OPEN-FILE NO. 87-24a

Hydrogeology and Water Quality of Significant Sand and Gravel Aquifers

in parts of Franklin, Kennebec, Knox, Lincoln, Penobscot, Somerset, and Waldo Counties, Maine

Significant Sand and Gravel Aquifer Maps 18, 30, and 31

by

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HYDROGEOLOGY AND WATER QUALITY OF SIGNIFICANT SAND AND GRAVEL AQUIFERS IN PARTS OF FRANKLIN, KENNEBEC, KNOX, LINCOLN, PENOBSCOT, SOMERSET, AND WALDO COUNTIES, MAINE: SIGNIFICANT SAND AND GRAVEL AQUIFER MAPS 18, 30, AND 31

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This project was jointly funded and conducted by the Maine Geological Survey, the U.S. Geological Survey, and the Maine Department of Environmental Protection.

Published by the
Maine Geological Survey
DEPARTMENT OF CONSERVATION
State House Station #22
Augusta, Maine 04333

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Open-File No. 87-24a

1987

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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
	<u>Length</u>	
inch (in.)	25.40	millimeter (mm)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	Kilometer (km)
	<u>Area</u>	
square mile (mi^2)	2.590	square kilometer (km^2)
	<u>Flow</u>	
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
gallons per minute (gal/min)	0.0630	liter per second (L/s)
million gallons per day (Mgal/d)	0.0438	cubic meter per second (M^3/s)
	<u>Transmissivity</u>	
square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)

<u>Other Abbreviations used in this report</u>

µS/cm, microsiemens per centimeter at 25°Celsius
mg/L, milligrams per liter
µg/L, micrograms per liter
Temperatures in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32)/1.8$$

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

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ABSTRACT

A reconnaissance-level hydrogeologic study was made of 1,380 square miles in Franklin, Kennebec, Knox, Lincoln, Penobscot, Somerset, and Waldo Counties in Maine. This area includes Maps 18, 30, and 31 of the Significant Sand and Gravel Aquifer Map Series published by the Maine Geological Survey.

The 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 or near other surface water bodies. The aquifers are capable of yielding more than 10 gallons per minute to a properly installed domestic well. Significant aquifers underlie an area of almost 81 square miles, but yields that exceed 50 gallons per minute are estimated to be available from only 2 percent of this area. Typically, the water table is within 20 feet of land surface. On the basis of well-record data, the greatest known depth to bedrock exceeds 200 feet. The greatest known well yield is 800 gallons per minute from a gravel-packed well owned by the Pittsfield Water District.

The regional ground-water quality has the following characteristics: It is slightly acidic to moderately basic; calcium and sodium are the most abundant cations; bicarbonate is the most abundant anion; and the water is moderately hard. In some localities, concentrations of iron and manganese are high enough to limit the uses of this untreated water.

The ground-water quality in agricultural areas is characterized by higher concentrations of chemical constituents than is reflected by regional ground-water quality.

Fifty-five sites, including 23 solid-waste facilities and 29 salt-storage lots, were identified as potential point sources of ground-water contamination to sand and gravel aquifers in the study area.

INTRODUCTION

Significant sand and gravel aquifers commonly are the only sources of ground water capable of supplying the large volumes of water needed by municipalities and industries in Maine. They also are the source of water for many domestic wells and may serve as a source of recharge to underlying bedrock aquifers. A significant aquifer, as defined by the Maine State Legislature (38 MRSA Chapter 3, Section 482, 4-D), is a porous formation of sand and gravel that contains significant quantities of water that is likely to provide drinking water supplies.

Recognizing the value of significant sand and gravel aquifers, the Maine State legislature has adopted a number of provisions to restrict siting activities which may discharge contaminants to ground water in the aquifers. Many local governments also have based zoning ordinances on the protection of significant aquifers. To aid local and State governments in these efforts, the Maine Geological Survey (MGS) and the U.S. Geological Survey (USGS), with funding from Department of Environmental Protection (DEP) conducted a reconnaissance-level investigation of sand and gravel aquifers in most of the State. This investigation, conducted from 1978 through 1980, resulted in 59 maps that show approximate aquifer boundaries, estimates of potential well yields, and locations of some 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. Additionally, the maps contain little information on aquifer thickness and stratigraphy, and no information on water quality. Recognizing these shortcomings, the Maine State legislature directed the DEP 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). This bill instructed the DEP and MGS to delineate all sand and gravel aquifers capable of yielding more than 10 gal/min to a properly installed domestic well. This new series of maps is referred to as Significant Sand and Gravel Aquifer Maps.

To meet the demand for more accurate, complete, and current hydrogeologic information concerning Maine's sand and gravel aquifers, a detailed cooperative mapping project was initiated in June 1981 by the MGS, the USGS, and the DEP. Mapping was first conducted in the most densely populated and fastest growing parts of the State. Significant sand and gravel aquifers in northern York and southern Cumberland Counties were investigated during the 1981 field season (Tolman and others, 1983). Aquifers in parts of Androscoggin, Cumberland, Franklin, Kennebec, Lincoln, Oxford, Sagadohoc, and Somerset Counties were investigated during the 1982 field season (Tepper and others, 1985). Aquifers in parts of Androscoggin, Cumberland, Oxford, and York Counties were studied during the 1983 field season (Williams and others, 1987). The location of these study areas and planned study areas are shown on figure 1.

This report presents the results from the fourth year of the mapping project (1984 field season) and updates the Sand and Gravel Aquifer Map Series for maps 18, 30, and 31 (Brewer and others,1979; Cotton and others, 1981; Prescott and others, 1981). These maps have been locally modified on the basis of new data and are included in this report as plates 1-3.

Purpose and Scope

The purpose of this report is to identify locations in the area covered by Significant Sand and Gravel Aquifer Maps 18, 30, and 31 that are most favorable for development of water supplies and, therefore, in most need of protection. A secondary objective is to identify areas where iron, manganese or nitrate concentrations are greater than levels recommended by the Maine Department of Human Services (1983) or where the presence of possible sources of contamination may limit development.

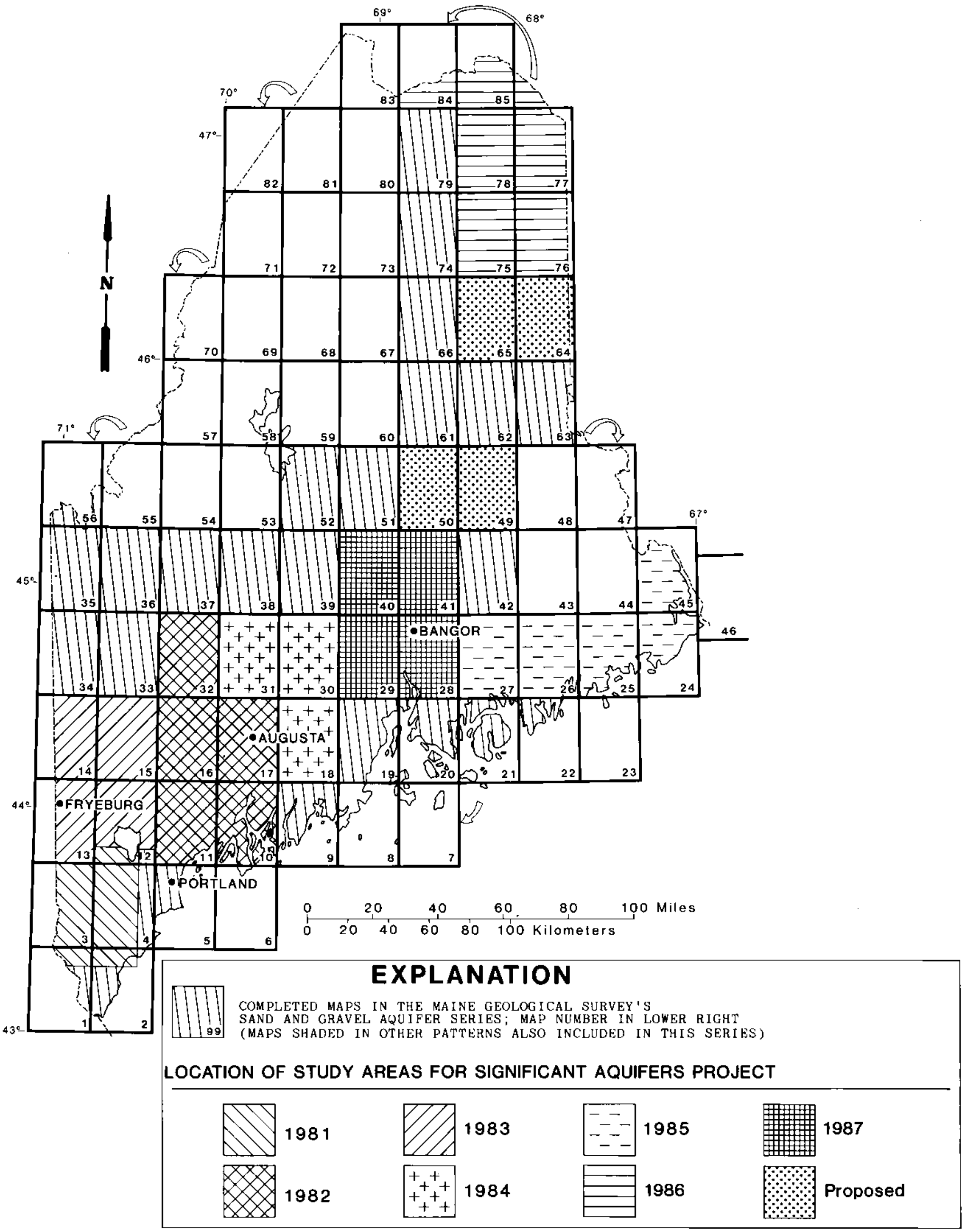

Figure 1. Location of study areas for Significant Aquifers Project.

The scope of the investigation included:

1. Surficial geologic mapping to define the boundaries of the glacial deposits.
2. Seismic-refraction investigations to determine the depth to water, depth to bedrock, and bedrock-surface topography.
3. A well inventory to supplement existing data on the depth to water, depth to bedrock, and well yields.
4. Observation-well drilling and test-boring to determine aquifer stratigraphy, thickness, and grain size (used to estimate transmissivity).
5. Water-quality sampling and analysis to characterize the regional ground-water chemistry.
6. Identification of potential sources of ground-water contamination.
7. Location of municipal well fields.

Previous Investigations

Surficial geologic mapping conducted in the study area by the MGS, and USGS has provided information on the areal extent of glacial sand and gravel deposits (Smith, 1974; Smith and Andersen, 1975; Thompson 1977a, 1977b, 1979; Thompson and Smith, 1977, 1978, and Smith and Thompson, 1977). Additional information on surficial geology, well depth, yield, ground-water levels, stratigraphy, estimated yield zones, and water quality can be found in Prescott (1968, 1969, 1980).

These reports were used as a basis for Sand and Gravel Aquifer Maps 18, 30, and 31 (Brewer and others, 1979; Cotton and others, 1981; and Prescott and others, 1981). Data collected for this study were compiled on the Sand and Gravel Aquifer Maps to produce plates 1-3.

METHODS OF STUDY

Approach

The approach used for this investigation was as follows:

1. Compile all existing hydrogeologic data onto each 1:50,000 scale map.
2. Collect information on existing domestic, municipal, and monitoring wells, boring logs, and test pits.
3. Identify sites of potential ground-water contamination.
4. Verify the original sand and gravel aquifer map boundaries by remapping surficial deposits.
5. Select locations for 12-channel and 1-channel seismic-refraction lines.
6. Conduct seismic-refraction investigations.
7. Drill test borings and install observation wells at sites which seem to have saturated sediments based on seismic data, which provide widespread areal coverage, which are accessible by the drilling and sampling equipment, and are likely to provide background water-quality samples.
8. Develop and sample wells.

9. Measure water levels in wells monthly.
10. Compile all data on 1:50,000 scale maps, and adjust aquifer boundaries as necessary.

Details concerning several of these steps are given below.

Identification of Sites of Potential Ground-Water Contamination

Potential ground-water contamination sites that are located on or near significant aquifers are shown on plates 1-3[1/]. These sites were identified primarily from files of the DEP Bureaus of Land, Water, and Oil and Hazardous Materials. The locations of State-owned salt-storage lots were determined from Maine Department of Transportation records. Letters were sent to town managers and local code-enforcement officers requesting their assistance in locating potential contamination sites. All site locations were field-checked.

The sites shown on plates 1-3 include waste disposal areas and salt-storage piles. Other sources of potential groundwater contamination not shown include malfunctioning septic systems, roads that are salted in the winter, manure piles and fertilized fields, and areas where pesticides are applied.

Surficial-Mapping Techniques

Mapping of the aquifer media was accomplished 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 textures of the deposits, and if water occurred in the pit. Shovel and auger holes were used to identify surficial materials in areas where exposures were lacking. Mapping of off-road areas was conducted by foot traverses and by examination of aerial photographs. Previously published maps and reports were utilized as a guide to field work (Prescott, 1969; Smith, 1974; Smith and Andersen, 1975; Thompson 1977a, 1977b, 1979; Thompson and Smith 1977, 1978; Smith and Thompson, 1977; Brewer and others, 1979; Cotton and others, 1981; Prescott and others, 1981).

In compiling the boundaries of the significant aquifers shown on plates 1-3, some ground-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. Many pit exposures within the mapped aquifers do not intersect the water table, and the pit floors are dry. In these cases, the aquifer has been mapped on the basis of the known or inferred saturated thickness at depth confirmed where possible by well, test-boring, or seismic data.

1/ The use of industry, firm or local government names in this report is for location purposes only and does not impute responsibility for any present or potential effects on the natural resources.

Seismic-Refraction Investigations

Seismic-refraction techniques were used to obtain profiles showing depth to water table, depth to bedrock, and the topography of the bedrock surface. In seismic exploration, sound waves are generated at the surface by a small explosion or hammer. The waves travel at different velocities through different materials--the denser the material, the faster the wave velocity. The velocity of sound through a material can be used to identify whether it is dry sand and gravel, saturated sand and gravel, till, or bedrock.

A 12-channel E G & G Geometrics Nimbus ES-1210F[1/] seismograph was used to determine saturated thickness and bedrock surface topography in areas where the depth to bedrock was estimated to be more than 75 ft (feet). The seismic lines range from 405 to 1,040 ft in length. In areas of particular interest, several lines were run end-to-end to provide extended profiles. Altitudes of the shot points and geophones were surveyed where relief on the land surface exceeded 5 ft along the line. 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 nearby wells and test borings were used to verify the results.

A single-channel Soil Test MD9A seismograph was used in areas where the depth to bedrock was estimated to be less than 75 ft. Information was obtained on depth to water table, depth to bedrock, and dip of the bedrock surface between the ends of each line. The seismic lines range from 60 to 300 ft in length. Interpretations and analyses were done according to methods developed by Mooney (1980), and Zohdy and others (1974). Seismic-refraction information was used in conjunction with well-inventory data and surficial mapping results to infer the boundaries of the sand and gravel deposits potentially capable of yielding 10 gal/min.

Drilling and Stratigraphic-Logging Methods

Twenty-two exploration borings were drilled to obtain water-quality data, thickness, and grain size of the sediments, and to verify seismic data on the depth to water table and depth to bedrock. For the purpose of this report, the term "test boring" (TB) refers to an uncased exploration boring. These borings were backfilled after test information was obtained. The term "observation well" (OW) refers to a cased exploration boring. Exploration borings are identifed first by the appropriate OW or TB designation, followed by the corresponding Significant Sand and Gravel Aquifer Map Number, and concluded by a sequential number in the order the borings were drilled. The observation wells were used to obtain water levels and water-quality samples during the period of investigation.

1/ Use of brand, firm or trade names in this report is for descriptive purposes only and does not constitute endorsement by the Maine Geological Survey, the U.S. Geological Survey, or the Department of Environmental Protection.

A 6-inch-diameter hollow-stem auger drill rig was used for drilling. Samples of the sediment penetrated above the water table are brought to the surface by the rotation of the augers. Where detailed stratigraphic information was needed below the water table, a split-spoon sampler was used to collect undisturbed sediment samples ahead of the drill stem. Borehole production and sample collection was conducted according to established guidelines in Chapter 2, National Handbook of Recommended Methods for Water-Data Acquisition (Federal Interagency Work Group, 1977). Most wells were drilled to refusal, which may occur when either bedrock, compact sediments, or sediments containing large cobbles are encountered. Borings were terminated before reaching refusal when either the depth of the deposits exceeded the depth limit of drilling or time did not permit continued drilling.

Observation-Well Installation and Development

Nineteen exploration borings were cased with 2-inch, schedule-40 PVC (polyvinyl chloride) pipe to collect water samples and to measure water levels. PVC screens with slot widths from 0.006 to 0.010 in were used. All casing couplings were fastened with 3/8-in sheet-metal screws rather than with PVC cement, because the release of tetrahydrofuran from PVC cement can increase total organic carbon concentrations, thereby causing erroneous results in determinations of concentrations of volatile organic compounds (National Research Council, 1982). The casing and screen were placed inside the hollow-stem auger, and the boring was allowed to collapse around the casing as the drill stem was withdrawn. Bentonite powder was backfilled from 1.0 ft below ground surface to the ground surface to prevent water from infiltrating around the casing. Six exploration borings did not penetrate the entire thickness of unconsolidated deposits because of depth limitations of the drill rig and/or time constraints.

At most sites, immediately after the casing was in position, water was pumped down the observation well to aid well development. All observation wells were thoroughly developed 2 to 3 weeks after emplacement by removing at least 10 well volumes of water from each well by surging and pumping with compressed air. This procedure removes the fine materials from the screen and develops the hydraulic connection with the aquifer.

Procedures for Water-Quality Sampling and Analysis

All 19 observation wells were sampled to determine water quality. To ensure that water samples were representative of the geochemical environment, the observation wells were pumped with a Johnson-Keck model SP-81 submersible pump or bailed with a PVC bailer until pH, temperature, and specific conductance measurements stabilized and at least three well volumes of water were removed.

Field measurements of pH and specific conductance were made with portable meters (Orion Model 231 for pH, Fisher 152 for specific conductance). Alkalinity was measured in the field using Standard Method 403, subsection 4c-4d (American Public Health Association and others, 1976).

Unfiltered samples for nitrate, chloride, sulfate, and total organic carbon determinations were collected in new plastic containers, which had been rinsed three times with sample water. Samples for dissolved metal analyses also were collected in rinsed plastic containers. These samples were filtered and then acidified with nitric acid. Samples for volatile organic analyses were collected in baked glass vials which were rinsed with sample water before collection. To prevent loss of gases, these bottles were filled and immediately sealed, so that no air space remained. All samples were kept on ice and delivered to the DEP laboratories 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, 1976). Analyses of volatile organics were done using a purge-and-trap method on a gas chromatograph equipped with a mass spectrophotometer.

HYDROGEOLOGY OF SIGNIFICANT SAND AND GRAVEL AQUIFERS

Geologic framework

Maine was covered at least twice by continental glaciers during the Pleistocene Epoch, which occurred from approximately 2,000,000 to 10,000 years ago. The last ice sheet, known as the Laurentide Ice Sheet, advanced into Maine from eastern Canada about 20,000 years ago, in late Wisconsinan time. The ice sheet flowed southeastward beyond the present coastline and into the Gulf of Maine.

Glacial History

After the maximum advance of the Late Wisconsin glaciation, the margin of the Laurentide Ice Sheet began to retreat from its terminal position on the continental shelf. By about 13,000, years before present (YBP), the ice margin approximated 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. As deglaciation continued, the remnant ice cap deposited glaciofluvial, glaciolacustrine, and glaciomarine sediments, which record the style and pattern of glacial retreat in coastal Maine. Below the marine limit, glacial landforms such as eskers, deltas, fans, and meraines, are associated with a glaciomarine deposit, the Presumpscot Formation (Bloom, 1960). Radiocarbon dates determined largely from marine mollusks recovered from the Presumpscot Formation bracket Maine's marine deglacial history to between 13,200 and 11,000 YBP (Smith, 1985). When the ice retreated beyond the reach of the sea, vast amounts of meltwater reworked the glacial sediment and deposited fluvial and shoreline sediments over the Presumpscot Formation.

The deglacial period of the study area has a complex history of sea-level change. During the maximum advance of the last glaciation, sea level stood approximately 330 ft below its position today. Following the ice advance, worldwide climatic warming caused melting of the glaciers, and the sea level began to rise. Areas like coastal Maine, which were depressed by the weight of the ice, were flooded by sea water soon after the ice melted, however, crustal rebound in coastal Maine was faster than worldwide sea-level rise, so the local sea level in coastal Maine fell until rebound slowed, approximately 10,000 YBP. Since then, sea level has been rising along most of Maine's coast.

Surficial materials in study area

As the glacier advanced, it eroded soil and rock debris and incorporated it into the ice. This material, which was deposited directly from the ice as a discontinuous layer on the bedrock surface, is called "till." The till was deposited at the base of the ice (lodgement or basal till) as the the glacier advanced, and from melting ice (ablation till) as the glacier stagnated and retreated (Thompson, 1979). Till is a poorly sorted, usually nonstratified heterogeneous 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 good aquifer. Although till usually is a poor ground water producer, its hydrological qualities and areal extent, in part, determine 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 well sorted, sandy, less compact till.

Till deposits can vary in thickness but generally, it is not more than about 10-ft thick. Great thicknesses of till may occur on the southern side of some streamlined hills, known as drumlins, good examples of which occur on map 31 north and east of Smithfield. These hills include Dodling Hill, Green Hill, and Bear Mountain. The long axis of all these hills trends northwest-southeast, indicating the direction of flow of the last ice sheet that covered the region.

In places, the ice margin paused in its retreat, and ridges of sediment were deposited into the sea in front of the ice. These ridges are termed moraines; an excellent example is the Waldoboro Moraine, a portion of which is shown on map 18, just south of Feylers Corner as a narrow ridge, traceable northeastward to Benner Corner. Numerous smaller moraines occur throughout the study area as ridges with a similar trend as the Waldoboro Moraine. The moraines are comprised of sand and gravel, with till and marine clay interbedded.

As the ice margin retreated in Maine, meltwater streams transported and deposited quantities of sand and gravel, predominantly in the valleys. Coarse sediments transported by the streams accumulated in channels within or beneath the ice or between the ice and adjacent valley walls, or were deposited into the sea at or near the glacier front. These deposits are termed ice-contact stratified drift, and include such features as eskers or crevasse fillings, which are long sinuous ridges, and subaqueous fans and kame deltas, which are cone-shaped or flat-topped hills. Sediments laid down by meltwater streams in valleys beyond the ice margin are termed outwash plain deposits, and often display pitted surfaces due to blocks of ice having been buried by the outwash and later melting. No glacial lake deposits were found in the study area.

An extensive esker complex is shown on map 31 along the Kennebec River valley, from north of Madison, south to Norridgewock, then out of the main valley south to Smithfield to the eastern shore of Great Pond. Other good examples are shown on map 30, including the esker system from Fairfield to Gould Corner, the complex along Horseback Road from Clinton north to Canaan Bog, and on the eastern part of map 30 from Thompson south to Thorndike.

Some good examples of kame deltas and subaqueous fans include the large fan east of Smithfield, and a large delta north of Smithfield, north of Gould Cemetery. Note that these features occur in association with an esker complex. As the ice retreated, the delta and fan were deposited into the sea in front of the ice; their sediments were supplied by the esker stream. These deposits can be regarded as ice-marginal features, indicative of the general location of the ice front as it retreated northward.

An excellent example of a large, marine delta fed by an esker is the Globe delta, map 18, near Globe. The Muddy Pond delta, north of the Globe delta is a good example of a marine delta fed by meltwater streams flowing at a distance from the ice margin before reaching the sea. The flat area southeast of Norridgewock (the Plains, map 31) is representative of glacial outwash which was deposited in shallow water during regression of the sea. This feature is underlain by marine sediments.

During the deglaciation of Maine, marine transgression occurred as a result of depression of the earth's crust by the weight of the ice sheet, and by rising sea level. The marine submergence was most extensive along the coastal lowland, but it also reached far into central Maine along the major river valleys. The altitude of the marine limit rises inland, and in the study area is generally between altitude 279 ft north of Jefferson, map 18, to an altitude of 375 ft just north of Smithfield, map 31, (Thompson and Borns, 1985). The marine sediments are regionally extensive in the low areas and generally consist of glaciomarine silt and clay, although places are sandy. These glaciomarine sediments are collectively referred to as the Presumpscot Formation. It occurs in areas below the marine limit, commonly overlies sand and gravel or till, may be up to 100 ft thick. It generally is not a good aquifer. Representative areas underlain by the Presumpscot Formation include the region around Norridgewock Airport, map 31, and throughout the lowlands in the southeast part of map 18.

Wetland deposits occur in swamps and bogs, and are underlain by till, marine clay, or local impermeable deposits in stratified drift. Many of the wetland areas are characterized by compact peat deposits. The permeability of the wetlands is generally low, however, porosity and storativity of the deposits can be high. Some large wetland areas include Big Meadow Bog in the northeast corner of map 30, and Mercer and The Serpentine Bogs on map 31.

Eolian deposits, sand dunes, occur in places throughout the study area. One location is west of Dodling Hill along the west side of State Route 8, map 31. Another occurs west of Decker Corner, map 30, south of the Kennebec-Somerset County line. These types of deposits are generally not utilized as aquifers.

Recent alluvium deposits generally consist of interbedded sand, gravel, and silt and cobble gravel, and occupies much of the flood plain of the major rivers in the study area, including the Kennebec and Sandy Rivers.

Stratigraphy of Glacial Deposits

Figure 2 is an interpretive, schematic diagram that shows the generalized regional stratigraphic relationships of the deposits in the study area. This figure is based on field studies, test-boring logs (tables 1-3), and seismic interpretation conducted in the region. Not all of the units shown on this figure will necessarily be found in any one place.

Figure 2 infers the relative age of the deposits. From bottom to top, the oldest unit is bedrock, and next youngest is till. Overlying the till is sand and gravel, representing ice-contact stratified drift. This material generally is older than the marine deposits, which overlie the sand and gravel. However, in places these two units are interbedded and appear to be contemporaneous in age. A thin veneer of sand and gravel that overlies the marine clay may represent a late outwash deposit, or modern stream sediments (alluvium); these sands and gravels are the youngest surficial deposits in the study area.

Representative hydrogeologic sections of typical glacial deposits found in the study area are shown on figures 3 and 4. Hydrogeologic section A-A' is a north-south transect through an outwash plain in Norridgewock (plate 3, map 31). Hydrogeologic section B-B' is an west-east transect through an esker in Pittsfield (plate 2, map 30). The stratigraphic relationships of deposits in hydrogeologic section A-A' is more representative of subsurface conditions than hydrogeologic section B-B' because of better subsurface control.

Depths to the water table and bedrock surface, represented on fig. 3 are based on 12-channel seismic line NOR-10 and 10A (fig. 7), and an observation well log OW 31-3 (table 3). Numerous test borings performed by Mueser, Rutledge, Wentworth, and Johnston Consulting Engineers (Scott Paper Company, written commun., 1985), for Scott Paper Company provide extensive subsurface data for the hydrogeologic section. The detailed logs of these borings have been generalized for this hydrogeologic section.

The stratigraphy shown in figure 3 is a relatively thin till layer, overlain by marine sediments, in turn overlain by outwash sediments. The till is generally from 5 to 20 ft in thickness, and is up to 40 ft thick in places. Where the till is thickest, bedrock knobs underlie the till. Overlying the till is the marine unit, the Presumpscot Formation (Bloom, 1960). The upper surface of the Presumpscot Formation has a topographic expression similiar to that of the till. This similarity may not be due solely to draping of marine sediments over till, but may in part be due to erosion of the upper surface of the marine sediments by the outwash deposit streams. The outwash deposits filled in the low areas on the surface of the marine deposits and completely covered some of the till and marine sediments.

Figure 4 is based on 12-channel seismic lines NEW-1 and 1A (figure 6), and observation well log OW 30-2 (table 2). This diagram has minimal control on the subsurface stratigraphic relations, except for depth to bedrock under the seismic lines. However, the stratigraphy is probably representative of other esker systems in the study area. The figure shows a thin veneer of the till over bedrock. The till may be discontinuous or much thicker than represented in the figure. The thick sand-and-gravel deposit on the western side of the figure is the esker. Marine sediments flank and in places overlie the esker. Outwash deposits overlie the marine sediments.

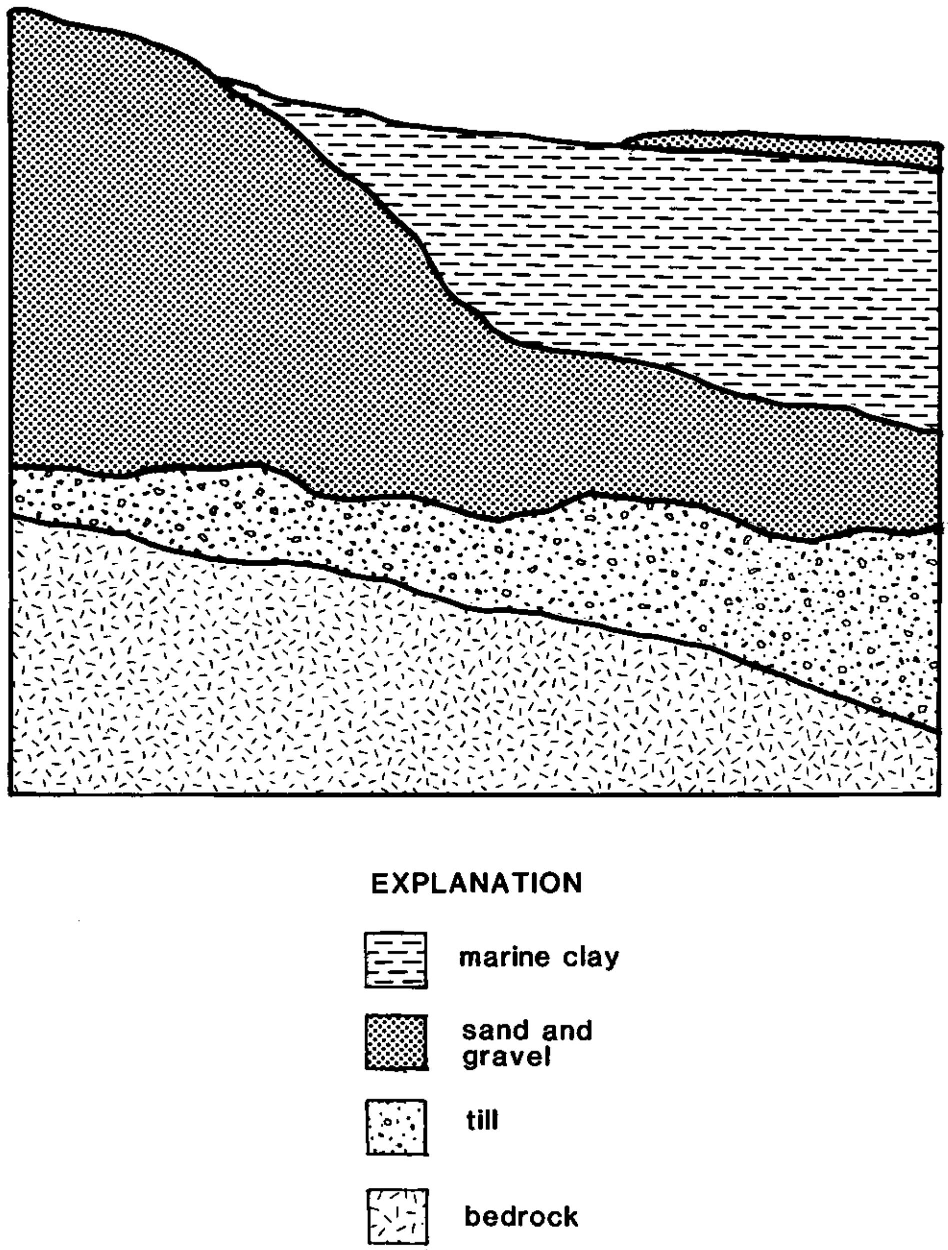

Figure 2. Generalized regional stratigraphic relationships in glacial deposits (not to scale).

Table 1.--Observation well and test boring logs, Map 18, Area [1]

Identification number: Composed of three elements:
Code TB (test boring abandoned after data collection) or OW (observation well installed for collection of water-level and water quality data); Significant Sand and Gravel Aquifer Map Number; 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 plate 1.

Site description: A brief site description is given.

Description of materials: Logs of observation well 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 boulder to very fine sand. "Poorly sorted" indicates approximately equal amounts, by weight, of all grain sizes.

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

Marine clay--Sorted, sometimes stratified sediment varying in size from clay to silt, deposited during the marine transgression during deglaciation, approximately 13,000 years B.P. Color is typically light brown or blue-gray.

End of boring--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."

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[1] See tables 4, 5, and 7 for information on grain-size analyses and estimated transmissivities and well yields.

Table 1.--Observation well and test boring logs, Map 18 Area (Continued)

TB 18-1. Latitude: 44°17'09" N, Longitude: 69°35'33" W.
Located in Windsor, on the northern perimeter of the Windsor Fairgrounds parking lot off State Route 32. Boring was dry.

Material	Depth (feet)	Thickness (feet)
Sand, very fine to very coarse; granules; and pebbles	0-37	37
Sand, very fine to coarse	37-42	5
Sand, very fine to very coarse; granules	42-47	5
Sand, very fine to very coarse; granules; and pebbles	47-50	3
Refusal (boulder)	50	--

No observation well was installed because no water was encountered.

OW 18-1 & OW 18-2. Latitude: 44°23'00" N, Longitude: 69°31'30" W
Located in China, on gravel pit road off Dirigo Road. OW 18-2 located 4 ft north of OW 18-1. Approximate depth to water in OW 18-1 is 11 ft, and in OW 18-2 is 12 ft.

Material	Depth (feet)	Thickness (feet)
Sand, fine to very coarse; granules; and pebbles	0- 7	7
Sand, medium to coarse	7-12	5
Sand, fine to coarse	12-27	15
Sand, coarse to very coarse, granules; and pebbles	27-30	5
Sand, very fine to very coarse; some interbedded silt, poorly sorted	30-35	5
Marine clay and silt	35-45	10
Silt; sand, fine to very coarse; granules; and pebbles	45-51	6
Marine clay; silt; sand, fine to very coarse; granules; and pebbles	51-57	6
Granules and pebbles, very angular	57-60	3
Refusal (bedrock)	60	--

OW 18-1 is screened from 24.5 to 29.5 ft below land surface with 0.008-in. slotted PVC screen. OW 18-2 is screened from 50.3 to 55.3 ft below land surface with 0.010-in. slotted PVC screen.

Table 1.--Observation well and test boring logs, Map 18 Area (Continued)

OW 18-3.--Latitude: 44°16'35" N, Logitude: 69°24'59" W.
Located in Washington, in gravel pit off State Route 105, south of Muddy Pond. Depth to water is approximately 6 ft.

Material	Depth (feet)	Thickness (feet)
Sand, fine to very coarse; granules; and pebbles	0- 2	2
Sand, medium to very coarse; granules; and pebbles	2-12	10
Sand, very fine to very coarse; granules; and pebbles, poorly sorted	12-20	8
Sand, very fine to fine, interbedded with silt and clay	20-40	20
Marine clay and silt interbedded with a well sorted very fine sand	40-106	66
Till	106-107	1
Refusal (bedrock)	107	--

OW 18-3 is screened from 30.2 to 35.2 ft below land surface with a 0.006-in. slotted PVC screen.

Table 1.--Observation well and test boring logs, Map 18 Area (Continued)

OW 18-4.--Latitude: 44°13'17" N, Longitude: 69°23'28" W.
Located in Washington, off State Route 220 in Laite's gravel pit.
Depth to water is approximately 12 ft.

Material	Depth (feet)	Thickness (feet)
Sand, fine to very coarse; granules; and pebbles	0- 2	2
Sand, medium to very coarse; granules; and pebbles	2-12	10
Sand, medium to very coarse; granules; pebbles and cobbles	12-22	10
Sand, medium to very coarse; granules; and pebbles	22-27	5
Fine sand, silt, and marine clay	27-34	7
Sand, fine to very coarse; granules; and pebbles, stratified with marine clay	34-39	5
Sand, very fine to fine, and grey silt	39-44	5
Sand, fine to very coarse; granules; and pebbles	44-45	1
Till	45-55	10
Refusal (bedrock)	55	--

OW 18-4 is screened from 35.6 to 40.6 ft below land surface with a 0.006-in. slotted PVC screen.

Table 2.--Observation well and test boring logs, Map 30, Area [1]/

Identification number: Composed of three elements:
Code TB (test boring abandoned after data collection) or OW (observation well installed for collection of water-level and water quality data), Significant Sand and Gravel Aquifer Map Number, 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 plate 2.

Site description: A brief site description is given.

Description of materials: Logs of observation well 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 boulder to very fine sand. "Poorly sorted" indicates approximately equal amounts, by weight, of all grain sizes.

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

Marine clay--Sorted, sometimes stratified sediment varying in size from clay to silt, deposited during the marine transgression during deglaciation, approximately 13,000 years B.P. Color is typically light brown or blue-gray.

End of boring--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."

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[1]/ See tables 4, 5, and 7 for information on grain-size analyses and estimated transmissivities and well yields.

Table 2.--Observation well and test boring logs, Map 30 Area (Continued)

OW 30-1. Latitude: 44°35'52" N, Longitude: 69°17'59" W.
Located in Unity, off the Dump Road in a gravel pit. Depth to water is approximately 13 ft.

Material	Depth (feet)	Thickness (feet)
Sand, very fine to fine; silt	0- 2	2
Sand, very fine to very coarse, interbedded with silt; granules; and pebbles.	2-30	28
Clay and silt interbedded with sand, very fine to very coarse; granules; and pebbles	30-44	14
Till	44-52	8
Refusal(bedrock)	52	--

OW 30-1 is screened from 23.4 to 28.4 ft below land surface with a 0.008-in. slotted PVC screen.

OW 30-2.--Latitude: 44°46'10" N, Longitude: 69°21'24" W.
Located in Pittsfield, off Peltoma Avenue near the Pittsfield Police Department firing range. Depth to water is approximately 7 ft.

Material	Depth (feet)	Thickness (feet)
Silt; sand, very fine to very coarse; granules; and pebbles	0- 2	2
Sand, medium to very coarse; granules; and pebbles, brown	1-17	15
Marine clay with black striations; interbedded with sand, very fine to fine; and silt; blue-grey	17-29	12
Marine clay, blue-grey with black striations	29-40	11
Till	40-45	5
Refusal (bedrock)	45	--

OW 30-2 is screened from 12 to 17 ft below land surface with 0.006-in. slotted PVC screen.

Table 2.--Observation well and test boring logs, Map 30 Area (Continued)

OW 30-3.--Latitude 44°46'02" N, Longitude 69°21'24" W.
Located in Pittsfield, south of the Pittsfield transfer station in a gravel pit off Peltoma Avenue. Approximately 5 vertical ft of sand, gravel, and cobbles have been removed from the area. Depth to water is approximately 8 ft.

Material	Depth (feet)	Thickness (feet)
Sand, medium to very coarse; granules; pebbles; and cobbles	0- 2	2
Sand, medium to very coarse; granules; and pebbles	2-24	22
End of boring	24	--

OW 30-3 is screened from 17.5 to 22.5 ft below land surface with 0.010-in. slotted PVC screen.

OW 30-4.--Latitude 44°51'55" N, Longtitude 69°26'09" W.
Located in Palmyra, off State Route 152 in gravel pit at Thompson. Approximately 10 vertical ft of sand, gravel, and cobbles have been removed from this area. Depth to water is approximately 3 ft.

Material	Depth (feet)	Thickness (feet)
Sand, medium to very coarse; granules; pebbles; and cobbles	0- 2	2
Sand, very fine to very coarse; brown; moderately well sorted.	2-17	15
Silt interbedded with sand, very fine to very coarse; granules; and pebbles	17-50	33
Sand, very fine to medium, well sorted; interbedded with silt; grey	50-59	9
Till	59-67	8
Refusal (bedrock)	67	--

OW 30-4 is screened from 13.8 to 18.8 ft below land surface with 0.008-in. slotted PVC screen.

Table 2.--Observation well and test boring logs, Map 30 Area (Continued)

OW 30-5.--Latitude: 40°44'10" N, Longitude: 69°34'41" W.
Located in Canaan, off State Route 23 across from the Pooler Road Junction.
Depth to water is approximately 29 ft.

Material	Depth (feet)	Thickness (feet)
Silt	0- 2	2
Marine clay, blue-grey	2- 7	5
Clay; green; with sand, very fine to very coarse; and granules occasionally	7-12	5
Clay; green; with some amounts of sand, very fine to very coarse; granules; and pebbles	12-30	18
Sand, very fine to very coarse; moderately well sorted; with minor amounts of silt.	30-37	7
Sand, very fine to very coarse; with some granules; and pebbles	37-55	18
Till	55-59	4
Refusal (bedrock)	59	--

OW 30-5 is screened from 40.2 to 45.2 ft below land surface with 0.008-in. PVC screen.

Table 2.--Observation well and test boring logs, Map 30 Area (Continued)

OW 30-6.--Latitude 44°49'48" N, Longitude 69°35'56" W.
Located in Canaan, off the road between Mitchell Corner and Browns Corner.
Depth to water is approximately 6 ft.

Material	Depth (feet)	Thickness (feet)
Silt	0- 2	2
Clay, green-gray	2-12	10
Clay, blue-grey	12-25	13
Sand, fine to very coarse; granules; and pebbles; blue-grey	25-30	5
Sand, fine to very coarse, granules; and pebbles; clean	30-48	18
Sand, very fine to fine; silt; blue-grey	48-50	2
Till	50-69	19
Refusal (bedrock)	69	--

OW 30-6 is screened from 35.6 to 40.6 ft below land surface with 0.010-in. PVC screen.

Table 2.--Observation well and test boring logs, Map 30 Area (Continued)

OW 30-7.--Latitude: 44°40'42" N, Longitude: 69°30'50" W.
Located in Clinton, at the perimeter of a pasture near the intersection of the Horseback and Rogers Roads. Depth to water is approximately 5 ft.

Material	Depth (feet)	Thickness (feet)
Clay, brown-blue	0- 2	2
Clay, green-grey	2- 7	5
Clay, blue; interbedded with medium sand	7-20	13
Till	20-24	4
Refusal (boulder?)	24	--

OW 30-7 is screened from 17.4 to 22.4 ft below land surface with 0.006-in. PVC screen.

TB 30-1.--Latitude: 44°40'41" N, Longitude: 69°30'51" W.
Located in Clinton, in a gravel pit near the intersection of the Horseback Road and the Rogers Road. Approximately 10 vertical ft of sand and gravel have been removed from this area. Boring was dry.

Material	Depth (feet)	Thickness (feet)
Silt; sand, very fine to very coarse; granules; and pebbles	0-12	12
Sand, coarse to very coarse; granules; and pebbles	12-17	5
Till	17-19	2
Refusal (boulder?)	19	--

No observation well was installed. An observation well was installed at the OW 30-7 site.

Table 3.--Observation well and test boring logs, Map 31, Area [1]

Identification number: Composed of three elements:
Code TB (test boring abandoned after data collection) or OW (observation well installed for collection of water-level and water quality data); Signigicant Sand and Gravel Aquifer Map Number; 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 plate 3.

Site description: A brief site description is given.

Description of materials: Logs of observation well 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 boulder to very fine sand. "Poorly sorted" indicates approximately equal amounts, by weight, of all grain sizes.

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

Marine clay--Sorted, sometimes stratified sediment varying in size from clay to silt, deposited during the marine transgression during deglaciation, approximately 13,000 years B.P. Color is typically light brown or blue-gray.

End of boring--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."

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[1] See table 4, 5, and 7 for information on grain-size analyses and estimated transmissivities and well yields.

Table 3.--Observation well and test boring logs, Map 31 Area (Continued)

OW 31-1. Latitude: 44°37'25" N, Longitude: 69°39'07" W.
Located in Fairfield, in a pasture off State Route 23. Depth to water is approximately 7 ft.

Material	Depth (feet)	Thickness (feet)
Silt and clay, green-grey	0- 7	7
Clay, green-grey	7-12	5
Clay, green-grey-blue with interbedded fine sand	12-15	3
Silt with sand, fine to coarse	15-22	7
Sand, medium to very coarse, and granules	22-25	3
Till	25-29	4
Refusal(boulder?)	29	--

OW 31-1 is screened from 20.5 to 25.5 ft below land surface with a 0.006-in. slotted PVC screen.

OW 31-2.--Latitude: 44°47'18" N, Longitude: 69°42'52" W.
Located in Skowhegan, off State Route 150 across from the industrial park. Depth to water is approximately 6 ft.

Material	Depth (feet)	Thickness (feet)
Sand, fine to very coarse; with granules	0- 2	2
Sand, very fine to coarse; moderately well sorted; brown-grey; with minor amounts of silt and clay	2-12	10
Sand, very fine to medium, well sorted; with minor amounts of silt	12-25	13
Clay, blue-grey, interbedded with silt to medium sand, brown-grey	25-55	30
Clay, blue-grey	55-80	25
Till	80-84	4
Refusal (bedrock)	84	--

OW 31-2 is screened from 16 to 21 ft below land surface with 0.006-in. PVC screen.

Table 3.--Observation well and test boring logs, Map 31 Area (Continued)

OW 31-3 and OW 31-4: Latitude: 44°41'45" N, Longitude: 69°46'56" W. Located in Norridgewock, on northern perimeter of a field off Martin Stream Road. Depths to water are approximately 5 ft in OW 31-3 and 8 ft in OW 31-4.

Material	Depth (feet)	Thickness (feet)
Silt to very fine sand	0- 2	2
Sand, medium to very coarse; granules; and pebbles	2- 7	5
Medium sand	7-20	13
Clay, blue-grey; interbedded with silt and sand, very fine to medium; grey	20-30	10
Clay, blue-grey-green; interbedded with fine sand, varying from blue-grey to brown	30-35	5
Sand, very fine to medium; well sorted; brown; with minor amounts of silt	35-40	5
Clay, blue grey, interbedded with grey silt and sand, very fine to medium	40-55	15
Clay, blue-grey, with some silt	55-60	5
Clay, blue-grey	60-79	19
End of boring	79	--

OW 31-3 is screened from 36.2 to 41.2 ft below land surface with 0.006-in. PVC screen. OW 31-4 is screened from 15.3 to 20.3 ft below land surface with 0.008-in. PVC screen.

Table 3.--Observation well and test boring logs, Map 31 Area (Continued)

OW 31-5.--Latitude: 44°43'35" N, Longitude: 69°49'05" W.
Located in Norridgewock, at the end of dirt road across from the Norridgewock Water District pump station on Winding Hill Road. Depth to water is approximately 23 ft.

Material	Depth (feet)	Thickness (feet)
Silt; sand, very fine to very coarse; and granules	0- 2	2
Sand, medium to very coarse; granules; and pebbles	2- 8	6
Sand, very fine to medium, well sorted; brown; with minor amounts of silt	8-40	32
Sand, medium to very coarse; granules; and pebbles	40-45	5
Sand, very fine to medium, well sorted, brown; with minor amounts of silt	45-60	15
Sand, fine to very coarse; interbedded with granules and pebbles	60-67	7
Poorly sorted mix of pebbles; granules; sand, very fine to very coarse; and silt	67-74	7
Refusal (boulder or tight gravel)	74	--

OW 31-5 is screened from 45 to 50 ft below land surface with 0.008-in. PVC screen.

Table 3.--Observation well and test boring logs, Map 31 Area (Continued)

OW 31-6.--Latitude 44°43'14" N, Longitude: 69°48'48" W.
Located in Norridgewock, on dirt road across from the Norridgewock Water District pump station on Winding Hill Road. Depth to water is approximately 31 ft.

Material	Depth (feet)	Thickness (feet)
Fine sand, brown	0- 7	7
Sand, fine to medium	7-12	5
Silt; sand, very fine to very coarse; granules; and pebbles	12-17	5
Silt to fine sand with some minor amounts of clay	17-22	5
Silt and very fine sand	22-27	5
Sand, coarse to very coarse; granules; and pebbles	27-45	18
Poorly sorted mix of silt; sand, very fine to very coarse; granules; and pebbles	45-49	4
End of boring	49	--

OW 31-6 is screened 43.1 to 48.1 ft below land surface with 0.010-in. PVC screen

Table 3.--Observation well and test boring logs, Map 31 Area (Continued)

OW 31-7.--Latitude, 44°51'48" N, Longitude, 69°51'33" W.
Located in Madison, on private drive to Runacres Farm off River Road. Depth to water is approximately 13 ft.

Material	Depth (feet)	Thickness (feet)
Silt	0- 2	2
Sand, very fine to very coarse; granules; and pebbles; moderately sorted	2-24	22
Sand, very fine to very coarse, well sorted; interbedded with silt	24-35	11
Sand, medium to coarse	35-45	10
Interbedded sand, very fine to very coarse; with granules; and pebbles	45-55	10
Sand, very fine to coarse, interbedded with silt	55-70	15
Sand, very fine to coarse, brown-grey, well sorted; some minor amounts of silt	70-85	15
Sand, very fine to medium, grey, well sorted; some minor amounts of silt	85-100	15
Interbedded sand, very fine to coarse, grey	100-109	9
Till	109-113	4
Refusal (Bedrock?)	113-	--

OW 31-7 is screened from 35.2 to 40.2 ft below land surface with 0.010-in. PVC screen

Table 3.--Observation well and test boring logs, Map 31 Area (Continued)

OW 31-8.--Latitude: 44°51'36" N, Longitude: 69°52'05" W.
Located in Anson, in gravel pit south of the North Anson Landfill. Approximately 30 vertical ft of sand and gravel have been removed from this area. Depth to water is approximately 10 ft.

Material	Depth (feet)	Thickness (feet)
Sand, coarse to very coarse; granules; and pebbles	0- 5	5
Sand, very fine to medium; with some silt	5-17	12
Sand, very fine to coarse; well sorted; some minor amounts of silt	17-40	23
Medium grey sand	40-50	10
Sand, very fine to medium, grey	50-55	5
Refusal (Till)	55	--

OW 31-8 is screened from 26 to 30 ft below land surface with 0.010-in. PVC screen.

TB 31-1.--Latitude: 44°51'42" N, and Longitude: 69°52'05" W.
Located in North Anson at the northern perimeter of the North Anson Landfill. Boring was dry.

Material	Depth (feet)	Thickness (feet)
Pebbles; granules; sand, very fine to very coarse; and silt	0- 2	2
Clay and silt, brown	2- 7	5
Clay, green-brown	7-12	5
Clay, blue-grey	12-37	25
End of boring	37	--

No well was installed because no water was encountered.

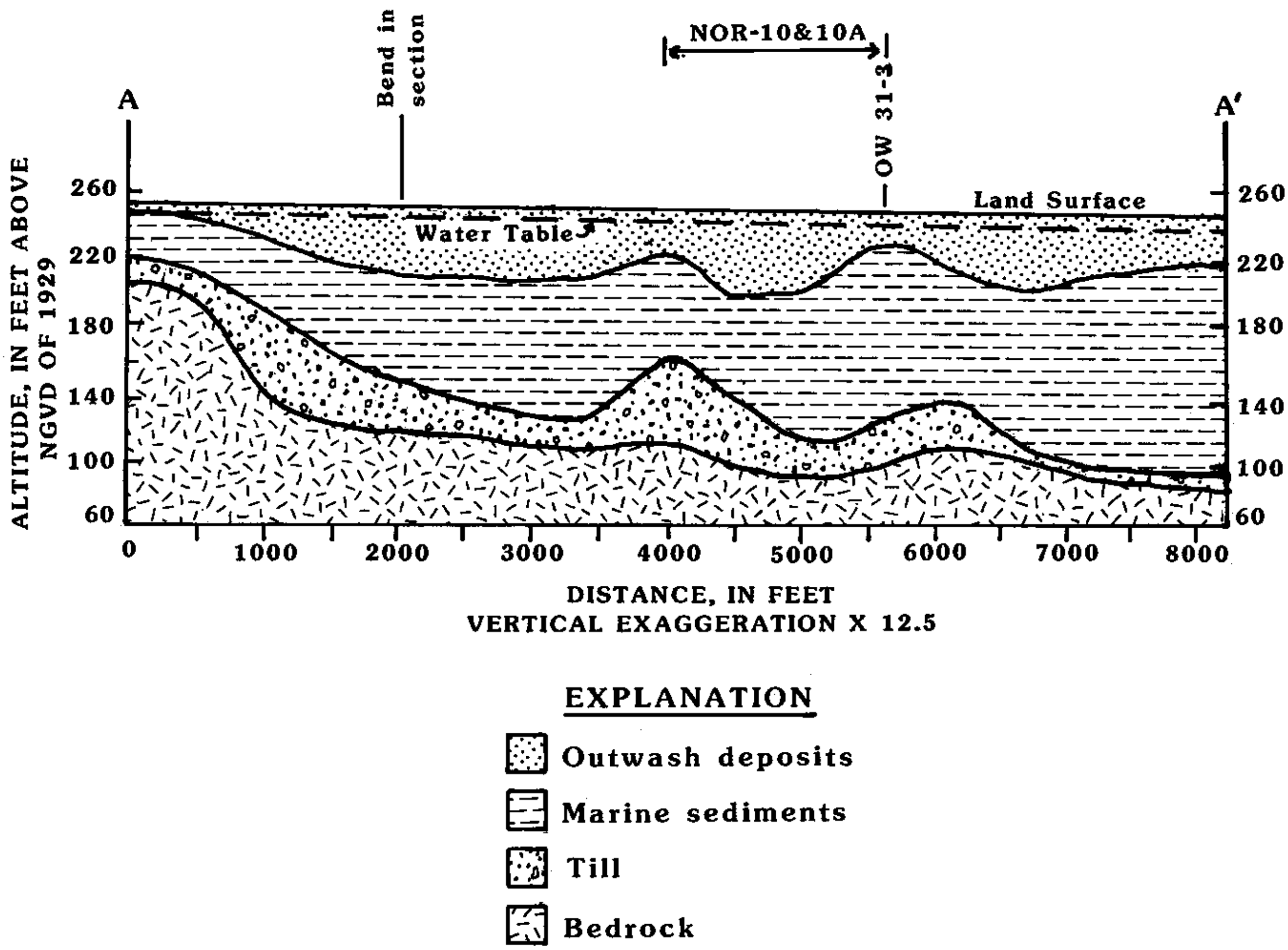

Figure 3 -- Stratigraphy of surficial deposits through outwash deposits along line A-A' shown on Plate 3 - map 31 area.

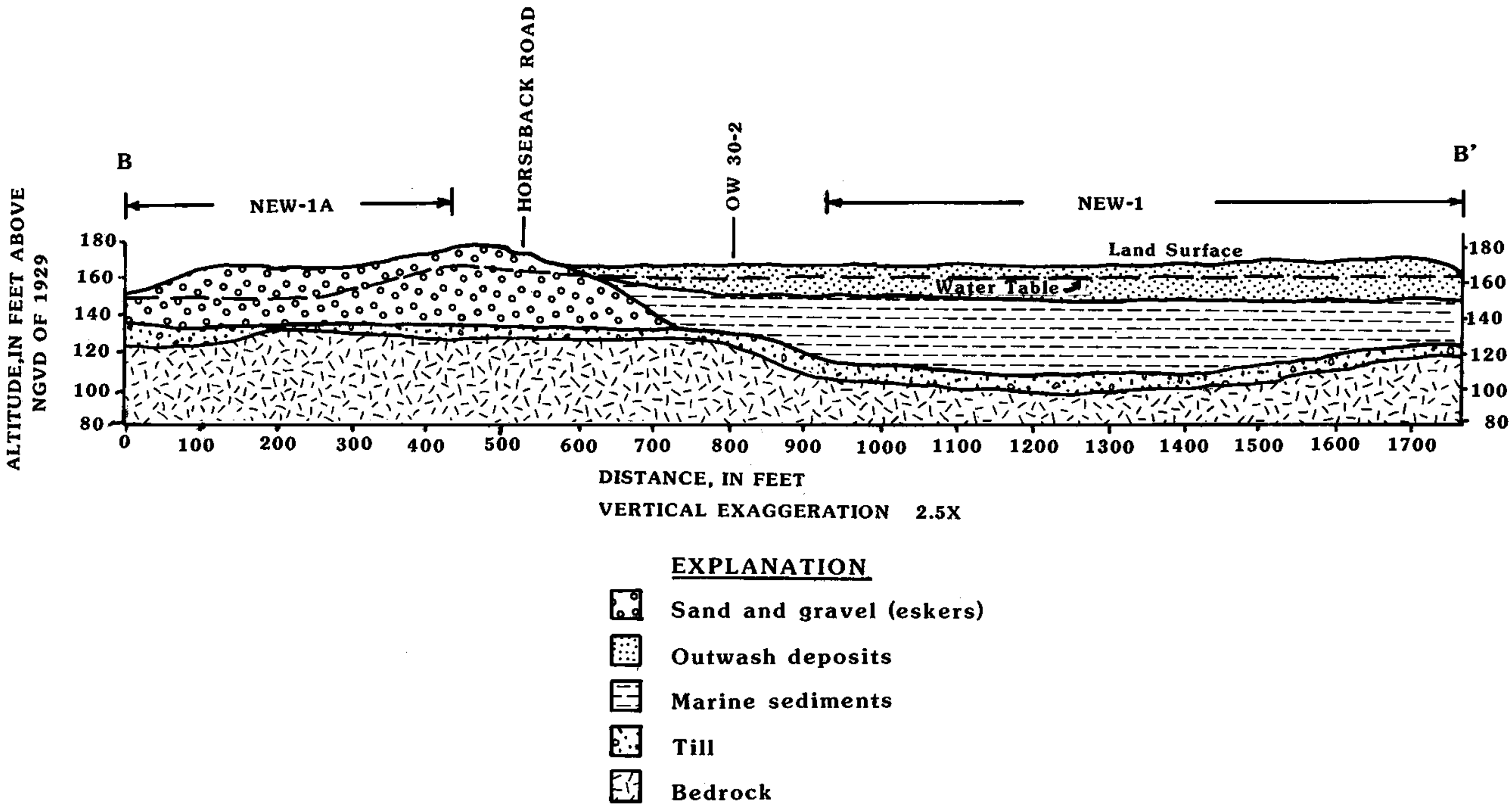

Figure 4.-- Stratigraphy of surficial deposits through an esker along line B-B' shown on Plate 2 - Map 30 Area.

Hydrology

The significant sand and gravel aquifers consist of ice-contact, ice-stagnation, and glacial outwash deposits, and Holocene stream alluvium. These are present primarily in the valleys of the major river systems and their tributaries, or near other surface-water bodies that can serve as sources of recharge. The aquifer boundaries and estimated yield zones shown on plates 1-3 are based on available information, and are subject to modifications as additional data become available.

The major aquifers are located in deposits associated with the Sebasticook and Kennebec Rivers (maps 30 and 31). The highest yields are obtainable from wells constructed in areas where coarse-grained deposits, commonly eskers, are located in proximity to these rivers or to lakes.

The most productive and most developed aquifer system is located along the Sebasticook River in the Pittsfield area (map 30). The highest reported yield in the area, 800 gal/min, is from a well operated by the Pittsfield Water District.

Hydraulic Properties

Hydraulic conductivity

Hydraulic conductivity is the rate at which water can move through a permeable medium (Fetter, 1980). It depends on a variety of physical factors, including porosity, particle size and distribution, shape of particles, and arrangement of particles (Todd, 1980). The hydraulic conductivity is the most important hydraulic property of sediments to be considered when discussing ground-water flow and well yield (Caswell, 1978). Typical hydraulic conductivities expressed in feet per day, are 0.000001 to 0.001 for marine clay, .0000001 to .01 for till, 0.001 to 10 for silt, 0.1 to 100 for silty sand, 1 to 1,000 for clean sand, and 500 to 100,000 for gravel (Freeze and Cherry, 1979).

Because the hydraulic conductivity depends, in part, on the size, shape, and arrangement of sediment particles, it is best measured directly in the field on an undisturbed section of aquifer. When field measurements are impractical, the hydraulic conductivity of the aquifer material can be estimated in the laboratory. The median particle diameter and the degree of sorting of representative observation well sediment samples were determined by grain-size analyses. These analyses were performed at the USGS laboratory in Harrisburg, Penn., using a dry-sieve method (Folk, 1974). The results of these analyses (table 4) were used to estimate hydraulic conductivity, using nomographs by Masch and Denny (1966). Those nomographs relate mean grain size and degree of sorting to hydraulic conductivity. The estimates, shown in table 4, are comparable with those of Morrissey (1983) for outwash sand (15 to 80 ft/d). They are, however, lower than his estimates for coarse-grained materials (150 to 200 ft/d).

Table 4.--Grain-size analysis, sorting, and estimated hydraulic conductivity of aquifer materials

Sample description	Observation well number	Depth of interval sampled (feet)	Median diameter (phi) 1/	Degree of sorting 2/	Estimated hydraulic conductivity (feet per day) 3/
Fine to coarse sand with some gravel	OW 18-1	32-34	- 1.0	poor	10
Clay with some very fine sand	OW 18-3	62-64	5.8	poor	10
Silt to gravel	OW 18-4	47-49	5.8	poor	10
Coarse sand with angular rock fragments up to 1 in.	OW 30-1	27-29	- 1.6	poor	10
Very tight silt to coarse sand	OW 30-6	67-69	5.0	poor	10
Fine sand to gravel up to 1 in.	OW 31-5	67-69	- 2.6	poor	10
Silt; fine to coarse sand	OW 30-2	17-19	3.4	poor	11
Fine to medium sand	OW 18-3	28-30	3.0	poor	13
Medium to coarse sand	OW 31-2	7-12	1.6	poor	20
Fine to medium sand	OW 31-2	17-19	2.8	moderately well	20
Fine sand	OW 31-7	87-89	2.6	moderately well	21
Coarse sand and gravel up to 1/4 in.	OW 18-3	12-17	- 0.2	poor	24
Fine to medium sand	OW 31-5	37-39	2.4	moderately well	24
Fine sand with some medium sand	OW 31-5	52-54	2.9	well	24
Fine to coarse sand	OW 31-7	72-74	2.3	moderately well	27

Table 4.--Grain-size analysis, sorting, and estimated hydraulic conductivity of aquifer materials..(Continued)

Sample description	Observation well number	Depth of interval sampled (feet)	Median diameter (phi) [1/]	Degree of sorting[2/]	Estimated hydraulic conductivity (feet per day)[3/]
Silt to medium sand	OW 31-3	37-39	1.9	moderate	31
Silt, fine sand, coarse sand	OW 30-4	57-59	1.5	moderate	40
medium to coarse sand	OW 31-8	27-29	1.0	poor	40
Medium to coarse sand with some silt	OW 31-7	32-34	- 1.1	poor	47
Medium to very coarse sand	OW 30-4	12-14	1.3	moderately well	67
Fine to very coarse sand	OW 30-5	32-34	0.4	poor	67
Coarse to very coarse sand	OW 30-4	7-12	0.6	moderate	80
Coarse to very coarse sand	OW 31-6	47-49	0.1	poor	107
Coarse to very coarse sand with up to 1/4 in. gravel	OW 31-7	--	- 0.2	moderate	147

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

2/ Sorting classified by Inclusive Graphic Standard Deviation

> 1.0	- poor
.75 - 1.0	- moderate
.50 - .75	- moderately well
> .50	- well

3/ Masch and Denney (1966)

Transmissivity

Transmissivity is the rate at which water is transmitted through a unit width of an aquifer or confining bed under a hydraulic gradient of one. It is a function of properties of the liquid, the porous media, and the thickness of the porous media (Fetter, 1980). The transmissivity is equal to the average hydraulic conductivity multiplied by the saturated thickness. Freeze and Cherry (1979) suggest that transmissivity values greater than 14,000 ft^2/d represent favorable aquifers for water-well exploration. However, aquifers with lower transmissivities also may be capable of transmitting large quantities of water.

Approximate transmissivities of sand and gravel aquifers were calculated at 17 sites from the complete stratigraphic logs of observation wells. Sediment from each interval in the saturated part of the exploration boring (tables 1-3) was assigned a hydraulic conductivity value, based on sample descriptions, grain size, and sorting (table 4). This hydraulic conductivity was multiplied by the interval thickness to obtain an approximate interval transmissivity. The interval transmissivities were then summed to give a total transmissivity for that part of the aquifer penetrated by the exploration boring. The transmissivities are presented in table 5. The exploration borings for three observation wells did not penetrate the entire aquifer thickness. Aquifer transmissivities at these wells were calculated based on characteristics of the known materials; actual transmissivities may be higher.

Depths to the Water Table and Bedrock Surface

Depths to the water table and bedrock surface in the significant sand and gravel aquifers have been determined from seismic-refraction investigations, well inventory, project drilling, mapping of bedrock outcrops, and previous investigatons. In the significant sand and gravel aquifers, the depth to the water table differs considerably from place to place, but is typically within 20 ft of the land surface. Based on seismic-refraction data, the greatest depth to bedrock (approximately 180 ft) is in the Smithfield area (seismic line NOR-23, fig. 7). A nearby private well penetrates overburden to 200 ft without reaching bedrock (map 31).

Seismic-refraction techniques were used extensively to determine both depth to water table and depth to bedrock. In the study area, the velocity of sound in unsaturated sand and gravel varies from 500 to 2,000 ft/s, with an average velocity of 1,265 ft/s. Saturated sand and gravel have velocities varing from 4,150 to 6,100 ft/s, with an average velocity of 5,110 ft/s. Bedrock seismic velocities in the study area vary from 10,400 to 33,140 ft/s, with an average velocity of 16,100 ft/s.

A summary of the information collected with the single-channel seismograph is presented in table 6. Hydrogeologic cross-sections from seismic-refraction surveys conducted with the 12-channel seismograph are presented in figures 5-7 (at back of report). The locations of 50 single-channel and 65 12-channel seismic refraction lines conducted throughout the study area are shown on plates 1-3.

Table 5. Approximate transmissivity data for selected observation wells

(ft^2/day, feet squared per day)

MAP 30

Observation well number	Transmissivity (ft^2/day)
30-1	590
30-2	950
30-3	> 1,000[1/]
30-4	2,200
30-5	1,500
30-6	1,300
30-7	170

MAP 31

Observation well number	Transmissivity (ft^2/day)
31-1	260
31-2	960
31-3&4	960
31-5	> 840
31-6	>1,300
31-7	3,600
31-8	1,700

MAP 18

Observation well number	Transmissivity (ft ^{1} /day)
18-1&2	1,100
18-3	1,000
18-4	520

[1/] Exploration boring did not penetrate the entire aquifer thickness; therefore, the value represents a minimum transmissivity

Table 6.--Depth to water and depth to bedrock based on single-channel seismic data.

Aquifer map number	Seismic line identifier	USGS topographic quadrangle	Town	Location [1]	Seismic line length (feet)	Depth to water (feet)[2] A[3]	Depth to water (feet)[2] B	Depth to bedrock (feet)[2] A	Depth to bedrock (feet)[2] B
Map 18	CHL-K	China Lake	China	1.5 miles south southeast from Dirigo Corner	150	18	21	46	48
Map 18	CHL-F	do.	do.	0.25 mile southeast from Pine point on camp road parallel to south shore of China Lake.	190	17	15	67	67
Map 18	JEF-C	Jefferson	Waldoboro	1.5 miles south on State Route 220 from Globe in bottom of gravel pit.	160	15	8	42	48
Map 18	LIB-C	Liberty	Montville	1.5 miles east southeast from Liberty along southeast shore of Trues Pond.	130	8	8	26	23
Map 18	NWH-A	North Whitefield	Whitefield	1.5 miles northwest of North Whitefield	160	36	29	--	--
Map 18	PAL-A	Palermo	Albion	1.0 mile north of Dutton Pond	230	6	6	--	--
Map 18	RAZ-D	Razorville	Washington	0.75 mile northwest of Razorville, east of Muddy Pond.	250	7	4	--	--
Map 18	UNN-A	Union	Warren	0.35 mile northwest of White Oak Corner, in gravel pit.	100	12	9	25	28
Map 18	WAS-A	Washington	Liberty	1.8 miles southwest of Maddock Corner on the Plains Road.	180	7	5	48	56
Map 18	WAS-B	Washington	Liberty	0.25 mile south from Fish Turn on dirt road.	90	5	6	15	19
Map 18	WAS-J	do.	Appleton	Near Appleton Dump.	130	8	6	26	25
Map 18	WKM-A	Weeks Mills	China	In road shoulder, 0.75 mile south of Erskine Academy on State Route 32.	160	5	4	39	52
Map 18	WKM-A	do.	do.	0.6 mile north of the junction of State Route 32 and Ingraham Road on State Route 32, in bottom of gravel pit.	150	14	13	--	--
Map 18	WKM-C	do,	Windsor	In gravel pit off State Route 32, 0.25 mile north of the junction State Route and Ingraham Road.	190	38	36	83	76

[1] locations of single-channel seismic lines are shown in plates 1-3.

[2] feet below land surface

[3] A and B refer to opposite ends of the seismic line: A is north or west end, B is south or east end.

Table 6.--Depth to water and depth to bedrock based on single-channel seismic data. (Continued)

Aquifer map number	Seismic line identifier	USGS topographic quadrangle	Town	Location [1]	Seismic Line length (feet)	Depth to water (feet)[2] A[3]	Depth to water (feet)[2] B	Depth to bedrock (feet)[2] A	Depth to bedrock (feet)[2] B
Map 30	ALB-C	Albion	Albion	In bottom of gravel pit, 0.4 mile north northeast of the mouth of Mill Stream.	100	6	5	26	21
Map 30	ALB-F	do.	do.	In gravel pit, 0.15 mile east of cemetary no.4 on U.S. Route 202.	80	8	8	20	26
Map 30	BUR-A	Burnham	Canaan	In road shoulder starting at culvert of South Bog Stream, 1.65 miles north northeast of Dixon Corner.	100	9	11	29	23
Map 30	CL-B	Clinton	Canaan	2.75 miles north of the Clinton/Canaan Town Line on State Route 23, in gravel pit, 650 ft west of the highway.	90	11	12	--	--
Map 30	CL-C	do.	do.	In upper level of gravel pit, 0.2 mile north of the junction of the Canaan/Clinton Town line and State Route 32.	170	17	15	54	41
Map 30	CL-E	do.	Clinton	In road shoulder at the junction of Hinckley and Gustafson Roads.	130	10	9	39	38
Map 30	CL-K	do.	do.	On dirt road perpendicular to the John Flat Road, 0.35 mile south of the Somerset/Kennebec County Line.	110	8	6	21	34
Map 30	FAI-A	Fairfield	Fairfield	In road shoulder on northside of Maplewood Cemetary.	180	5	6	--	--
Map 30	FAI-D	do.	do.	In gravel pit, 0.85 mile south southwest of the junction of U.S. Route 95 and State Route 129.	200	11	6	--	--
Map 30	NEW-B	Newport	Pittsfield	On dirt road in cemetary north of the Pittsfield Municipal Airport.	130	4	5	38	44
Map 30	NEW-C	Newport	Pittsfield	In road shoulder north of Peltoma bridge.	160	9	12	53	54
Map 30	PIT-A	Pittsfield	Palmyra	0.5 mile northwest of Thompson.	180	28	25	71	84
Map 30	SKN-A	Skowhegan	Cornville	On east/west dirt road less than 0.1 mile from Mitchell Corner.	150	4	7	60	49
Map 30	SKN-B	do.	Canaan	On jeep trail between west branch Black Stream and road from Brown's Corner to Mitchell Corner, 0.5 mile northwest of Brown's Corner.	180	5	3	44	53

Table 6.--Depth to water and depth to bedrock based on single-channel seismic data. (Continued)

Aquifer map number	Seismic line identifier	USGS topographic quadrangle	Town	Location [1]	Seismic Line length (feet)	Depth to water (feet)[2] [3]A	B	Depth to bedrock (feet)[2] A	B
Map 30	UNI-B	Unity	Unity	In road shoulder, at the junction of State Routes 139 and 220 on 139.	80	6	5	33	65
Map 30	UNI-D	do.	do,	1.55 miles east south east of the mouth of Mussey Stream.	130	14	16	--	--
Map 30	UNI-F	do.	do.	At the Unity Dump.	160	24	23	--	--
Map 30	UNP-A	Unity Pond	Burnham	On dirt road, 0.15 from main road and 0.75 mile south of Peltoma bridge.	100	7	7	17	17
Map 30	UNP-C	do.	do.	On dirt road, 1.7 miles south of Peltoma Bridge.	110	9	6	24	44
Map 30	UNP-F	do.	do.	On dirt road, 0.65 miles southeast of Reynolds Corner.	160	6	4	49	55
Map 31	BEL-B	Belgrade Lakes	Rome	In gravel pit, off Mercer Road 1.3 miles north of Rome School.	110	3	2	--	--
Map 31	BEL-E	do.	do.	In private dirve perpendicular to State Route 225, 0.75 mile northeast of the junction of State Route 225 and 27.	150	13	9	38	49
Map 31	HIN-A	Hinckley	Skowhegan	On dirt road, off U.S. Route 201, 4.0 miles north of the junction with State Route 23.	130	6	7	43	36
Map 31	HIN-C	do.	do.	On abandoned railroad bed, 2.1 miles north northwest of the junction of State Route 23 and U.S. Route 301 at Hinckley.	150	8	7	48	59
Map 31	NOR-D	Norridgewock	Norridgewock	On Airport Road, 0.75 miles north of the junction of Airport Road and U. S. route 2.	120	5	4	34	31
Map 31	NOR-F	do.	do.	On dirt road perpendicular to State Route 139, 1.35 miles southeast of the junction of State Route 139 and U.S. Route 2 and 201.	120	5	6	44	40

Table 6.--Depth to water and depth to bedrock based on single-channel seismic data. (Continued)

Aquifer map number	Seismic line identifier	USGS topographic quadrangle	Town	Location [1]	Seismic Line length (feet)	Depth to water (feet)[2] A[3]	Depth to water (feet)[2] B	Depth to bedrock (feet)[2] A	Depth to bedrock (feet)[2] B
Map 31	NOR-H	Norridgewock	Smithfield	On dirt road perpendicular to Star Route8, 1.3 miles northeast of the junction of State Routes 8 and 137 in Smithfield	150	7	7	47	50
Map 31	NOR-I	do.	Norridgewock	On Winding Hill road, 4.7 miles from the junction of U.S. Routes 2 and 201.	210	14	14	56	83
Map 31	NOR-J	do.	do.	On shoulder of State Route 8, 0.35 mile south from the junction of Martin Stream Road.	180	7	7	--	--
Map 31	ROM-A	Rome	Belgrade	In gravel pit, 0.1 mile west of Point Road and 0.4 mile southwest of the junction of Chandler and Point Roads.	150	17	17	40	51
Map 31	ROM-D	do.	do.	In gravel pit off Horse Point Road.	120	23	27	--	--
Map 31	ROM-F	do.	do.	In gravel pit 200 feet north of Chandler Road and 0.45 mile east northeast of the junction of Chandler Road and Star Route 27.	150	7	6	45	39
Map 31	ROM-G	Rome	Belgrade	On camp road, 0.5 mile southeast of Herson Point.	100	8	7	25	30
Map 31	ROM-H	do.	do.	On top of covered landfill, 0.4 east of the junction of Chandler Raod and State Route 27.	150	7	5	24	45
Map 31	SKN-F	Skowhegan	Skowhegan	On ball field, 0.1 mile from State Route 150 and 1.5 miles north of the junction of State Route 150 and U.S. Route 2.	160	9	10	--	--
Map 31	SKN-G	do.	do.	On dirt road, 2.0 miles north of the junction of State Route 150 and U.S. Route 2.	200	5	6	54	56

Determinations of depths to the water table and bedrock surface are necessary to provide a three-dimensional hydrogeologic picture of aquifer geometry. Saturated thickness at selected points can be determined by subtracting the depth to the water table from the depth to bedrock (plates 1-3). Depth to bedrock data and bedrock surface profiles (figures 5-7, at back of report) can be used to estimate the amount of casing required for wells construction in bedrock and to locate buried valleys that may contain water-bearing sediments.

Estimated Well Yields

The significant sand and gravel aquifers consist of ice-contact, ice-stagnation, outwash, and alluvial deposits which have sufficient areal extent, hydraulic conductivity, and saturated thickness to sustain a yield of 10 gal/min or more to a properly installed domestic well. Yields obtainable from wells constructed in different parts of the significant sand and gravel aquifers were estimated from yields reported by well drillers and well owners, previously published studies and from estimates based on saturated thickness, transmissivity, and areal extent of the aquifers. A method used to approximate well yields in a water-table aquifer was developed by Mazzaferro, 1980. This technique, T x B/750 = well yield gal/min, is based on transmissivity (T) and saturated thickness (B) of a well with a combined casing and gravel pack diamenter of 1.5 ft. Considered in the derivation of this equation is a storage coefficient of 0.2. The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit change in head. Other factors also included in the equation are a pumping period of 180 days, a well field density of 4 wells per square mile and the effects of partial penetration and dewatering of the aquifer.

The approximate yields calculated for selected observation wells are presented in table 7. These yields represent a theoretical yield for the indivaual well and do not consider characteristics of the quifer as a whole. Areas where wells are estimated to yield between 10 to 50 gal/min and more than 50 gal/min are shown in separate shading patterns on plates 1-3.

Although the study area includes 1,380 mi^2, areas mapped as underlain by significant sand and gravel aquifers include only about 81 mi^2 (6 percent) of this area. Yields exceeding 50 gal/min are estimated to be obtainable in only 2 mi^2 (0.1 percent) of the study area. The highest yields are obtainable in areas where the deposits are coarse grained, have a thick saturated zone, or are hyraulically connected to an adjacent body of surface water, which is a source of recharge. The highest reported well yield in the sand and gravel deposits is 800 gal/min from the Pittsfield Water District gravel-packed well adjacent to the Sebasticook River. Other high yield wells in the area include municipal wells in Norridgewock (one well with a yield of 750 gal/min) and Clinton (two wells with a yield of 360 gal/min).

Water-Level Fluctuations

Monthly water-level measurements made at 19 observation wells installed in the study area are shown in table 8; selected hydrographs from these observation wells are shown in figure 8. Water-level measurements were made periodically from January through November 1985.

Table 7. Approximate well yields for selected observation wells

MAP 30

Observation well number	Yield (gal/min)
30-1	30
30-2	50
30-3	> 25[1/]
30-4	190

MAP 31

Observation well number	Yield (gal/min)
31-2	100
31-3&4	90
31-5	> 55
31-6	> 30
31-7	480
31-8	100

MAP 18

Observation well number	Yield (gal/min)
18-1&2	70
18-3	130
18-4	30

[1/] Exploration boring did not penetrate the entire aquifer thickness; therefore, the value represents a minimum yield

Table 8.--Water-level data for observation wells, January through November 1985.

Observation well number	Town	January 9	January 10	January 31	February 27	March 28	May 7	June 3	June 25	July 30	October 4	October 31	November 26
		Depth to water (in feet below land surface)											
18-1	China	11.73	--	12.10	11.02	10.38	10.32	10.23	10.77	11.24	11.92	11.89	11.24
18-2	do.	12.58	--	12.68	12.03	10.84	10.25	10.41	10.98	11.71	12.85	13.00	12.54
18-3	Washington	7.11	--	7.28	6.70	6.48	6.58	6.68	6.86	7.07	7.39	7.35	7.00
18-4	do.	13.52	--	13.95	12.18	11.11	11.66	12.03	12.41	12.79	13.38	13.22	12.16
30-1	Unity	13.29	--	13.39	11.35	12.64	13.10	13.41	13.66	13.91	13.80	13.64	12.99
30-2	Pittsfield	7.28	--	7.25	6.30	4.85	5.56	6.14	6.62	6.65	6.96	6.29	5.35
30-3	do.	6.25	--	6.18	8.04	6.84	5.04	5.80	6.47	5.84	7.92	7.18	4.73
30-4	Palmyra	3.02	--	2.92	2.59	1.33	1.71	2.19	2.24	2.35	2.41	2.12	1.46
30-5	Canaan	--	30.81	30.91	30.78	29.95	29.96	30.27	30.60	30.70	31.13	30.90	30.43
30-6	do.	7.08	--	7.14	7.10	6.54	6.23	6.38	6.49	6.60	6.95	6.75	6.55
30-7	Clinton	--	5.16	5.47	4.66	3.99	3.70	4.20	4.43	4.65	4.97	4.03	4.03
31-1[1/]	Fairfield	--	8.69	8.99	7.50	6.43	6.34	6.94	7.39	8.04	8.41	--	--
31-2	Skowhegan	--	7.32	7.53	6.76	5.90	5.98	6.38	6.72	7.02	7.72	7.58	6.92
31-3	Norridgewock	--	4.11	4.39	3.26	2.85	3.07	3.95	4.28	5.02	5.20	4.97	4.36
31-4	do.	--	7.89	8.09	7.15	6.09	6.61	7.07	7.52	8.13	8.75	8.34	7.85
31-5	do.	--	24.27	24.27	24.40	24.32	24.09	24.07	24.20	24.27	24.35	24.03	24.24
31-6	do.	--	31.65	32.11	31.74	32.06	31.34	31.34	31.84	32.18	32.18	32.53	32.34
31-7	Madison	--	13.78	13.38	13.76	11.99	11.68	12.38	13.06	13.21	14.16	13.16	12.75
31-8[2/]	Anson	--	9.85	9.33	10.06	10.77	--	--	--	--	--	--	--

1/ This casing was extended beyond reach pending filling around the well. The filling never occurred so the water levels could not be measured during the last two visits.

2/ This well was buried when the landfill was expanded.

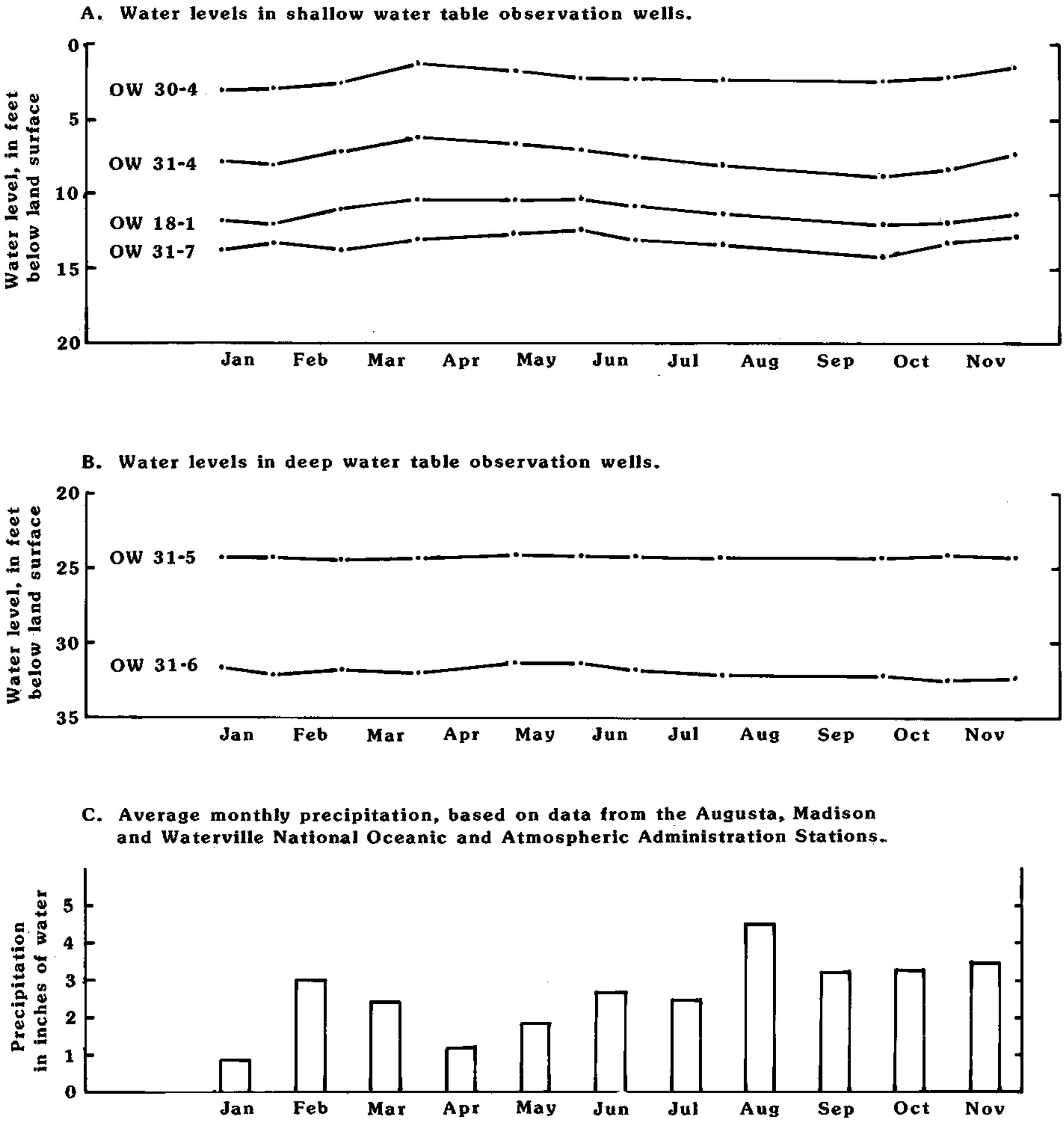

Figure 8. Ground-water levels in selected observation wells and average monthly precipitation, January through November 1985.

Water-levels in all observation wells fluctuated within a 3-ft range (table 9). Water-level fluctuations were least in OW 18-3, 30-6 and 31-5, which fluctuated less than 1 ft over the 11 month period.

Monthly precipitation data from National Oceanic and Atmospheric Administration stations in Augusta, Madison, and Waterville are compared with water-level data in figure 8. Rising water levels occurred from February to May. This is in response to a combination of factors, including monthly rainfall, and snow melt that infiltrate the aquifer, and negligible evapotranspiration. When the growing season begins in May, evapotranspiration increases, resulting in a steady decline in water levels to the end of the growing season in September or October. Water levels begin to rise again in October or November.

Maximum depth to water was less than 15 ft in all but three wells (table 9)--a depth shallow enough for suction lift pumps. Five wells had minimum depths to water of 5 ft or less. The thin unsaturated zone renders the ground water vulnerable to potential contamination in these areas.

WATER QUALITY OF SIGNIFICANT SAND AND GRAVEL AQUIFERS

Factors Influencing Water Quality

The chemical quality of ground water in sand and gravel aquifers is determined by a number of factors. The primary control is the chemical composition of the sand and gravel. Most of the sand and gravel in the study area is derived from noncalcareous, crystalline bedrock, which generally consists of silicate minerals of low solubility. Ground water in regions with this type of bedrock tends to have low concentrations of dissolved solids (Matthess, 1982).

Chemical reactions that occur as water passes through the soil zone also can affect ground-water chemistry. Where the saturated thickness of unconsolidated deposits is great, the water flow paths are long, hence, greater time is available for the dissolution of soluble material in the aquifer (Caswell, 1978). Residence time also depends on hydraulic conductivity, hydraulic gradient, and the porosity of the unconsolidated deposits.

The chemical composition of precipitation also can affect ground-water quality. In coastal regions where precipitation contains sea salt, the concentrations of sodium and chloride in ground water are typically higher than in inland areas (Matthess, 1982). Elevated concentrations of sodium and chloride also can result from saltwater intrusion in coastal areas. Saline water is present in some aquifer zones in Maine that was entrapped during the late Wisconsin marine submergence (Tepper, 1980).

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

1. Landfill disposal of household and industrial wastes, which may include petroleum derivatives and hazardous and radioactive materials.

2. Storage and spreading of road-deicing salt.

Table 9.--Statistical analysis of water level data for observation wells in the study area, January to November 1985

Observation well number	Town	Number measure-ments	Mean depth to water (in feet below (land surface)	Standard deviation	Depth to water in feet below land surface		Range of values (feet)
					Maximum	Minimum	
18-1	China	11	11.2	0.7	12.10	10.23	1.87
18-2	do.	11	11.8	1.0	13.00	10.25	2.75
18-3	Washington	11	7.0	.3	7.39	6.48	.91
18-4	do.	11	12.6	.9	13.95	11.11	2.84
30-1	Unity	11	13.2	.7	13.91	11.35	2.56
30-2	Pittsfield	11	6.3	.8	7.28	4.85	2.43
30-3	do.	11	6.4	1.1	8.04	4.73	3.31
30-4	Palmyra	11	2.2	.5	3.02	1.33	1.69
30-5	Canaan	11	30.6	.4	31.13	29.95	1.18
30-6	do.	11	6.7	.3	7.14	6.23	.91
30-7	Clinton	11	4.5	.6	5.47	3.70	1.77
31-1[1/]	Fairfield	9	7.6	1.0	8.99	6.34	2.65
31-2	Skowhegan	11	6.9	.6	7.72	5.90	1.82
31-3	Norridgewock	11	4.1	.8	5.20	2.85	2.35
31-4	do.	11	7.6	.8	8.75	6.09	2.66
31-5	do.	11	24.2	.1	24.40	24.03	.37
31-6	do.	11	31.9	.4	32.53	31.34	1.19
31-7	Madison	11	13.0	.8	14.16	11.68	2.48
31-8[2/]	Anson	4	10.0	.6	10.77	9.33	1.44

[1/] The casing on this well was extended out of reach pending filling around the well. The filling never occurred so water levels could not be measured during the last two visits.

[2/] This well was buried when the local landfill was expanded.

3. Introduction of human wastes into ground water through septic tanks, disposal of septic wastes, or by spreading or landfilling of sludge from municipal sewer systems.

4. Agricultural activities, which include stockpiling and spreading animal wastes, spreading commercial fertilizers, and spraying pesticides.

5. Leaking waste-storage or disposal lagoons.

6. Leaking fuel or chemical storage tanks.

7. Spills of toxic or hazardous materials along transportation routes.

8. Large withdrawals from wells can induce saltwater intrusion in coastal areas or infiltration of poor quality water where a well is near contaminated surface water.

9. Contaminants in precipitation may degrade both ground water and surface water. For example, in New Hampshire and New York, "acid rain" has been reported to lower pH of precipitation, which subsequently lowers pH in ground water. Increased aluminum and other trace-metal concentrations have been observed in ground water (Bridge and Fairchild, 1981).

The most commonly used indicators to detect ground-water contamination include above-background levels of nitrate--a contaminant derived from sewage, animal waste, fertilizer, and landfill; chloride--a contaminant introduced by road salt, saltwater intrusion, fertilizers and landfill wastes; and specific conductance--an indicator of the presence of dissolved, ionized contaminants.

Physical and Chemical Characteristics of Samples

Background Water Quality

The following discussion is based on analyses of samples collected from nine wells within the study area. Characteristics of these wells are given in table 10. The wells are located in areas which are believed to be upgradient of any known sources of contaminants and should, therefore, be representative of background water quality. Because of the small number of background water-quality wells installed within the study area, a statistical summary of the water-quality information collected throughout south-central Maine (Tolman and others, 1983; Tepper and others, 1985; Williams and others, 1987; and this study) also is included in this discussion.

Table 10.--Characteristics of observation wells in the study area sampled for background water-quality data

Observation well number	Town	Latitude	Longtitude	Altitude[1/]	Depth[2/]	Predominant Land Use around well	Date sampled
18-3	Washington	44°16′35″	69°24′59″	290	36	gravel pit	10-23-84
18-4	do.	44°13′20″	69°23′36″	290	41	do.	10-23-84
30-4	Palmyra	44°51′26″	69°26′13″	235	19	do.	10-25-84
30-5	Clinton	44°40′42″	69°30′50″	145	46	do.	10-29-84
30-6	Canaan	44°49′51″	69°55′58″	290	41	field	10-29-84
30-7	do.	44°44′12″	69°34′44″	195	23	do.	10-31-84
31-4	Norridgewock	44°41′47″	69°46′58″	245	20	do.	10-31-84
31-6	do.	44°43′14″	69°48′50″	185	48	forest	11-01-84
31-7	Madison	44°51′49″	69°51′33″	270	40	field	11-01-84

1/ Altitude of observation well at land surface datum in feet

2/ Depth of bottom of observation well in feet below land surface datum

Statistical data can be used to characterize the background water quality and to compare concentrations of consituents in a given sample to the concentration mean of all other samples. The mean and the standard deviation of analyzed constituents are presented in table 11. The mean is equal to the sum of the measurements divided by the number of measurements; it is the average concentration for a given constituent. The standard deviation is a numerical expression of the amount of variation there is from the mean value.

The statistical data in table 11 here must be interpreted cautiously, because only a limited number of wells were sampled. The data from this study are included in the statistical information of south-central Maine in table 11B.

Temperature

The temperature of ground water normally has a small seasonal fluctuation and is usually within a few degrees of the mean annual air temperature in a given area. In Maine, ground-water temperatures are typically from 4.4 to 10.0°C (Caswell, 1978). The temperature of ground water in the background water-quality samples within the study area ranged from 7.4 to 12.1°C, with a mean of 9.3°C. The mean ground-water temperature in wells throughout south-central Maine was 8.9°C.

Specific conductance

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

Specific conductance can be used to estimate dissolved solid concentrations which were not measured directly. The concentration of dissolved solids, in milligrams per liter can be estimated by multiplying the specific conductivity by a factor, usually between 0.55 and 0.75 (Hem, 1985). Although there are no drinking-water standards set for conductance, the Maine Department of Human Services (1983) has recommended a maximum concentration limit of 500 mg/L of dissolved solids in drinking water.

Specific conductance values in the background water-quality samples within the study area ranged from 28 to 347 µS/cm. Adjusting the values using the factors given by Hem, a range of 15 to 260 mg/L was estimated for dissolved solids, indicating that dissolved solids concentrations in the study area are well below the recommended maximum level. In south-central Maine, the average specific conductance is 84 µS/cm.

Table 11.--Background water-quality in sand and gravel aquifers in south-central Maine

PART A. Chemical characteristics of wells in study area (all values in milligrams per liter except as noted).

Observation well number	Temperature (°C)	Conductivity (microsiesmens /cm)	pH values	Alkalinity as $CaCO_3$	Chloride dis solved	Nitrate + nitrite as N	Sulfate dissolved	Sodium dissolved	Potassium dissolved	Calcium dissolved	Magnesium dissolved	Hardness as $CaCO_3$	Iron dissolved	Manganese dissolved	[1]TOC	[2]VOP
18-3	9.1	49	7.0	15	1.0	0.03	4.3	2.5	1.5	5.0	1.1	17	<0.03	0.008	14	[3] N/A
18-4	9.4	154	7.5	44	12	.31	6.1	6.5	3.4	19	3.7	64	.16	.048	14	N/A
30-4	12.1	190	7.3	79	2.4	.01	3.8	2.6	2.9	33	3.2	96	< .03	.440	3	N/A
30-5	9.3	234	7.9	97	2.0	.03	7.3	9.0	2.3	27	10	109	< .03	.100	<1	N/A
30-6	8.8	183	8.6	79	3.6	.04	6.8	5.4	2.1	20	9.0	87	< .03	.030	2	<1
30-7	10.4	347	7.6	150	1.0	.04	49	15	3.2	45	11	158	< .03	.140	<1	N/A
31-4	8.5	28	6.4	5	1.0	< .01	<3	1.3	.5	2.2	.6	8.3	.16	.190	<1	<1
31-6	7.4	132	7.2	49	4.4	.33	6.4	4.9	2.1	15	3.4	52	< .03	< .005	<1	<1
31-7	9.0	84	6.8	37	0.5	.21	3.2	1.6	1.5	12	1.4	36	< .03	.440	<1	<1
Number	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	4
Minimum	7.4	28	6.4	5	0.5	< .01	<3.0	1.3	.5	2.2	.6	8.3	< .03	< .005	<1	<1
Maximum	12.1	347	8.6	150	12	.33	49	15	3.4	45	11	158	.16	.44	14	<5
Median	9.1	154	7.3	49	2.0	.04	6.1	4.9	2.1	19	3.4	64	< .03	.10	<1	N/A
Mean	9.3	156	[4] 7.00	61	3.1	.11	[5] 9.8	5.4	2.2	20	4.8	70	[5] .05	[5] .16	[5] 4	N/A
STD DEV	1.3	99	N/A	44	3.6	.13	14.8	4.4	.9	14	4.1	48	.06	.17	6	N/A

PART B. Chemical characteristics of wells throughout south-central Maine [6].

Number	54	54	53	53	53	53	53	54	54	54	54	54	54	53	34	30
Minimum	6.5	17	5.3	3.4	< .5	< .01	<3.0	1.3	.4	1.2	.2	.4	< .02	< .05	<1	<1
Maximum	15	347	8.6	147	12	0.80	49	15	4.8	45	11	158	10	1.50	30	<1
Median																
Mean	8.9	85	[3] 6.1	26	3.4	.11	6.4	5.4	1.8	9.6	2.1	34	.76	.28	5	<1
STD DEV	1.5	58	N/A	27	2.9	.14	6.9	3.0	1.1	8.5	2.2	30	2.11	.35	7	0

1 TOC, Total organic carbon.

2 VOP, Volatile organic pollutants, in micrograms per liter.

3 N/A, Not analyzed.

4 Calculated from hydrogen-ion activity.

5 Detection limit divided by 2 used for calculating means if concentration below detection limit.

6 Tolman and others, 1983; Tepper and others, 1985; Williams and others, 1987.

pH

The pH of water is a measure of hydrogen ion activity (concentration). The pH scale ranges from 0 to 14; each unit increase in the scale represents a ten-fold decrease in hydrogen-ion activity. A pH of 7 is considered neutral, less than 7 is acidic, and greater than 7 is alkaline. The primary control on pH in most ground water involves interaction of soil and rocks with gaseous carbon dioxide, bicarbonate, and carbonate ions. The pH in the background water-quality samples within the study area ranged from 6.4 to 8.6, with a mean (calculated from hydrogen-ion concentration) of 7.0. The U.S. Environmental Protection Agency (1979) has set a minimum pH drinking-water standard of 6.5 and a maximum of 8.5, because increased solution of metal from pipes can occur at lower pH. Seven of the nine background water quality samples within the study area are within this range. Well OW 30-6, with a pH of 8.6, is the only well of the 54 sampled throughout south-central Maine that exceeded the maximum pH standard, but water in many wells outside the study area had a pH value below 6.5.

Alkalinity

Akalinity is a measure of the capacity of a solution to resist a change in pH as an acid is added. The alkalinity is a measure of the concentrations of carbonate (CO^{-2}), bicarbonate (HCO_3^-) and hydroxyl (OH^-) ions. In ground water within the pH range found in the study area, the bicarbonate ion is the dominant anionic species. Alkalinity is reported in table 5 in terms of an equivalent quantity of calcium carbonate (CaCO). The alkalinity concentrations within the study area ranged from 5 to 150 mg/L, with a mean of 61 mg/L. The alkalinity concentrations in the wells throughout south-central Maine ranged from 3.4 to 150 mg/L, with a mean of 26 mg/L.

Chloride

Because chloride is a highly mobile ion and is not readily sorbed, it can be used to trace contamination from road-salting operations, salt-storage piles, landfills, and septic tanks. Chloride concentrations in the background water-quality samples within the study area ranged from 0.5 to 12 mg/L, with a mean concentration of 3.1 mg/L. Chloride concentrations in the wells throughout south-central Maine ranged from less than 0.5 to 12 mg/L, with a mean of 3.1 mg/L. These concentrations are all below the Maine Department of Human Services (1983) drinking-water standard of 250 mg/L.

Nitrate plus nitrite

Nitrogenous compounds are commonly 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 absorbed by soil, it functions as a reliable indicator of contamination from septic systems and waste-disposal sites. Nitrate can be converted to nitrite in the stomachs of infants; this may lead to the onset of methemoglobinemia--a potentially lethal disease (National Research Council, 1977). Because of this, the Maine Department of Human Services (1983) has established a limit of 10 mg/L nitrate-nitrogen (NO -N) in drinking water. Nitrate plus nitrite concentrations in the background water-quality samples within the study area ranged from less than 0.01 to 0.33 mg/L as N. The values in south-central Maine ranged from less than 0.01 to 0.80 mg/L. The mean nitrate plus nitrite concentration within the study area and in all of south-central Maine is 0.11 mg/L.

Sulfate

Sulfate is one of the major anions in natural waters. The Maine Department of Human Services (1983) has recommended an upper limit 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 within the study area ranged from less than 3.0 to 49 mg/L, with a mean of 9.8 mg/L. Sulfate concentrations in south-central Maine had the same range, with a mean of 6.4 mg/L.

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 containing only a few tenths of a milligram per liter of H_2S. Hydrogen sulfide gas is a common problem in ground water from wells drilled into bedrock that contains sulfide minerals (generally pyrite and pyrrhotite), but it is not a problem in most unconsolidated aquifers.

Sodium and potassium

Sodium and potassium are commonly among the major cations in ground water. The Maine Department of Human Services (1983) has not set maximum limits for potassium in drinking water. However, a drinking-water standard of 20 mg/L for sodium has been set to protect individuals on restricted sodium diets. These diets are usually recommended for people with heart, hypertension, or kidney problems (U.S. Environmental Protection Agency, 1976).

Concentrations of sodium in the background water-quality samples within the study area (and in south-central Maine) ranged from 1.3 to 15 mg/L, with a mean of 5.4 mg/L. Concentrations of potassium in the study area ranged from 0.5 to 3.4 mg/L, with a mean of 2.2 mg/L; potassium concentrations in south-central Maine ranged from 0.4 to 4.8 mg/L, with a mean of 1.8 mg/L.

Calcium, magnesium, and hardness

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

Concentrations of calcium, the principal cation in the background water-quality samples, ranged from 2.2 to 45 mg/L, in the study-area wells, and from 1.2 to 45 mg/L in the 54 wells in south-central Maine. Mean calcium concentrations were higher within the study area (20 mg/L) than in the entire south-central Maine area (9.6 mg/L). Magnesium concentrations were higher in the study area wells (0.6 to 11 mg/L; mean of 4.8 mg/L) than in all of south-cental Maine (range 0.2 to 11 mg/L; mean of 2.1 mg/L).

Hardness, a property associated with effects observed in the use of soap or with the encrustations left by some types of water when they are heated (Hem, 1985), is caused by divalent metallic cations, principally calcium and magnesium. Other divalent cations, including strontium, iron, and manganese, also may contribute to hardness. Hard water requires considerable amounts of soap to produce a foam or lather and can cause scale in hot water pipes, heaters, boilers, and other units that use hot water.

Hardness was calculated by Standard Method 309a (American Public Health Association, 1976) and is expressed in table 10b in terms of an equivalent concentration of calcium carbonate in mg/L. Water is considered soft if it contains 0 to 60 mg/L of hardness, moderately hard if it contains >60 to 120 mg/L, hard if it contains >120 to 180 mg/L, and very hard if it contains more than 180 mg/L (Hem, 1985). Ground water in the background water-quality samples within the study area, ranged from soft to hard (8.3 to 158 mg/L); the mean concentration of 70 mg/L is considered moderately hard. Hardness values in the entire south-central Maine region are lower than those in the study area; the mean hardness concentration in south-central Maine is 34 mg/L, which is considered soft.

Iron and manganese

Elevated iron and manganese concentrations have caused 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. 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, commonly described as rusty or metallic. When exposed to the air, water that contains dissolved iron and manganese may become turbid and aesthetically unacceptable because of the formation of colloidal precipitates.

The mean iron concentration in the background water-quality samples within the study area was 0.05 mg/L, which is below the Maine Department of Human Services (1983) recommended limit of 0.3 mg/L for drinking water. Water from none of the nine wells in this area had iron concentrations that exceeded this limit. However, water from the entire south-central Maine area had a mean iron concentration of 0.76 mg/L, which is more than twice the recommended limit. The mean concentration for manganese in the study area was 0.16 mg/L; in south-central Maine it was 0.28 mg/L. Both of these values exceed the maximum limit of 0.05 mg/L,recommended for drinking water by the Maine Department of Human Services (1983).

Filtration units can be installed by individual well owners to help remove objectionable levels of iron and manganese. Treatment to remove iron and manganese from public-water supplies obtained from wells that tap sand and gravel aquifers might be necessary 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. Some of these chemicals may be highly toxic, although the TOC-measurement technique does not distinguish between toxic and nontoxic organic species. TOC concentrations in the background water-quality samples within the study area ranged from less than 1 to 14 mg/L; over the entire south-central Maine area, TOC values vary from less than 1 to 30 mg/L. The mean TOC level in south-central Maine was 5 mg/L.

Volatile organic compounds

Volatile organics are a group of chemicals that include trichloroethane, trichloroethylene, tetrachloroethane, toluene, xylenes, benzenes, and fluorocarbons, among many others. The presence of these compounds is usually associated with a spill or with the disposal of oil, gasoline, pesticides, or industrial solvents and cleaners. Most of these compounds are not found in natural ground water.

Water from four wells within the study area and 30 wells in south-central Maine were analyzed for volatile organic compounds; none of these wells contained detectable levels of these substances.

Ground-water Quality in Agricultural Areas

Seventeen wells in south-central Maine have been installed adjacent to fields currently used for agricultural purposes. Seven wells were from this study area and ten from previous study areas (Tolman and others, 1983; Tepper and others, 1985; Williams and others, 1987). Characteristics of the wells in the study area are given in table 12. The mean concentrations of all analyzed constituents are higher in the wells installed in agricultural areas than in the background water-quality wells (Table 13). Nitrate plus nitrite concentrations showed the greatest differences between the agricultural and the background wells. Mean nitrate plus nitrite concentrations were 4.7 mg/L in the agricultural wells within the study area and 8.0 mg/L in the entire south-central Maine region, contrasted with 0.11 mg/L in both areas for background water-quality wells. However, even in the agricultural areas, no wells tested within the study area had nitrate plus nitrite levels exceeding Maine drinking-water standards.

Characteristics of Sites of Potential Ground-Water Contamination

Fifty-five sites of potential point source ground-water contamination of sand and gravel aquifers within the study area have been identified on plates 1-3. These sites include 23 solid-waste facilities, 29 salt-storage lots, and 3 sewage and industrial-waste lagoons. Many potential nonpoint contamination sources and some point sources, including septic systems, roads that are salted in the winter, agricultural activities, and leaking underground gasoline tanks are not shown on these plates because of their widespread occurrence.

Ground-water contamination from many of the sites shown in plates 1-3 has been documented by the DEP. However, no domestic or municipal wells are known to have been affected by these activities.

SUMMARY

The significant sand and gravel aquifers in the study area consist of ice-contact, ice-stagnation, and glacial outwash deposits, and Holocene stream alluvium found primarily in the valleys of the major river systems and their tributaries and often near other surface-water bodies.

Table 12.--Characteristics of observation wells in the study area near agricultural areas.

Observation well number	Town	Latitude	Longtitude	Altitude[1]	Depth[2]	Predominant land use around well	Date sampled
18-1	China	44°23′00″	69°31′31″	315	29	Agriculture	10-22-84
18-2	do.	44°23′00″	69°31′31″	315	56	do.	10-22-84
30-1	Unity	44°35′54″	69°18′04″	190	29	do.	10-23-84
31-1	Fairfield	44°37′25″	69°39′09″	155	26	do.	10-31-84
31-2	Skowhegan	44°47′15″	69°42′52″	230	21	do.	11-01-84
31-3	Norridgewock	44°41′47″	69°46′58″	245	20	field	10-31-84
31-5	do.	44°43′35″	69°49′08″	185	50	agriculture	10-30-84

1 Altitude of observation well at land surface datum, in feet.

2 Depth of bottom of observation well, in feet below land surface datum.

Table 13.--Water quality near agricultural areas

PART A. Chemical characteristics of wells in study area (all values in milligrams per liter except as noted).

Observation well number	Temperature (°C)	Conductivity (microsiesmens /cm)	pH values	Alkalinity as $CaCO_3$	Chloride dis solved	Nitrate + nitrite (as N)	Sulfate dissolved	Sodium dissolved	Potassium dissolved	Calcium dissolved	Magnesium dissolved	Hardness as $CaCO_3$	Iron dissolved	Manganese dissolved	[1]TOC	[2]VOP
18-1	10.1	187	7.0	26	9.0	8.5	6.6	3.9	1.6	25	3.6	93	<0.03	<0.005	14	[3] N/A
18-2	10.2	166	8.4	54	3.9	.72	15	3.0	2.7	26	3.2	80	.09	.200	<1	N/A
30-1	9.1	369	7.9	81	14	6.0	8.9	8.3	2.0	51	8.9	175	< .03	< .005	1	N/A
31-1	9.4	489	7.8	193	19	3.0	25	7.7	6.7	72	12	235	.05	.19	21	N/A
31-2	9.3	207	6.0	28	20	8.0	10	20	1.2	14	2.6	60	< .03	.23	<1	<1
31-3	8.3	169	6.8	56	3.9	2.4	14	4.0	1.3	19	5.9	76	< .03	1.60	<1	<1
31-5	8.0	202	8.3	60	6.6	4.2	14	4.2	3.0	27	5.0	96	< .03	< .005	<1	<1
Number	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
Minimum	8.0	166	6.0	26	3.9	0.72	6.6	3.0	1.2	14	2.6	60	< .03	< .005	<1	<1
Maximum	10.2	489	8.4	193	20	8.50	25	20	6.7	72	12	235	.09	1.60	21	<1
Mean	9.2	256	[4]6.7	72	11	4.7	13	7.3	2.6	33	5.9	116	[5]0.03	[5] .32	[5]5	<1
STD DEV	0.8	123	N/A	57	6.8	2.9	5.9	6.0	1.9	21	3.4	64	.03	.57	8	N/A

PART B. Chemical characteristics of wells in agricultural areas throughout south-central Maine.[6]

	Temperature (°C)	Conductivity (microsiesmens /cm)	pH values	Alkalinity as $CaCO_3$	Chloride dis solved	Nitrate + nitrite (as N)	Sulfate dissolved	Sodium dissolved	Potassium dissolved	Calcium dissolved	Magnesium dissolved	Hardness as $CaCO_3$	Iron dissolved	Manganese dissolved	[1]TOC	[2]VOP
Number	17	17	17	17	17	17	16	17	17	17	17	17	17	17	17	13
Minimum	7.6	76	5.5	3.8	3.9	0.12	<3.0	2.6	1.1	3.1	1.1	16	<0.03	<0.005	<1	<1
Maximum	10.2	780	8.4	193	26	78	25	20	7.3	120	18	438	16	19	27	<1
Mean	9.2	248	6.1	46	12	8.0	11	7.4	2.7	31	5.3	116	1.19	1.7	6	<1
STD DEV	.8	217	N/A	58	5.7	18	6.0	4.4	1.8	33	5.3	127	3.86	4.6	9	N/A

1 TOC, Total organic carbon.

2 VOP, Volatile organic pollutants, in micrograms per liter.

3 N/A, Not analyzed.

4 Calculated from hydrogen-ion activity.

5 Detection limit divided by 2 used for calculating means when concentrations below detection limit.

6 Tolman and others, 1983; Tepper and others, 1985; Williams and others, 1987.

Although the study area includes 1380 mi^2, areas mapped as significant aquifers underlie only 81 mi^2 (plates 1-3). Yields exceeding 50 gal/min are estimated to be available in only a 2-mi^2 area underlain by these significant aquifers. Highest yields are obtainable in areas of thick, coarse-grained, saturated deposits hydraulically connected to an adjacent body of surface water that is a source of recharge. The highest reported well yield in the sand and gravel deposits is 800 gal/min from the Pittsfield Water District well, adjacent to the Sebasticook River.

The water table within the significant sand and gravel aquifers is typically within 20 feet of the land surface. Based on well-record data, the greatest known depth to bedrock exceeds 200 feet in the Smithfield area.

On the basis of field observations, logs of exploration borings, and interpretation of the geologic history, the following stratigraphic relationships have been determined: Bedrock is overlain by till, which are overlain by ice-contact, outwash, and marine deposits, which is overlain by sand and gravel deposits of mixed origin. The thickness of the deposits and stratigraphic units differ considerably, depending on landforms and local depositional controls during deglaciation and postglaciation.

Hydraulic conductivities estimated from grain-size analyses range from 10 to 150 ft/d. Estimated transmissivities at observation wells in the study area range from 170 to 3600 ft /day. Estimated well yields at observation wells in water-table aquifers in the study area range from 20 to 460 gal/min.

The background water quality in sand and gravel aquifers in areas relatively unaffected by human activities had the following characteristics: The pH range is from 6.4 to 8.6; calcium and sodium are the most abundant cations; bicarbonate is the dominant anion; and the water is moderately hard. The regional water quality is suitable for drinking and most other uses although, in some localities, concentrations of iron and manganese are elevated to a level sufficient enough to limit use of untreated water.

The concentration of constituents in agricultural areas is higher than the regional background water quality.

Solid-waste facilities and salt-storage sites are the most common of the 55 potential ground-water contamination sites identified on or near sand and gravel aquifers in the study area. No water-supply wells are known to have been contaminated by activities at these sites.

Potential nonpoint-contamination sources include agricultural activities, road salting, and malfunctioning septic systems.

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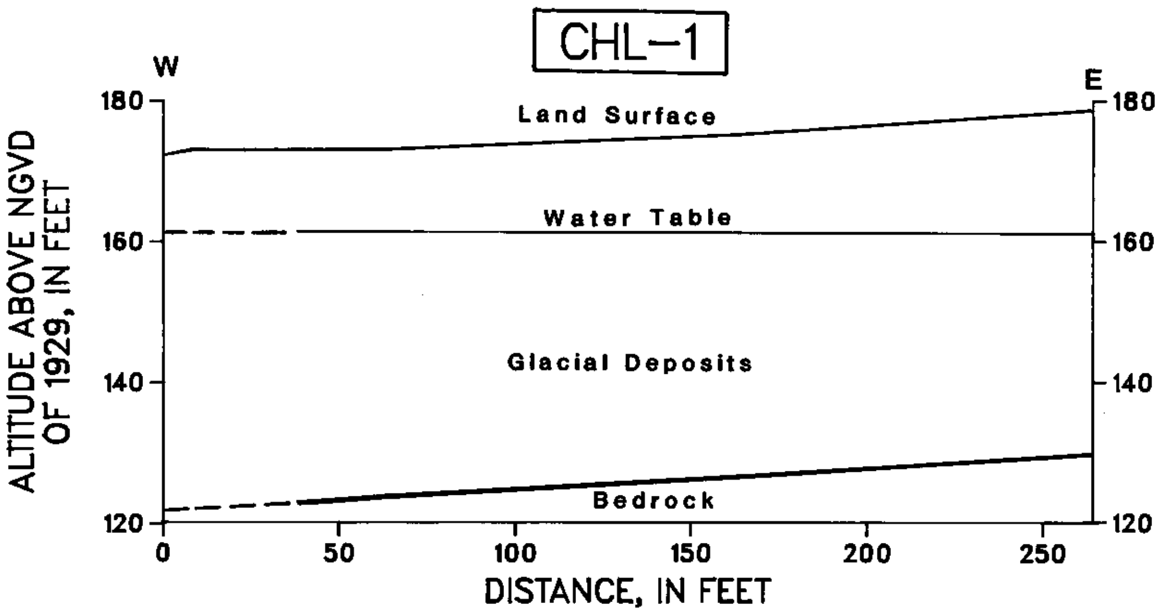
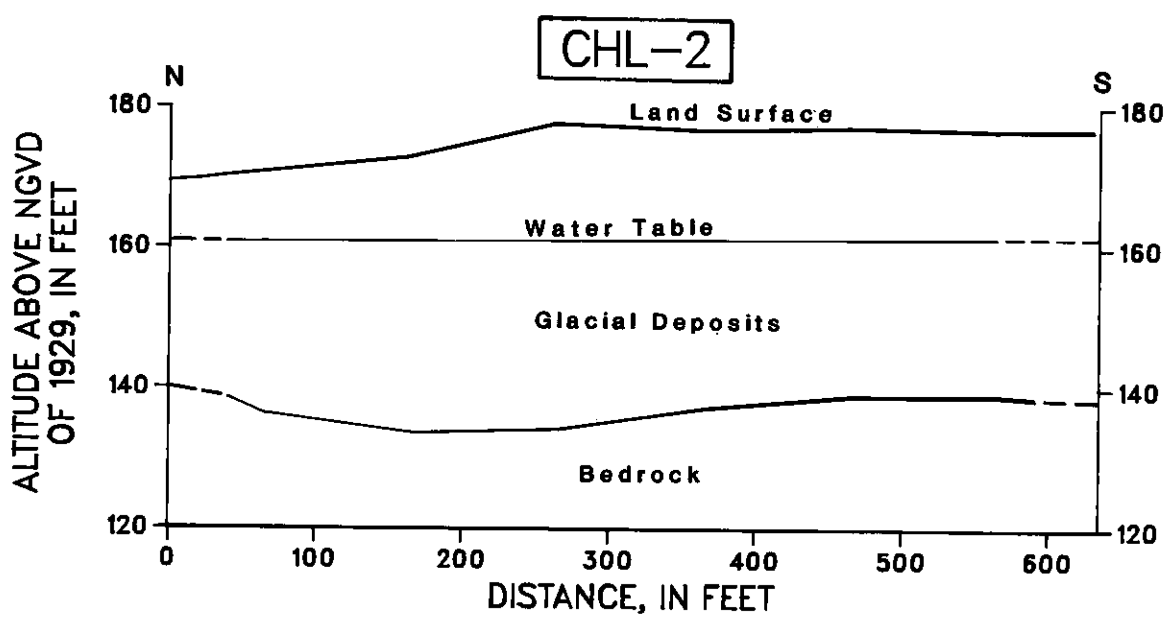
Figure 5.--12-channel seismic-refraction profiles: Plate 1, Map 18 Area

Hydrogeologic sections from seismic-refraction surveys conducted by the U.S. Geological Survey in 1984. Location of individual profiles are shown on plate 1. Data interpretation is based on a computer modeling program described by Scott and others (1972). Distances shown on the X-axes are measured from shot #1. In places, the altitude of the water table and bedrock surfaces have been shown with dashed lines. This is to emphasize the relative unreliability of this data.

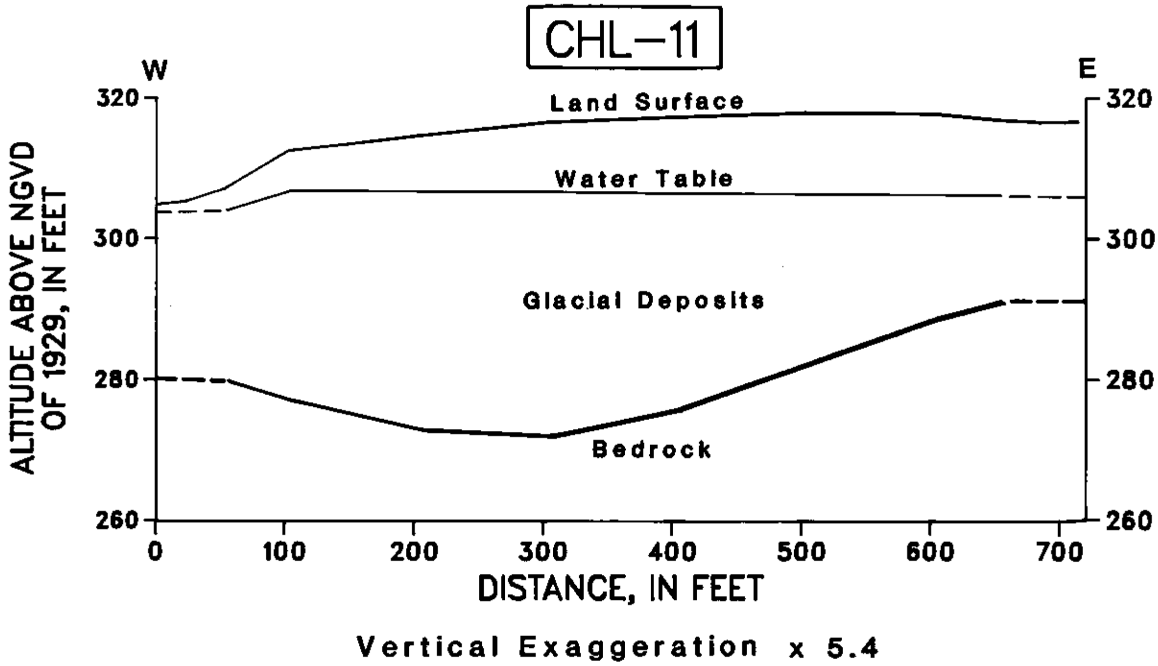


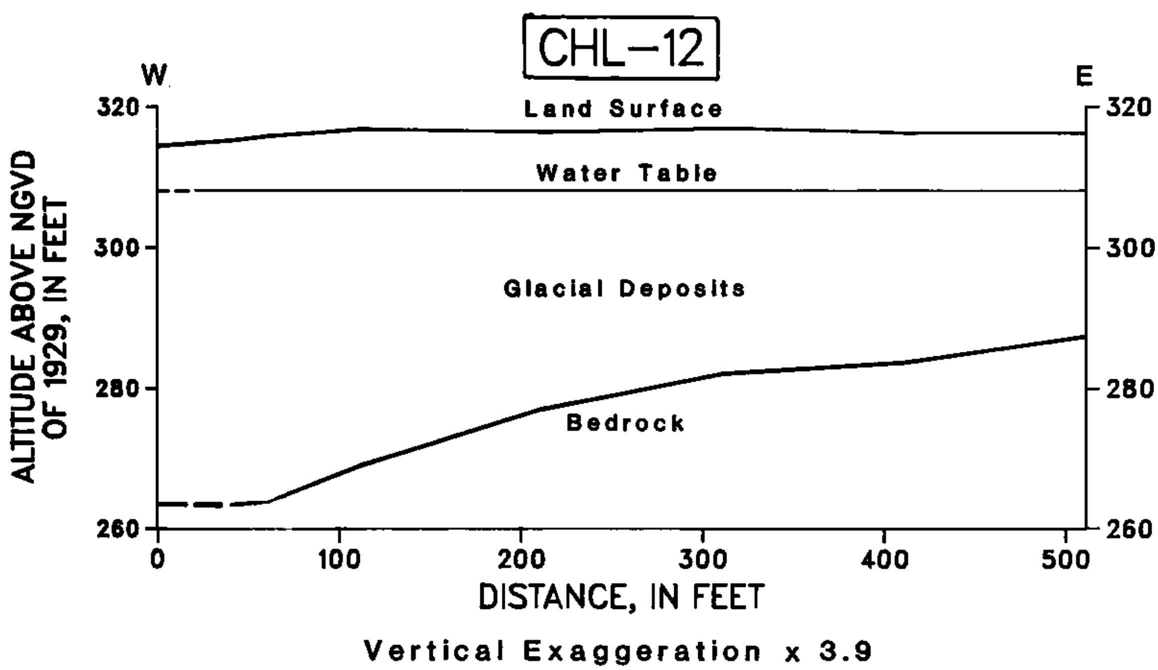
Vertical Exaggeration x 2.0



Vertical Exaggeration x 4.8

Figure 5. Continued.





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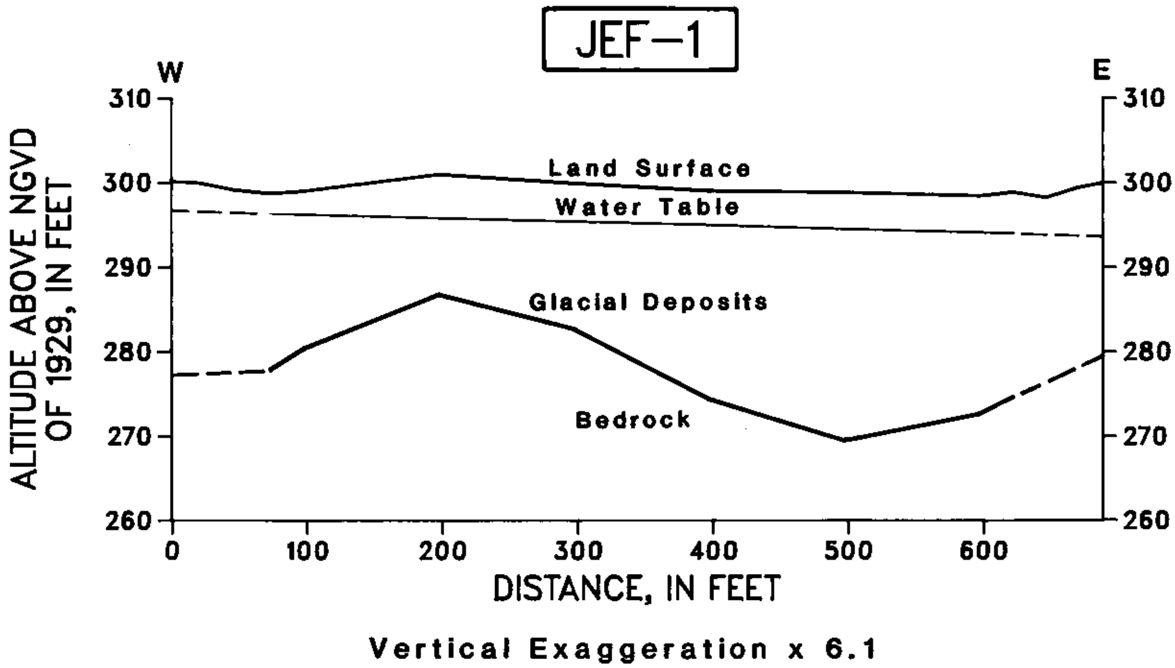

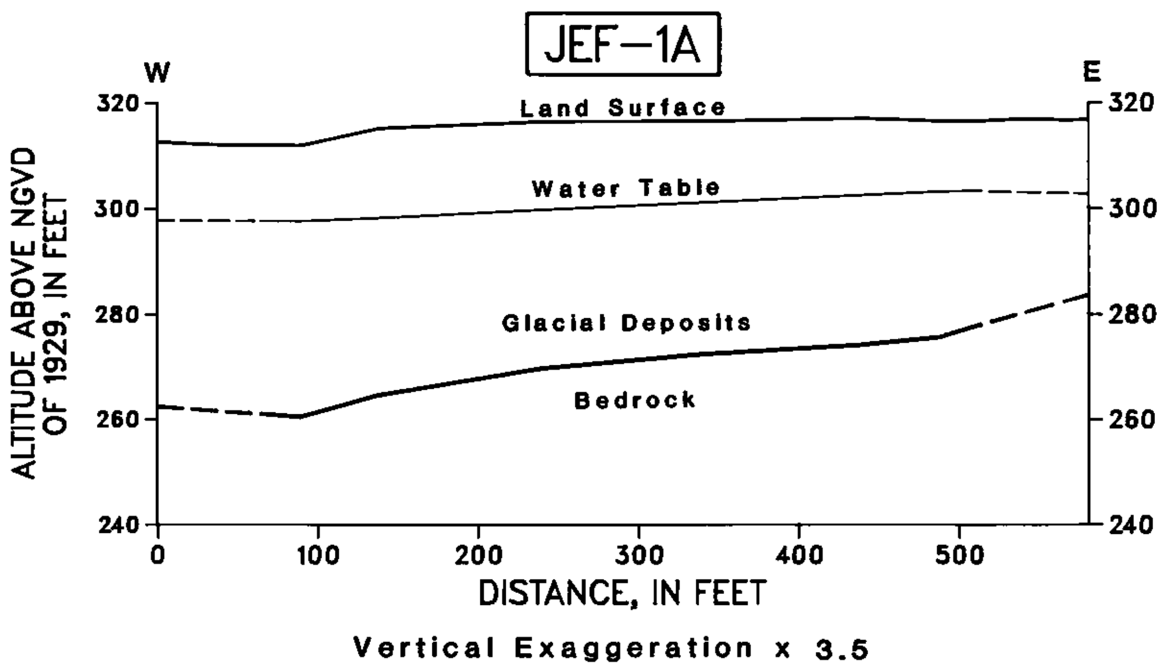

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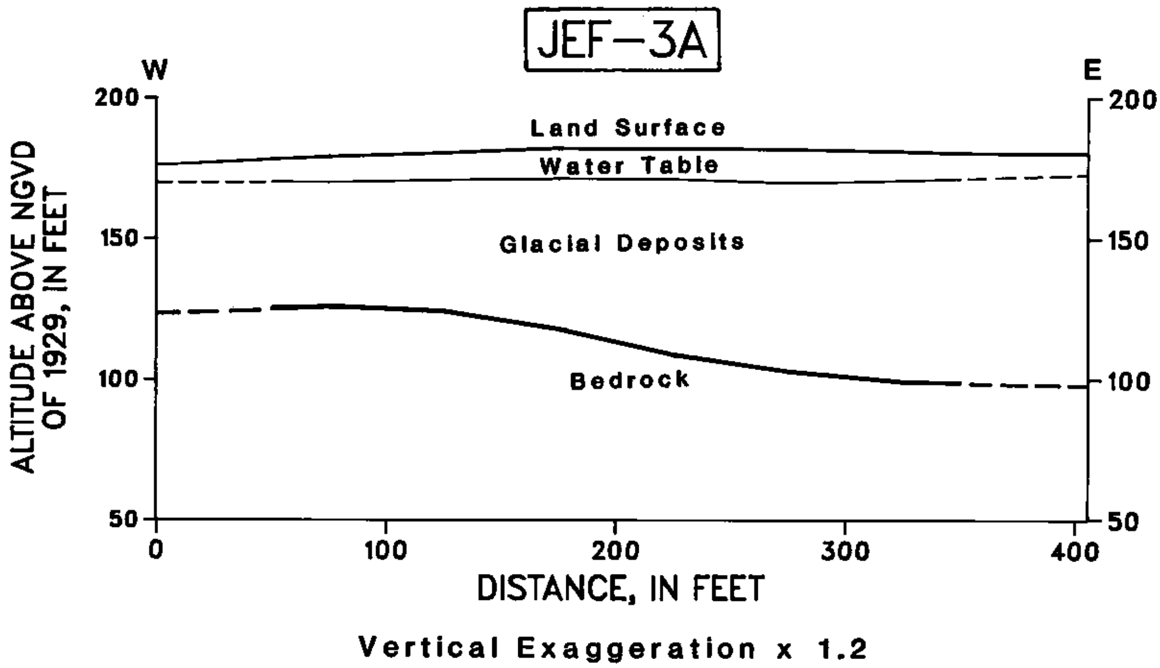

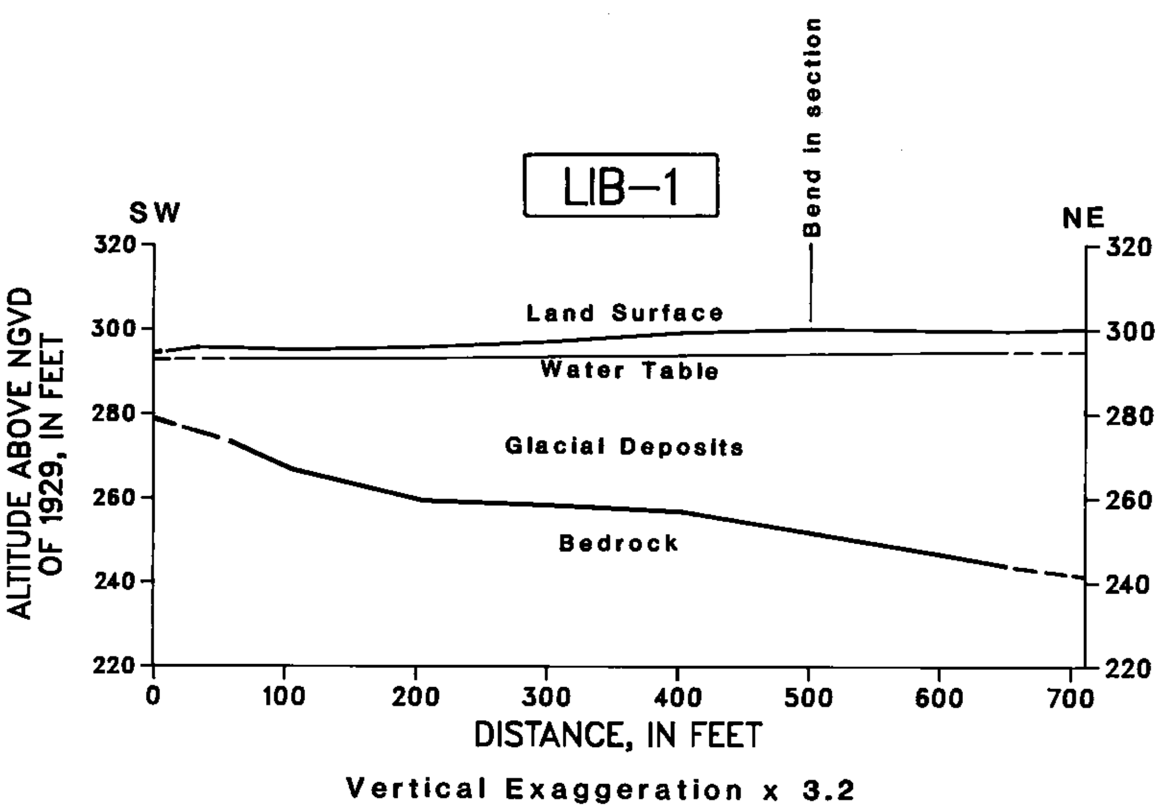

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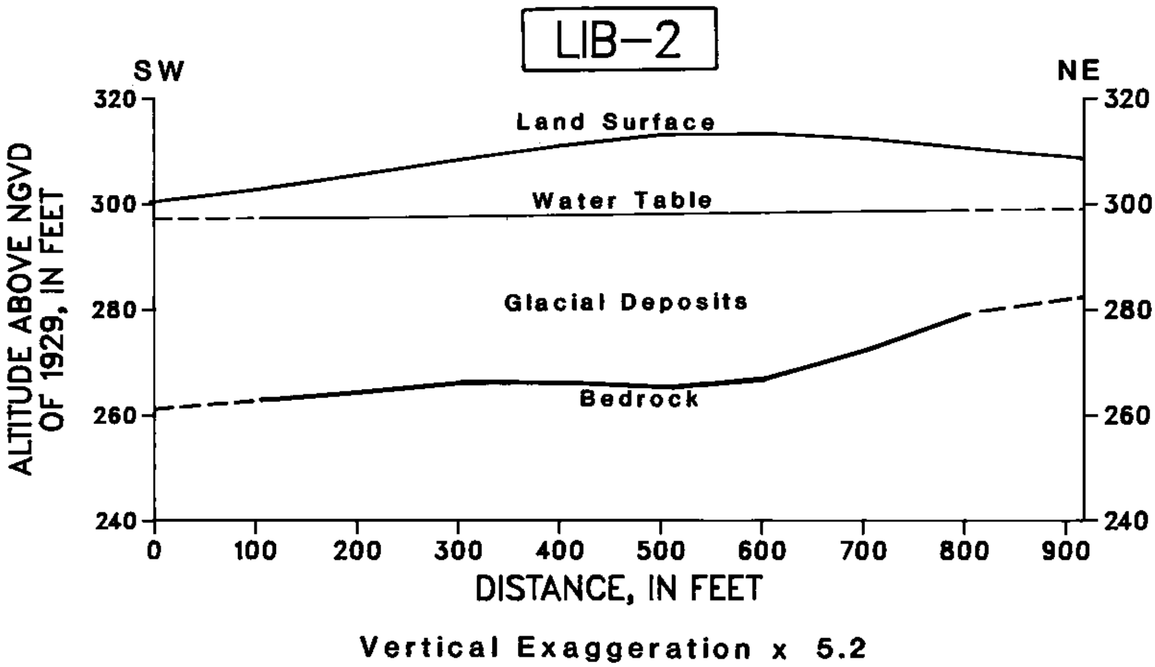

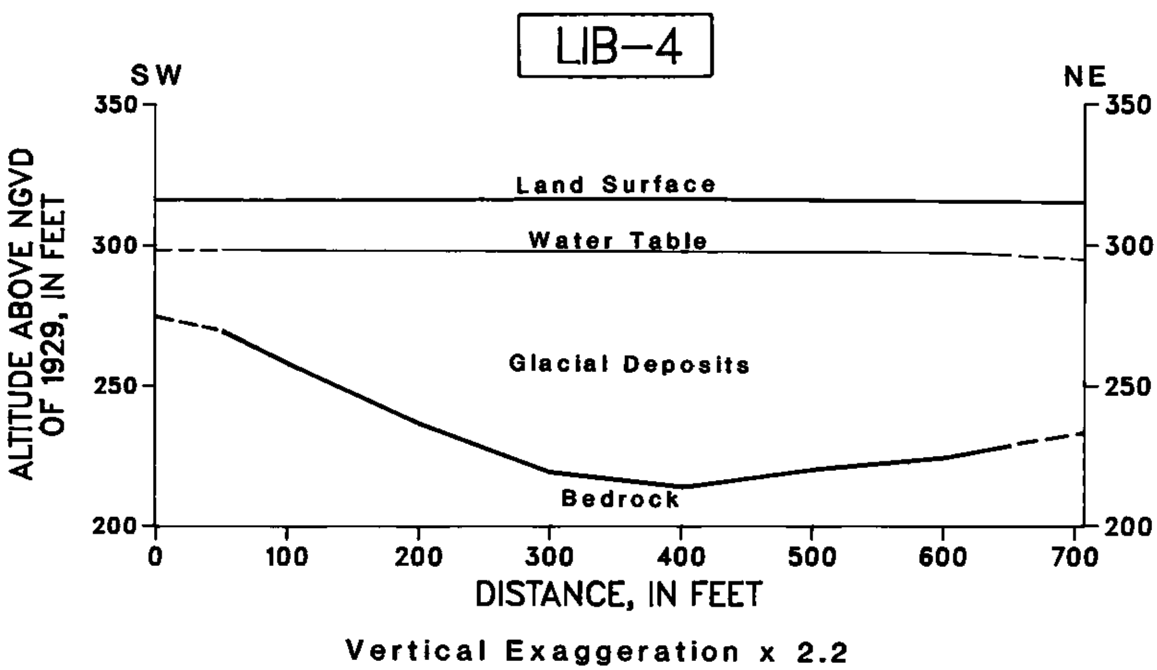

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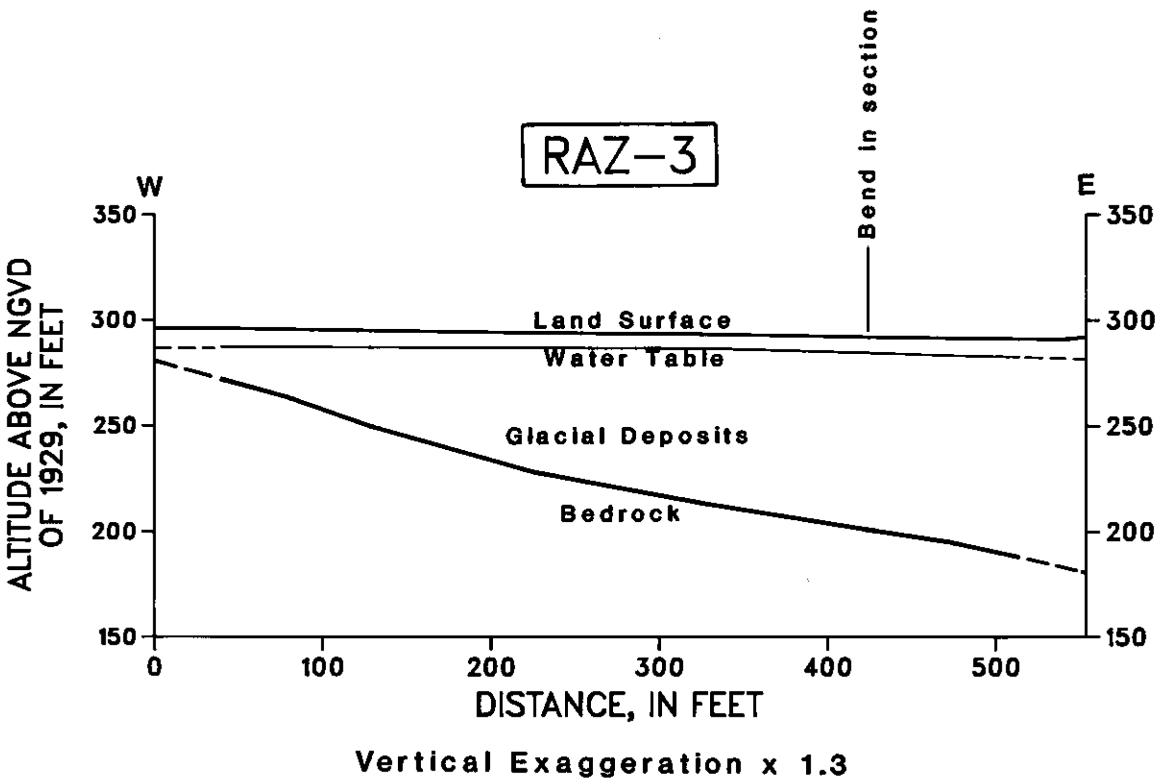

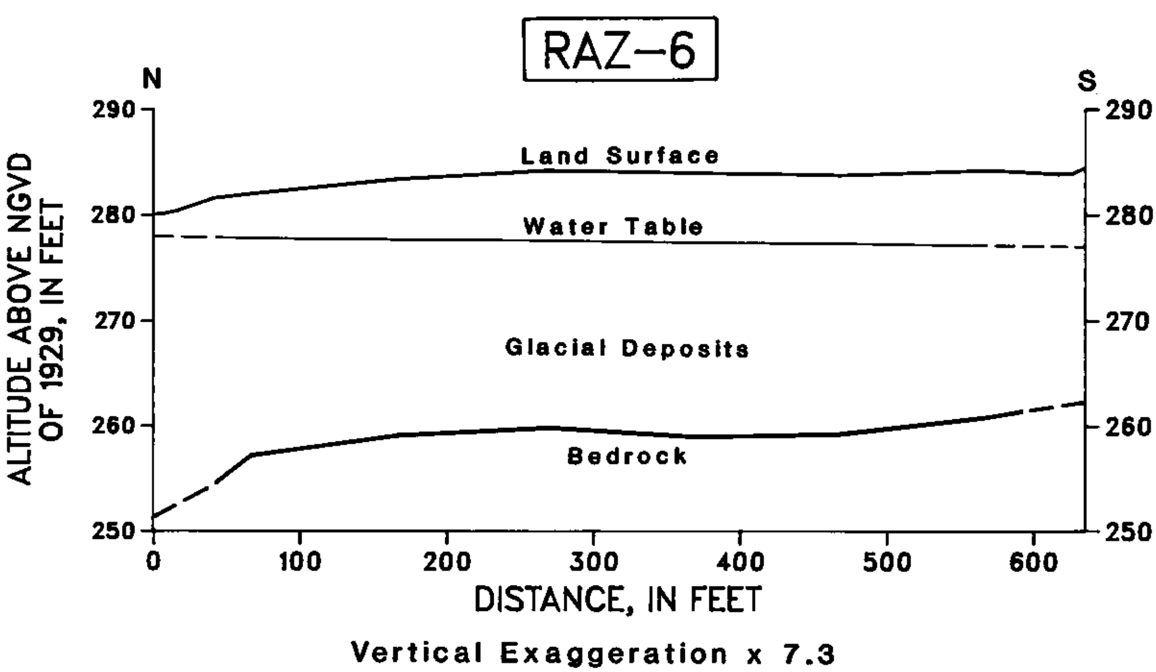

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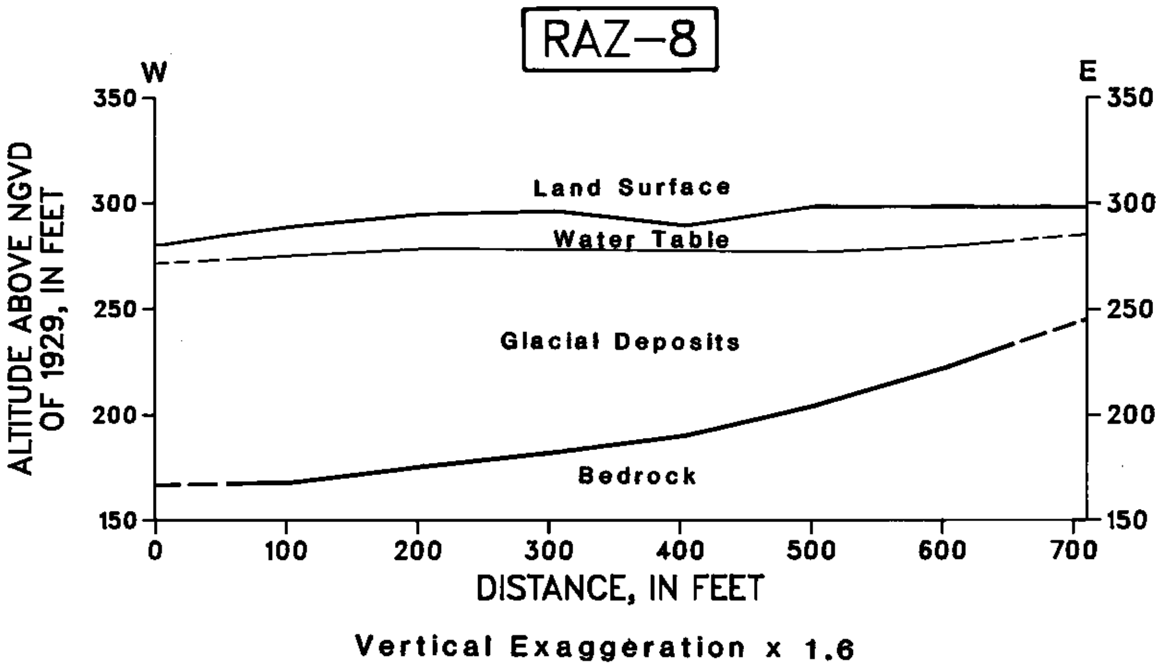

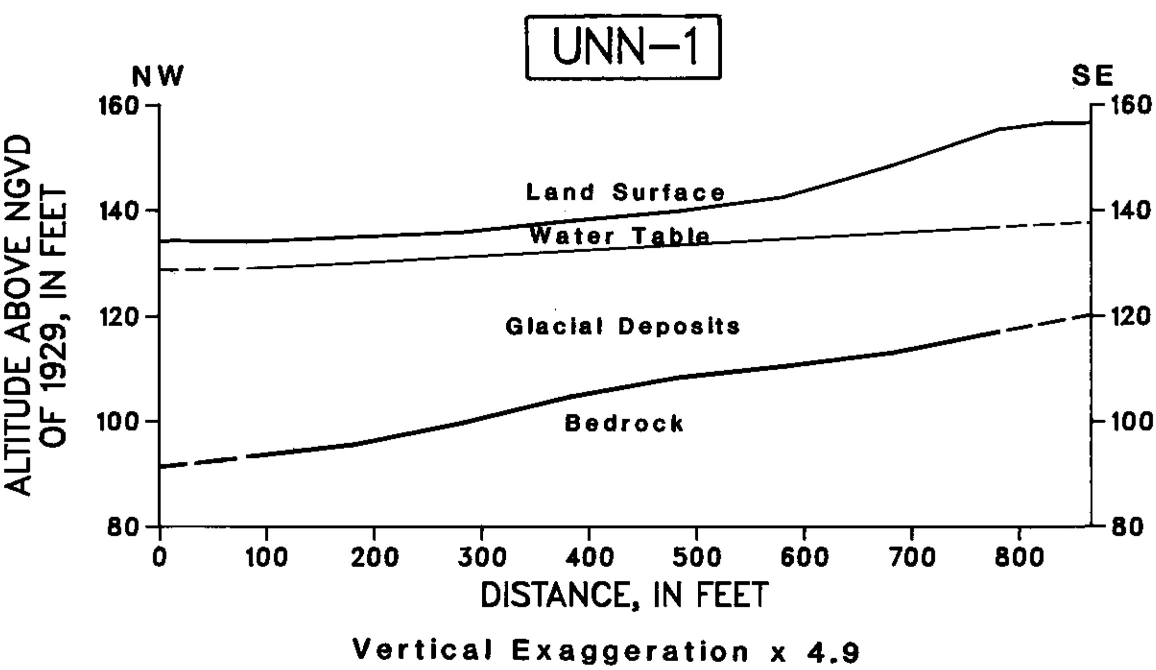

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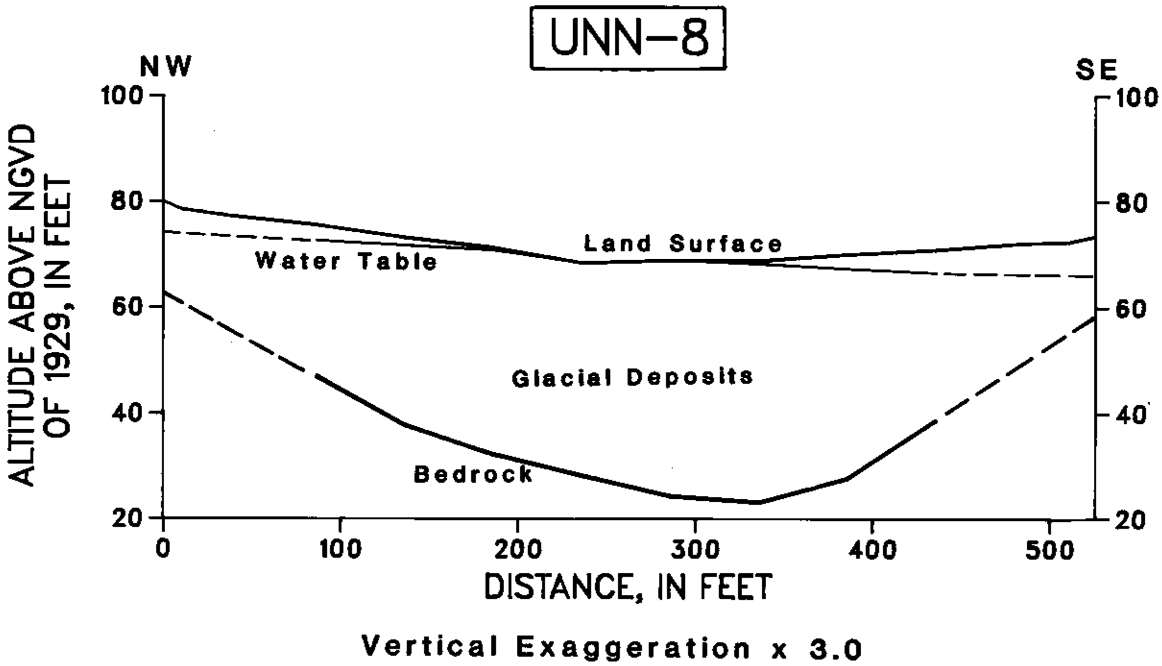

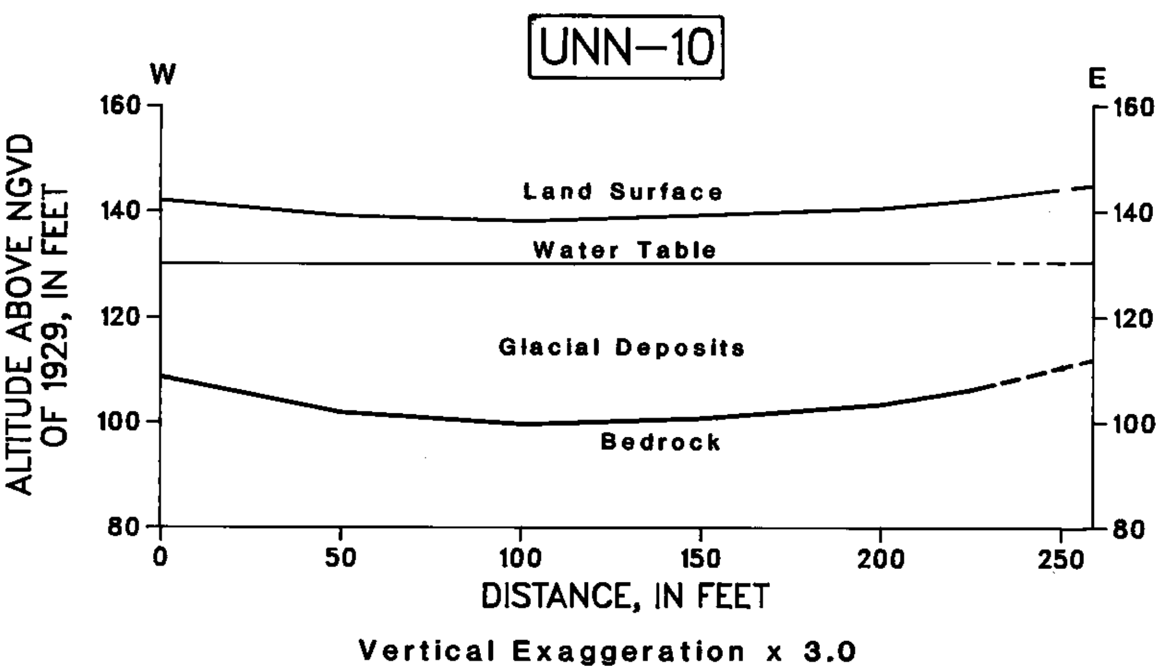

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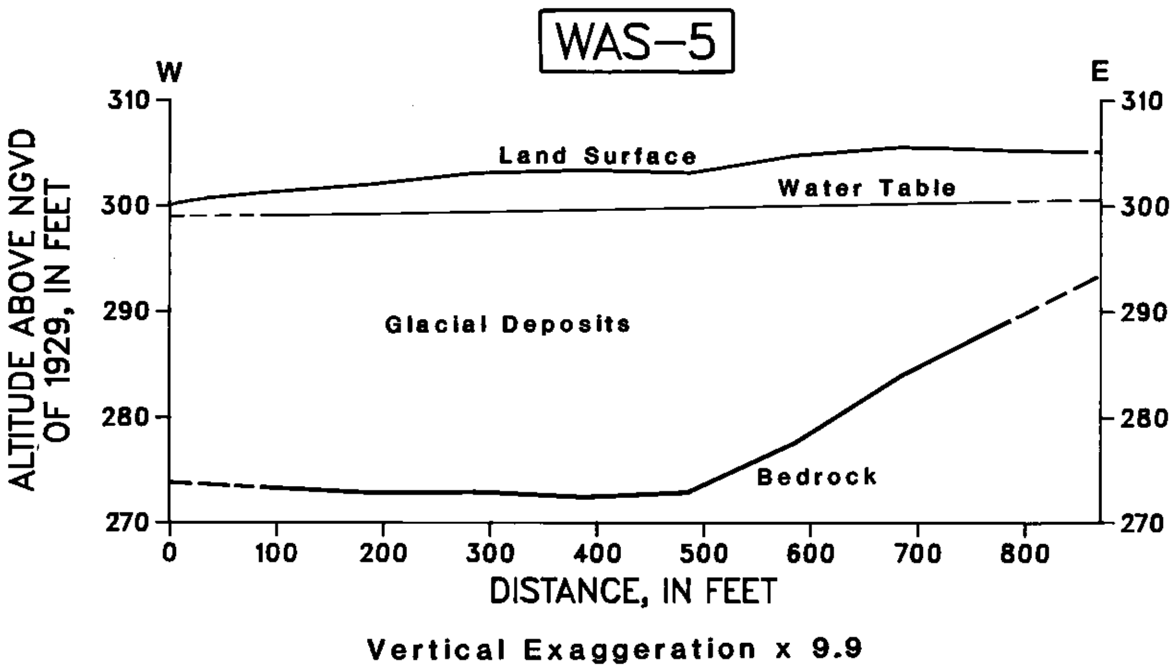

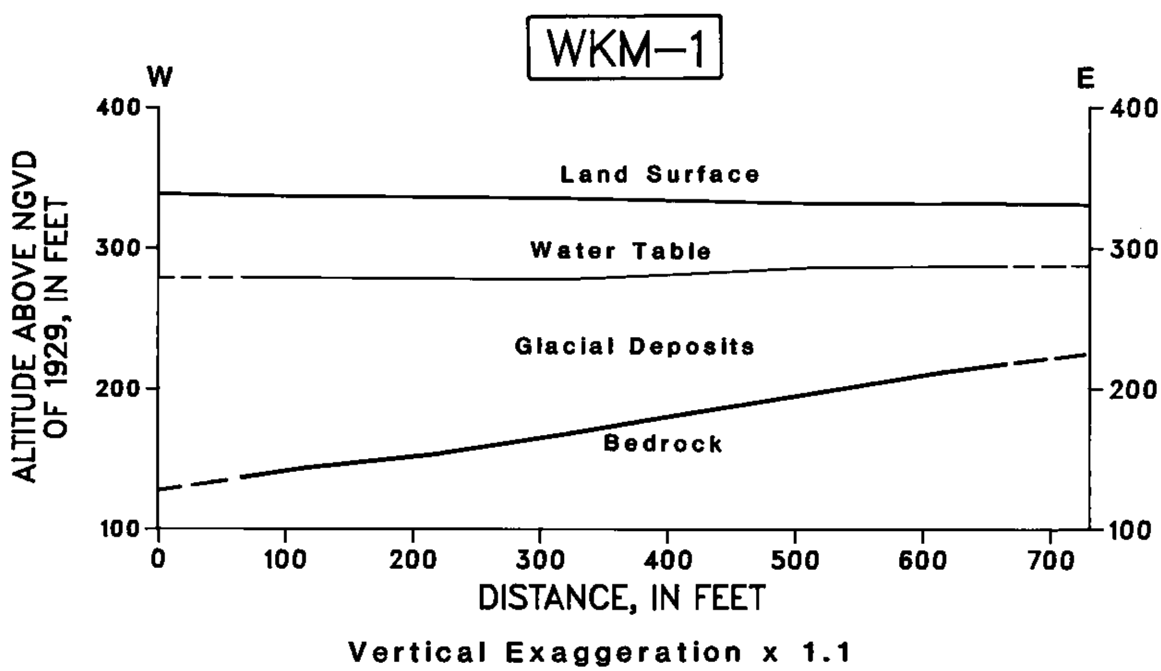

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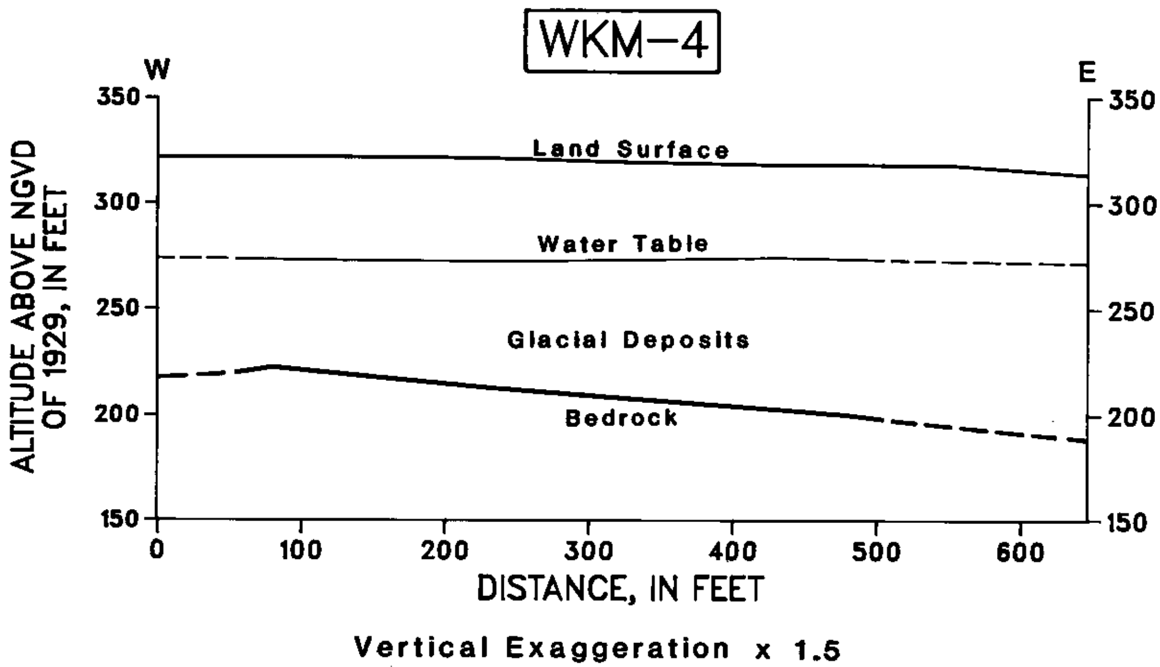

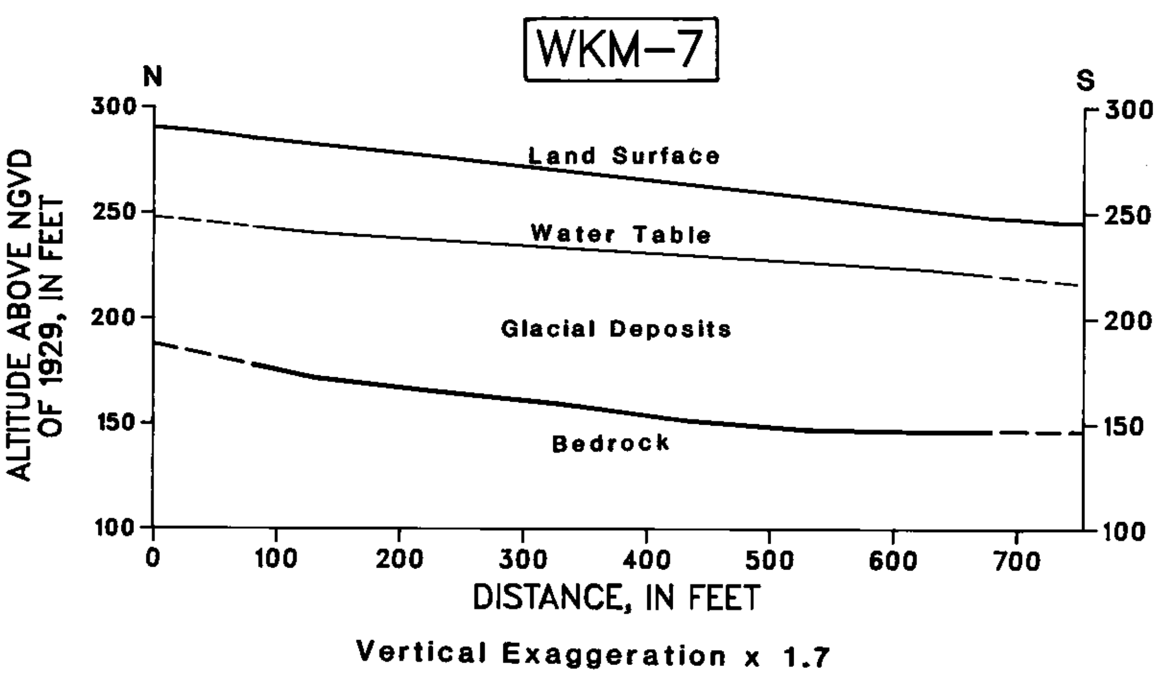

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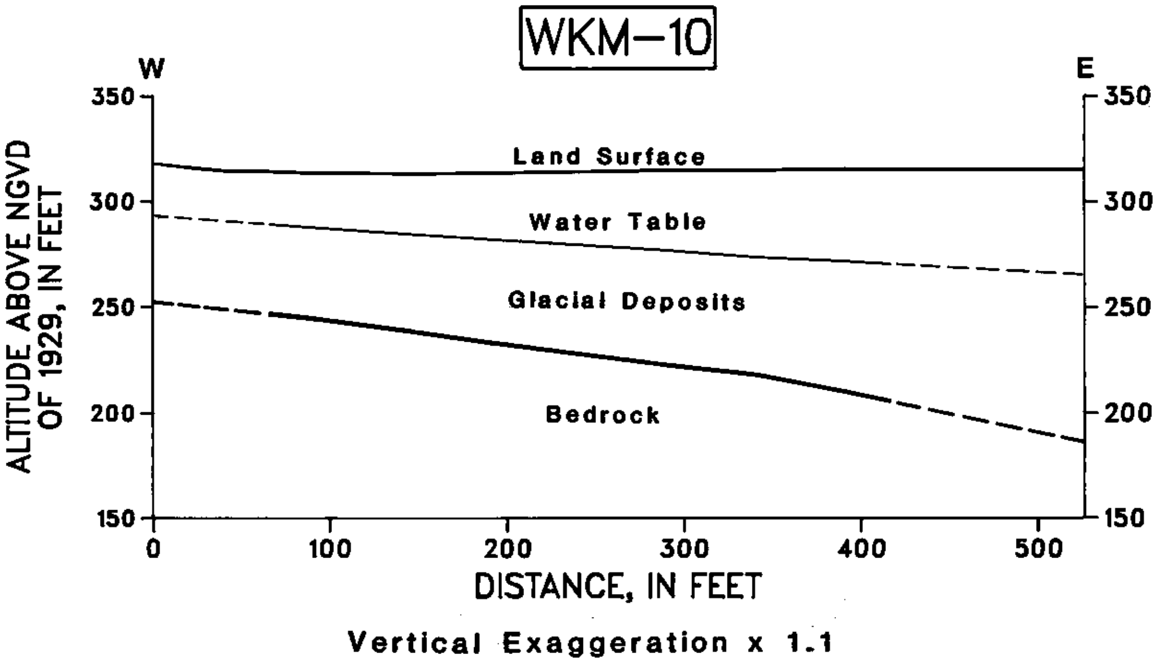


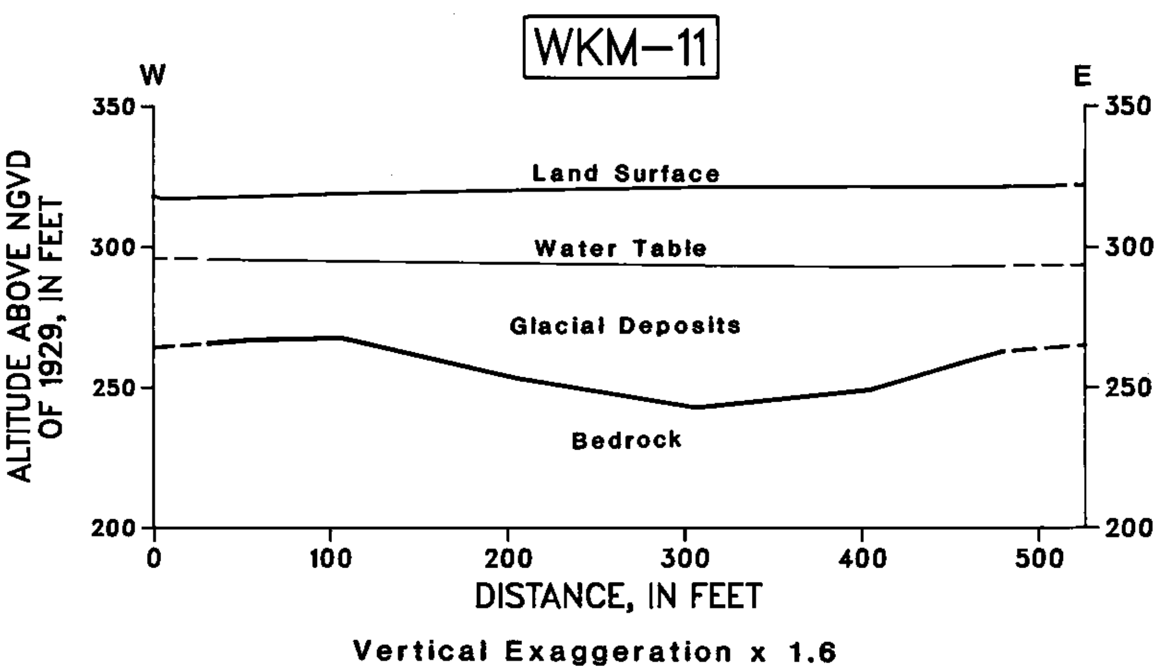
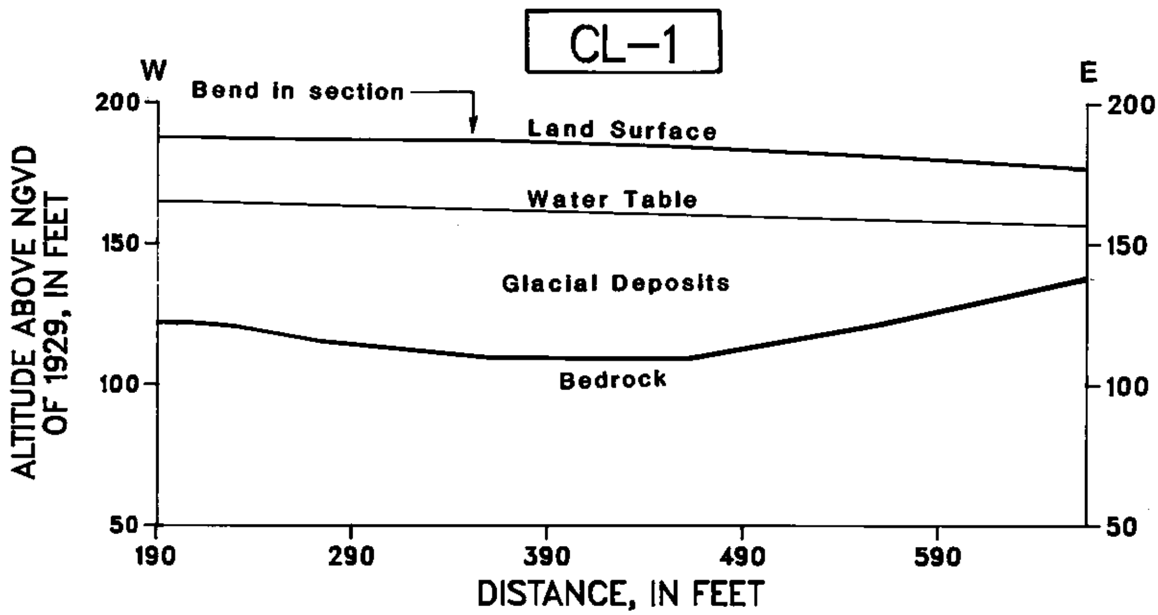
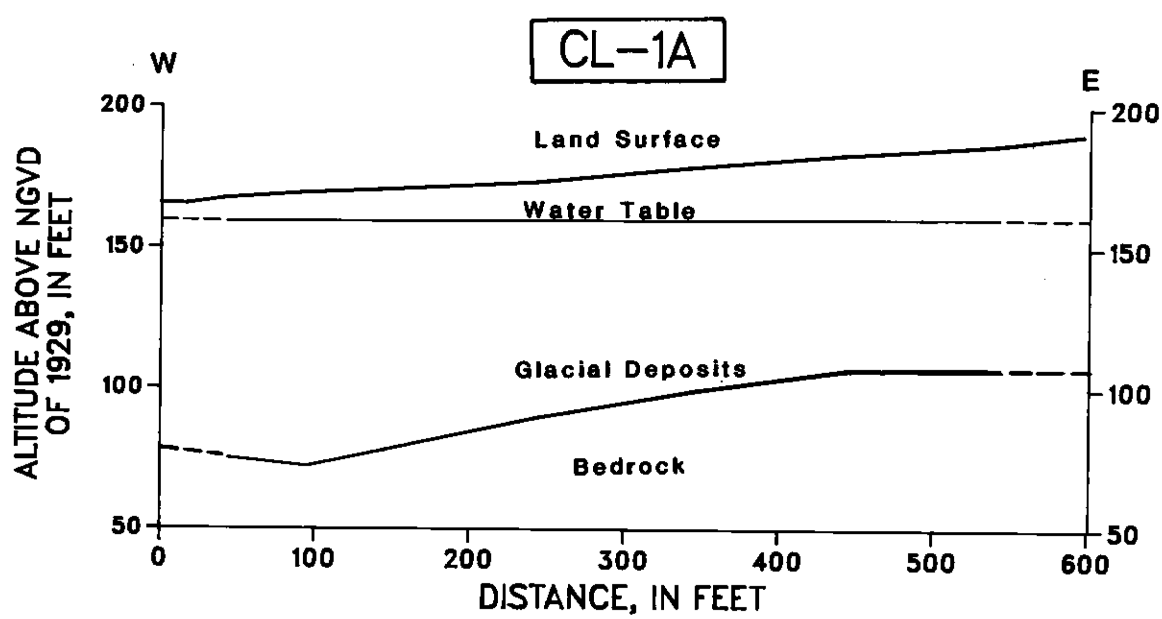


Figure 6.--12-channel seismic-refraction profiles: Plate 2, Map 30 Area

Hydrogeologic sections from seismic-refraction surveys conducted by the U.S. Geological Survey in 1984. Location of individual profiles are shown on plate 2. Data interpretation is based on a computer modeling program described by Scott and others (1972). Distances shown on X-axes are measured from shot #1. In places, the altitude of the water table and bedrock surfaces have been shown with dashed lines. This is to emphasize the relative unreliability of this data.



Vertical Exaggeration x 1.4



Vertical Exaggeration x 1.9

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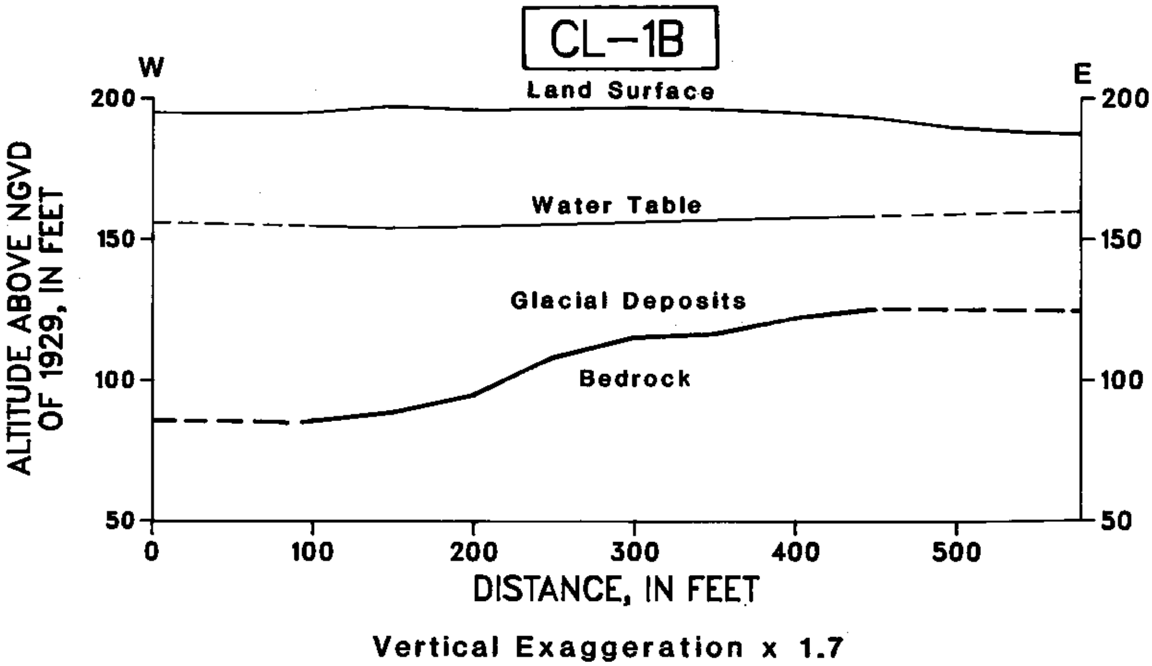

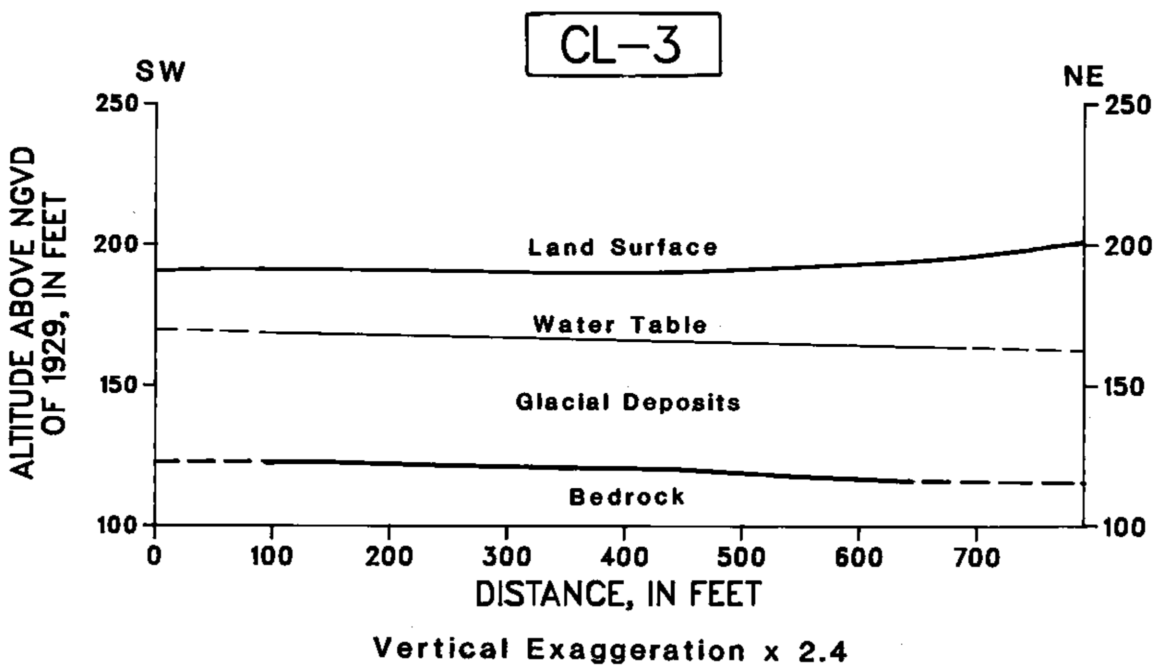

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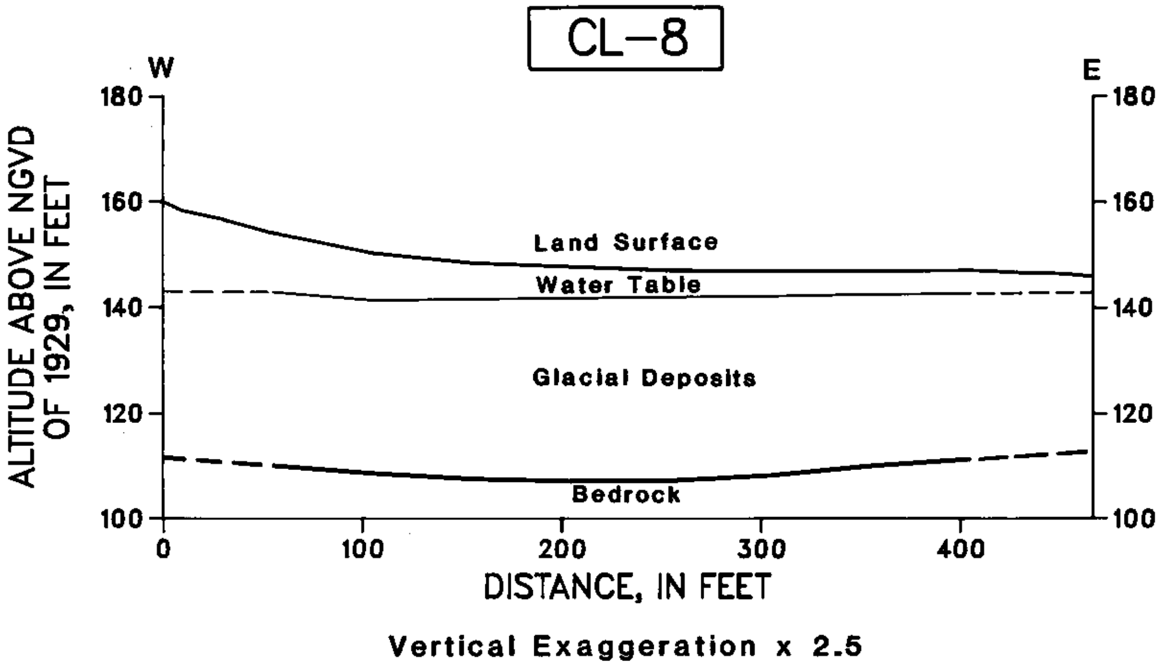

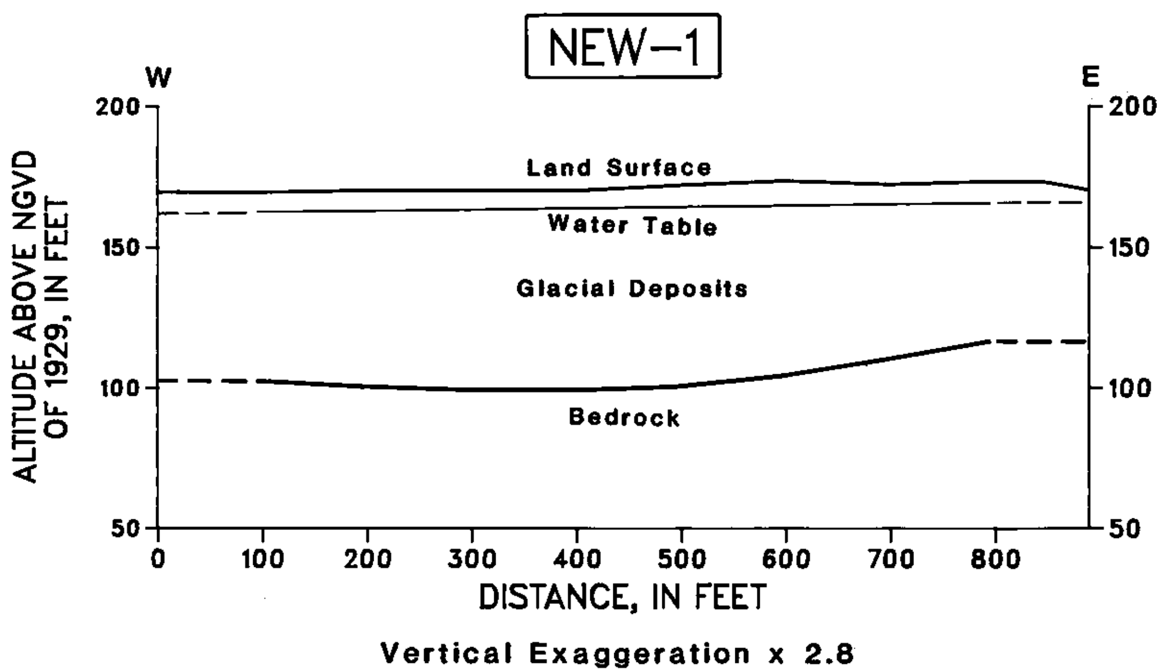

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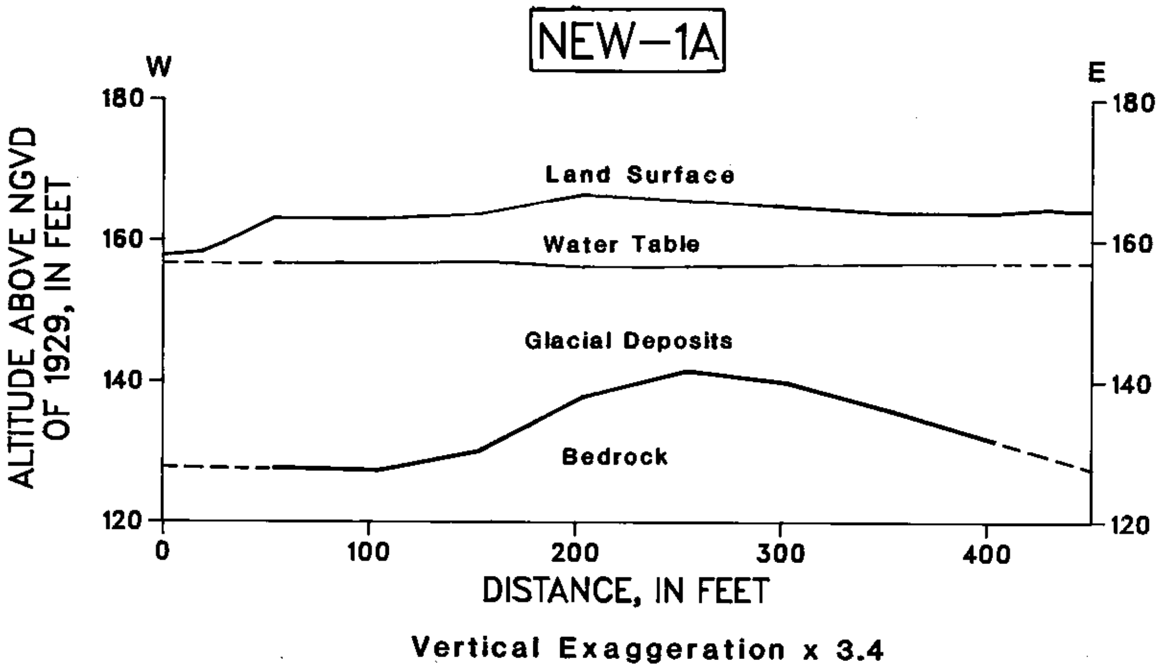

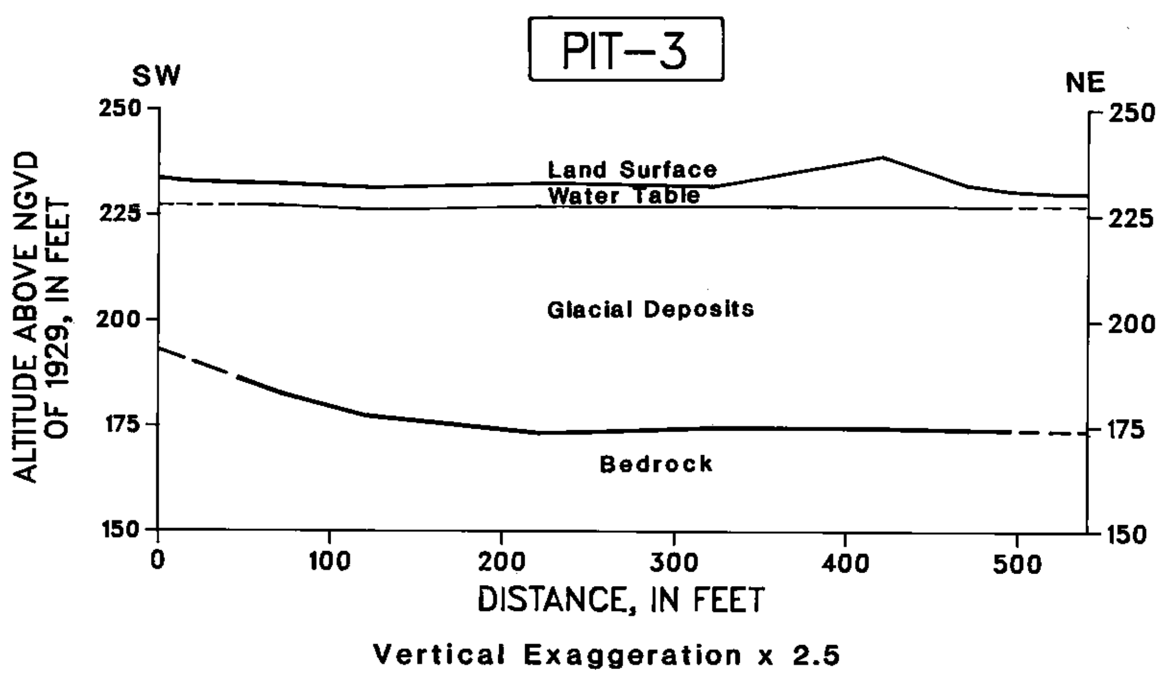

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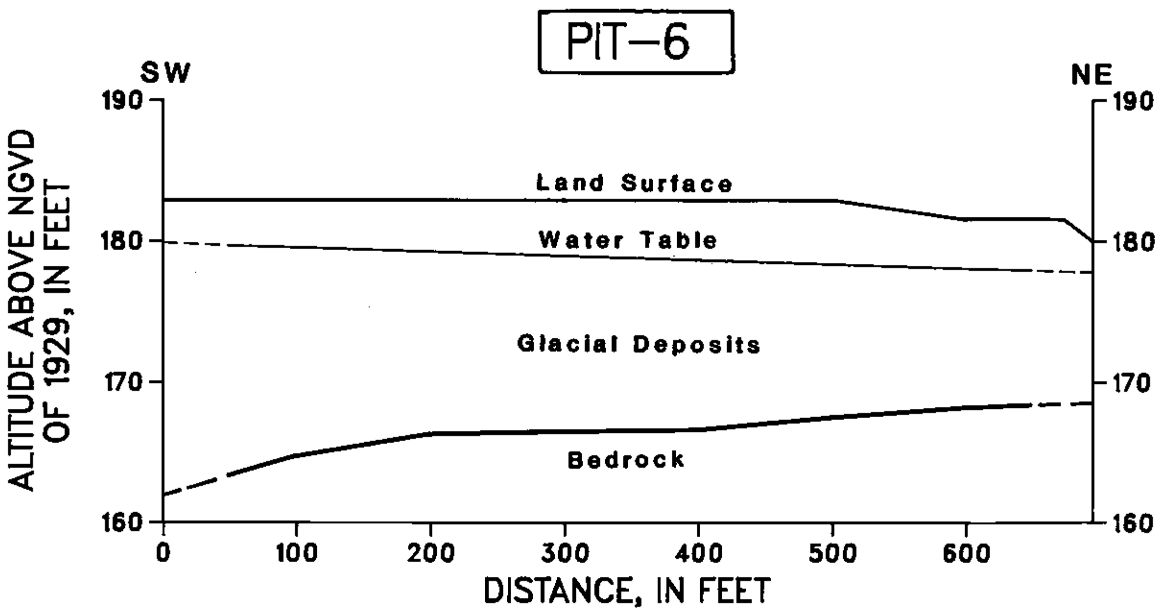

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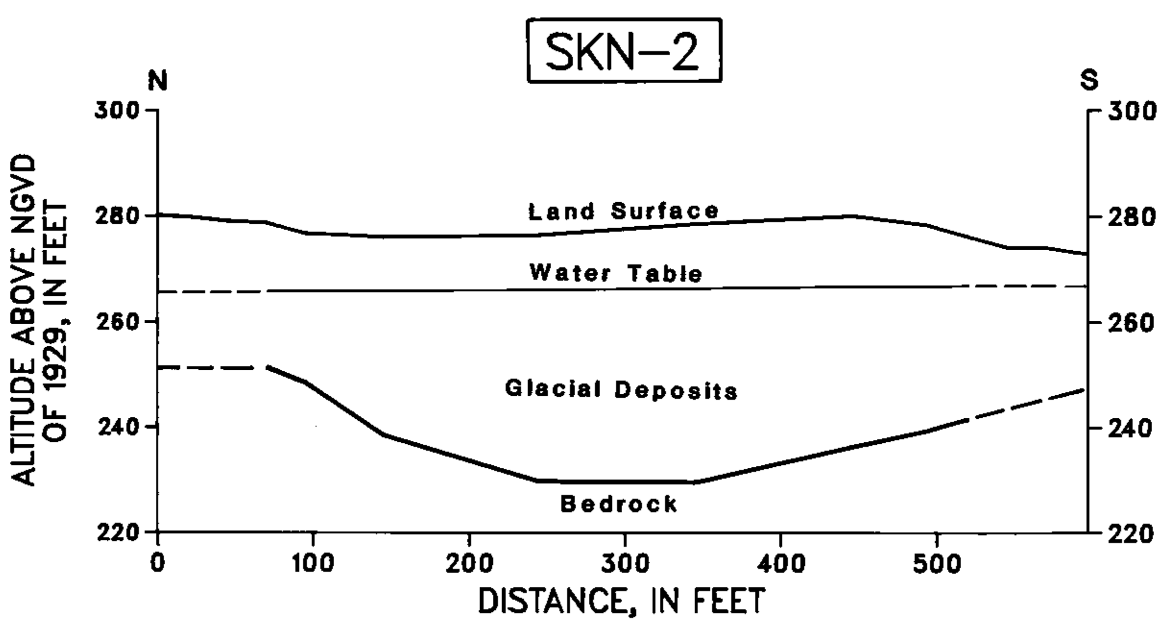
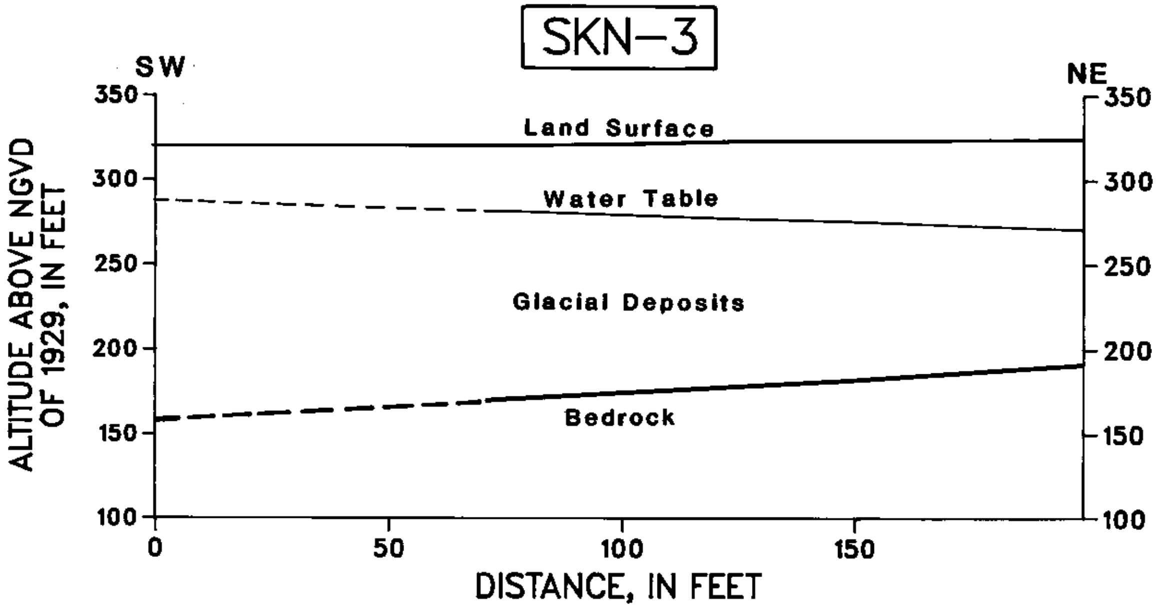
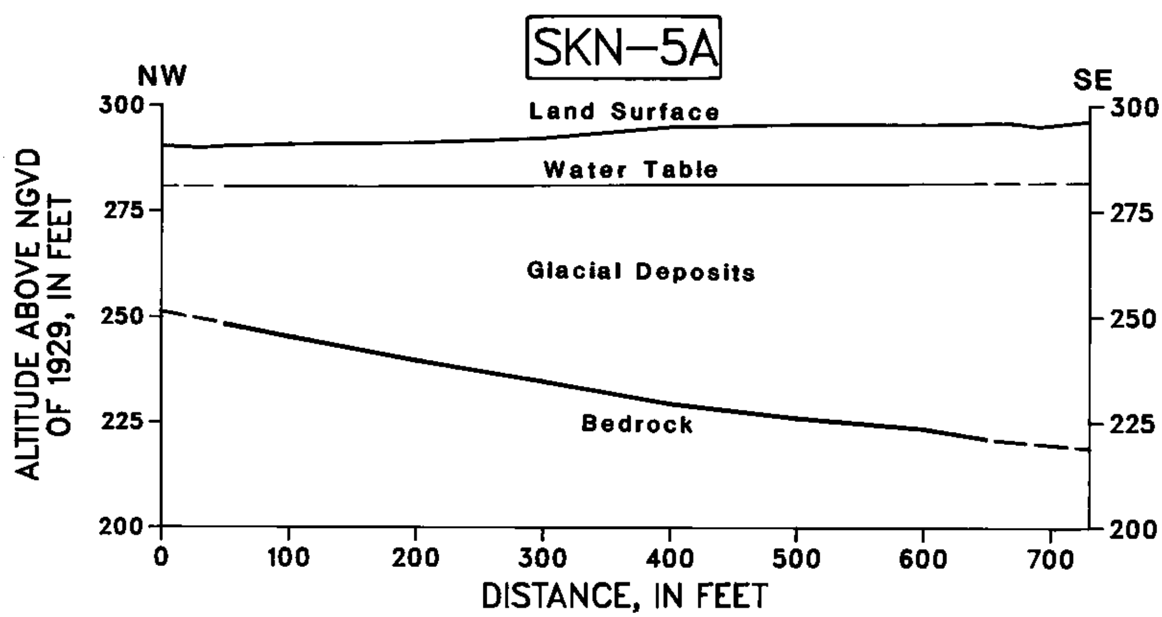


Vertical Exaggeration x 3.4

Figure 6. Continued.

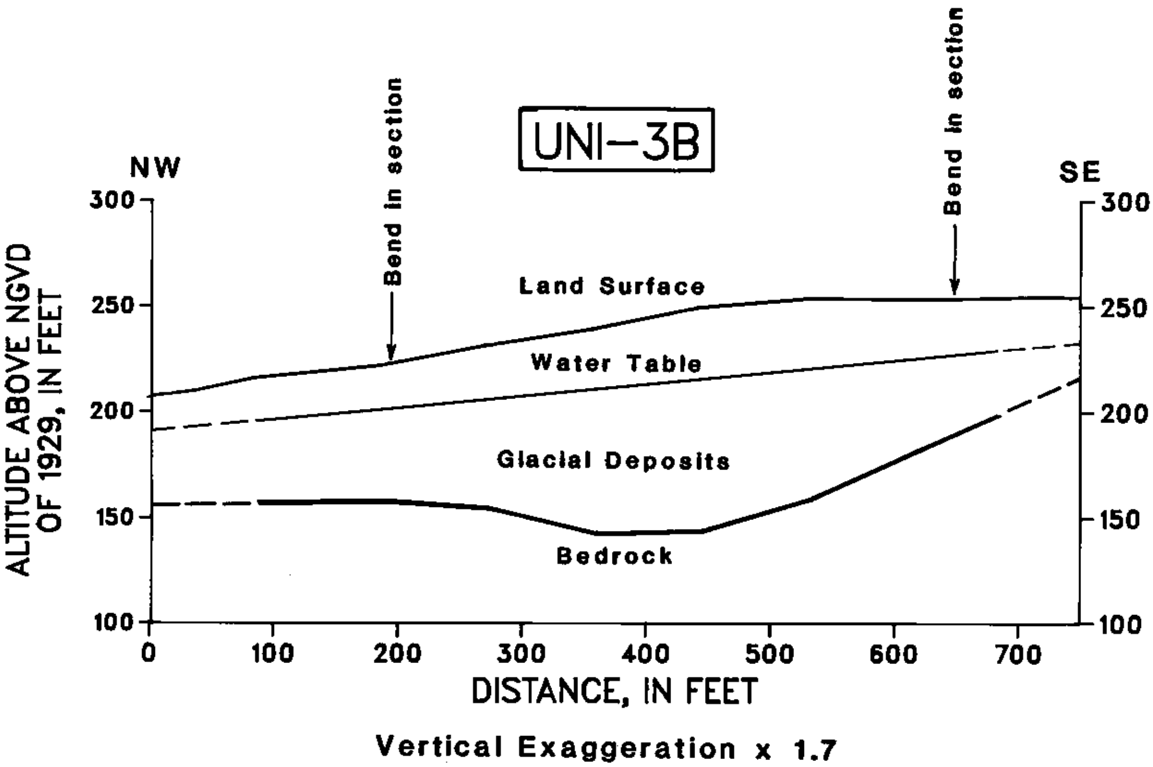


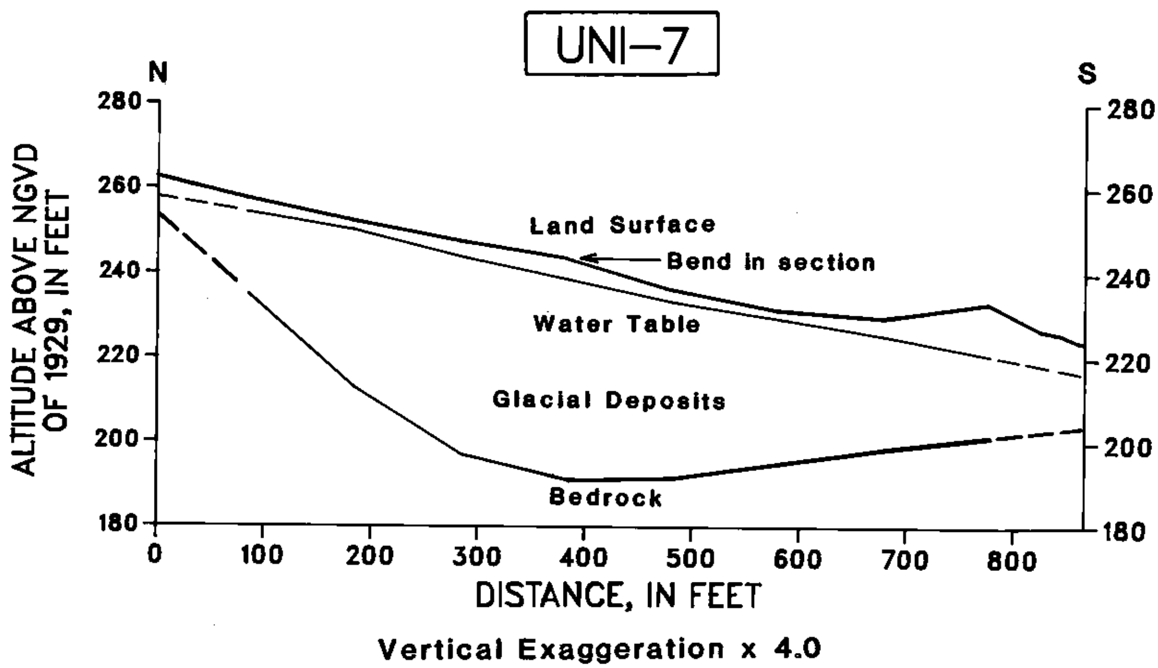
Vertical Exaggeration x 0.4



Vertical Exaggeration x 3.4

Figure 6. Continued.





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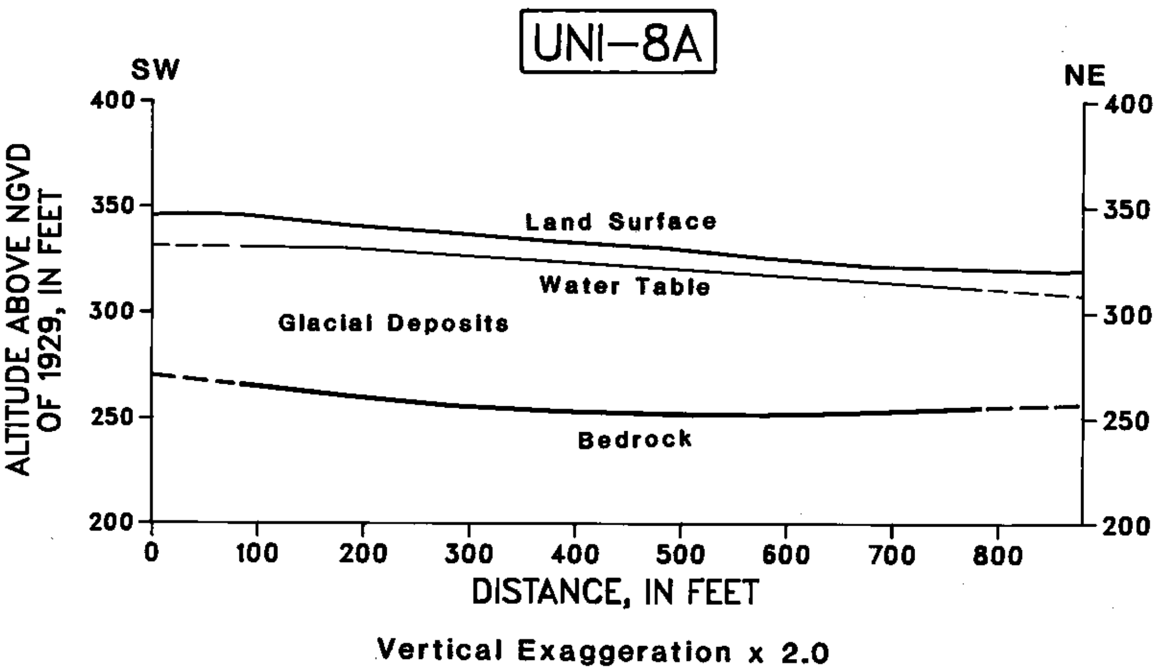
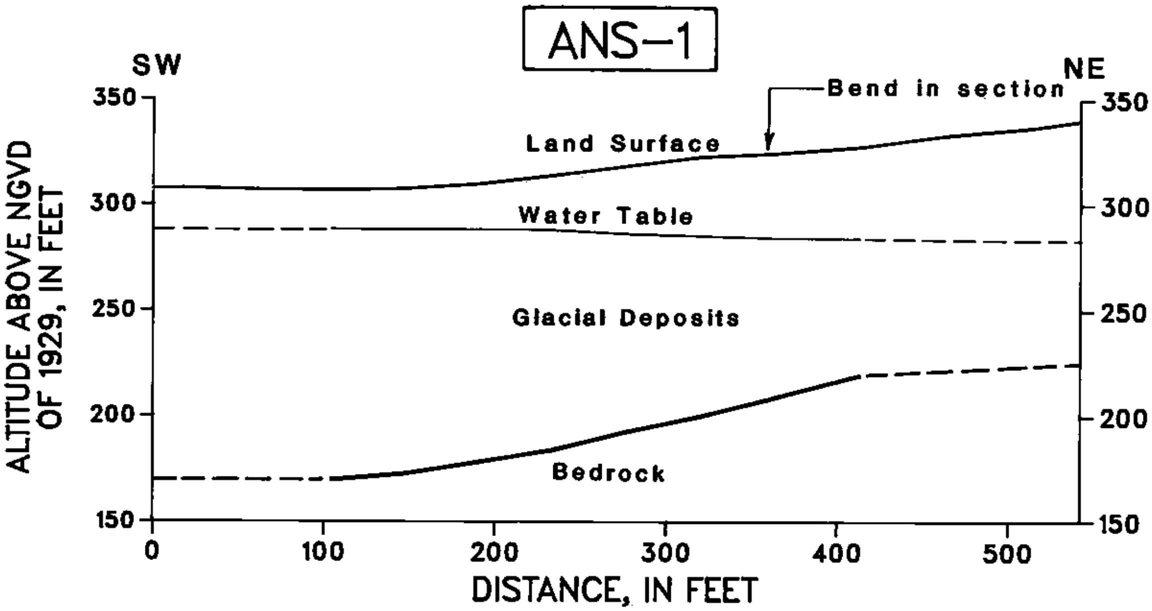


Figure 7.--12-channel seismic-refraction profiles: Plate 3, Map 31 Area

Hydrogeologic sections from seismic-refraction surveys conducted by the U.S. Geological Survey in 1984. Location of individual profiles are shown on plate 3. Data interpretation is based on a computer modeling program described by Scott and others (1972). Distances shown on X-axes are measured from shot #1. In places, the altitude of the water table and bedrock surfaces have been shown with dashed lines. This is to emphasize the relative unreliability of this data.



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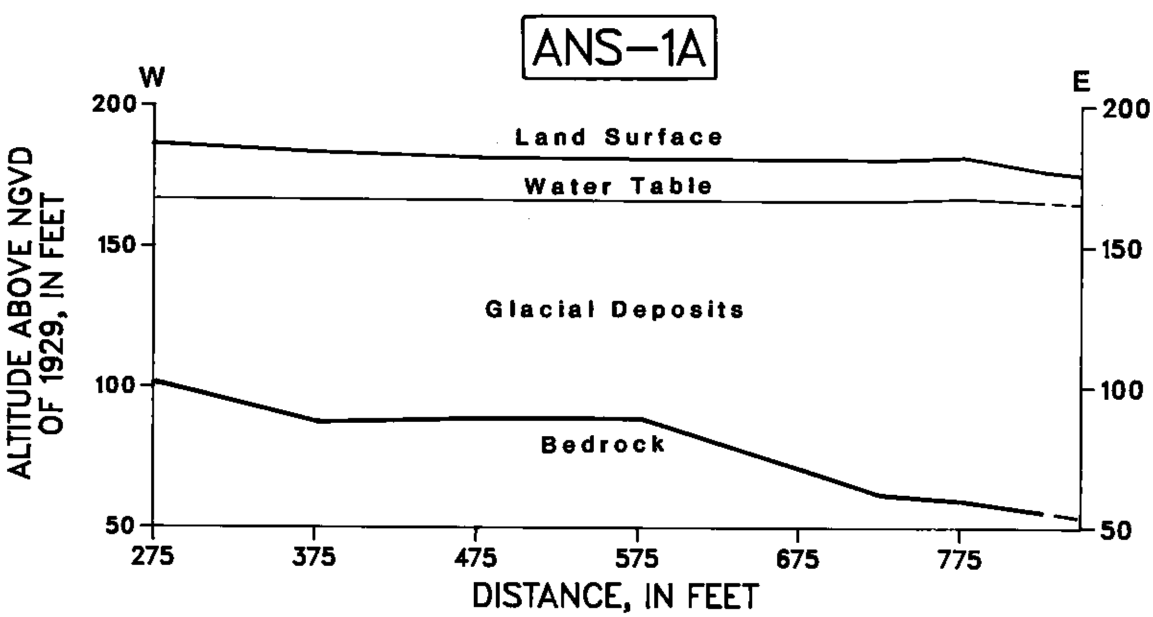
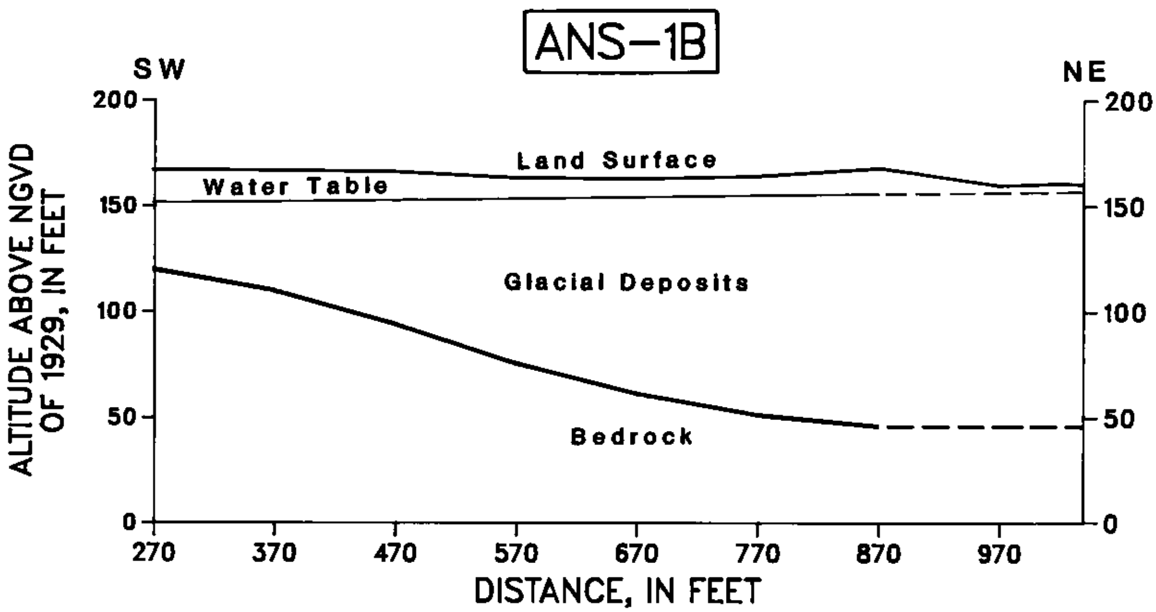


Vertical Exaggeration x 1.8

Figure 7. Continued.



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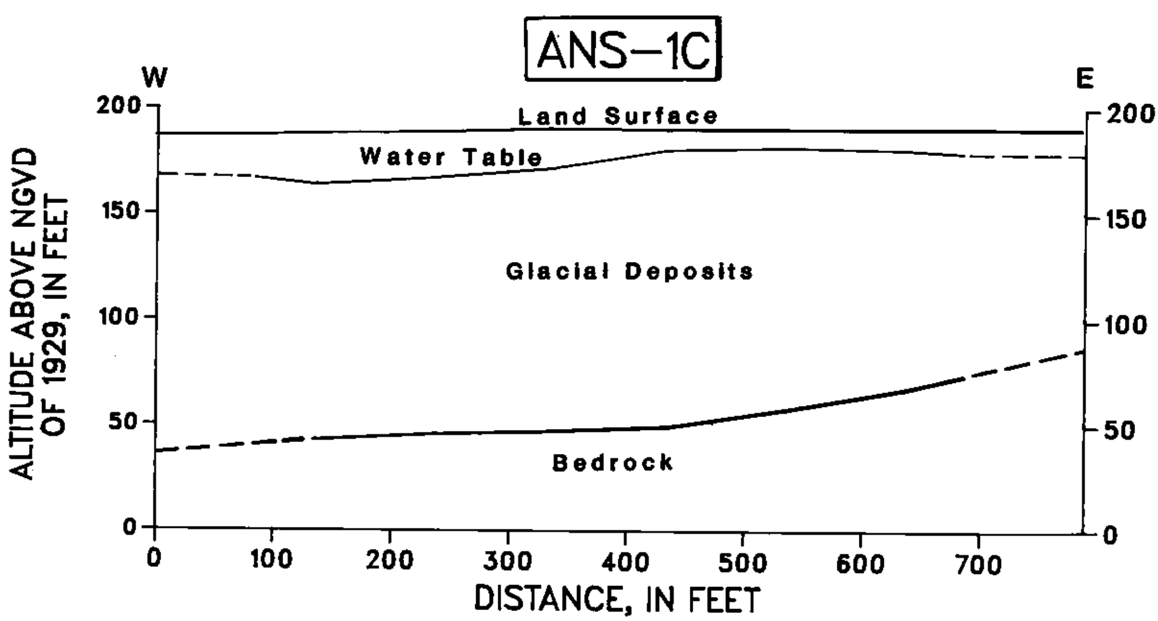

Vertical Exaggeration x 1.8

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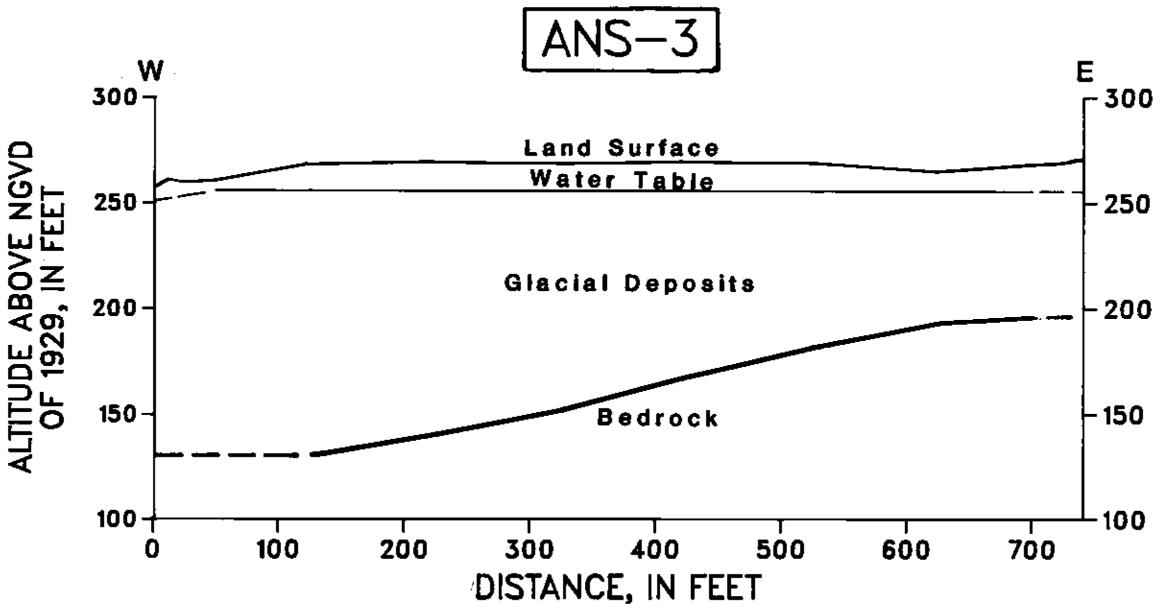

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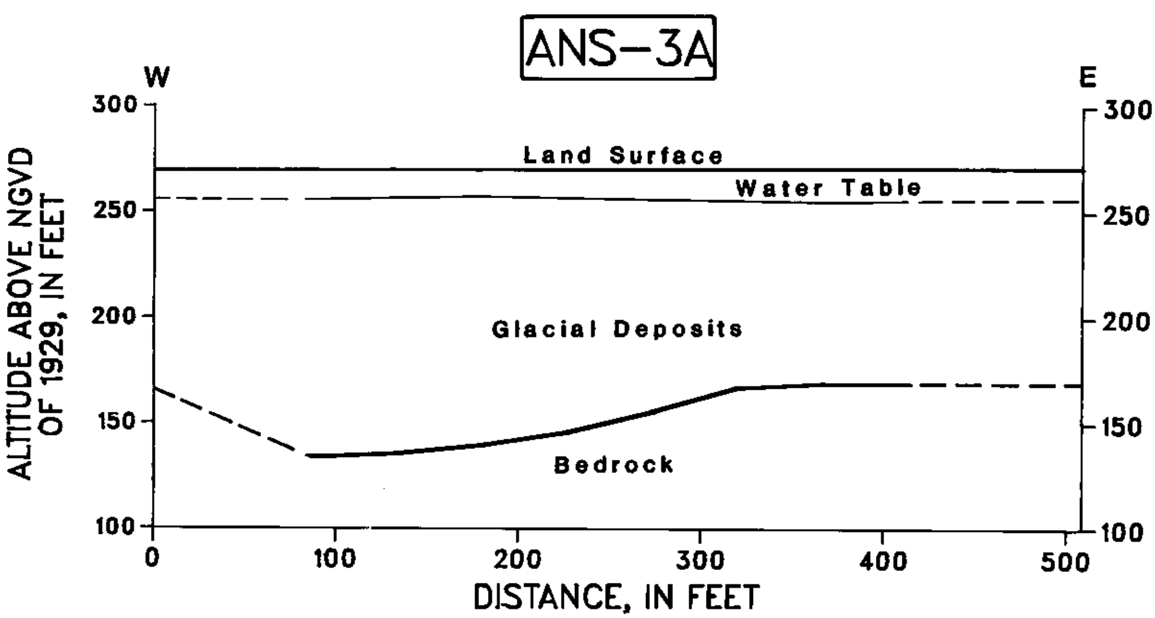

Vertical Exaggeration X 1.2

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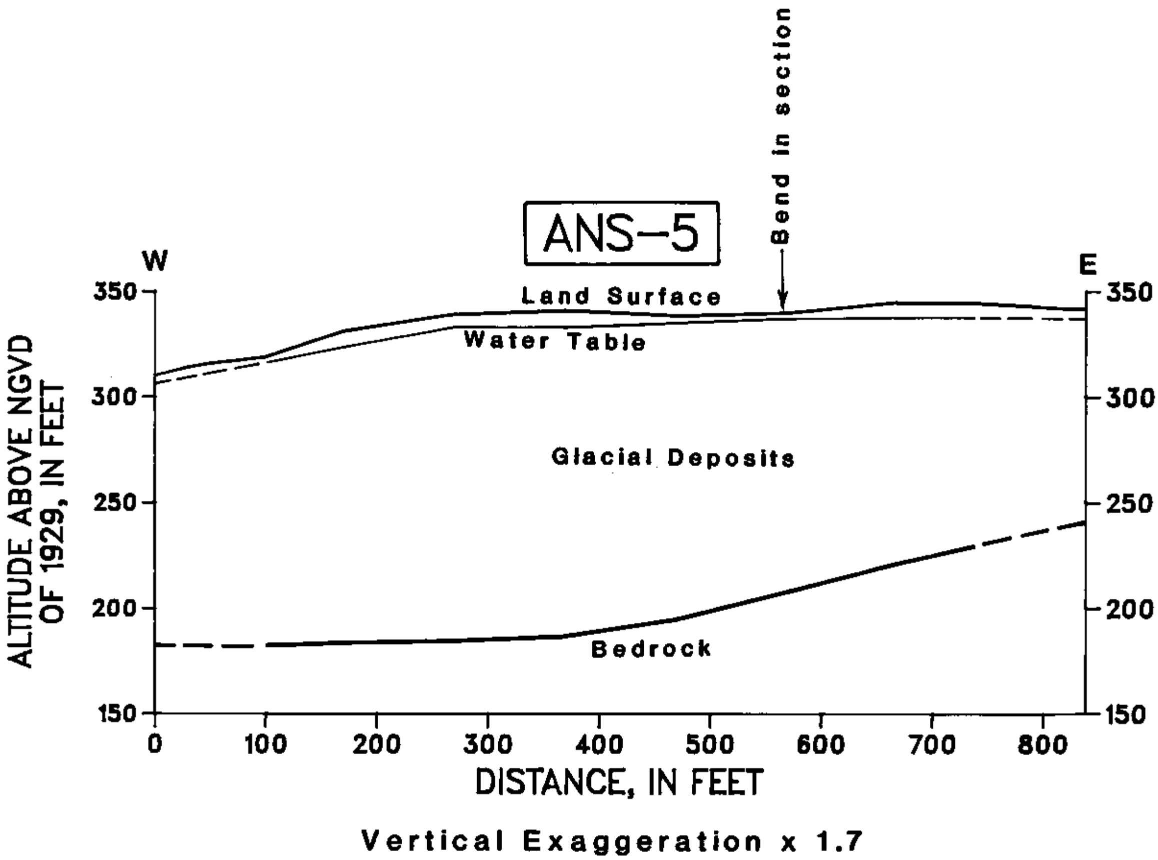

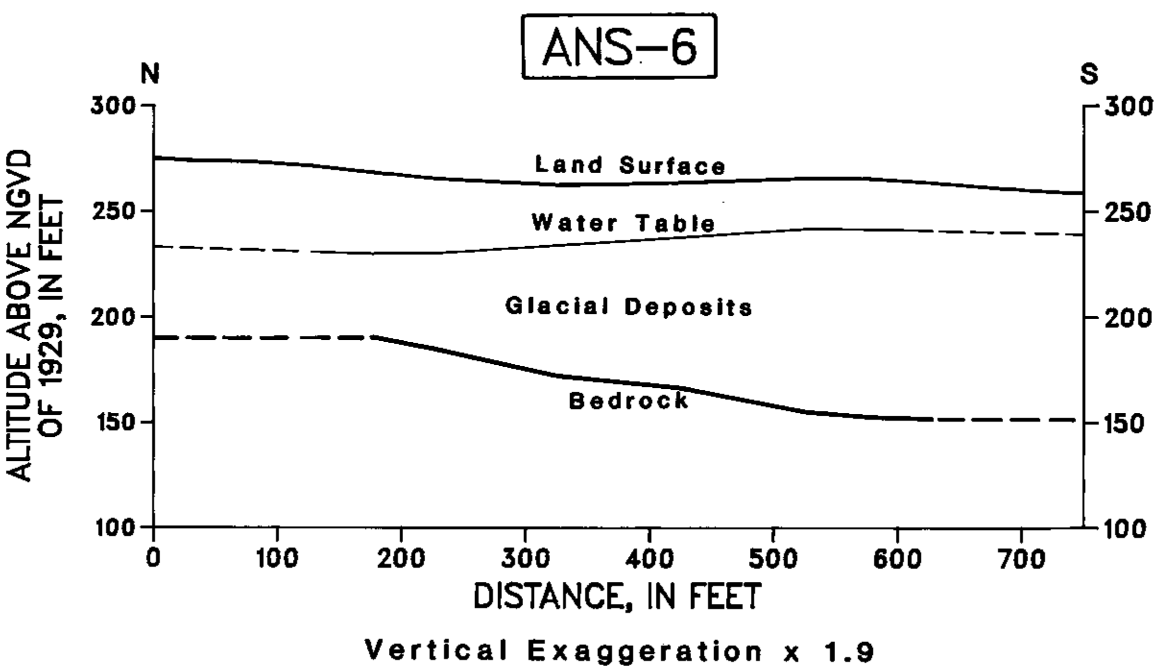

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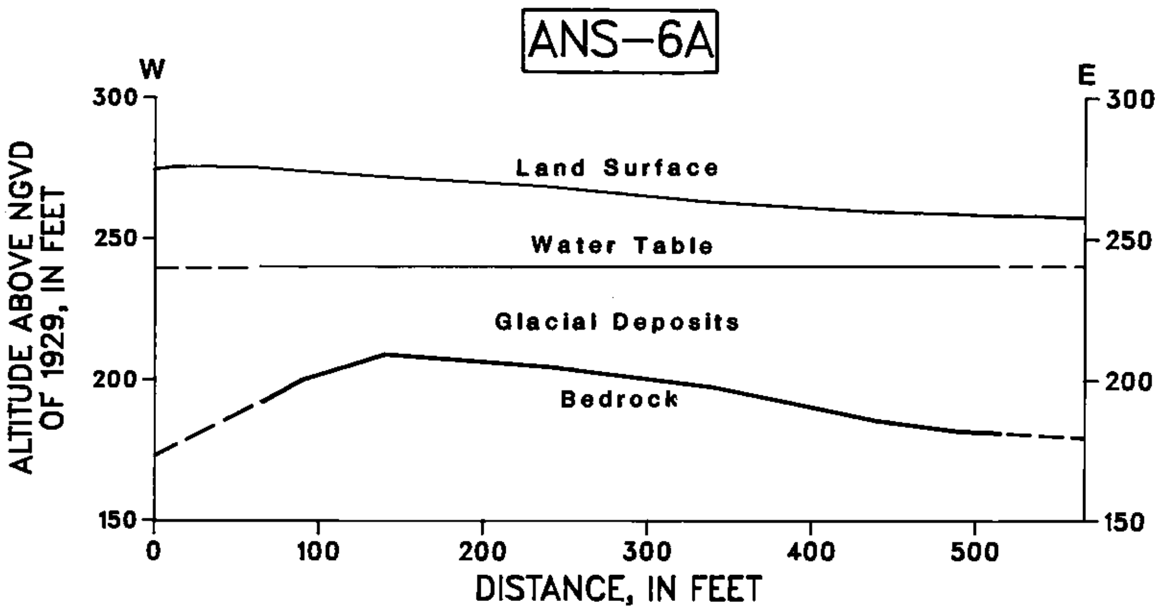

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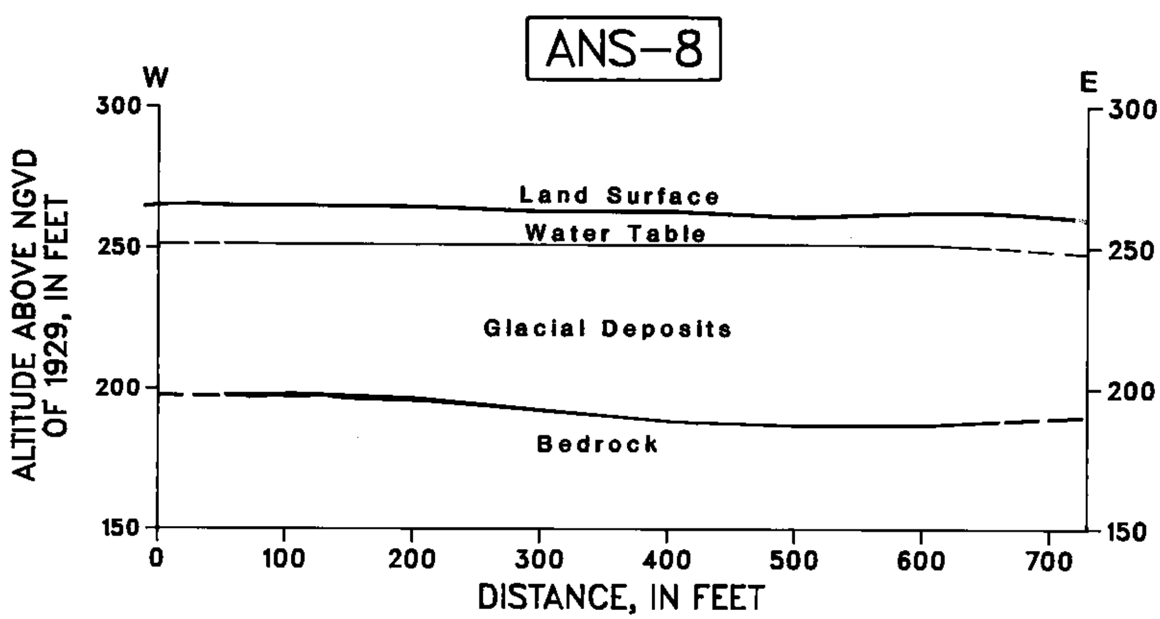

Vertical Exaggeration X 2.3

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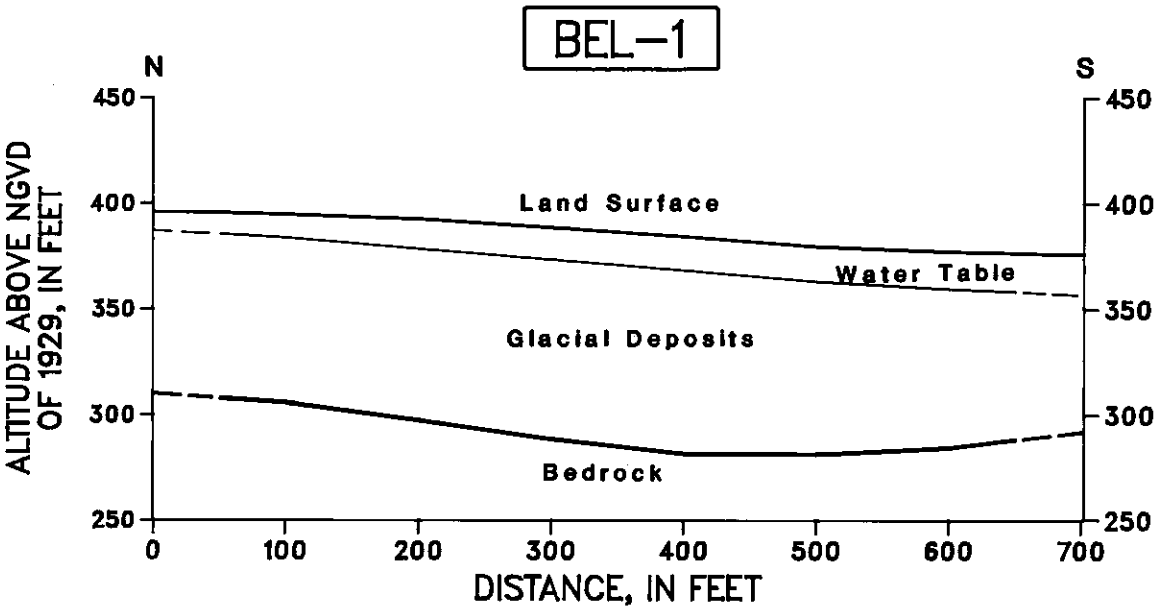

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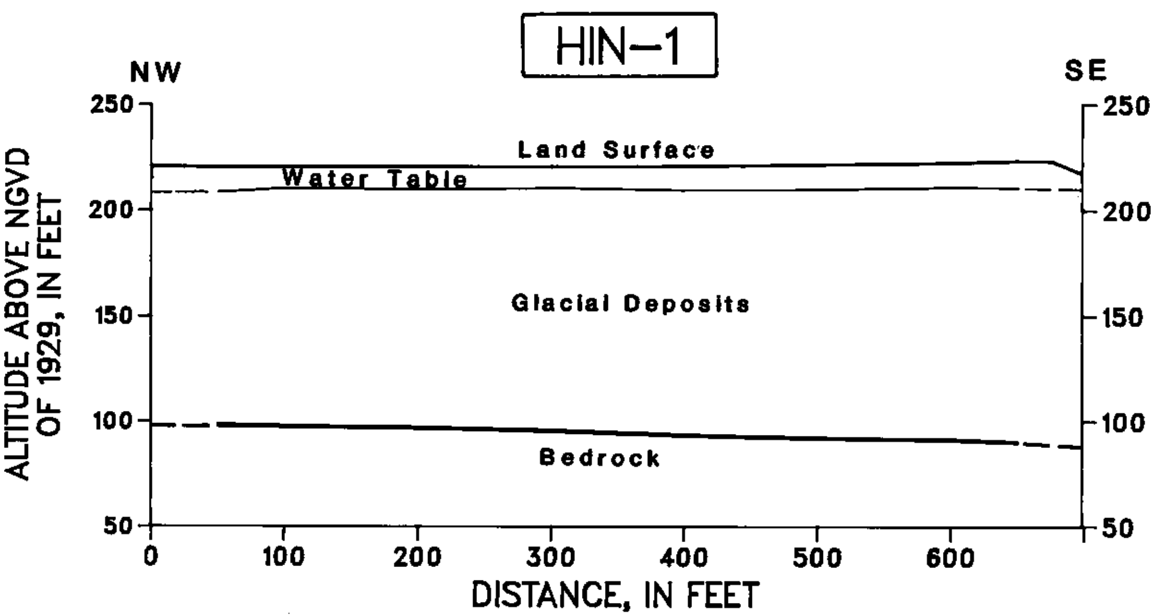

Vertical Exaggeration x 1.6

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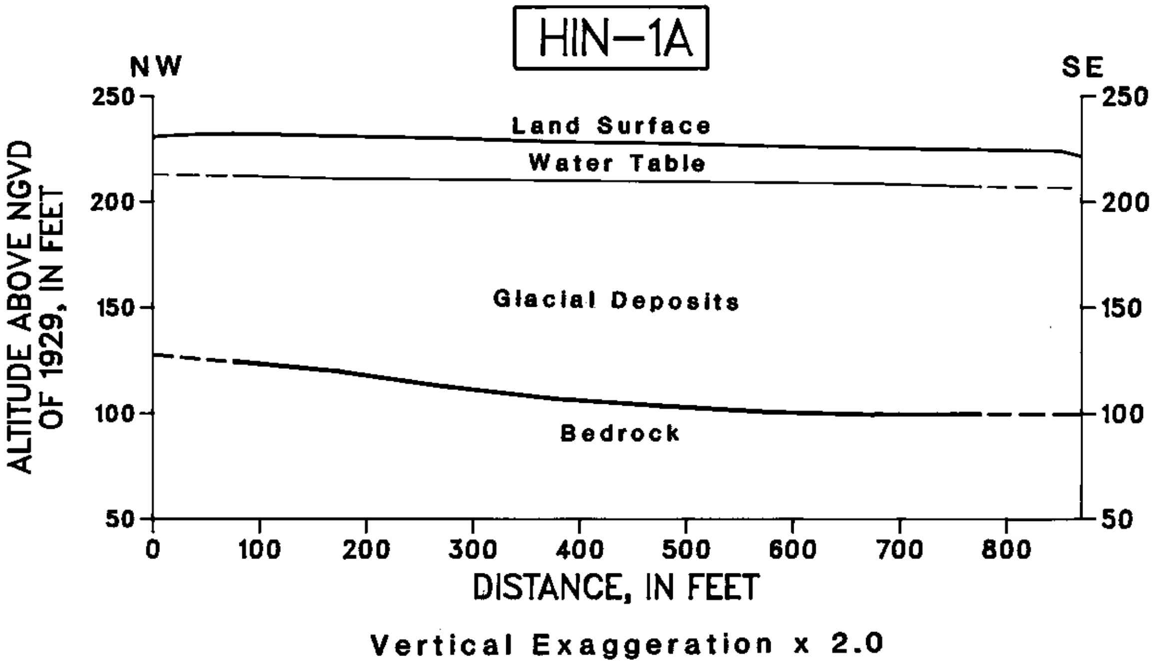

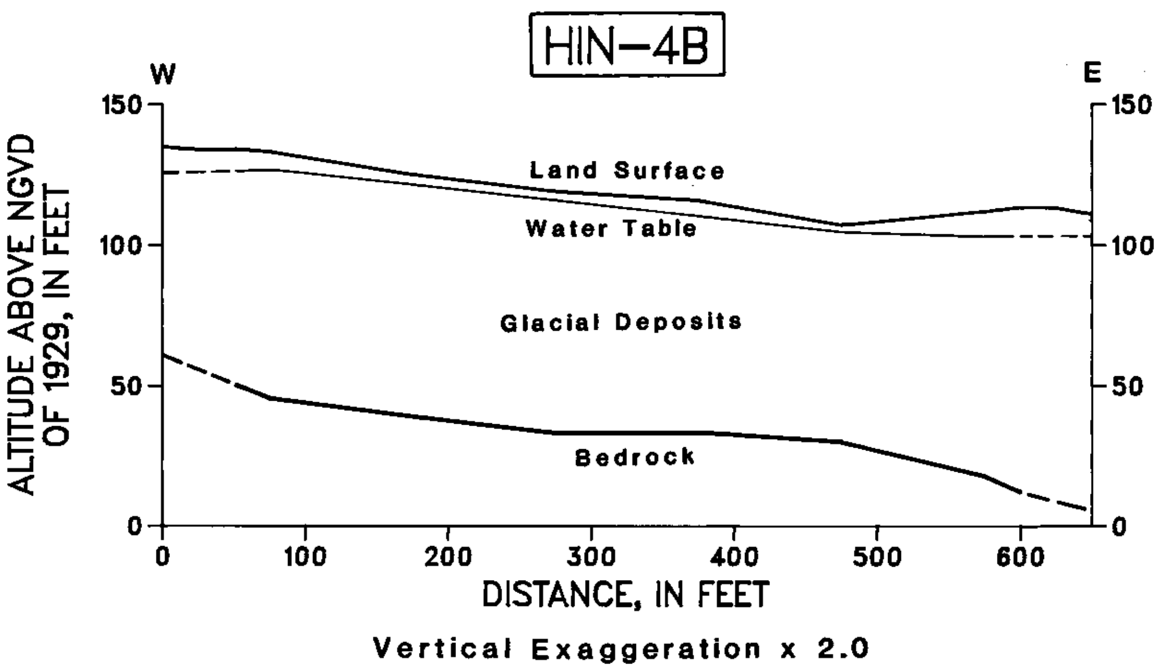

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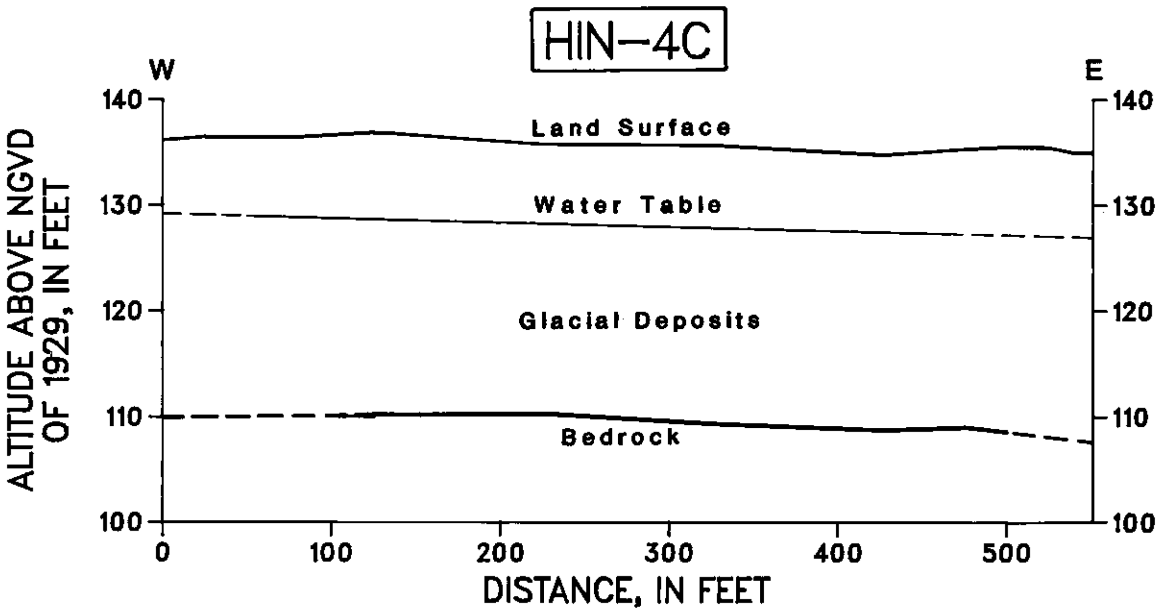

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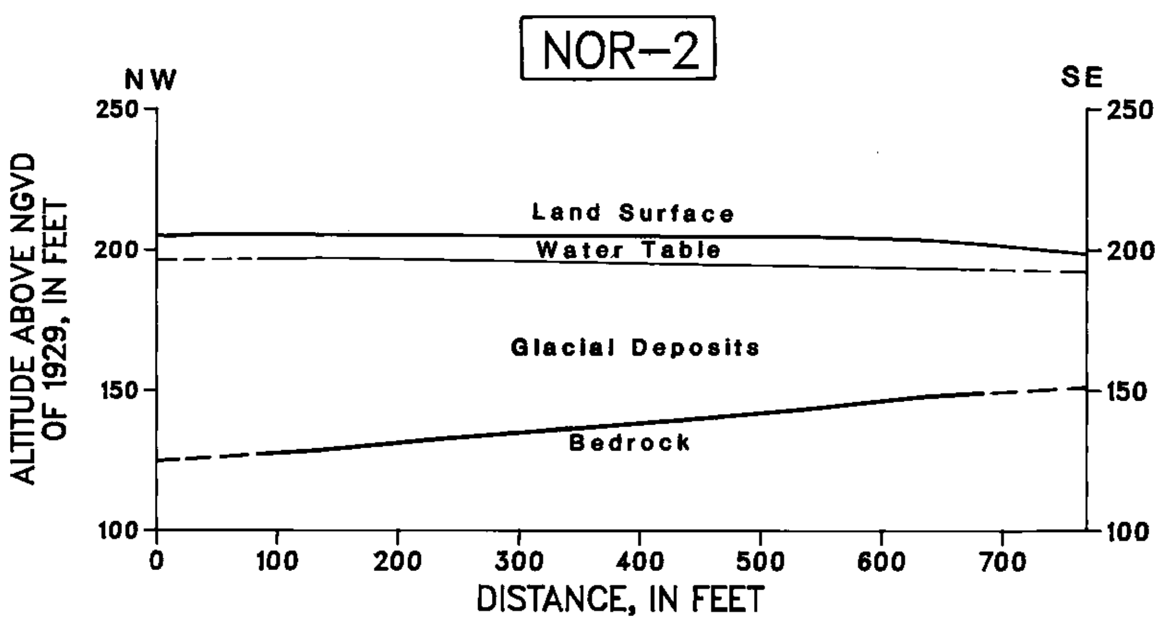

Vertical Exaggeration x 2.4

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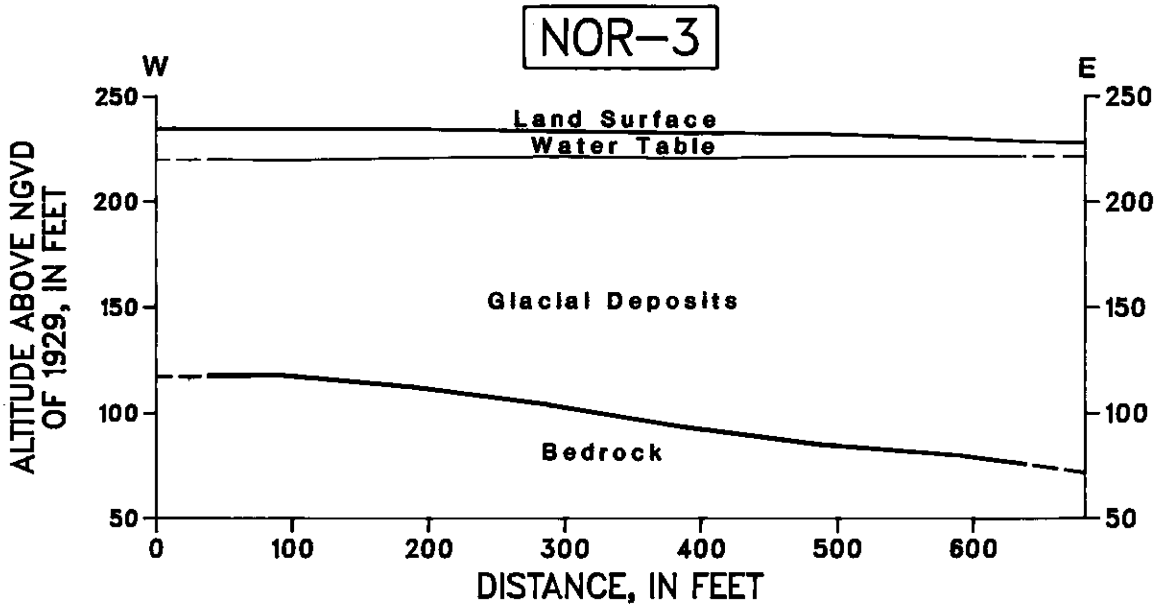

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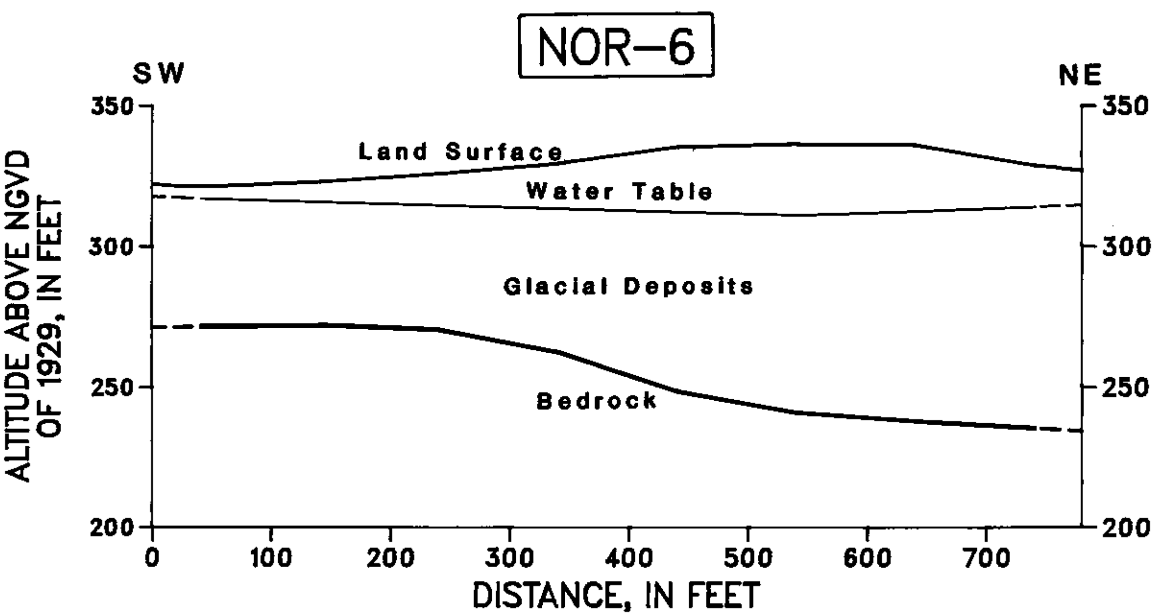

Vertical Exaggeration x 2.4

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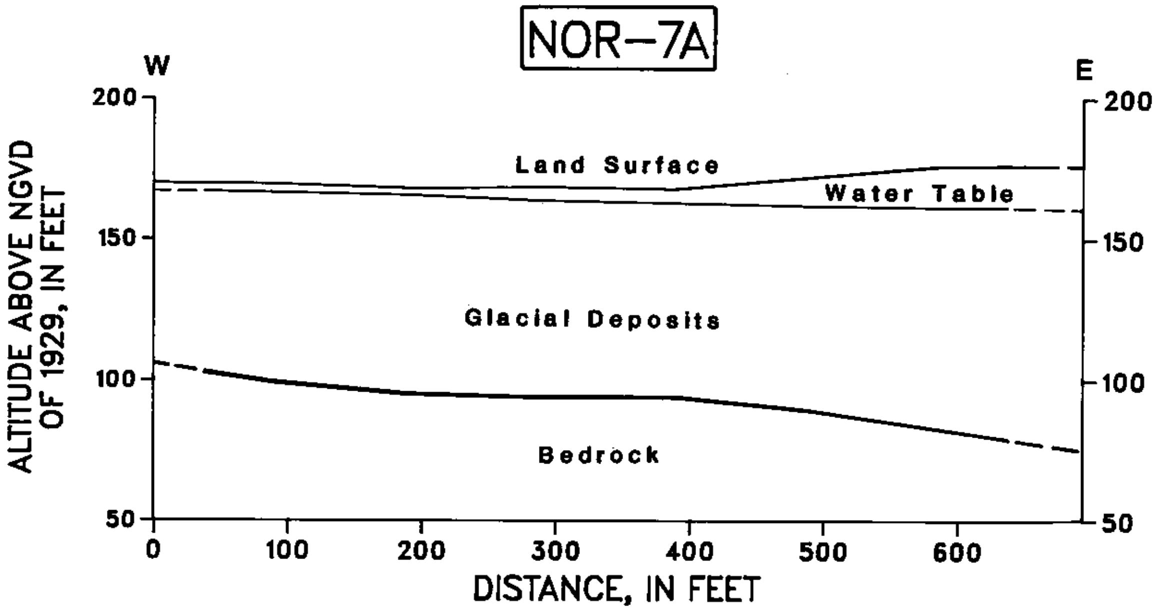

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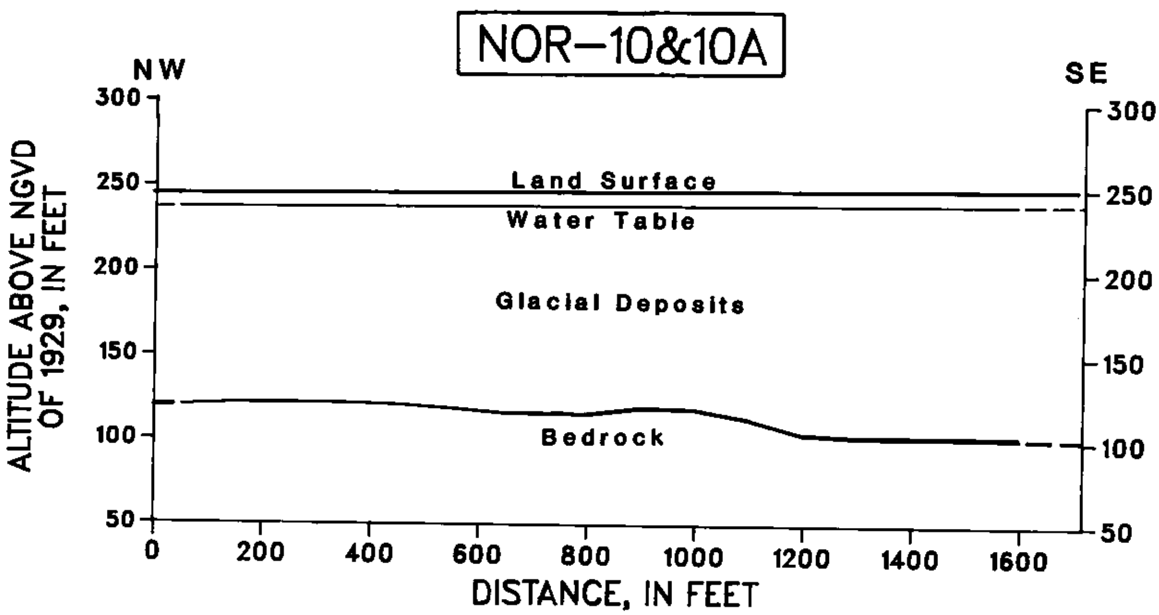

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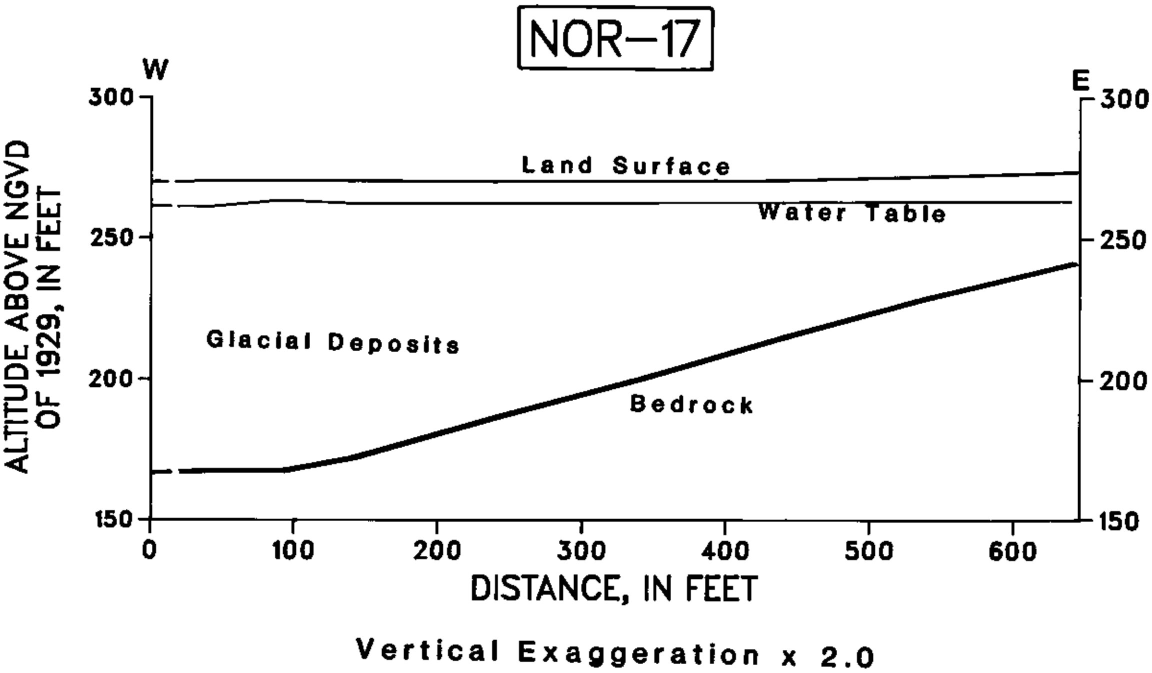


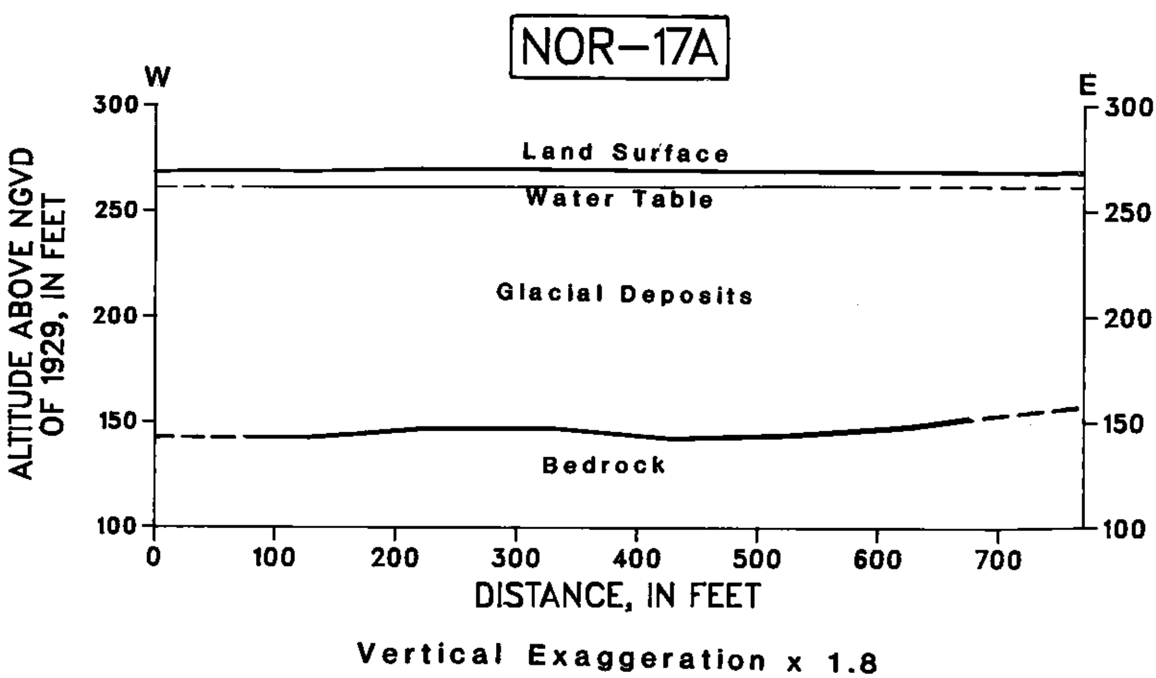
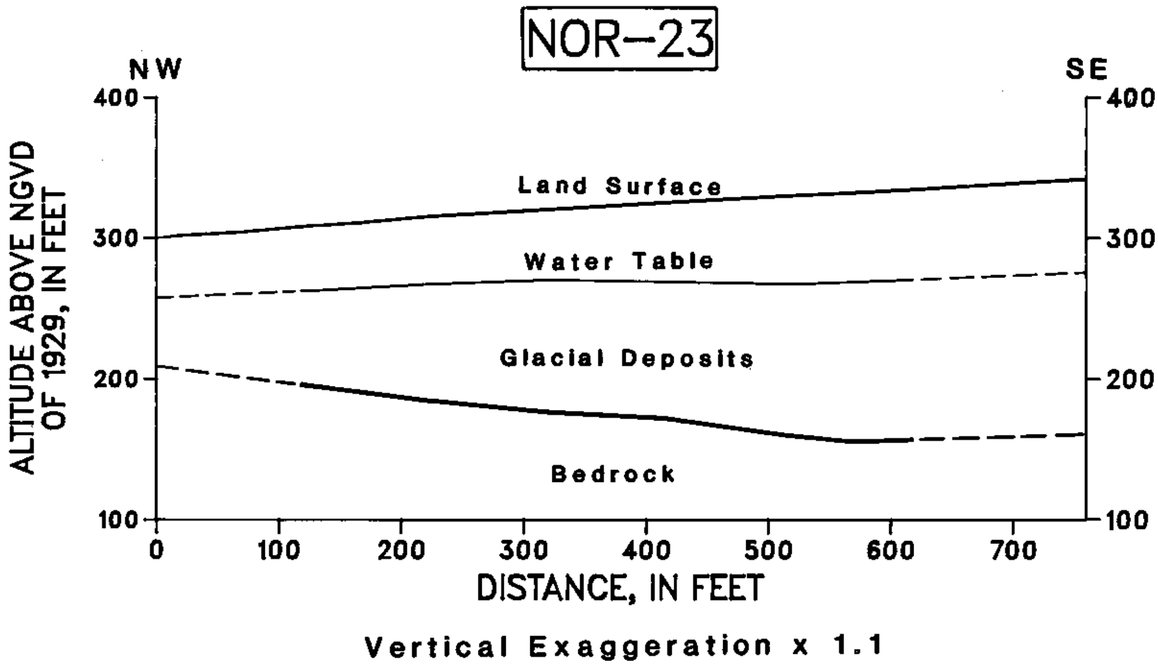


Figure 7. Continued.



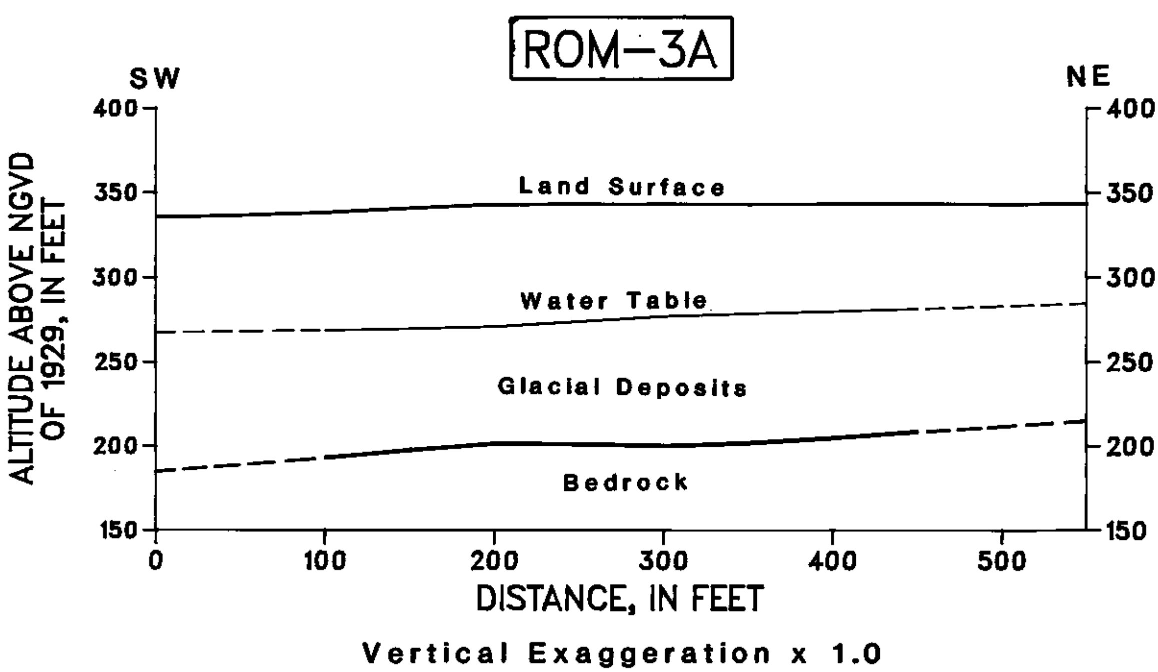
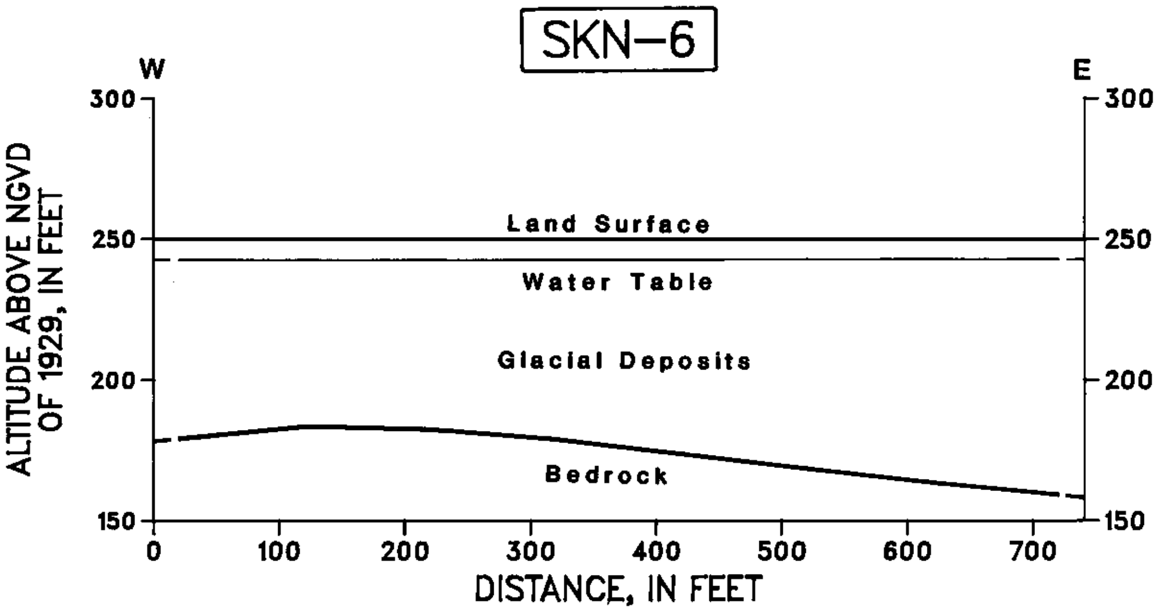
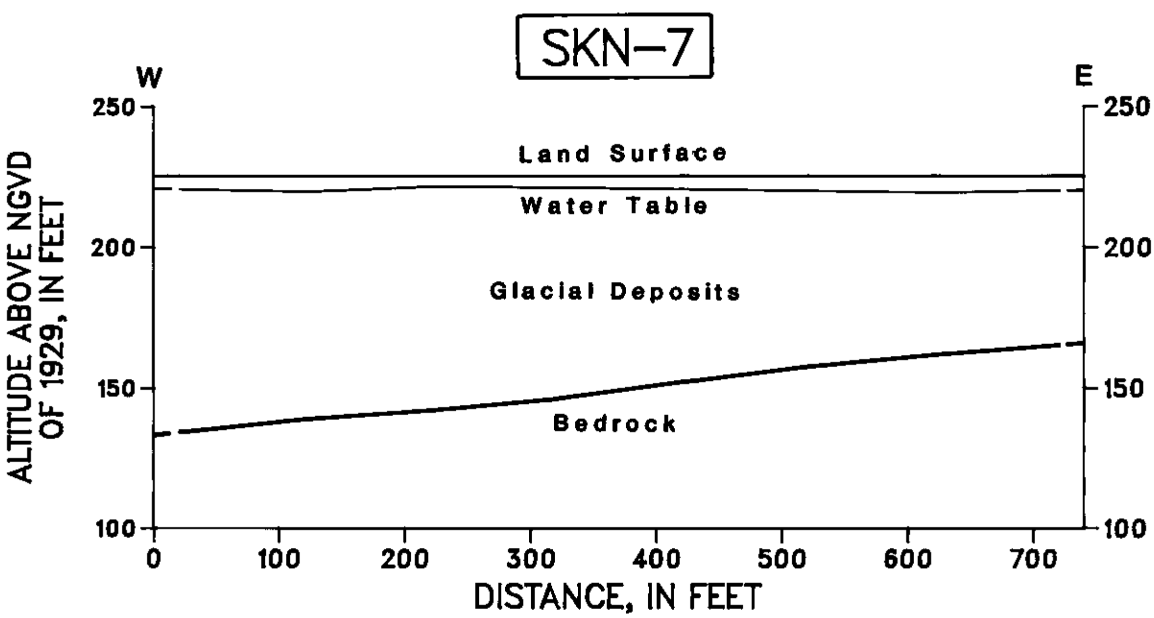


Figure 7. Continued.



Vertical Exaggeration x 2.3



Vertical Exaggeration x 2.3

Figure 7. Continued.