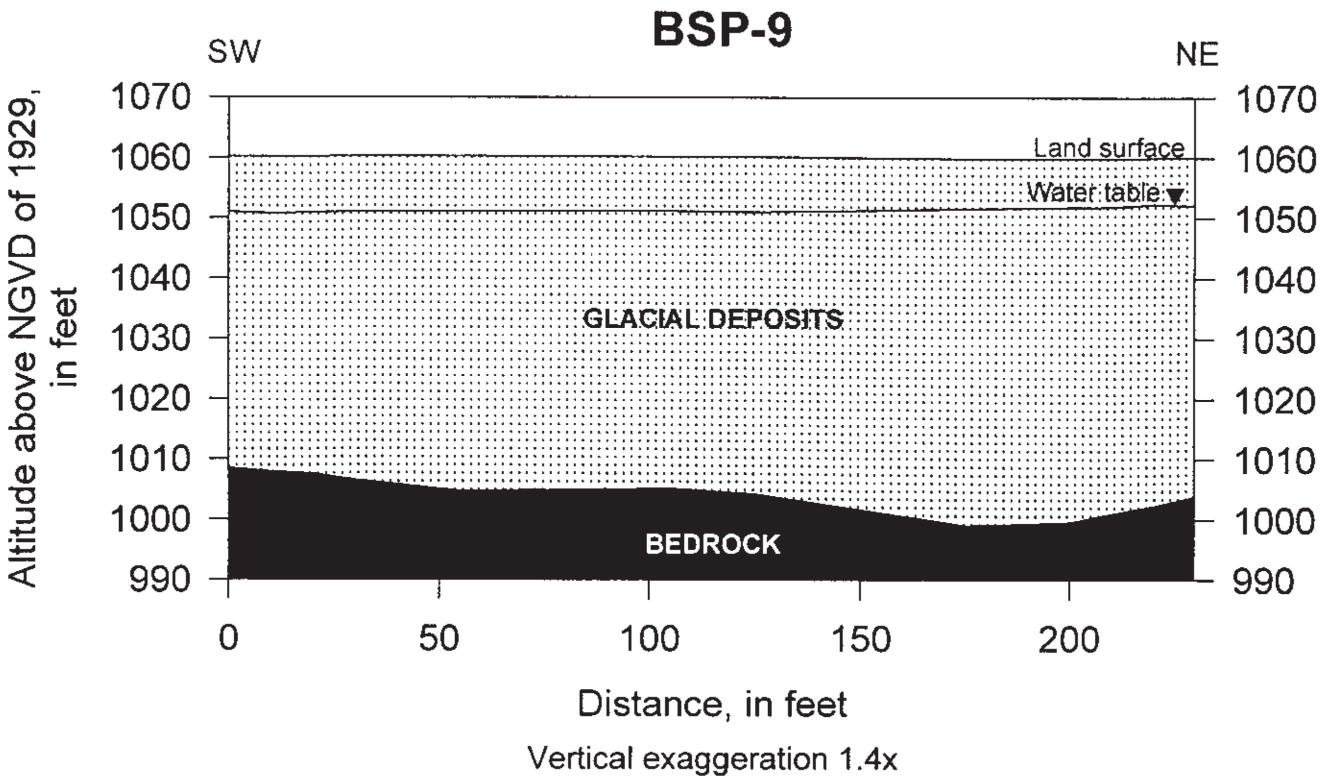

BMW-1
S
N
Altitude above NGVD of 1929, in feet
540
520
500
480
460
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.2x

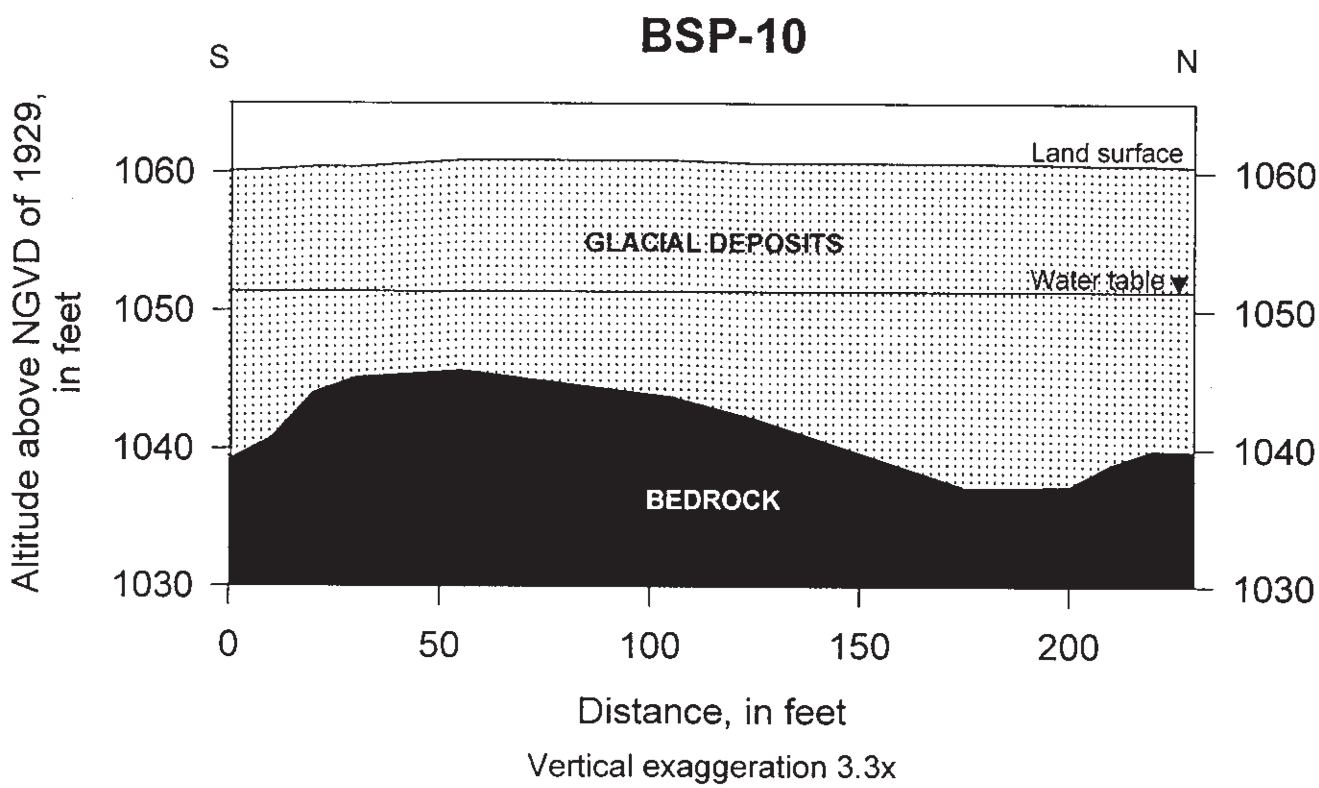

BMW-2
W
E
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
560
540
520
500
480
Altitude above NGVD of 1929, in feet
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.2x

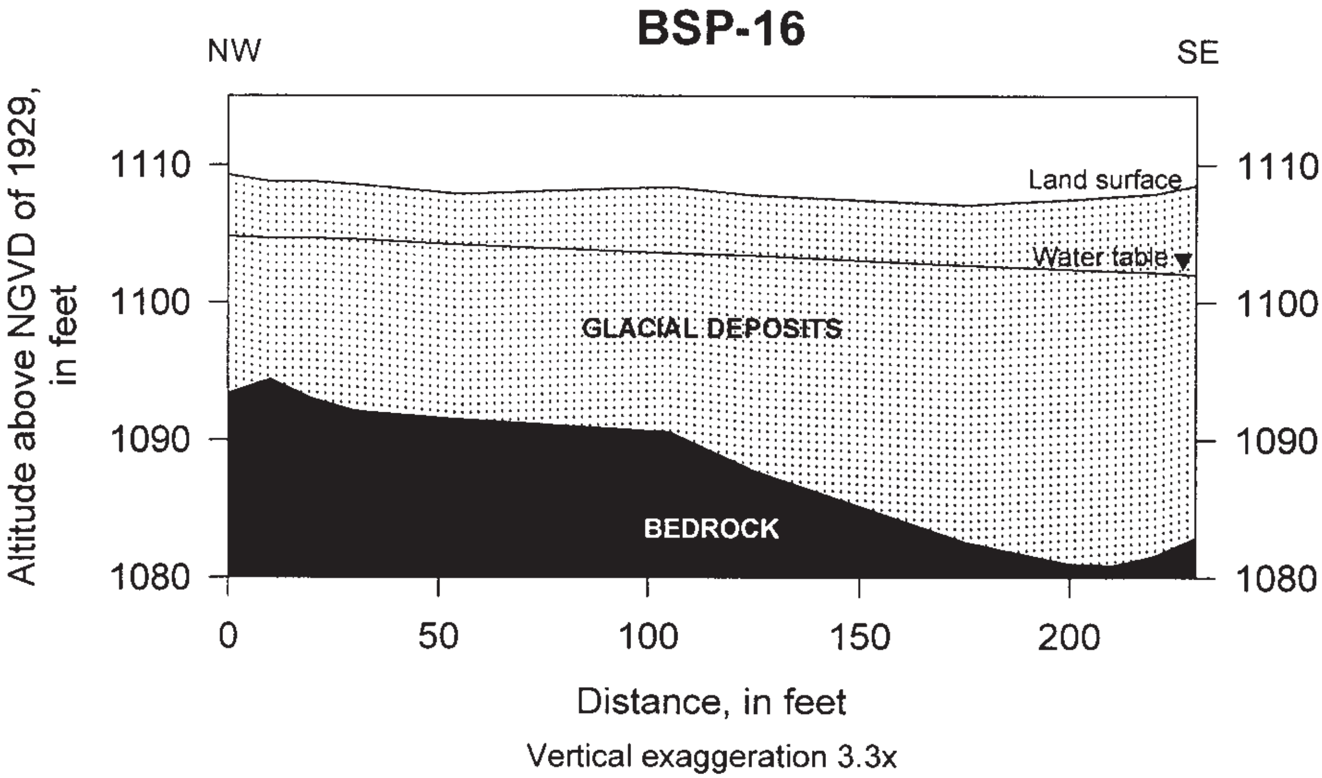

BSP-1
W
E
Water table
Land surface
GLACIAL DEPOSITS
BEDROCK
1060
1040
1020
1000
Altitude above NGVD of 1929, in feet
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.5x

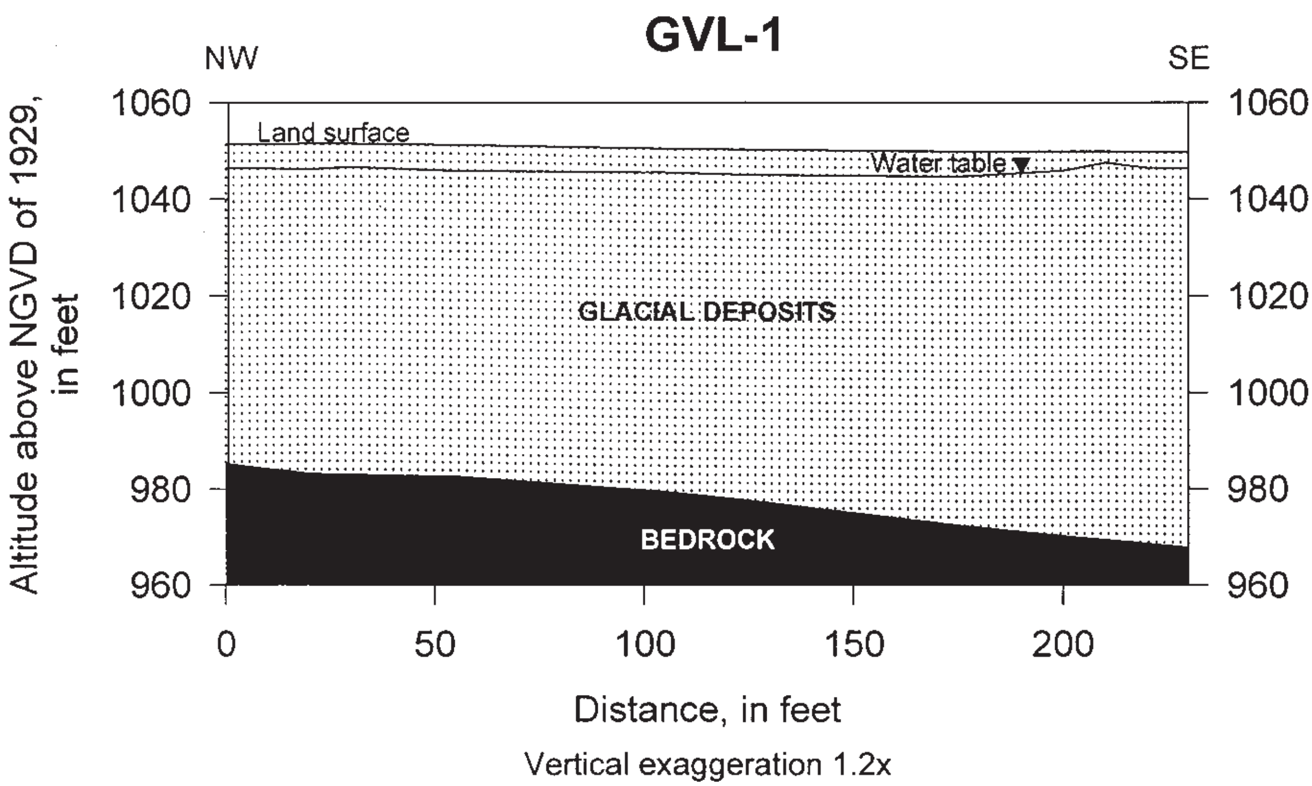

BSP-5
SW
NE
Altitude above NGVD of 1929, in feet
1260
1250
1240
1230
1220
1210
1200
Water table
Land surface
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.9x

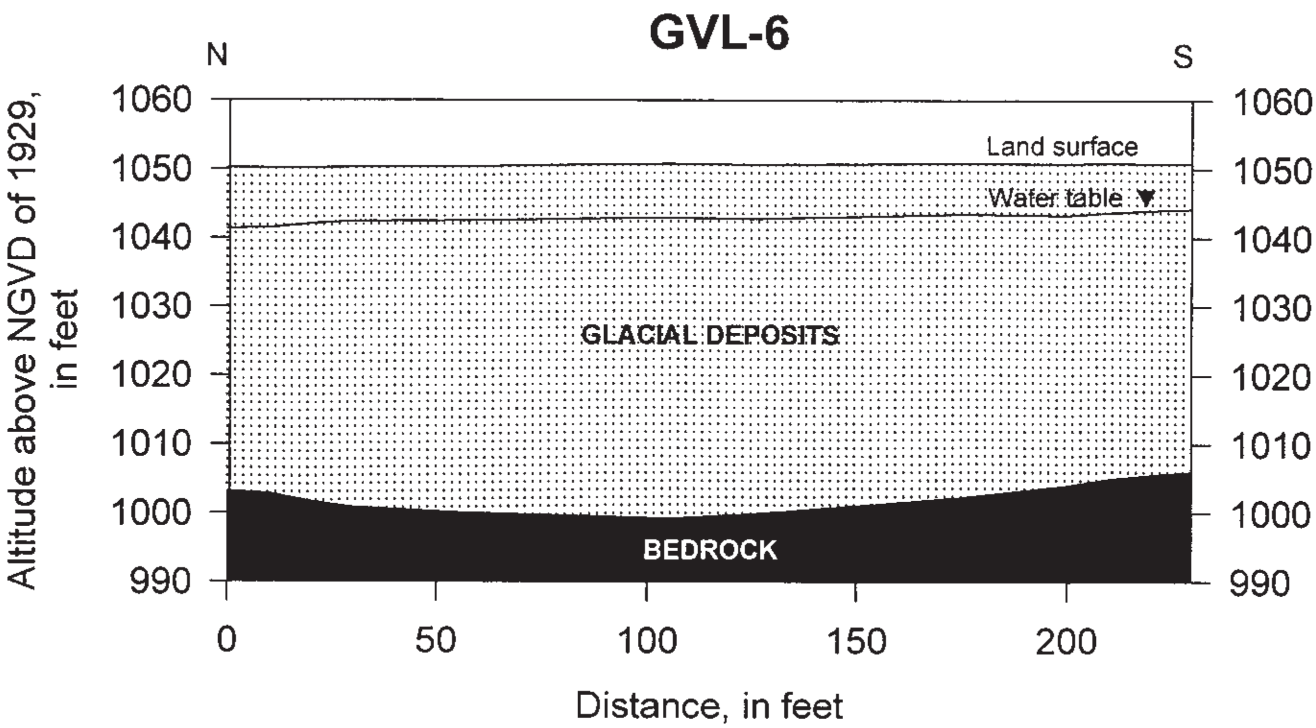

BSP-8
NW
SE
Altitude above NGVD of 1929, in feet
1060
1050
1040
1030
1020
1010
1000
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.9x


BSP-9
SW
NE
Altitude above NGVD of 1929, in feet
1070
1060
1050
1040
1030
1020
1010
1000
990
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.4x

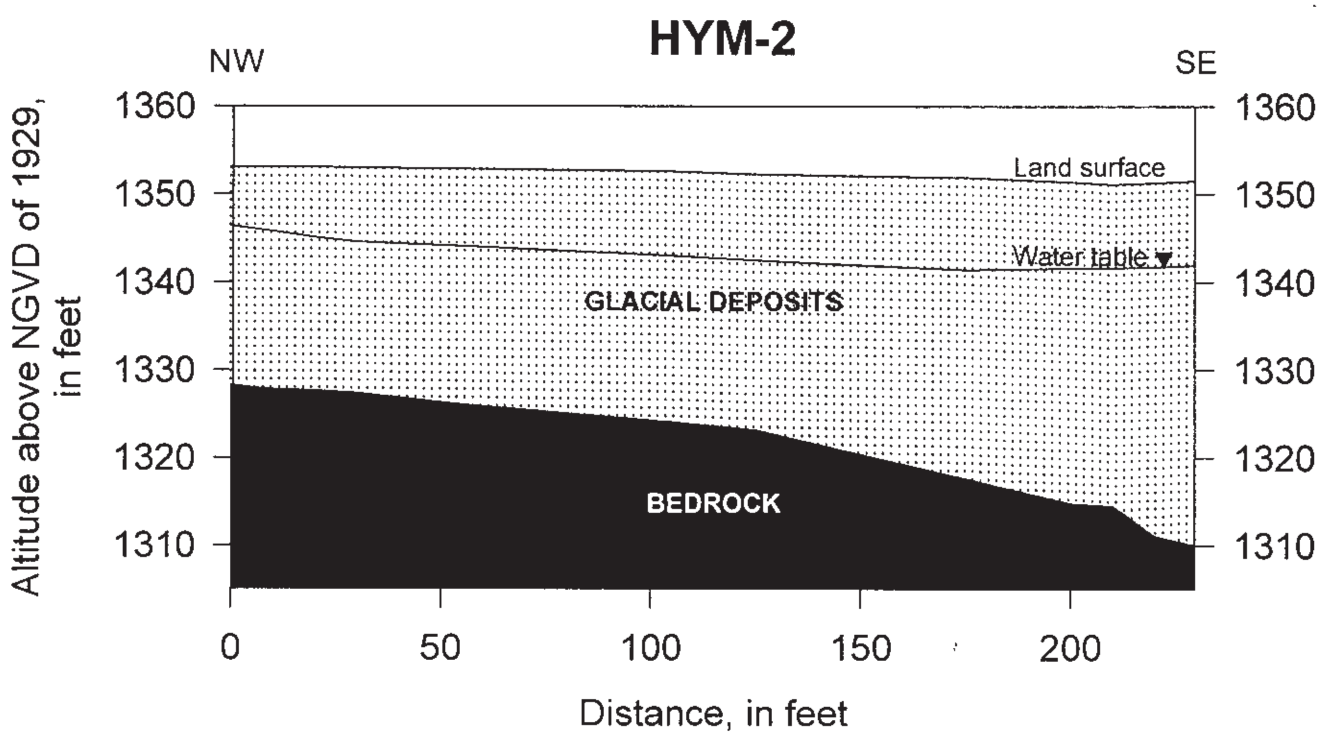

BSP-10
S
N
Altitude above NGVD of 1929, in feet
1060
1050
1040
1030
Land surface
GLACIAL DEPOSITS
Water table
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 3.3x


BSP-16
NW
SE
Altitude above NGVD of 1929, in feet
1110
1100
1090
1080
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 3.3x

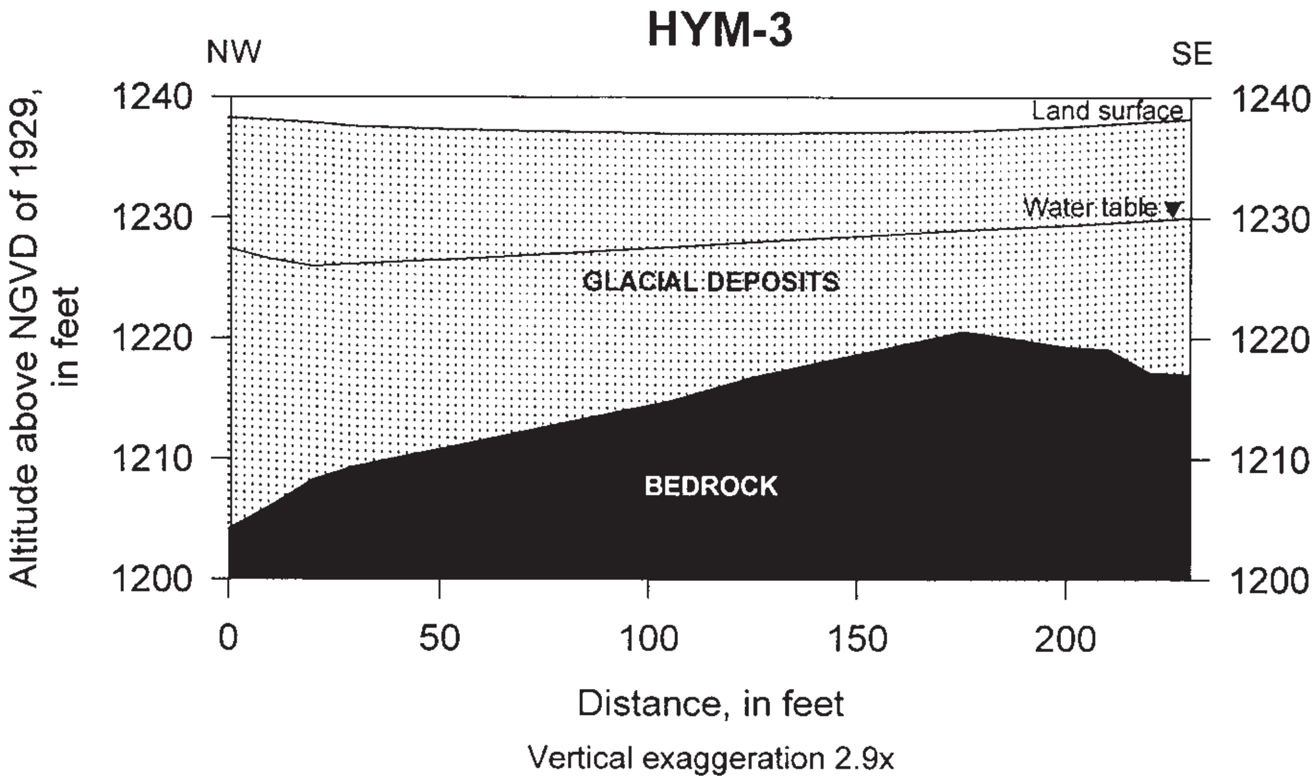

GVL-1
NW
SE
Altitude above NGVD of 1929, in feet
1060
1040
1020
1000
980
960
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.2x

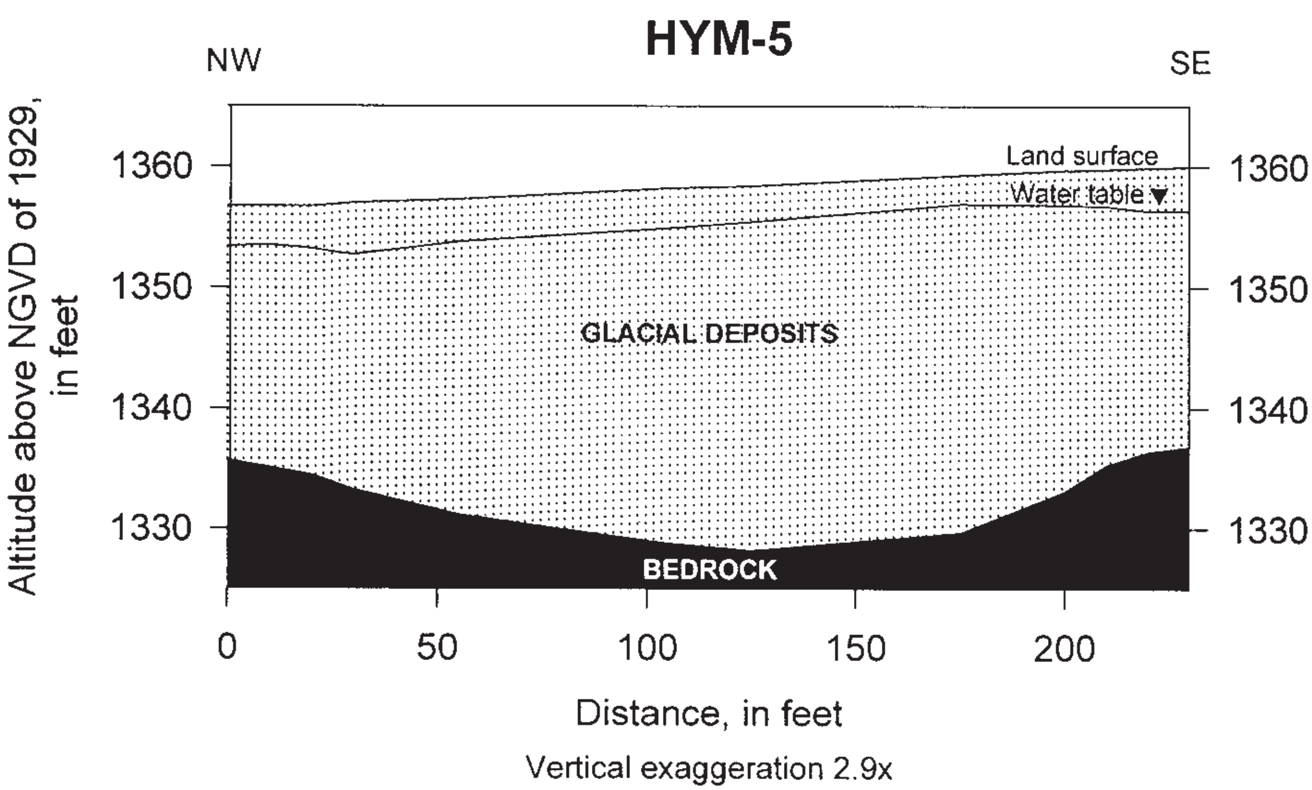


Vertical exaggeration 1.6x



Vertical exaggeration 2.1x


HYM-3
NW
SE
Altitude above NGVD of 1929, in feet
1240
1230
1220
1210
1200
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 2.9x


HYM-5
NW
SE
Altitude above NGVD of 1929, in feet
1360
1350
1340
1330
Land surface
Water table
GLACIAL DEPOSITS
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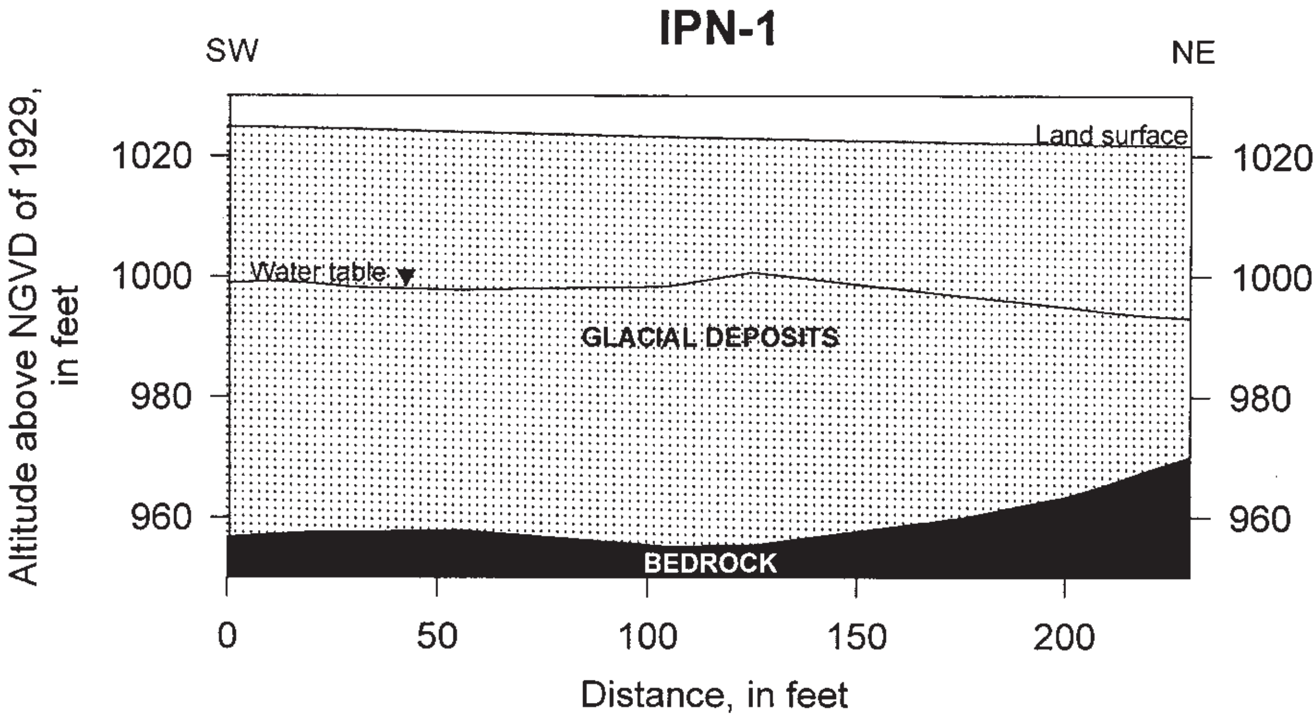
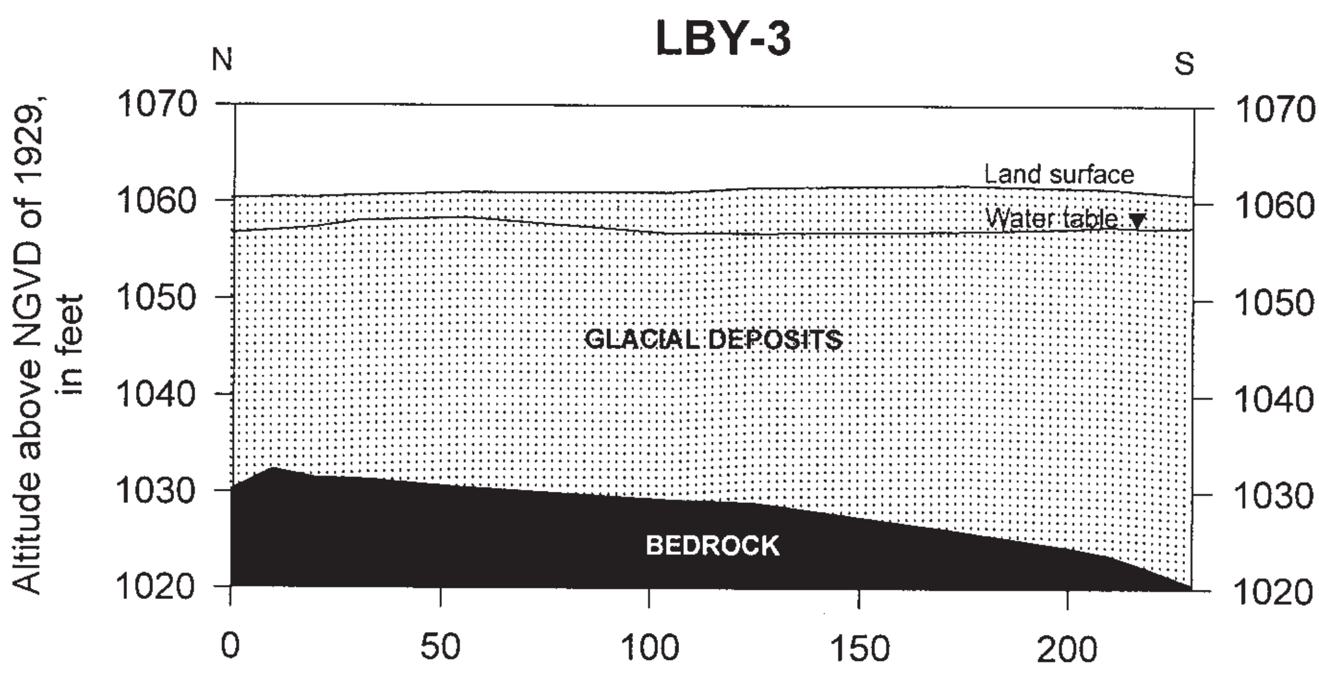
100
150
200
Distance, in feet
Vertical exaggeration 2.9x



Vertical exaggeration 1.4x



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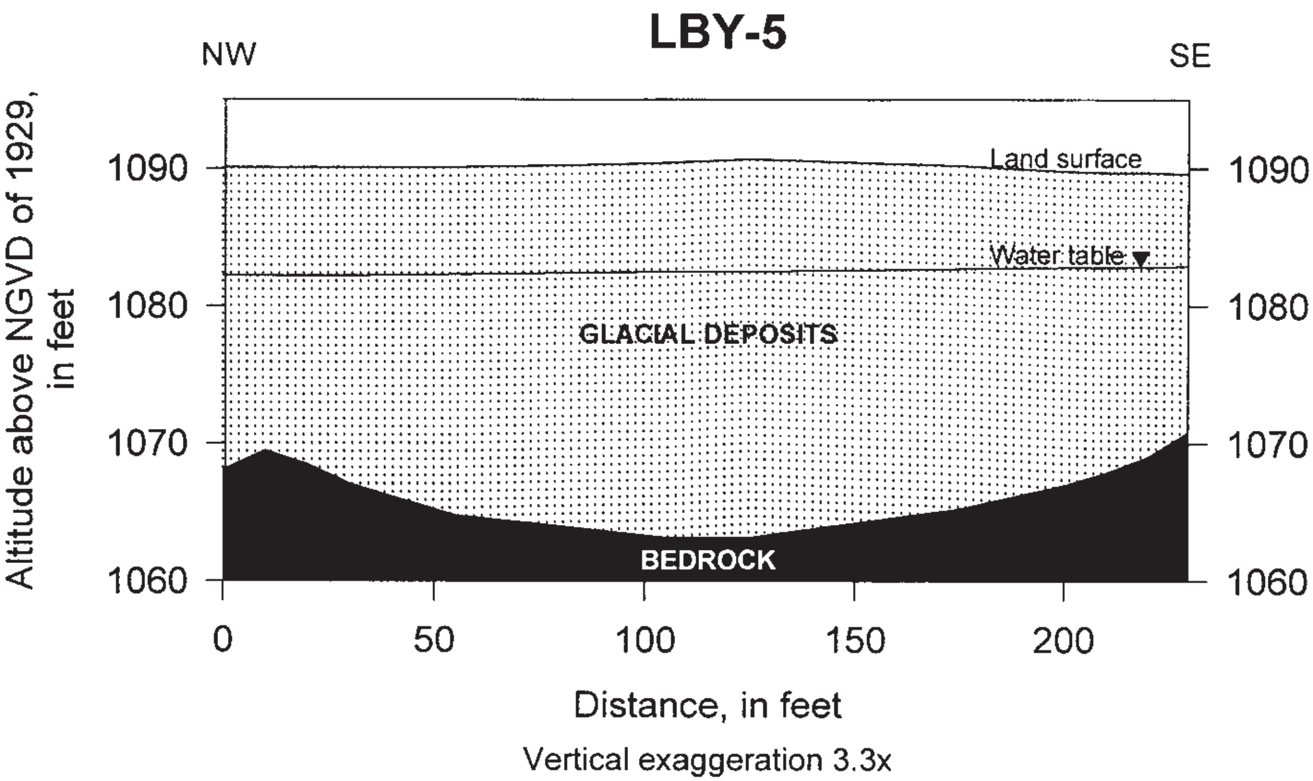
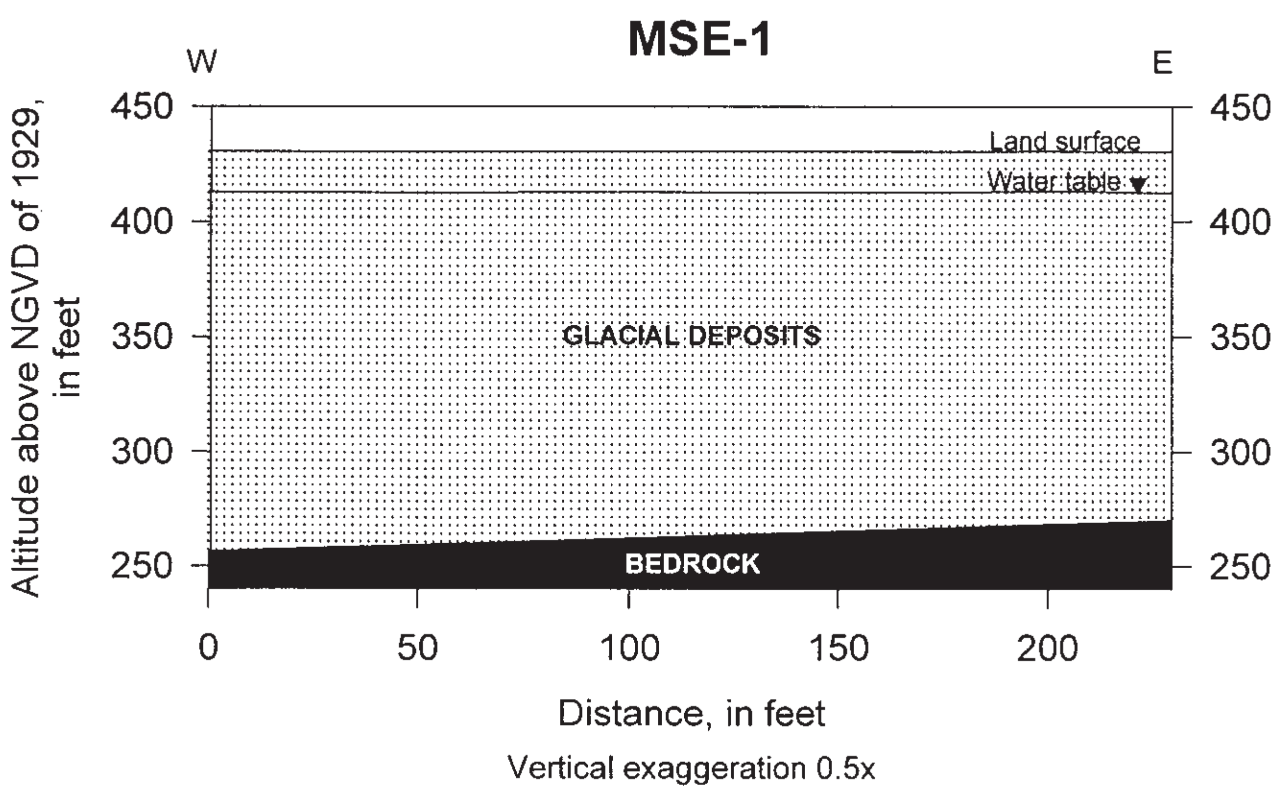
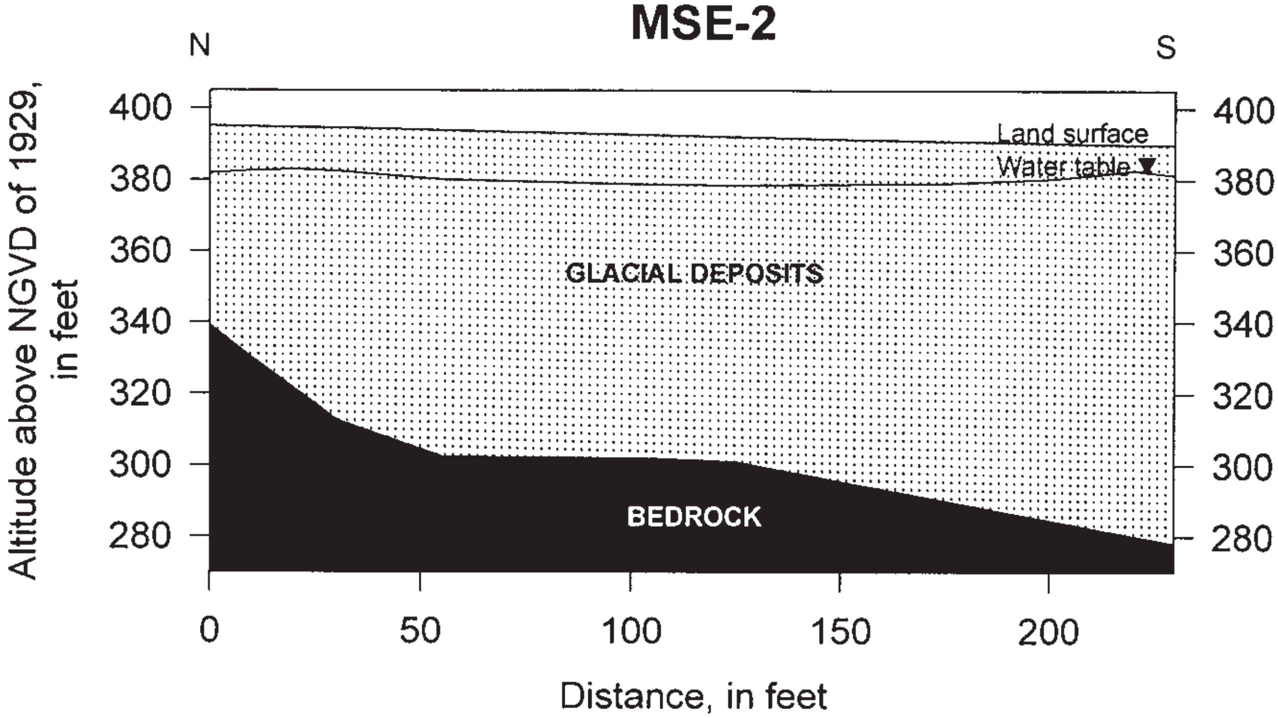

LBY-5
NW
SE
Altitude above NGVD of 1929, in feet
1090
1080
1070
1060
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 3.3x

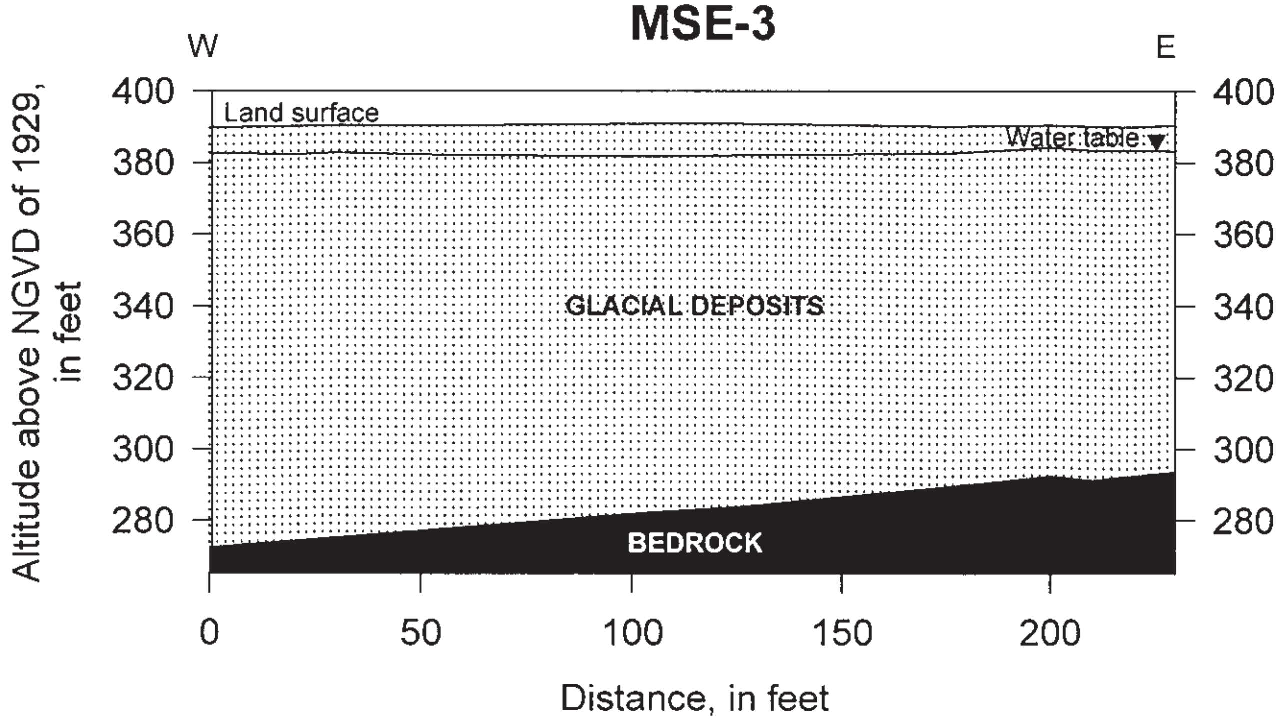

MSE-1
W
E
Altitude above NGVD of 1929, in feet
450
400
350
300
250
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 0.5x

MSE-2

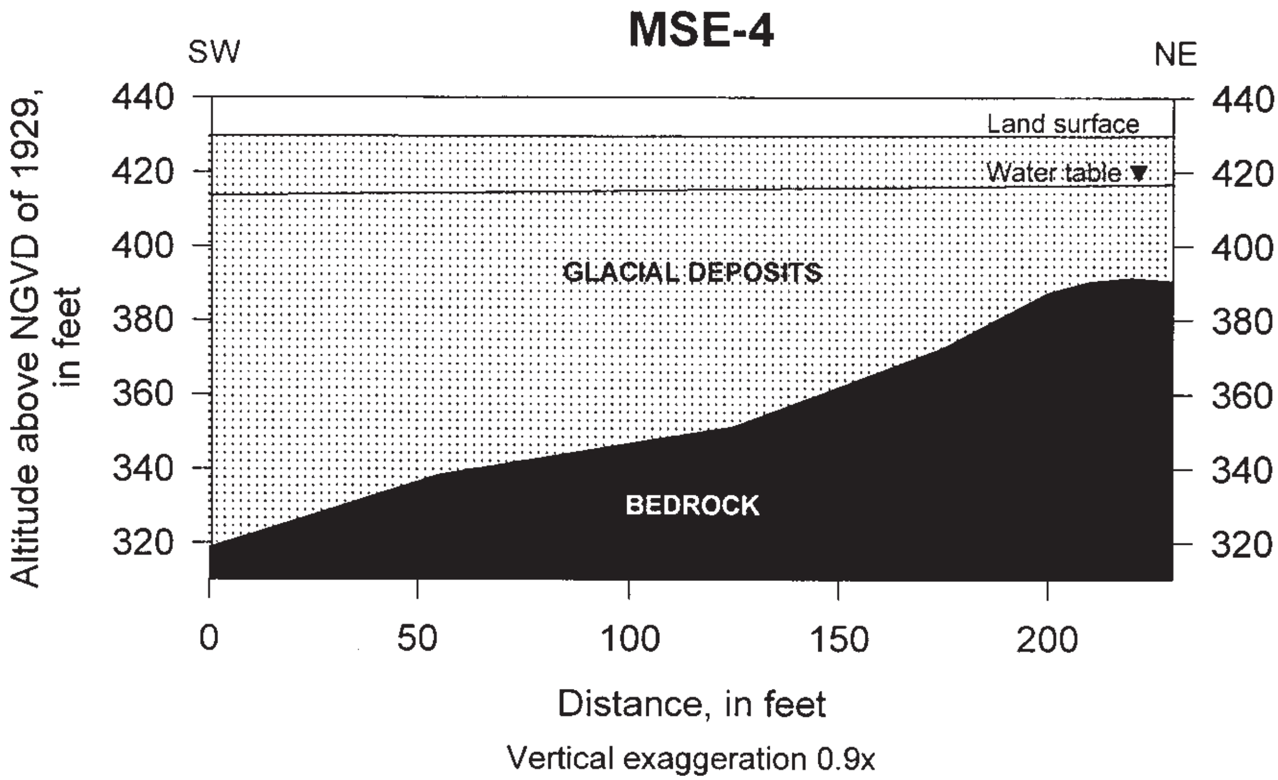


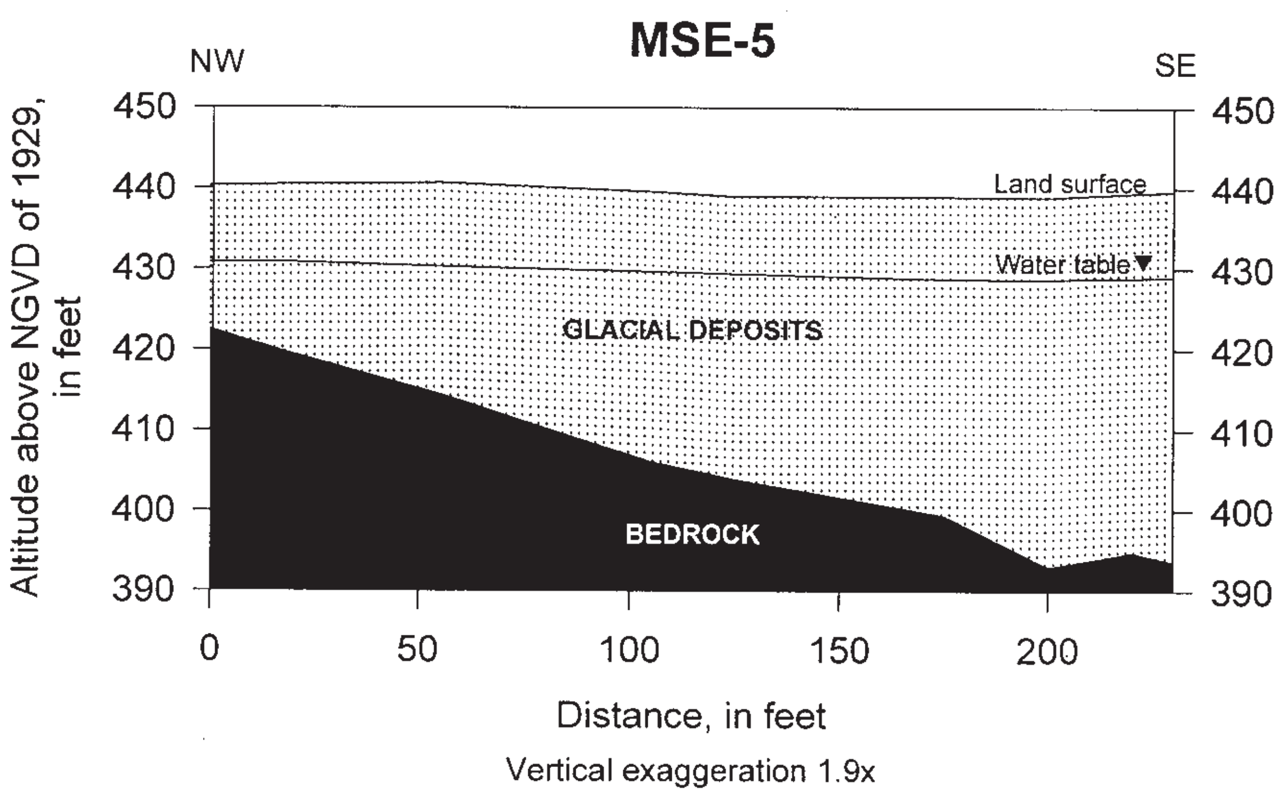
Vertical exaggeration 0.9x

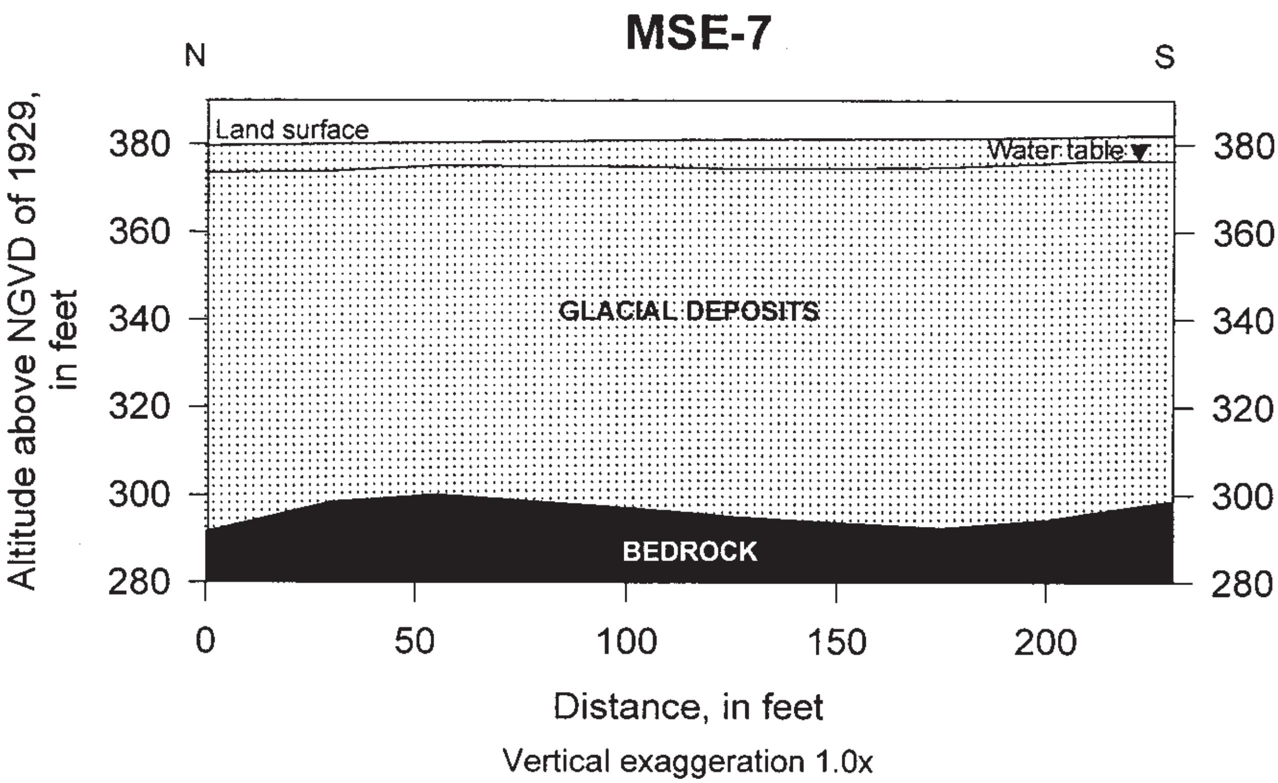
MSE-3

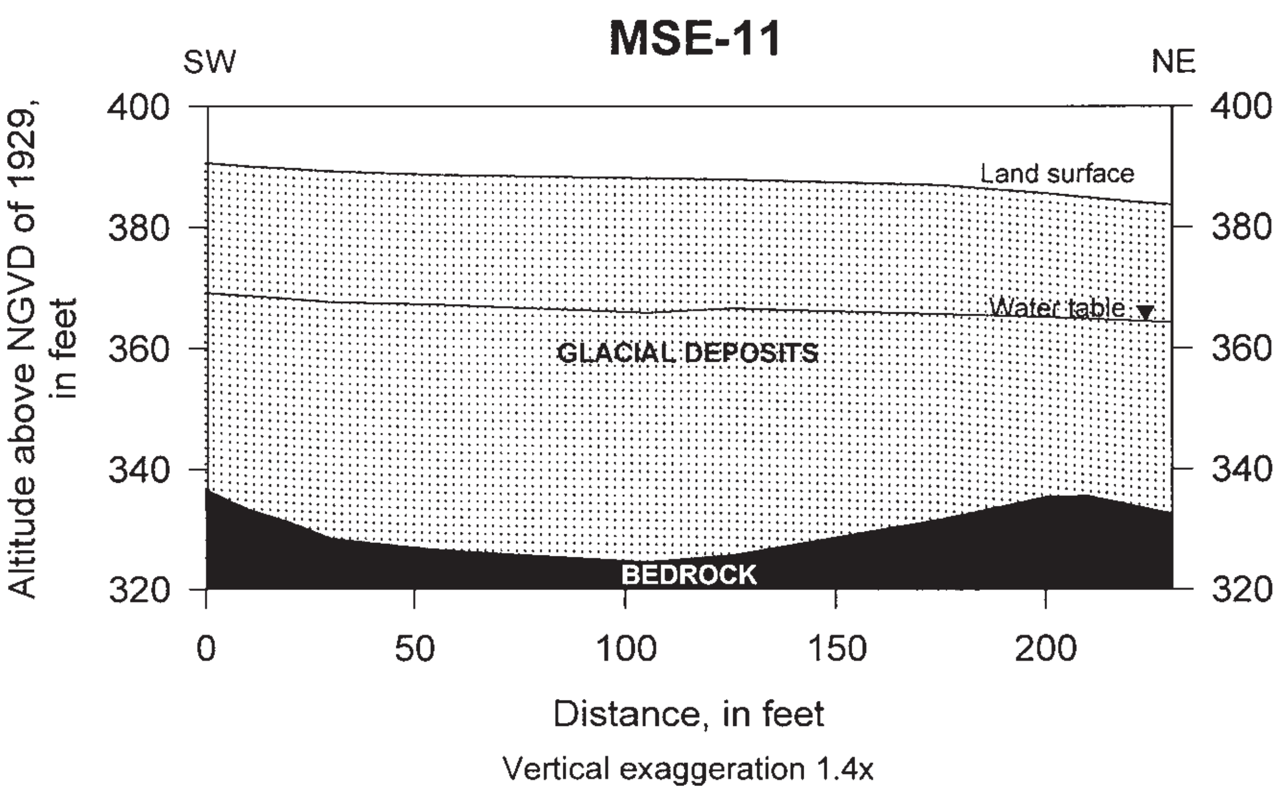


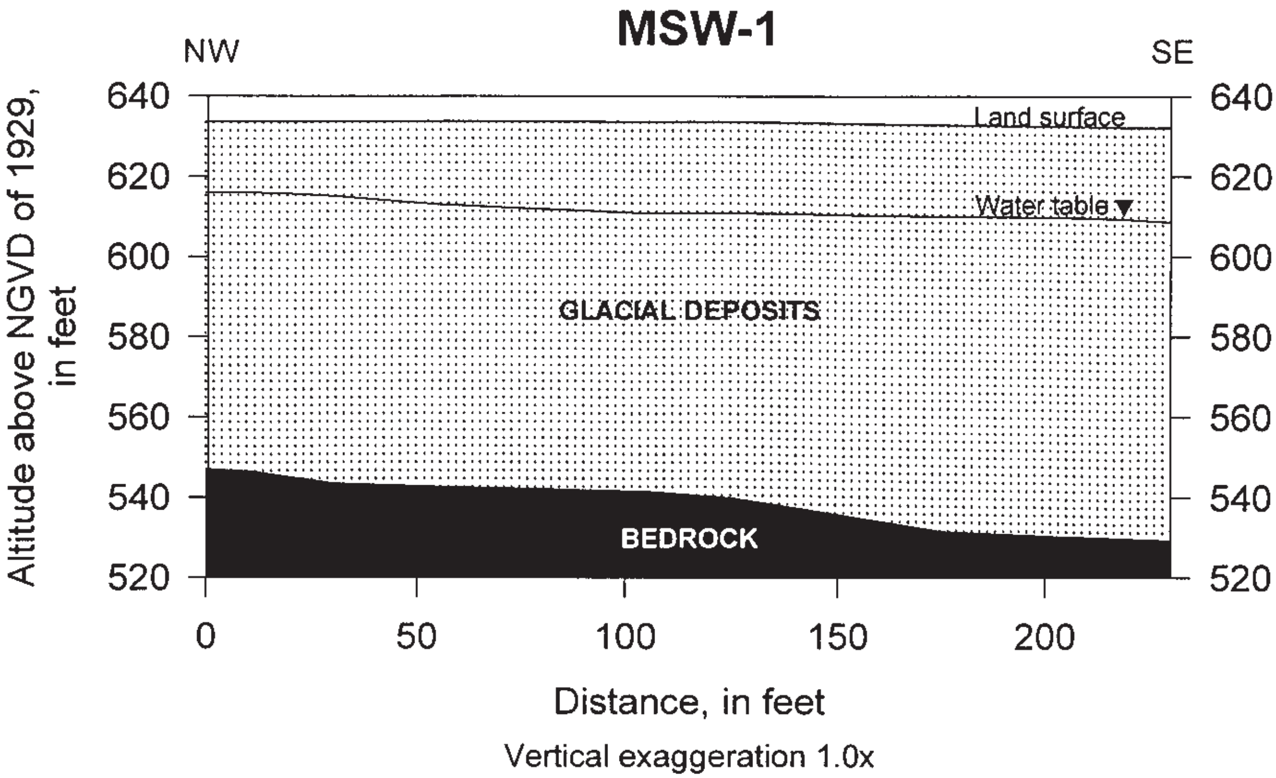
Vertical exaggeration 0.9x

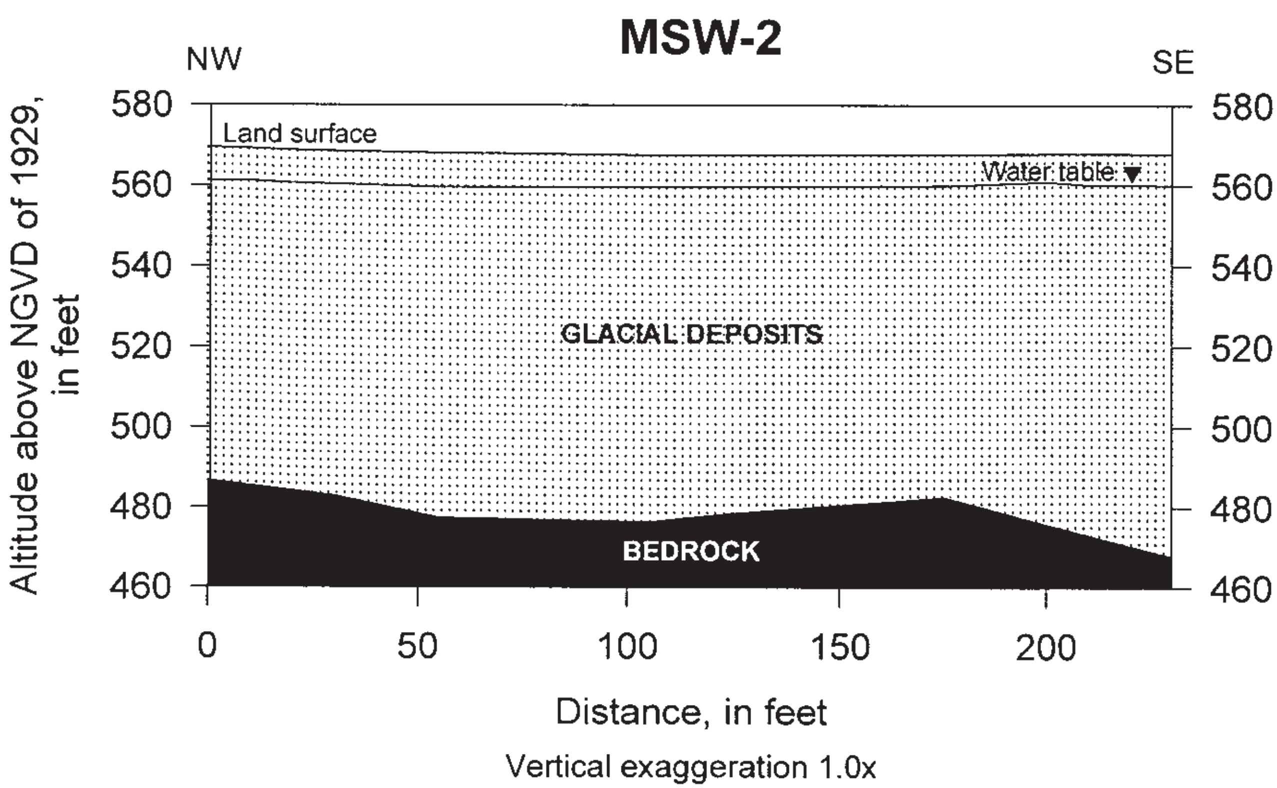

MSE-4
SW
NE
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
440
420
400
380
360
340
320
0
50
100
150
200
Distance, in feet
Vertical exaggeration 0.9x


MSE-5
NW
SE
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
450
440
430
420
410
400
390
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.9x


MSE-7
N
S
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
380
360
340
320
300
280
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.0x


MSE-11
SW
NE
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
400
380
360
340
320
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.4x


MSW-1
NW
SE
Altitude above NGVD of 1929, in feet
640
620
600
580
560
540
520
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.0x


MSW-2
NW
SE
Altitude above NGVD of 1929, in feet
580
560
540
520
500
480
460
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
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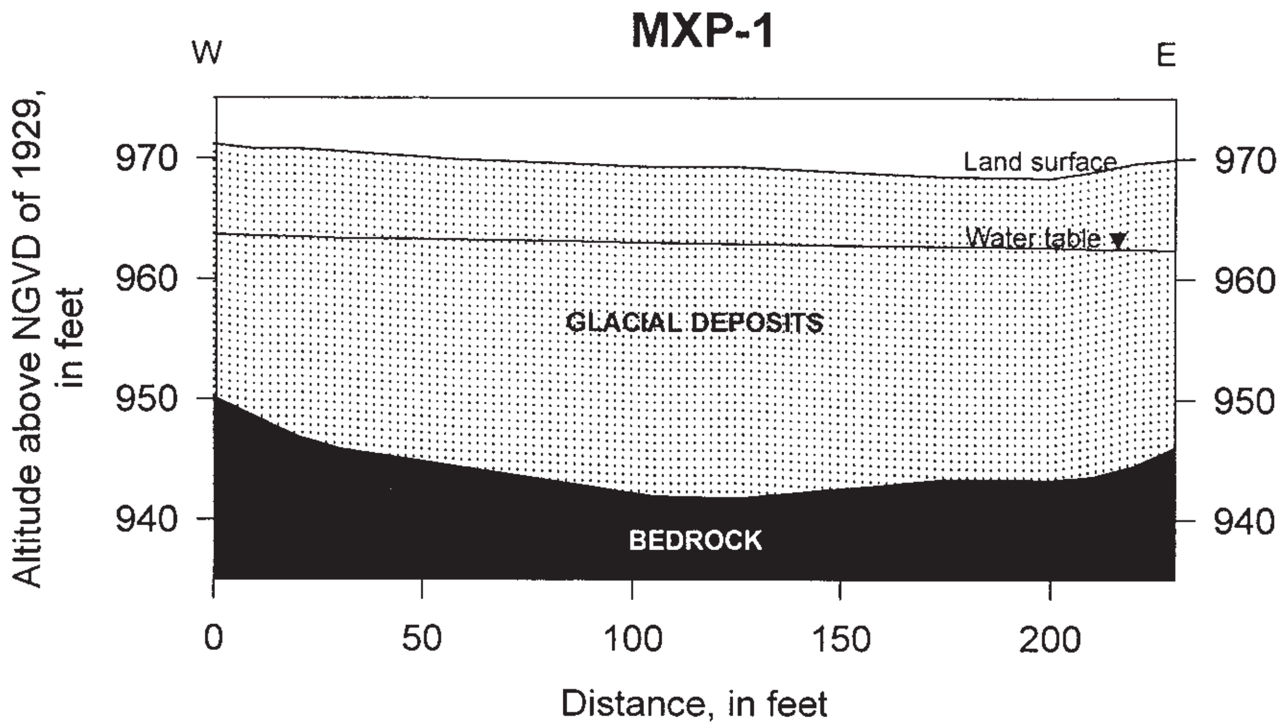
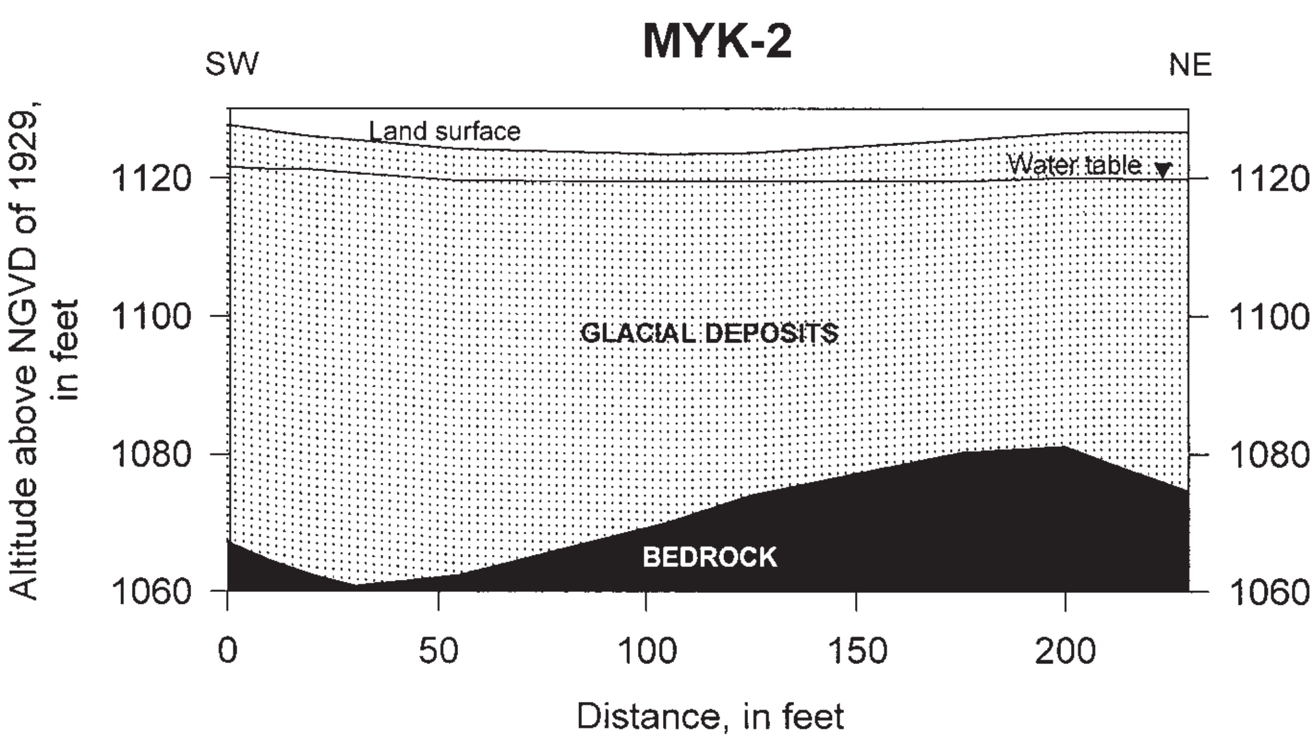
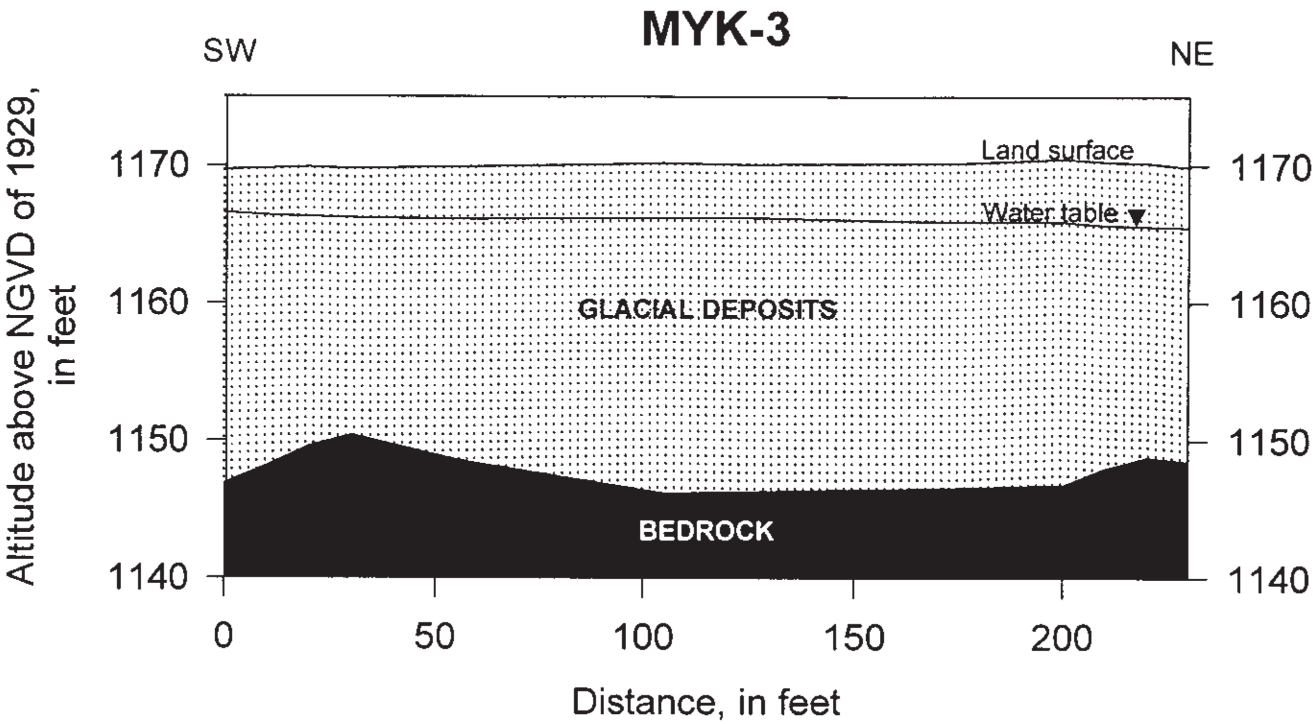
100
150
200
Distance, in feet
Vertical exaggeration 1.0x



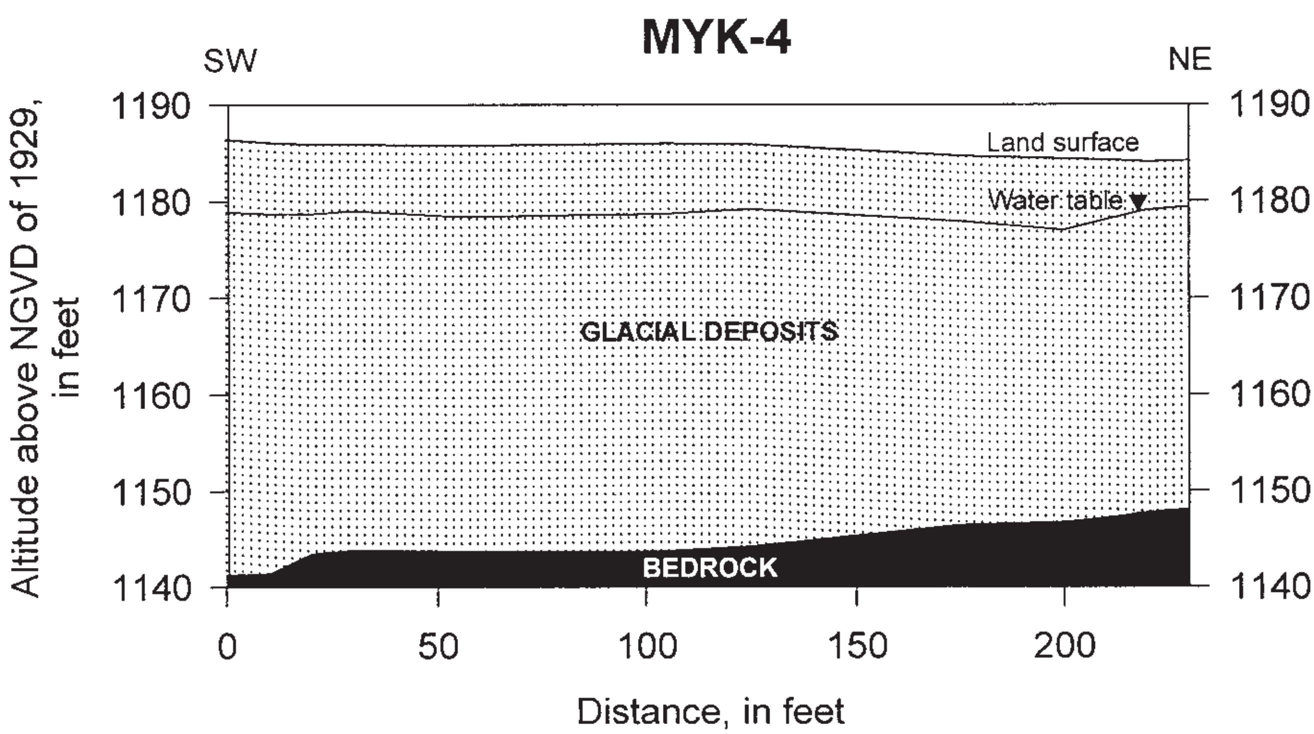
Vertical exaggeration 2.9x



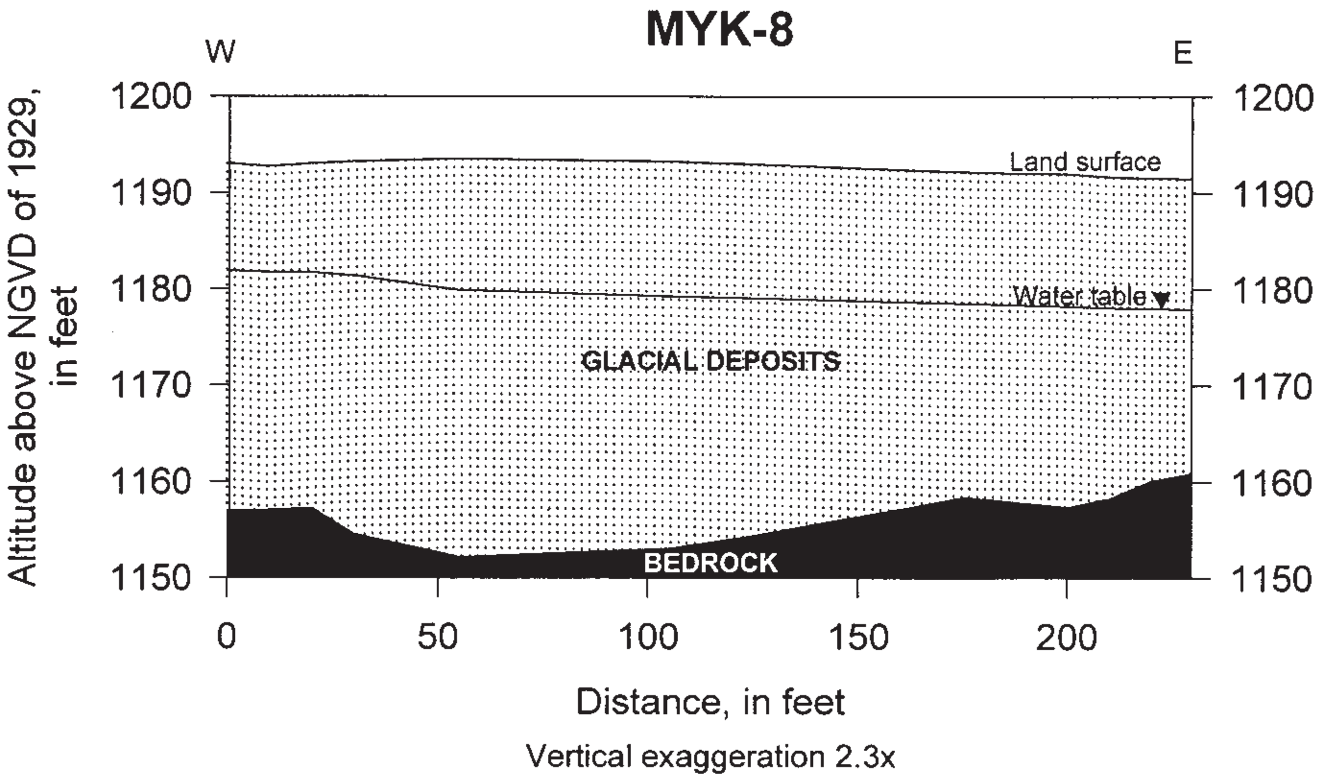
Vertical exaggeration 1.6x

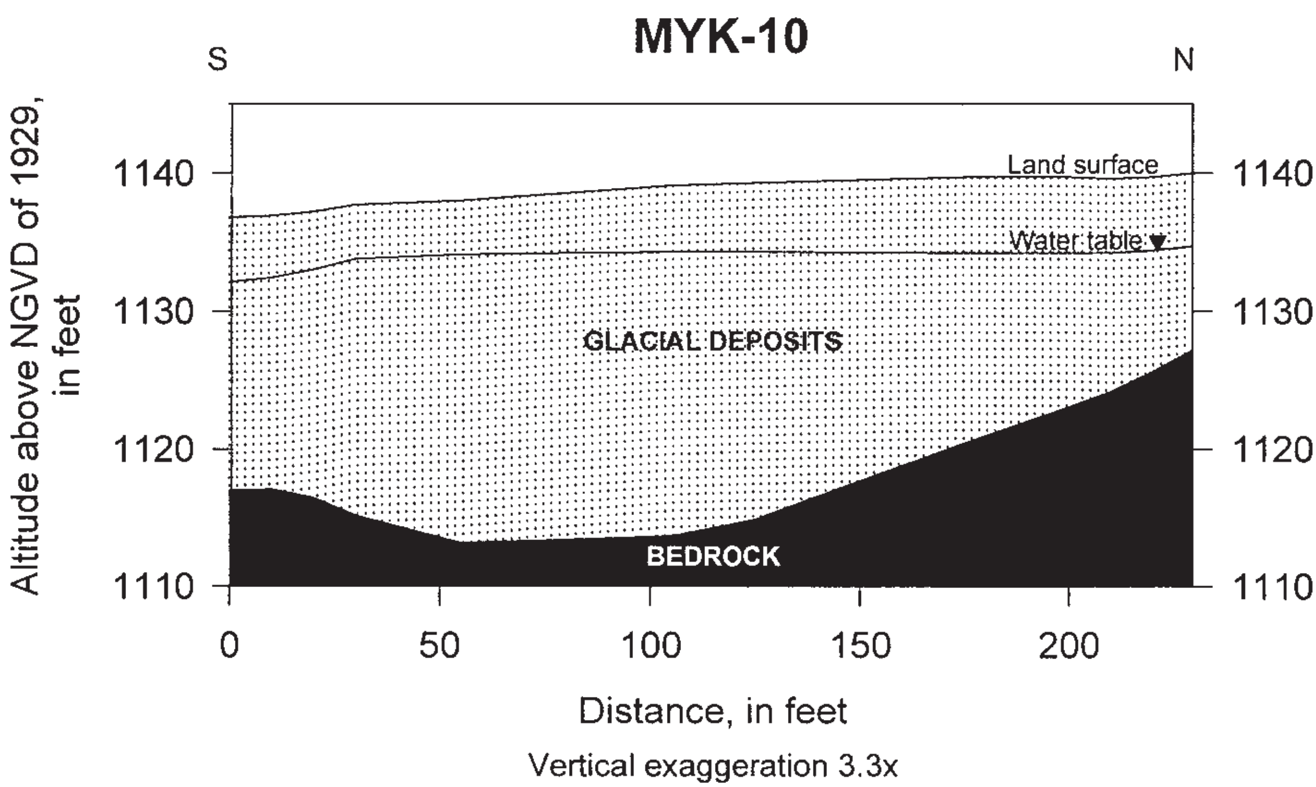


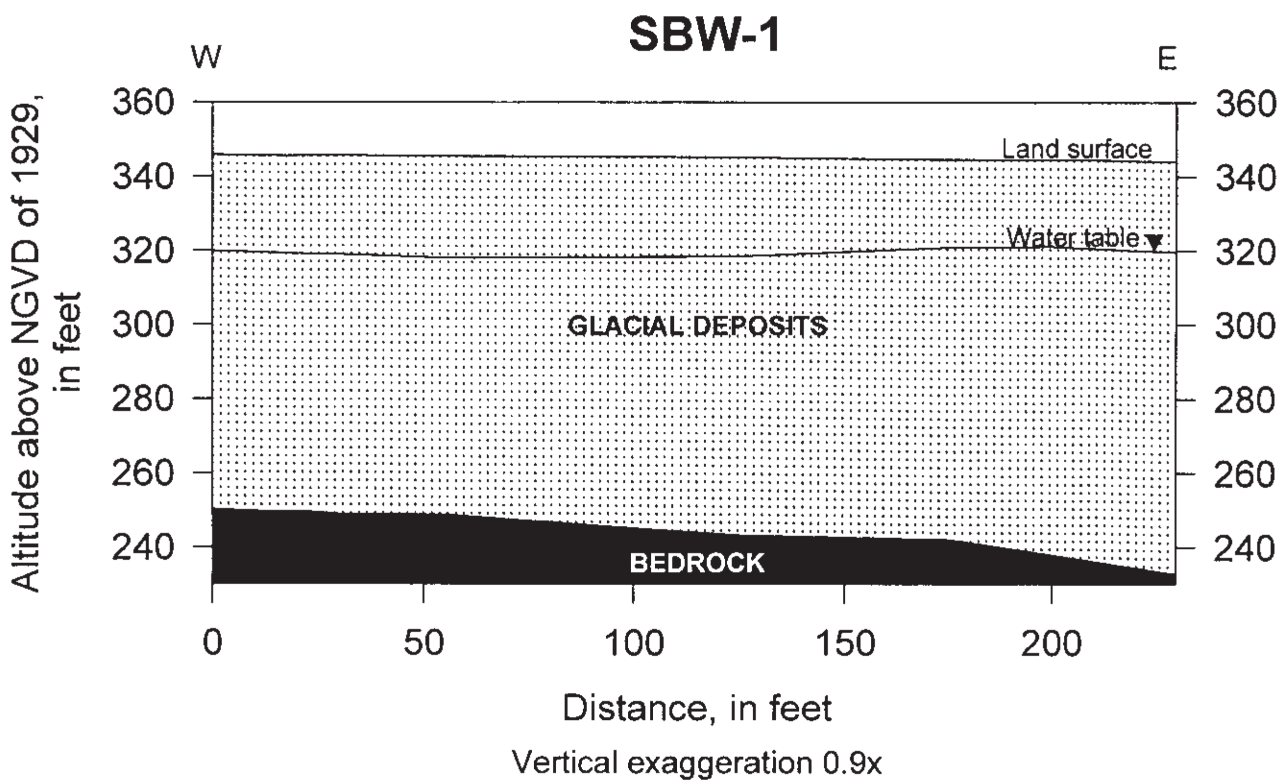
Vertical exaggeration 3.3x

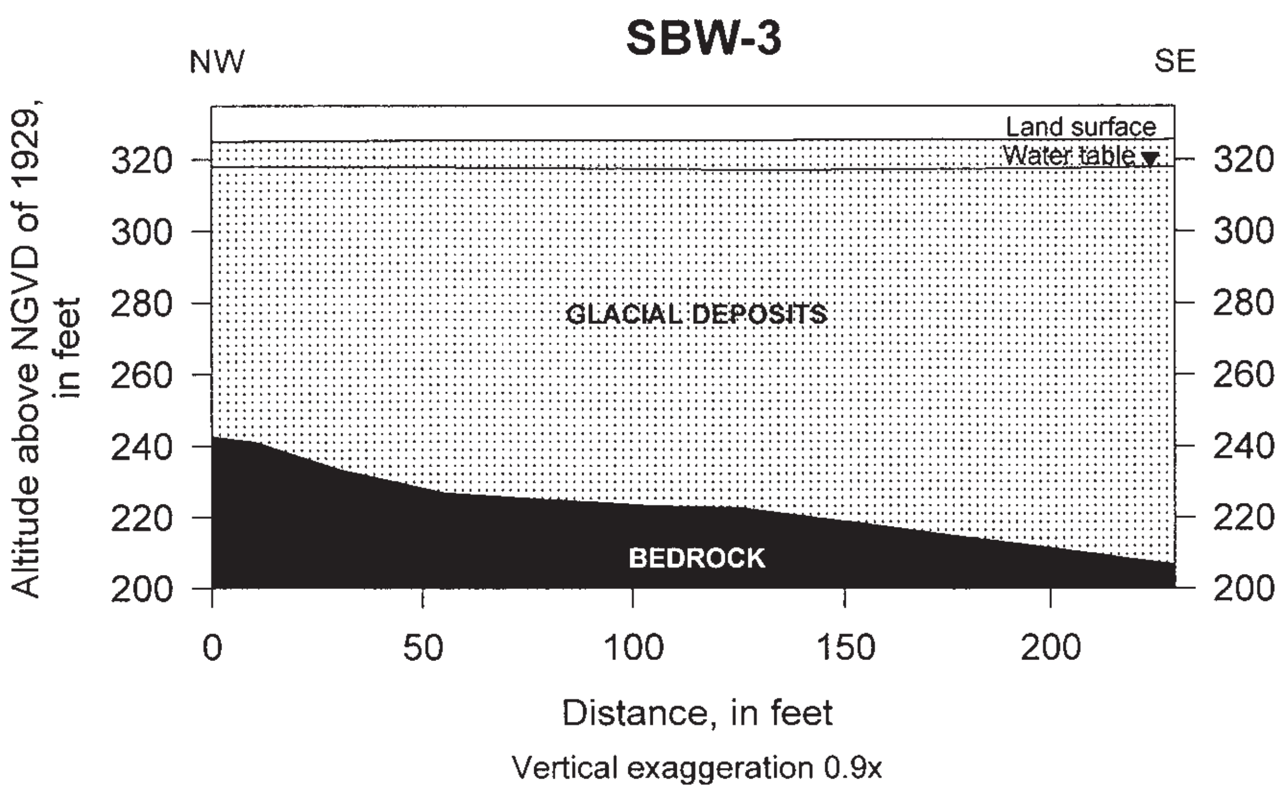


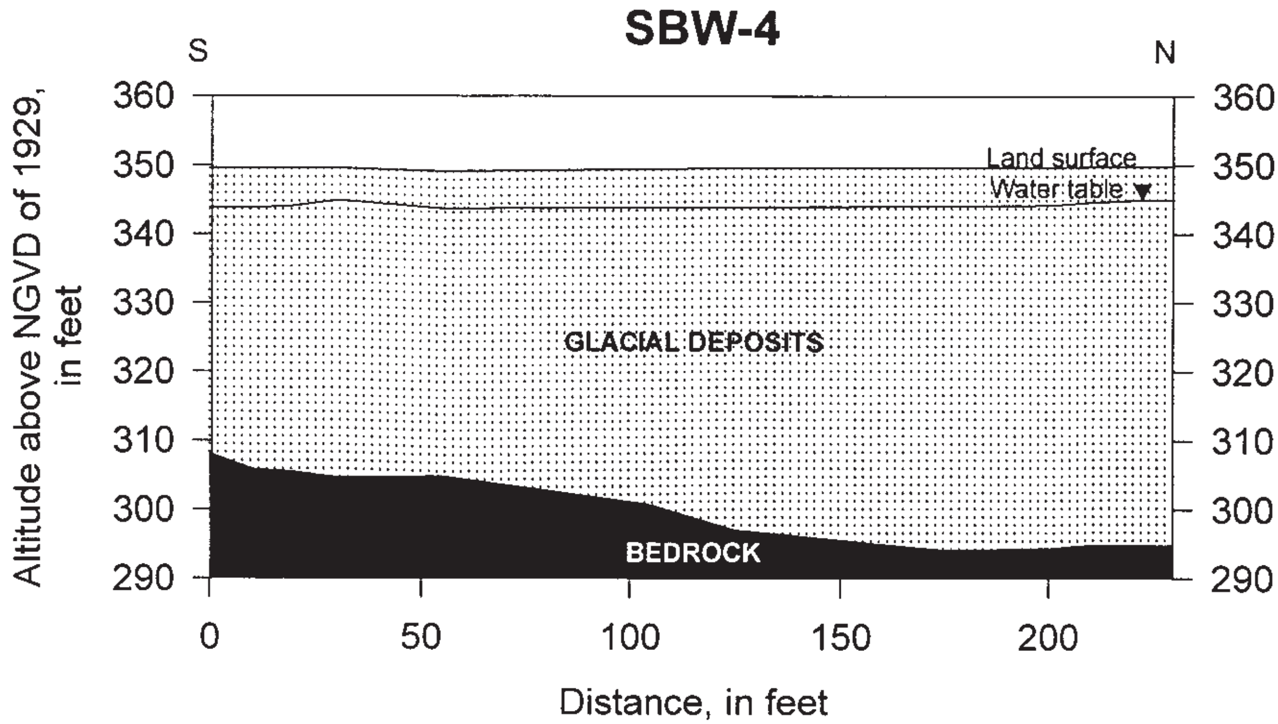
Vertical exaggeration 2.3x


MYK-8
W
E
Altitude above NGVD of 1929, in feet
1200
1190
1180
1170
1160
1150
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 2.3x

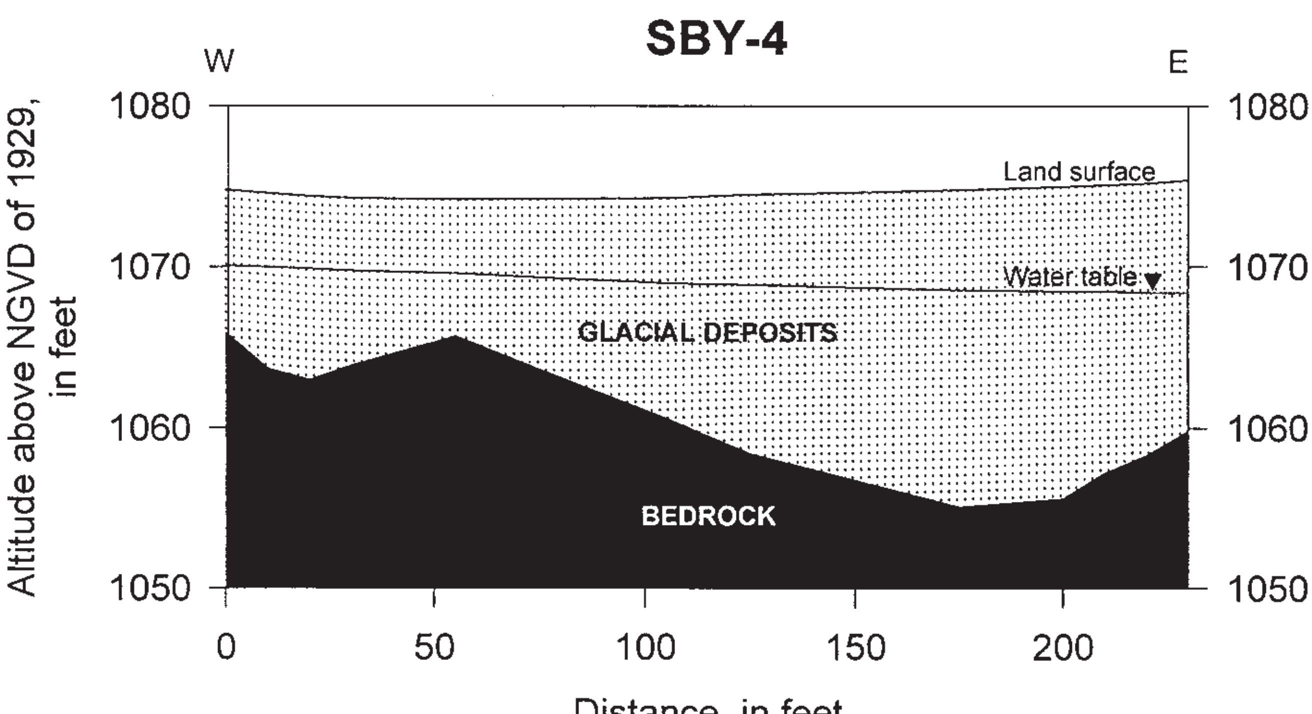

MYK-10
S
N
Altitude above NGVD of 1929, in feet
1140
1130
1120
1110
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 3.3x


SBW-1
W
E
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
360
340
320
300
280
260
240
0
50
100
150
200
Distance, in feet
Vertical exaggeration 0.9x

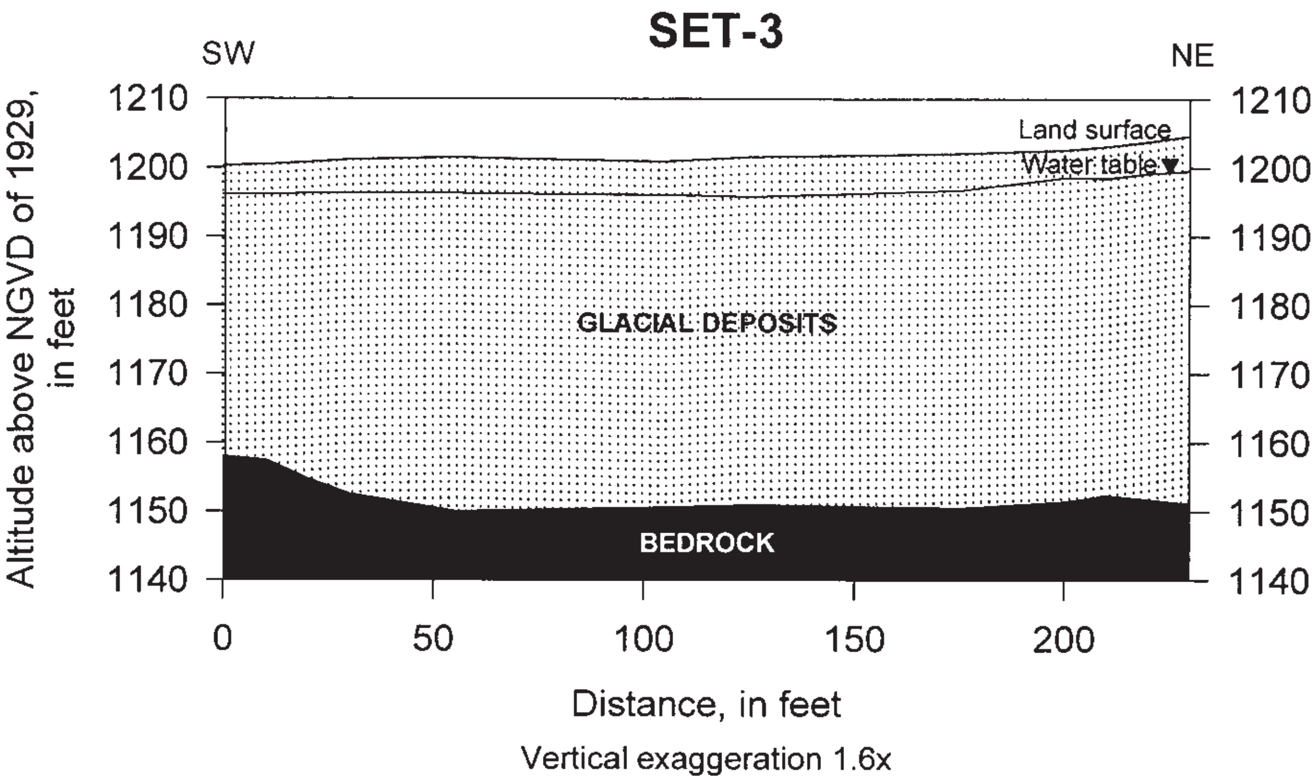

SBW-3
NW
SE
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
320
300
280
260
240
220
200
0
50
100
150
200
Distance, in feet
Vertical exaggeration 0.9x

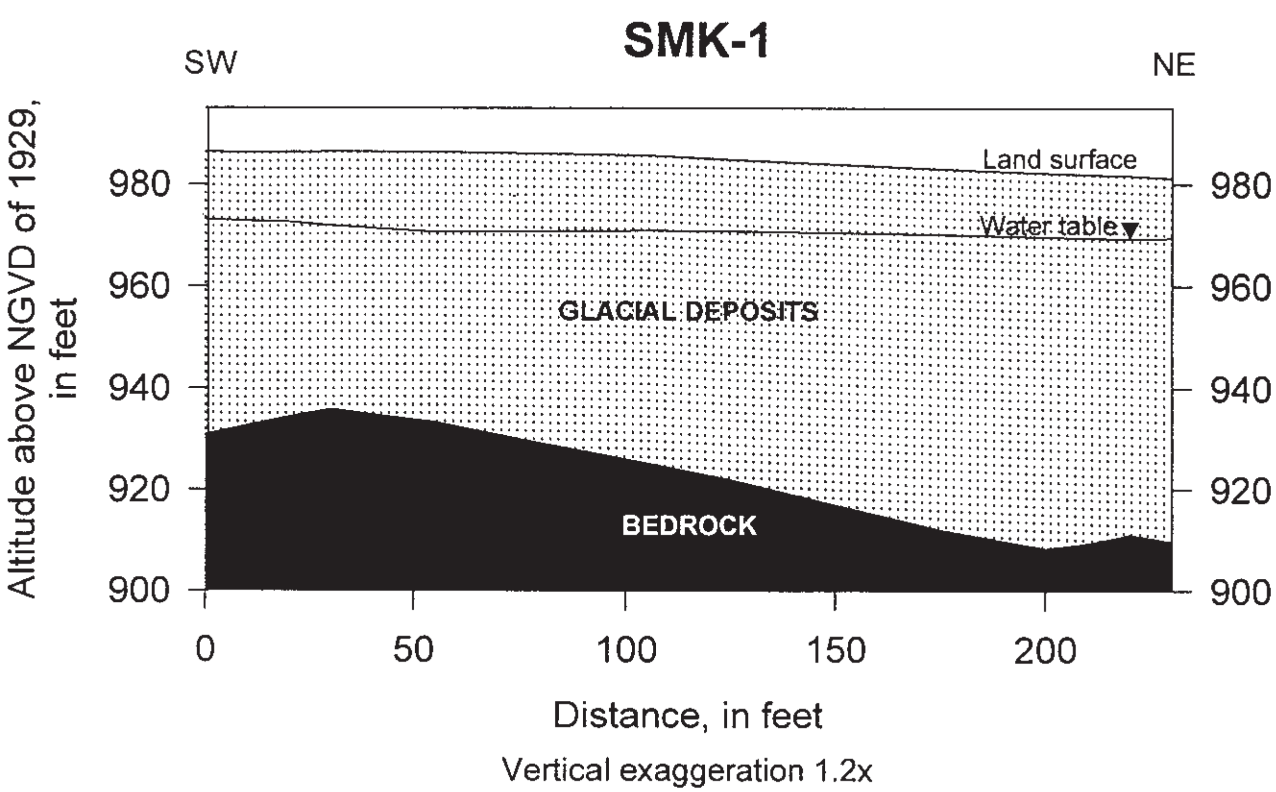


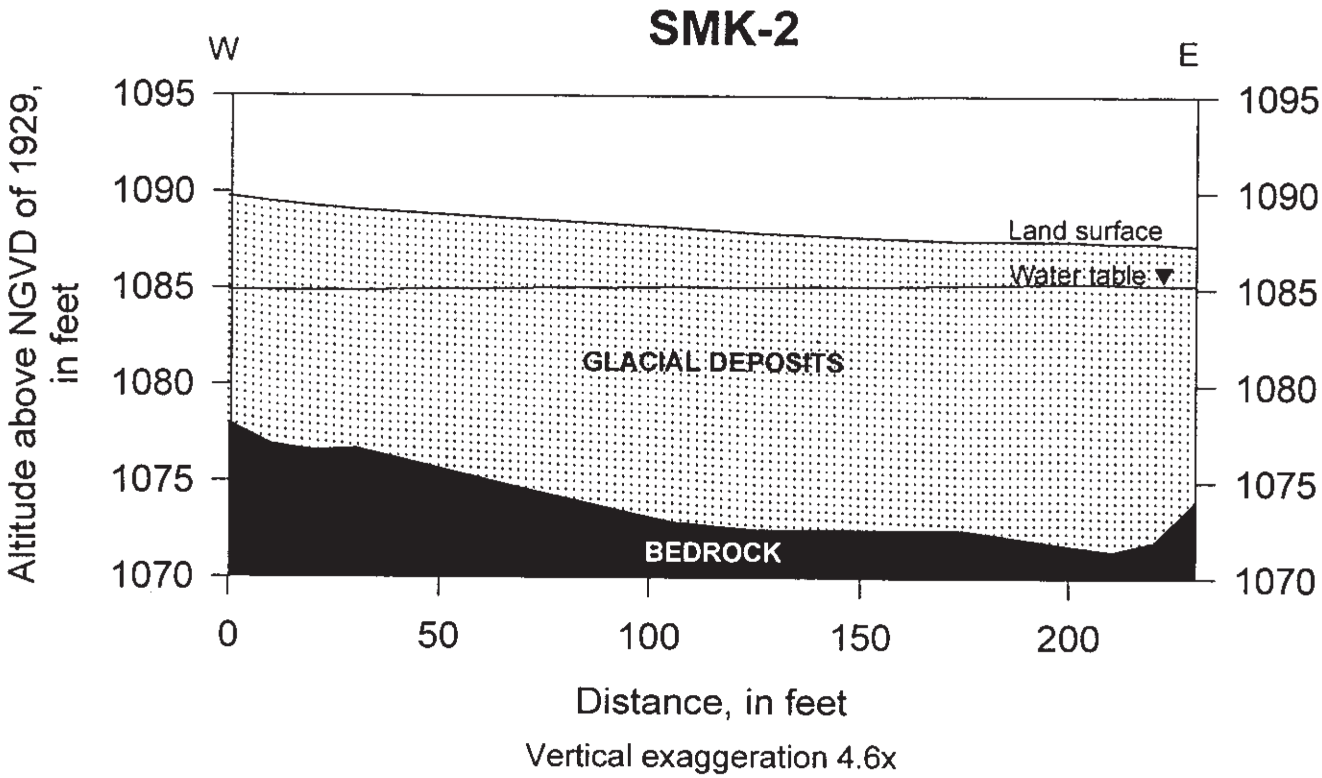
Vertical exaggeration 1.6x



Vertical exaggeration 3.8x


SET-3
SW
NE
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
1210
1200
1190
1180
1170
1160
1150
1140
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.6x


SMK-1
SW
NE
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
980
960
940
920
900
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.2x


SMK-2
W
E
1095
1090
1085
1080
1075
1070
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
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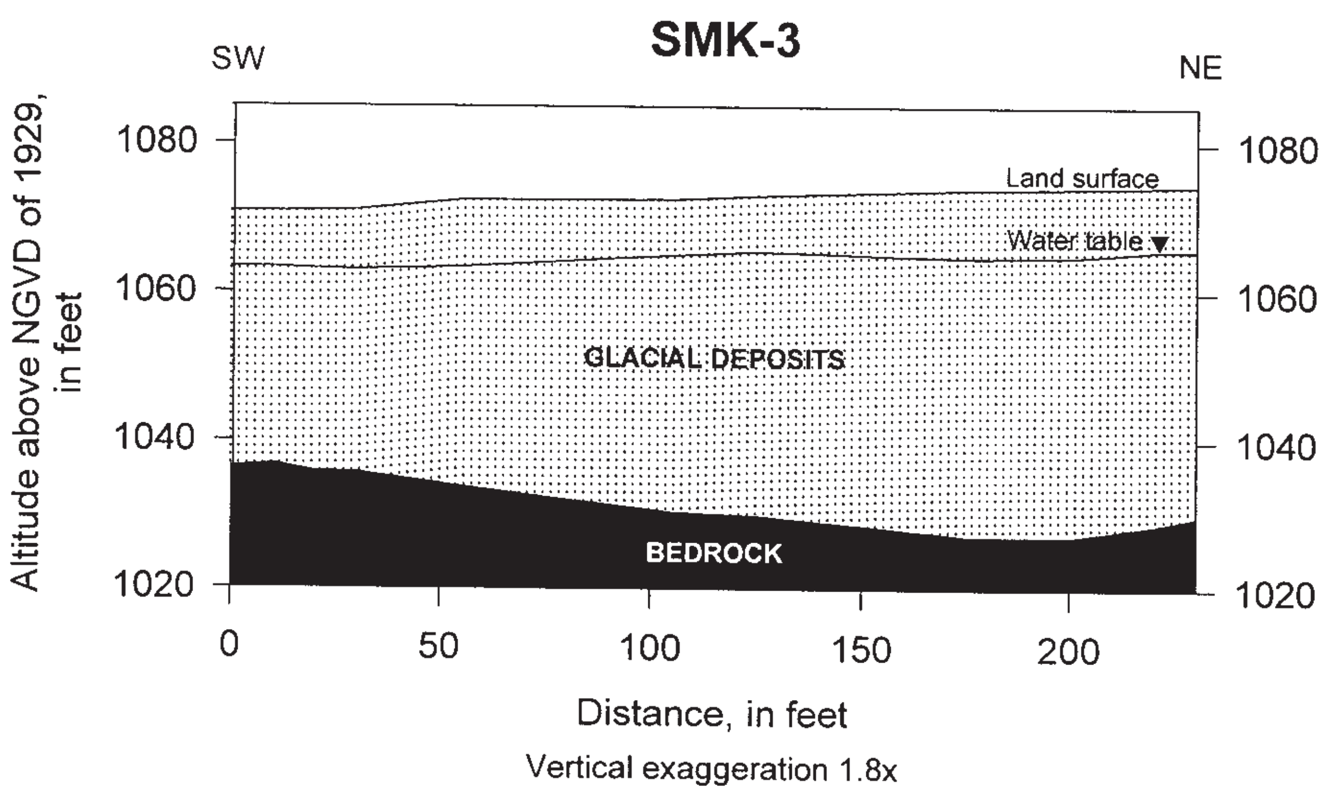
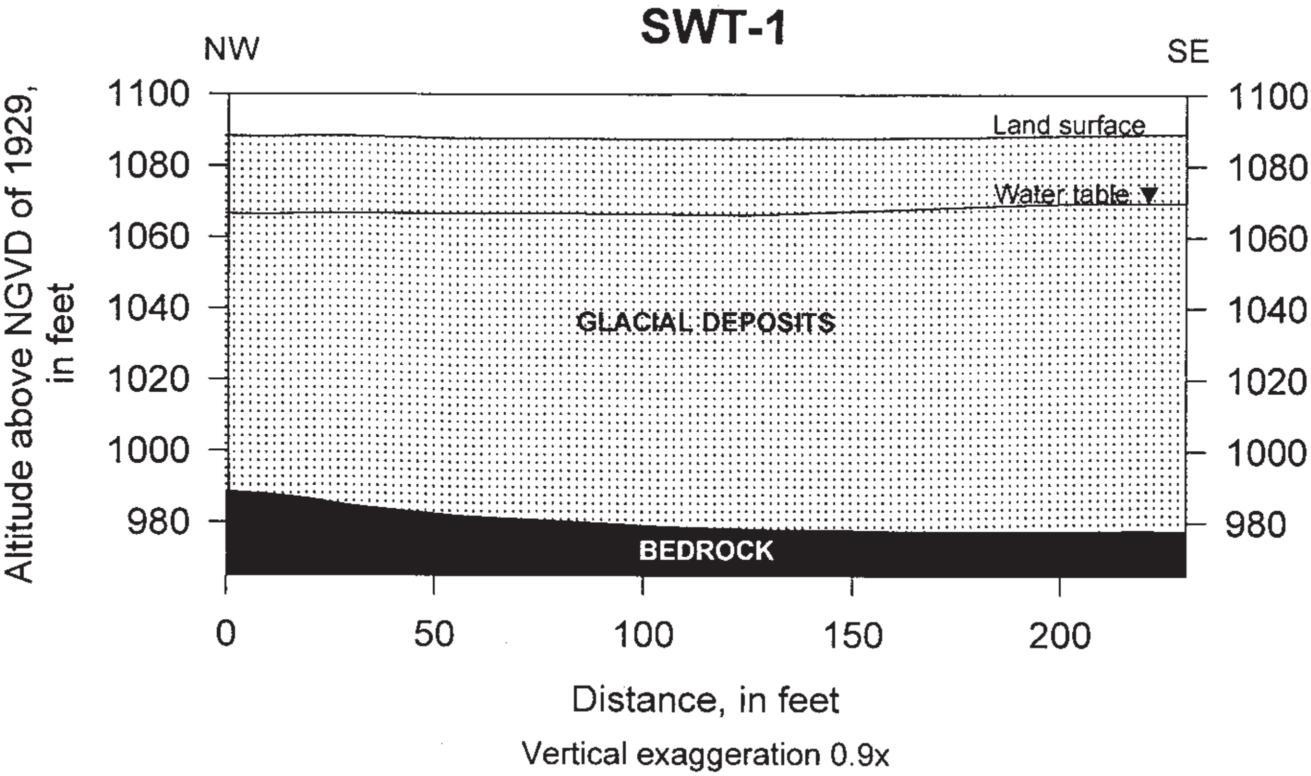
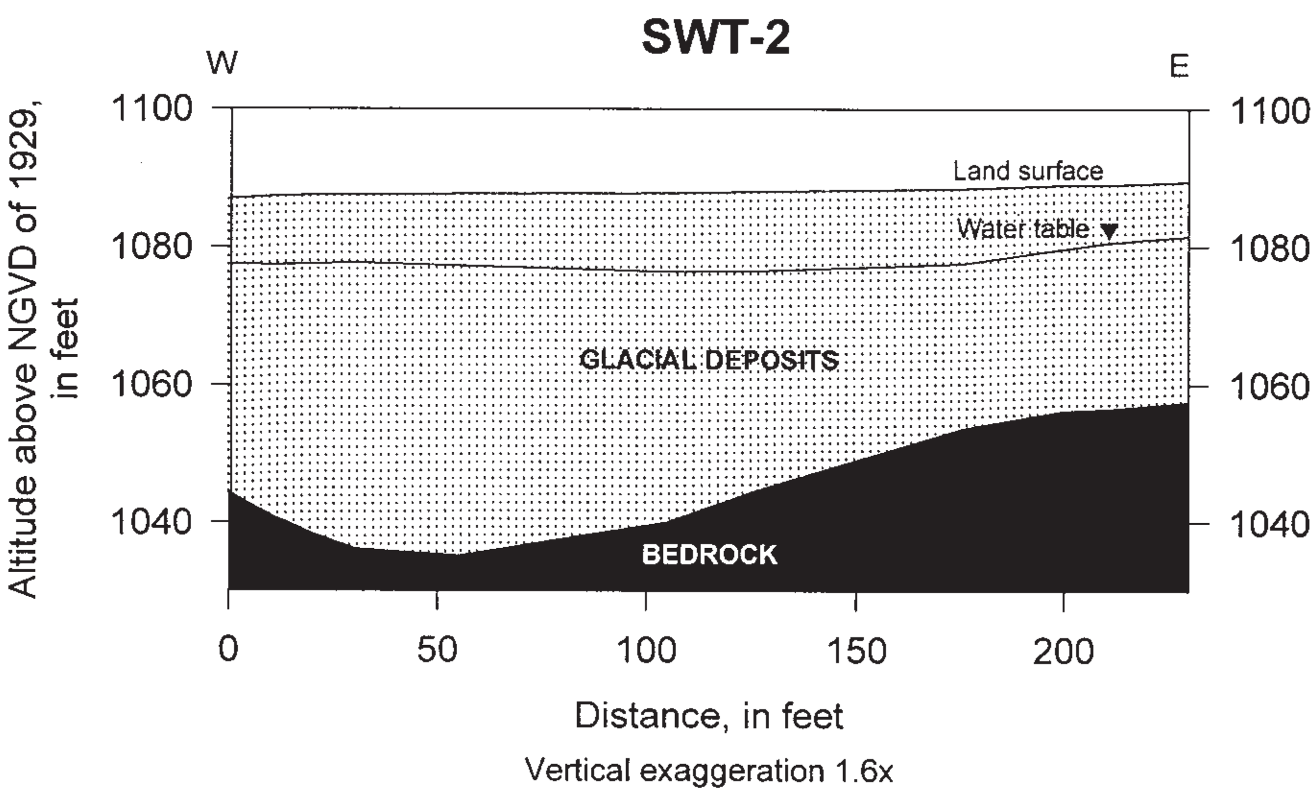
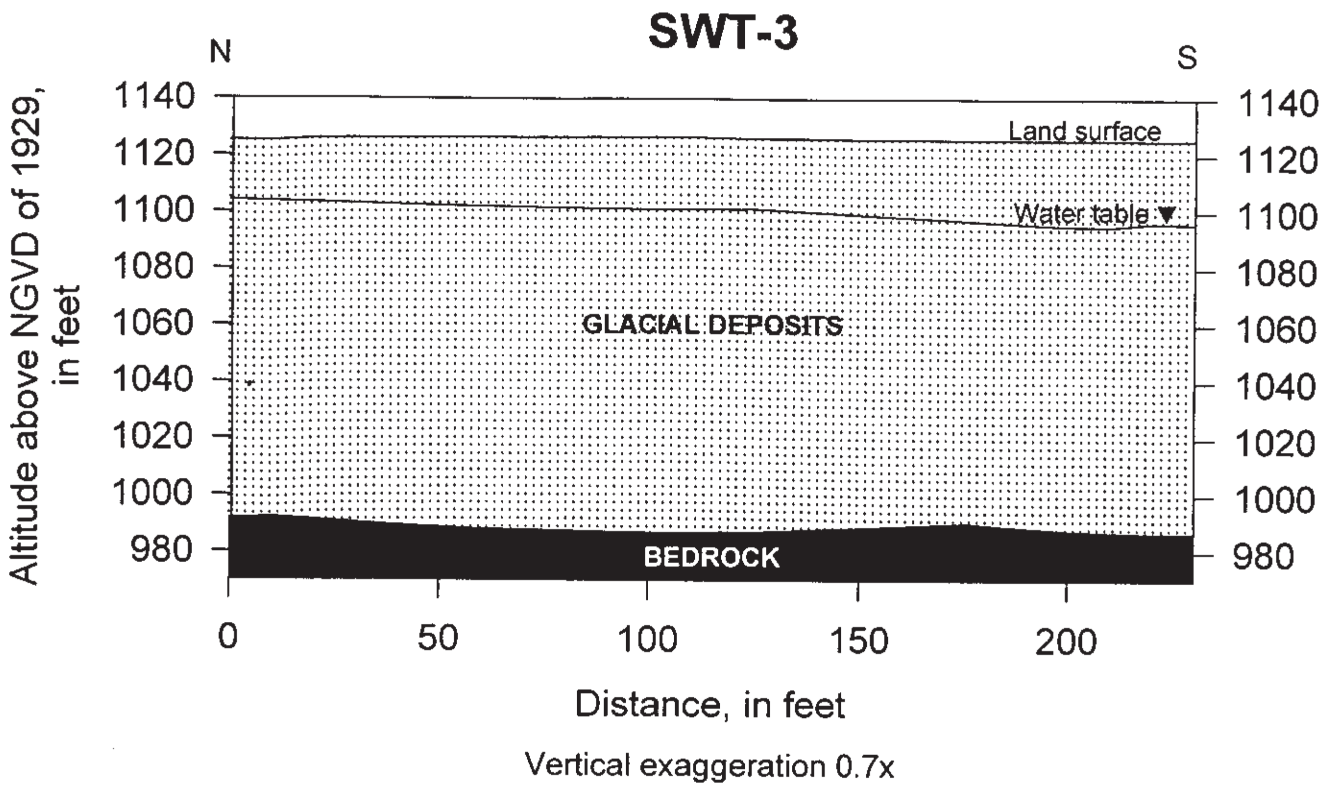
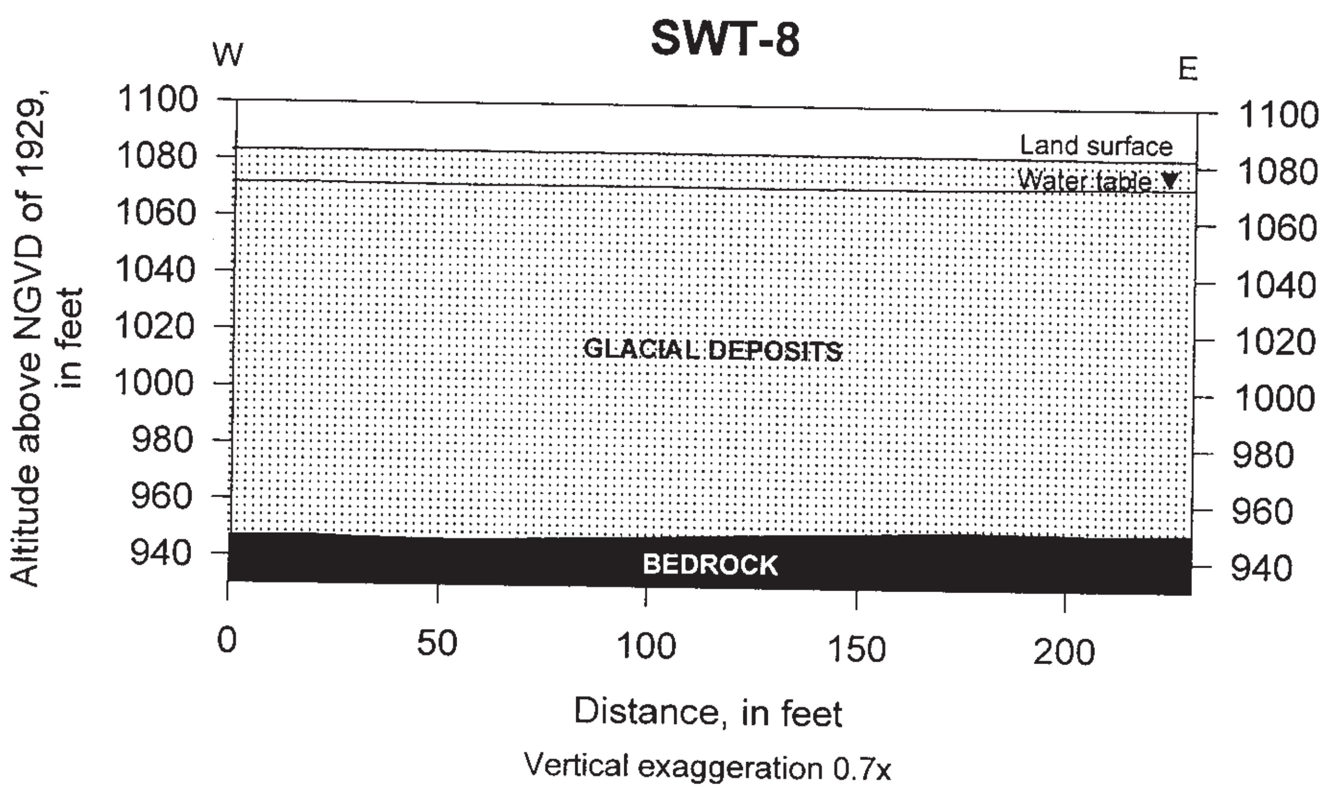
50
100
150
200
Altitude above NGVD of 1929, in feet
Distance, in feet
Vertical exaggeration 4.6x

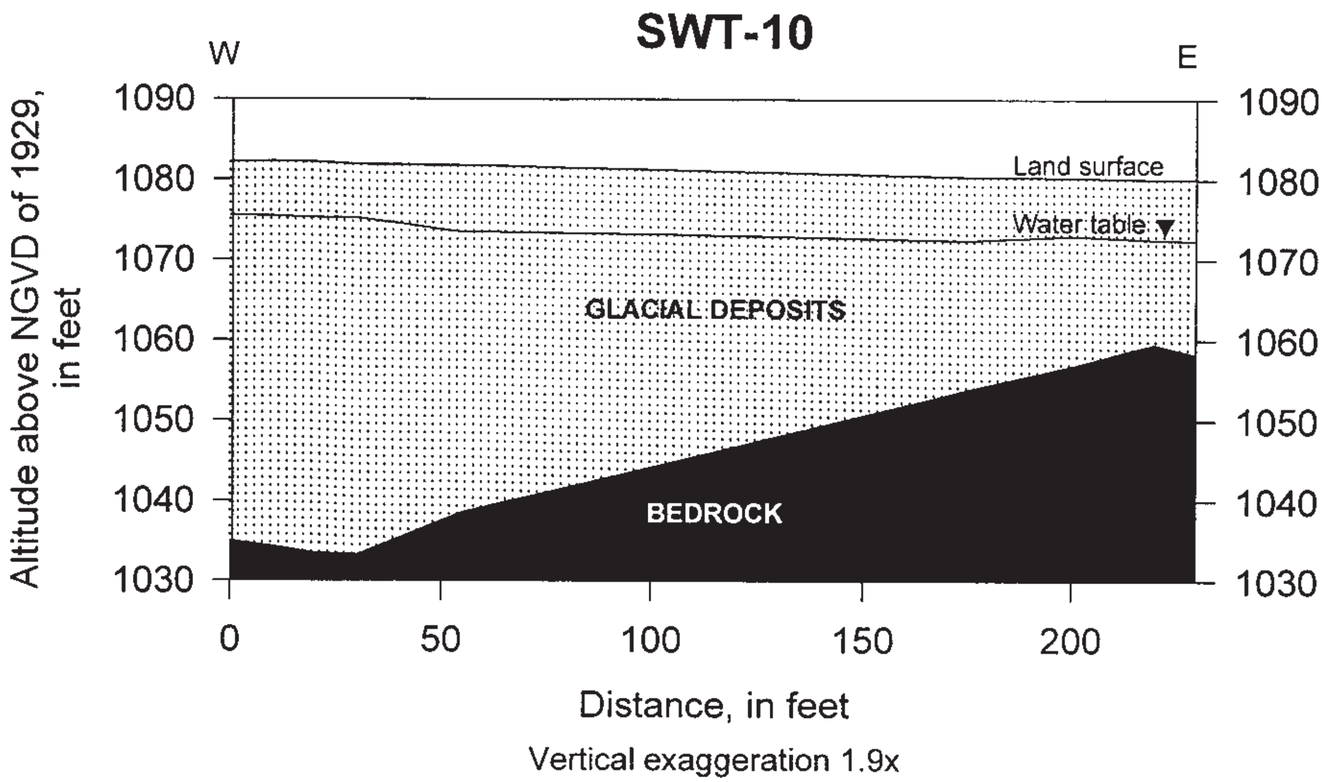

SMK-3
SW
NE
1080
1060
1040
1020
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Altitude above NGVD of 1929, in feet
Distance, in feet
Vertical exaggeration 1.8x


SWT-1
NW
SE
Altitude above NGVD of 1929, in feet
1100
1080
1060
1040
1020
1000
980
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 0.9x

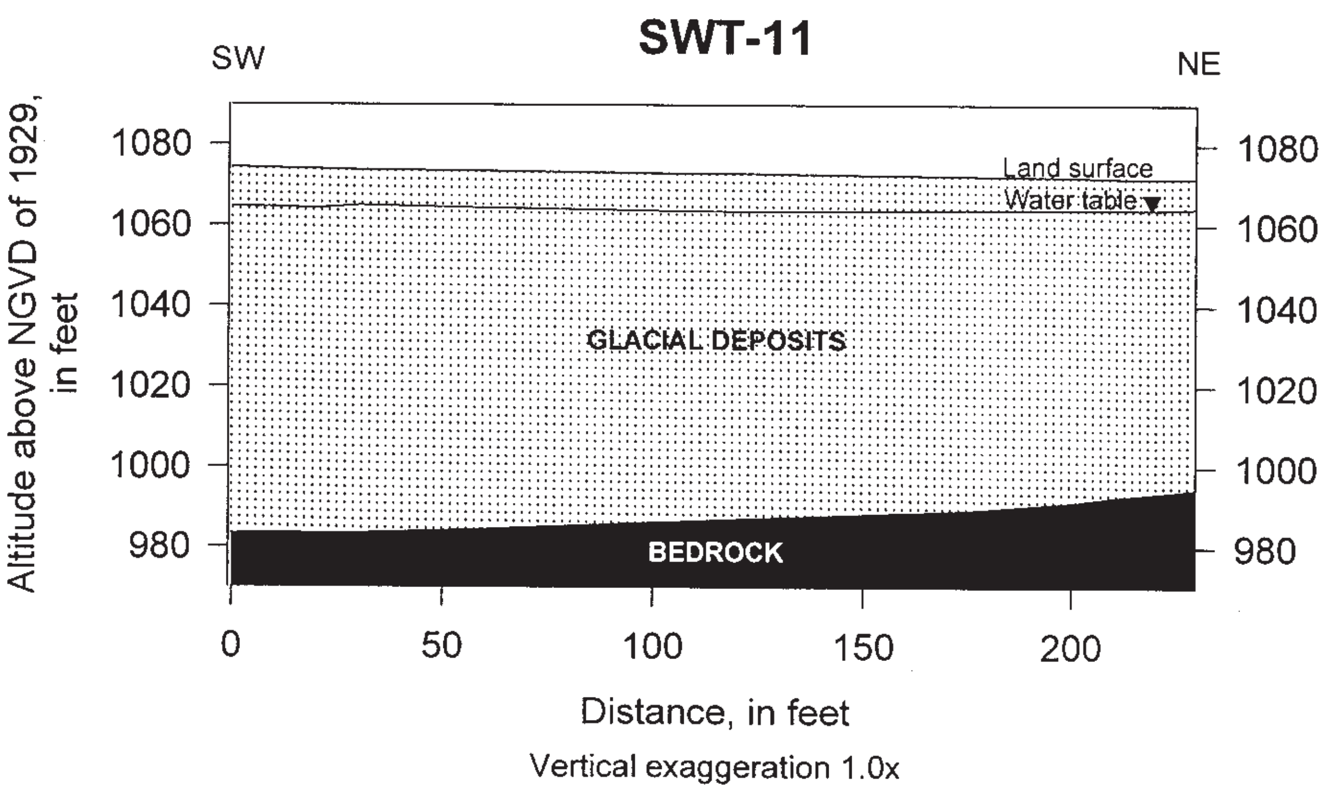

SWT-2
W
E
Altitude above NGVD of 1929, in feet
1100
1080
1060
1040
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.6x


SWT-3
N
S
1140
1120
1100
1080
1060
1040
1020
1000
980
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Altitude above NGVD of 1929, in feet
Vertical exaggeration 0.7x

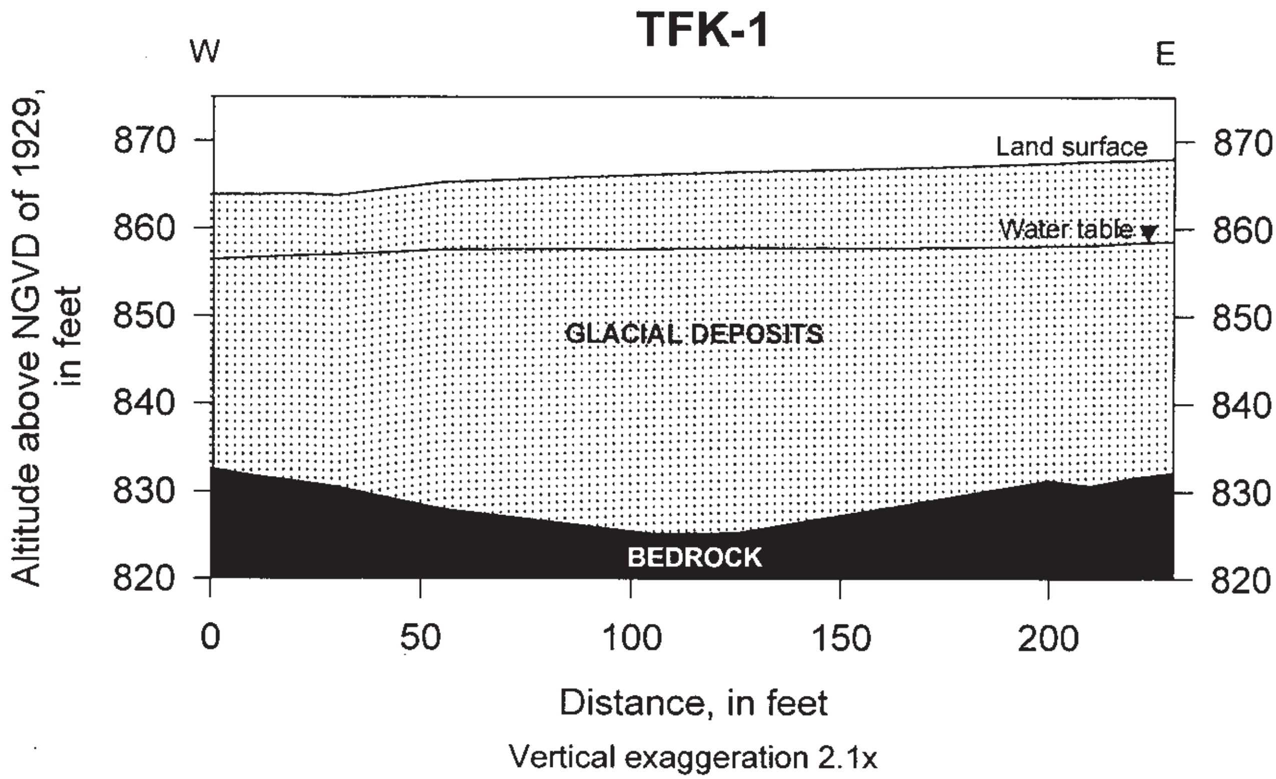

SWT-8
W
E
1100
1080
1060
1040
1020
1000
980
960
940
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Altitude above NGVD of 1929, in feet
Vertical exaggeration 0.7x



SWT-10
W
E
1090
1080
1070
1060
1050
1040
1030
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.9x



SWT-11
SW
NE
1080
1060
1040
1020
1000
980
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
Altitude above NGVD of 1929, in feet
0
50
100
150
200
Distance, in feet
Vertical exaggeration 1.0x


TFK-1
W
E
Altitude above NGVD of 1929, in feet
870
860
850
840
830
820
Land surface
Water table
GLACIAL DEPOSITS
BEDROCK
0
50
100
150
200
Distance, in feet
Vertical exaggeration 2.1x

Appendix 2

Observation-Well and Test-Boring Logs [1]

Identification number: composed of three elements:

OW (Observation Well installed for collection of water-level and water-quality data) or **TB** (test boring drilled but no observation well installed); year well was drilled in; and a sequential number in the order the exploration borings were drilled.

Location: Latitude and longitude are specified; observation wells and test borings are located on the associated maps.

Site description: A brief site description is given.

Description of materials: Logs of observation wells and test borings, based on the Wentworth scale, in Pettijohn (1975).

Terms used in logs of exploration borings:

Sand and Gravel—Sorted sediment varying in size from boulders to very fine sand.

Silt—sediment particles ranging in size from 1/16 mm to 1/256 mm.

Clay—Sediment particles 1/256 mm and smaller in size.

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

Loam—A mixture of sand, silt, and clay particles that exhibits light and heavy properties in roughly equal proportions.

EOH—Depth of bottom of exploration boring in which bedrock or refusal was not reached.

Refusal—Depth at which drill equipment could not penetrate further. If it is fairly certain that a boulder was encountered, the word “boulder” is shown in parentheses after the word “refusal”. If it is fairly certain that the bedrock surface was encountered, the word “bedrock” is shown in parentheses after the word “refusal”.

PVC — Polyvinyl chloride

[1] See tables 1, 2, and 3 for information on grain-size analyses, estimated transmissivities, and well yields.

OW 94-1. Latitude: 45°31'55" N., Longitude: 69°54'01" W.

Located on the Misery Knob quadrangle in Misery township in a gravel pit along a logging road south of Churchill Stream approximately 8.0 miles southwest of Somerset Junction. Water level is approximately 14 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to medium, gravel, silt	0 - 10	10	—	—
Silt	10 - 15	5	12 - 14	8
Sand, very fine to fine	15 - 30	15	17 - 19, 22 - 24, 27 - 29	3, 4, 4
Sand, fine	30 - 40	10	32 - 34, 37 - 39	5, 5
Sand, fine to medium	40 - 45	5	42 - 44	6
Sand, fine	45 - 60	15	47 - 49, 52 - 54, 57 - 59	10, 10, 10
Till	60 - 68	8	62 - 64	22
Refusal (bedrock)	68	—	—	—

OW 94-1 is screened from 36.0 to 46.0 feet below land surface with a 0.006-inch slotted, schedule 40, PVC screen.

OW 94-2. Latitude: 45°47'57" N., Longitude: 69°49'11" W.

Located on the Socatean Bay quadrangle in T1R3 NBKP in a gravel pit along a logging road just west of Socatean Stream, 3 miles upstream from it's confluence with Moosehead Lake. Water level is approximately 2 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Gravel, cobble to pebble, fine to coarse sand	0 - 5	5	—	—
Sand, fine to coarse, pebble gravel, some silt	5 - 35	30	7 - 9, 17 - 19, 27 - 29	16, 23, 41
Till, sandy	35 - 46	11	37 - 39	56
Refusal (bedrock)	46	—	—	—

OW 94-2 is screened from 7.5 to 17.5 feet below land surface with a 0.006-inch slotted , schedule 40, PVC screen.

OW 94-3. Latitude: 45°53'58" N., Longitude: 69°57'04" W.

Located on the Seboomook Lake West quadrangle in T2R4 NBKP along a logging road on the north side of Seboomook Lake 1.5 miles east of Pittston Farm. Water level is approximately 24 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to coarse, silt, gravel	0 - 28	28	17 - 19, 27 - 29	29, 8
Sand, very fine, silt,clay	28 - 38	10	27 - 29, 37 - 39	8, 30
Sand, fine to medium, pebbles, clay	38 - 55	17	37 - 39, 47 - 49	30, 50
Till, compact	55 - 59	4	57 - 59	50
Refusal (till)	59	—	—	—

OW 94-3 is screened from 35.0 to 45.0 feet below land surface with a 0.006-inch slotted, schedule 40, PVC screen.

OW 94-4. Latitude: 45°56'30" N., Longitude: 69°59'49" W.

Located on the Seboomook Lake West quadrangle in Comstock township (T4R18 WELS) in a gravel pit 0.2 miles west of a logging road and 0.2 miles north of Leadbetter Falls on the North Branch Penobscot River. Water level is approximately 14 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Gravel, cobble to pebble, silt, sand	0 - 11	11	—	—
Sand, fine to very fine, silt, gravel	11 - 49	38	12 - 14, 17 - 19, 27 - 29	58, 44, 40
			37 - 39, 47 - 49	58, 46
Till, sand, shale fragments, cobbles	49 - 63	14	62 - 63	59
Refusal	63	—	—	—

OW 94-4 is screened from 46.0 to 56.0 feet below land surface with a 0.006-inch slotted, schedule 40, PVC screen.

OW 94-5. Latitude: 45°24'01" N., Longitude: 69°37'28" W.

Located on the Greenville quadrangle in Little Squaw township in a gravel pit west of the Shirley Road 4.5 miles south of Greenville Junction. Water level is approximately 3 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to medium	0 - 13	13	7 - 9	5
Gravel, pebble, sand, some silt	13 - 25	12	17 - 19	16
Gravel, pebble, silt, fine sand, compact	25 - 35	10	27 - 29	59
Refusal	35	—	—	—

OW 94-5 is screened from 13.0 to 23.0 feet below land surface with a 0.006-inch slotted, schedule 40, PVC screen.

OW 94-6. Latitude: 45°25'48" N., Longitude: 69°37'59" W.

Located on the Big Squaw Pond quadrangle in Little Squaw township on the west side of the Shirley Road 2.5 miles south of Greenville Junction. Water level is approximately 11 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to medium	0 - 9	9	—	—
Cobbles, fine sand	9 - 19	10	17 - 19	47
Refusal (bedrock)	19	—	—	—

OW 94-6 is screened from 4.0 to 14.0 feet below land surface with a 0.006-inch slotted, schedule 40, PVC screen.

OW 94-7. Latitude: 45°15'56"N., Longitude: 69°40'12"W.

Located on the Bald Mtn. Pond quadrangle in Blanchard township in a gravel pit off a logging road west of Marble Brook 4.0 miles west of Blanchard village. Water level is approximately 13 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to coarse, gravel	0 - 10	10	—	—
Sand, fine to medium	10 - 20	10	17 - 19	37
Till	20 -23	3	22 - 23	25
Refusal	23	—	—	—

OW 94-7 is screened from 10.0 to 20.0 feet below land surface with a 0.006-inch slotted, schedule 40, PVC screen

OW 94-8. Latitude: 45°18'36"N., Longitude: 69°23'57"W.

Located on the Monson East quadrangle in Willimantic in a gravel pit on the north side of Wilson Stream 1.0 mile east of Willimantic village. Water level is approximately 5 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, medium to coarse, pebble gravel	0 - 16	16	12 - 14	17
Sand, fine, interbedded silt, clay	16 - 26	10	17 - 19	14
Till	26-30	4	—	—
Refusal	30	—	—	—

OW 94-8 is screened from 5.0 to 15.0 feet below land surface with a 0.006-inch slotted, schedule 40, PVC screen.

OW 94-9. Latitude: 45°18'10"N., Longitude: 69°24'40"W.

Located on the Monson East quadrangle in Willimantic on the east side of Willimantic Road 0.6 miles south of the bridge over Wilson Stream. Water level is approximately 21.0 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to medium, pebble gravel	0 - 5	5	—	—
Sand, fine to medium	5 - 102	97	22 - 24, 37 - 39, 47 - 49	11, 7, 11
			67 - 69, 87 - 89	11, 30
Sand, fine to very fine, silt	102 - 122	20	—	—
EOH (sand lock)	122	—	—	—

OW 94-9 is screened from 55.0 to 75.0 feet below land surface with a 0.006-inch slotted, schedule 40, PVC screen.

OW 94-10. Latitude: 45°18'11"N., Longitude: 69°19'37"W.

Located on the Sebec Lake West quadrangle in Willimantic along a camp road on the north shore of Sebec Lake 1.5 miles east of Earley Landing. Water level is approximately 6.0 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, medium to coarse, pebble gravel	0 - 5	5	—	—
Sand, coarse to very coarse, pebble gravel	5 - 10	5	5 - 6	—
EOH	10	—	—	—

OW 94-10 is screened from 11.0 to 13.5 feet below land surface with a 0.007-inch mesh, stainless steel drive point.

TB 94-1. Latitude: 45°35'36"N., Longitude: 69°49'28"W.

Located on the Indian Pond North quadrangle in Sapling township (T1R7 BKP WKR) in a small gravel pit on the south side of Capitol Road 6.2 miles west of the intersection of Capitol and Rt. 15. Water level is approximately 27 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to medium, pebble gravel	0 - 23	23	17 - 19	19
Sand, fine to very fine, silt, laminated	23 - 48	25	27 - 29, 32 - 34, 37 - 39	5, 2, 5
			42 - 44, 47 - 49	3, 12
Till	48 - 51	3	47 - 49	12
Refusal (bedrock)	51	—	—	—

No well was installed.

TB 94-2. Latitude: 45°29'58"N., Longitude: 69°55'18"W.

Located on the Black Brook Pond quadrangle in Chase Stream township in a small gravel pit on the east side of Chase Stream 0.9 miles south of the Capitol Road. Water level is approximately 5 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Pebble gravel, fine to coarse sand, rock fragments	0 - 8	8	7 - 8	23
Refusal (bedrock)	8	—	—	—

No well was installed.

TB 94-3. Latitude: 45°27'42"N., Longitude: 69°54'21"W.

Located on the Black Brook Pond quadrangle in Chase Stream township in a small gravel pit 0.2 miles west of Chase Stream Flowage and 4.05 miles south of the Capitol Road. Water level is approximately 14 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Cobble gravel fill	0 - 14	14	—	—
Peat	14 - 16	2	—	—
Till, sandy	16 - 34	18	17 - 19, 27 - 29	19, 35
Refusal (bedrock?)	34	—	—	—

No well was installed.

TB 94-4. Latitude: 45°32’48"N., Longitude: 69°56’37"W.

Located on the Misery Knob quadrangle in Misery township beside the Misery Road 5.15 miles west of Rt. 15. No water was encountered in the boring.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, medium to coarse, cobble gravel, rock fragments	0 - 10	10	7 - 9	55
Till	10 - 11	1	—	—
Refusal (till)	11	—	—	—

No well was installed.

TB 94-5. Latitude: 45°35’33"N., Longitude: 69°54’05"W.

Located on the Misery Knob quadrangle in Misery township in a gravel pit south of Rt. 15 0.4 miles west of the Misery Stream bridge. Water level is approximately 13 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	
Cobble gravel, some sand	0 - 9	9	—	—
Till	9 - 14	5	12 -14	33
Refusal (till)	14	—	—	—

No well was installed.

TB 94-6. Latitude: 45°37’03"N., Longitude: 69°58’32"W.

Located on the Misery Knob quadrangle in Sandwich Academy in a gravel pit 0.1 miles north of the Moose River and 0.35 miles upstream from the Demo Pond Road bridge. Water level is approximately 5 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, silt, pebble to cobble gravel	0 - 5	5	—	—
Till	5 - 9	4	7 - 9	42
Refusal (till)	9	—	—	—

No well was installed.

TB 94-7. Latitude: 45°41'43"N., Longitude: 69°56'32"W.

Located on the Brassua Lake West quadrangle in Brassua township in a gravel pit on the east side of the Demo Pond Road 8.45 north of the junction of Rt. 15 and the Demo Pond Road. Water level is approximately 10 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to coarse, pebble to cobble gravel	0 - 8	8	—	—
Till, sandy	8 - 23	15	12 - 14, 17 - 19, 22 - 23	75, 16, 25
Refusal (bedrock)	23	—	—	—

No well was installed.

TB 94-8. Latitude: 45°43'31"N., Longitude: 69°56'29"W.

Located on the Brassua Lake West quadrangle in Brassua township 0.3 miles along a logging road that heads east off the Demo Pond Road 0.4 miles north of the bridge over the South Branch Brassua Stream. No water was encountered.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to coarse, pebble to cobble gravel	0 - 7	7	—	—
Till	7 - 14	7	12 - 14	88
Refusal (till)	14	—	—	—

No well was installed.

TB 94-9. Latitude: 45°43'39"N., Longitude: 69°54'25"W.

Located on the Brassua Lake West quadrangle in Brassua township 2.2 miles along a logging road that heads east off the Demo Pond Road 0.4 miles north of the bridge over the South Branch Brassua Stream. Water level is approximately 10 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to coarse, pebble to cobble gravel	0 - 12	12	—	—
Till	12 - 14	2	12 - 14	48
Refusal (bedrock)	14	—	—	—

No well was in stalled.

TB 94-10. Latitude: 45°46'01"N., Longitude: 69°58'56"W.

Located on the Tomhegan Pond quadrangle in Soldier Town in a gravel pit on the west bank of North Branch Brassua Stream 1.3 miles upstream from the Soldier Town/Brassua townline. Water level is approximately 1 foot below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to coarse, pebble gravel	0 - 3	3	—	—
Till	3 - 5	2	—	—
Refusal (bedrock?)	5	—	—	—

No well was installed.

TB 94-11. Latitude: 45°49'07"N., Longitude: 69°51'05"W.

Located on the Socatean Bay quadrangle in West Middlesex Canal Grant in a gravel pit on the west shore of Socatean Stream 4.0 miles upstream from its confluence with Moosehead Lake. Water level is approximately 2 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to coarse, pebble gravel, silt	0 - 5	5	—	—
Sand, fine to medium, silt	5 - 10	5	—	—
Silt, fine sand	10 - 12	2	—	—
Till	12 - 13	1	12 - 13	19
Refusal (bedrock)	13	—	—	—

No well was installed.

TB 94-12. Latitude: 45°53'16"N., Longitude: 69°54'32"W.

Located on the Seboomook Lake West quadrangle in Plymouth township along a logging road between the Seboomook Campground road and Seboomook Lake 0.6 miles east of the Plymouth/Pittston Academy Grant townline. Water level is approximately 10 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to medium, pebbles, silt	0 - 10	10	—	—
Sand, fine, silt	10 - 15	5	12 - 14	8
Silt, clay	15 - 25	10	17 - 19	9
Clay, silt	25 - 96	71	27 - 29, 37 - 39, 47 - 49	2, 2, 2
			57 - 59	5
Refusal (bedrock?)	96	—	—	—

No well was installed.

TB 94-13. Latitude: 45°53'00"N., Longitude: 69°56'37"W.

Located on the Seboomook Lake West quadrangle in Pittston Academy Grant along a discontinued road 1.1 miles east of Pittston Farm. Water level is approximately 11 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to coarse, cobbles, silt	0 - 11	11	7 - 9	14
Sand, fine, silt, clay, interbedded	11 - 61	50	17 - 19, 37 - 39, 57 - 59	2, 5, 9
Sand, fine, pebbles	61 - 65	4	62 - 64	9
Refusal (bedrock)	65	—	—	—

No well was installed.

TB 94-14. Latitude: 44°55'24"N., Longitude: 69°39'51"W.

Located in the Seboomook quadrangle in Northeast Carry township in a sand pit between the Golden Road and the West Branch Penobscot River 0.1 miles east of the Seboomook/Northeast Carry townline. Water level is approximately 7 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine	0 - 19	19	7 - 9, 17 - 19	8, 7
Silt, clay	19 - 48	29	47 - 48	—
Refusal (bedrock)	48	—	—	—

No well was installed.

TB 94-15. Latitude: 45°55'07"N., Longitude: 69°39'59"W.

Located on the Seboomook quadrangle in Seboomook township in a gravel pit between the Seboomook Dam road and the West Branch Penobscot River 3.2 miles east of Seboomook Dam. Water level is approximately 10 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to coarse, pebbles	0 - 5	5	—	—
Sand, fine	5 - 13	8	12 - 14	7
Silt, clay	13 - 25	12	12 - 14	7
Sand, fine, silt, clay, interbedded	25 - 48	23	37 - 39, 47 - 49	14, 61
Refusal (bedrock)	48	—	—	—

No well was installed.

TB 94-16. Latitude: 45°53'04"N., Longitude: 69°57'52"W.

Located on the Seboomook Lake West quadrangle in Pittston Academy Grant in a gravel pit on the west side of North Road 0.65 miles south of Pittston Farm. Water level is approximately 12 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to coarse, pebble to cobble gravel, silt	0 - 9	9	7 - 9	25
Silt, fine sand, clay	9 - 14	5	12 - 14	40
Refusal (boulder?)	14	—	—	—

No well was installed.

TB 94-17 Latitude: 45°18'34"N., Longitude: 69°23'32"W.

Located on the Monson East quadrangle in Willimantic along a logging road north of Big Wilson Stream 0.8 miles east of the Willimantic-Elliotsville Road bridge over Big Wilson Stream. No water was encountered in the boring.

MATERIAL	DEPTH (feet)	THICKNESS (feet)	SAMPLE INTERVAL (feet)	BLOWS
Sand, fine to medium, pebbles	0 - 14	14	—	—
Sand, very fine, silt, clay	14 - 30	16	17 - 19, 27 - 29	11, 7
Sand, very fine, silt, clay, rock fagments, till	30 - 38	8	37 - 38	21
Refusal (bedrock)	38	—	—	—

No well was installed.