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Hydrogeology and Water Quality of Significant Sand and Gravel Aquifers

in parts of Aroostook County, Maine

Significant Sand and Gravel Aquifer Maps 75, 76, 77, 78, 84, 85

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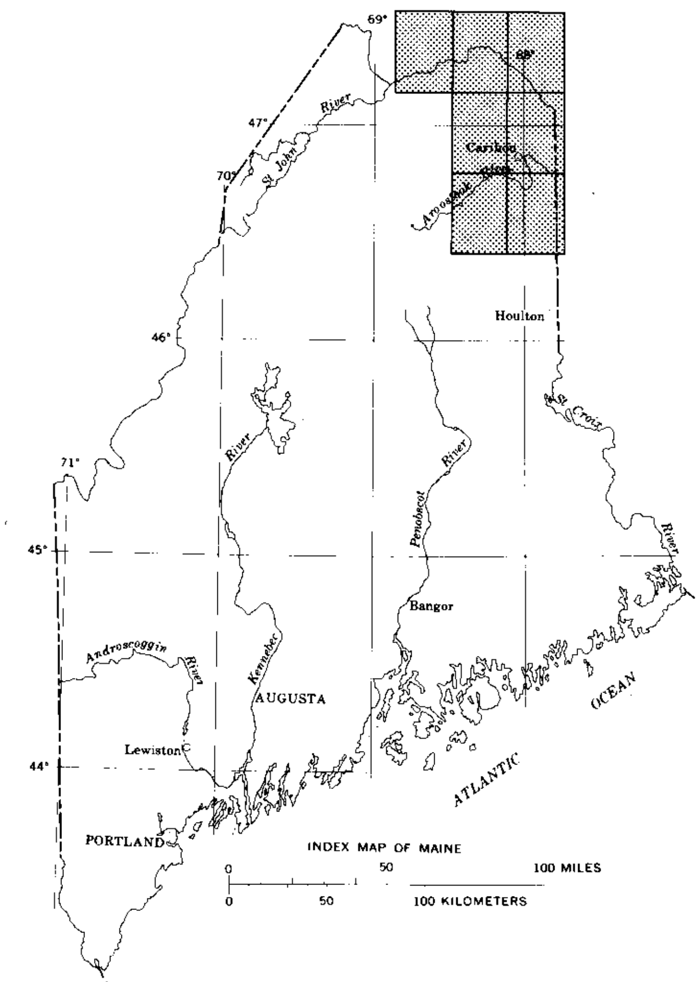

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HYDROGEOLOGY AND WATER QUALITY OF SIGNIFICANT SAND AND GRAVEL AQUIFERS IN PARTS OF AROOSTOOK COUNTY, MAINE: SIGNIFICANT SAND AND GRAVEL AQUIFER MAPS 75, 76, 77, 78, 84, AND 85

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CONVERSION FACTORS AND ABBREVIATIONS

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

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

Other abbreviations used in this report

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

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

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ABSTRACT

A reconnaissance-level hydrogeologic study was made of 2139 square miles in Aroostook County in Maine. Maps 75, 76, 77, 78, 84 and 85 of the Significant Sand and Gravel Aquifer Map Series published by the Maine Geological Survey cover the study area. 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 and near other surface-water bodies. By definition, significant aquifers are capable of yielding more than 10 gallons per minute to a properly constructed well. Significant aquifers comprise approximately 111 square miles (5 percent) of the study area; yields estimated to exceed 50 gallons per minute are believed to be available from only 1.5 square miles (less than one percent) of this area. Typically, the water table is within 15 feet of land surface. On the basis of well records, the greatest known depth to bedrock exceeds 214 feet. The greatest known well yield is approximately 1,710 gallons per minute from a gravel-packed well owned by a food processing company. The regional ground-water quality ranges from acidic to slightly basic; calcium, sodium, and magnesium are the most abundant cations; bicarbonate is the most abundant anion; and the water generally is hard. In some locations, concentrations of iron and manganese are large enough to limit the suitability of untreated water for some uses.

INTRODUCTION

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

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

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

A cooperative, detailed aquifer-mapping project was initiated in June 1981 by the MGS, USGS, and the DEP to satisfy the demand for more accurate, complete, and current hydrogeologic information concerning sand and gravel aquifers in Maine. The mapping first was conducted in densely populated and rapidly developing areas and subsequently has been extended throughout the state (Tolman and others, 1983; Tepper and others, 1985; Williams, Tepper, Tolman, and Thompson, 1987; Adamik and others, 1987; Weddle and others, 1988). The locations of areas studied during the Significant Aquifers Project are shown in figure 1.

This report presents the results from the sixth year of the mapping project (1986 field season) and updates the Sand and Gravel Aquifer Map Series for maps 75, 76, 77, 78, 84, and 85. These maps have been modified locally on the basis of new data and are available separately or with this report as plates 1-6 (Significant Sand and Gravel Aquifer Maps 75, 76, 77, 78, 84, and 85). The maps can be used as a base for detailed hydrogeological siting studies and planning. Furthermore, they provide a variety of information on aquifer favorability and vulnerability, as well as a preliminary estimate of well yield in certain areas.

Purpose and Scope

The purpose of this report is to present estimated well yields of aquifers in the area covered by Significant Sand and Gravel Aquifer Maps 75, 76, 77, 78, 84, and 85 in Aroostook County, Maine. A secondary objective is to describe the water quality in the aquifers and to identify areas where development may be limited by unsuitable water quality or by the presence of possible sources of contamination.

The scope of the investigation included:

(1) surficial geologic mapping to define the boundaries of the glacial deposits;
(2) presentation of supplemental information about the glacial geology of the area;
(3) seismic-refraction investigations to determine the depth to water, depth to bedrock, and bedrock-surface topography;
(4) a well inventory to supplement existing data on the depth to water, depth to bedrock, and well yields;
(5) observation-well and test-boring drilling to determine aquifer stratigraphy, thickness, and grain size (used to estimate transmissivity);
(6) water-quality sampling and analysis to characterize the regional ground-water chemistry;
(7) identification of potential sources of ground-water contamination, and
(8) location of municipal-well fields.

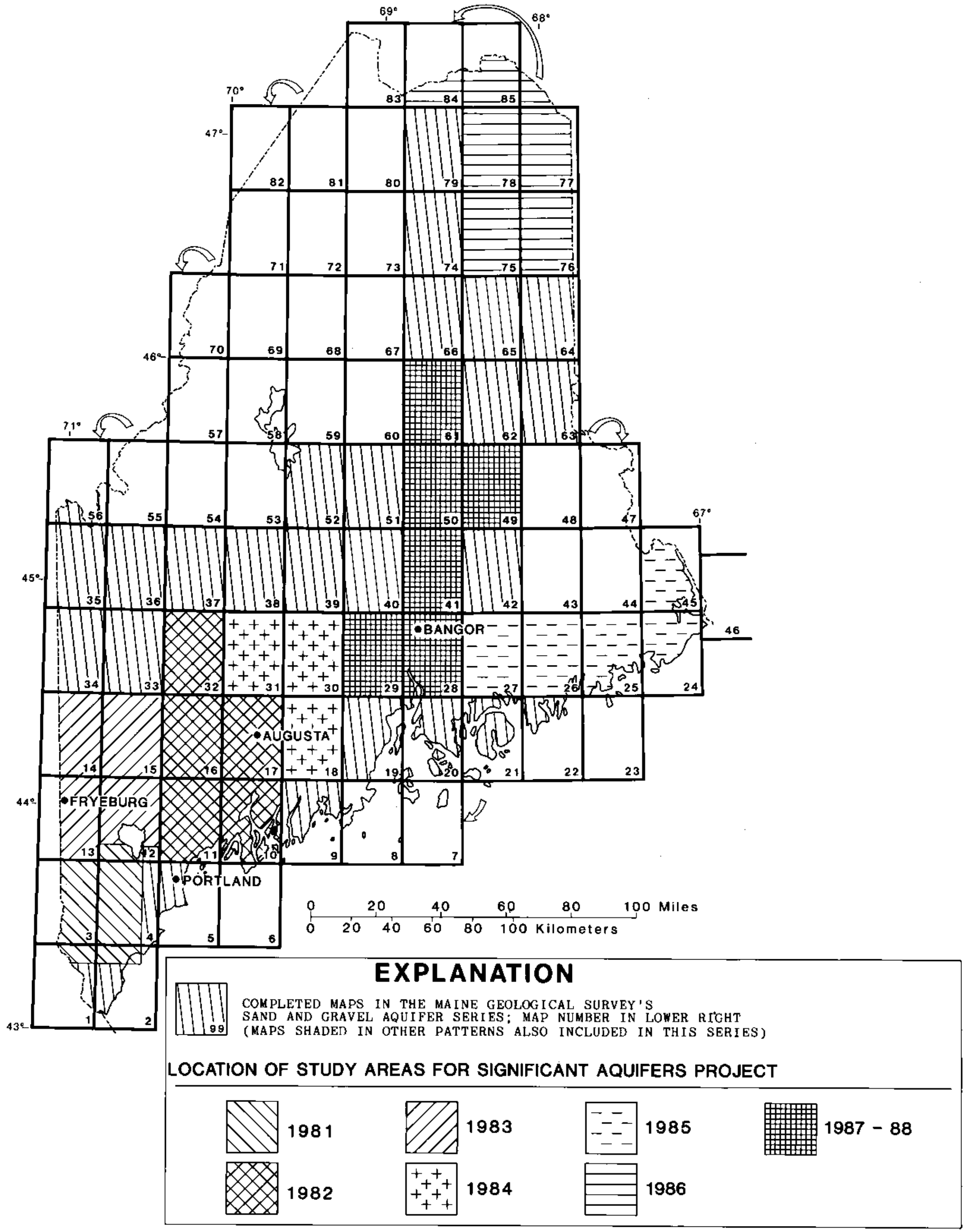

Figure 1. Location of study areas for the significant aquifers project and index to sand and gravel aquifer map series.

Previous Investigations

Surficial and bedrock geologic mapping conducted in the study area provided information on bedrock outcrops and the areal extent of sand and gravel deposits (Brewer, 1981; Brewer and others, 1986; Boucot and others, 1964; Genes, 1978 a-e, 1980 a,b, 1981 a-c, 1986 a,b; Genes and Newman, 1982; Pavlides, 1965, 1973, 1978; Roy, 1978, 1987). General geologic relations are presented on the bedrock and surficial geologic maps of Maine (Osberg and others, 1985; Thompson and Borns, 1985). Prescott, (1970, 1971 a, b, 1972, and 1973 a,b) published additional information on surficial geology, well depth, yield, ground-water levels, stratigraphy, estimated yield zones, and water quality. Prescott's reports were used as a basis for Sand and Gravel Aquifer Maps 75, 76, 77, 78, 84, and 85 (Tolman and Lanctot, 1980 a-f). Data collected for the present study were compiled on the same base as the early Sand and Gravel Aquifer Maps to produce the new maps, plates 1-6 in this report.

METHODS OF STUDY

Approach

The methodology of this investigation included:

(1) compilation of all existing hydrogeologic data on each 1:50,000-scale map;
(2) collection of information on existing domestic, municipal, and monitoring wells, boring logs, and test pits;
(3) identification of sites of potential ground-water contamination;
(4) verification of the original sand and gravel aquifer map boundaries by re-mapping surficial deposits;
(6) seismic-refraction surveys;
(7) test borings and observation-well installation;
(8) development and water-quality sampling of wells;
(9) monthly water-level measurements; and
(10) compilation of all data on 1:50,000-scale maps.

Details concerning several of these steps are given below.

Identification of Sites of Potential Ground-Water Contamination

Potential ground-water contamination sites located on or near significant aquifers are shown on plates 1-6 [1]/. These sites were identified primarily from files of the DEP Bureaus of Land Quality Control, Water Quality Control, and Oil and Hazardous Materials Control. The locations of State-owned salt and salt-sand storage lots were determined from Maine Department of Transportation records. All site locations were field-checked.

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

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

Surficial Mapping Techniques

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

In compiling the boundaries of the significant aquifers shown on plates 1-6, some land-surface contacts between aquifers and surrounding materials were shifted slightly into the aquifers to indicate that the tapering margins of some aquifers are unlikely to yield 10 gal/min or more. Many pit exposures within the mapped aquifers do not intersect the water table, and the pit floors are dry. In these cases, the aquifer was mapped on the basis of the known or inferred saturated thickness, and confirmed where possible by well, boring, or seismic data. The boundaries of the aquifer deposits are shown as solid lines where data substantiate the contacts, and are shown dashed where data are sparse.

Seismic-Refraction Surveys

Seismic-refraction techniques were used to obtain profiles showing the depth to water table, depth to bedrock, and topography of the bedrock surface. In seismic exploration, seismic waves are generated at the surface by a small explosion or hammer blows. The waves travel at different velocities through different materials--the denser the material, the faster the wave velocity. If the generalized geology of an area is known, the velocity of seismic waves through a material can be used to characterize its composition. In this study, seismic refraction was used to distinguish between dry sand and gravel, saturated sand and gravel, till, and bedrock. To permit these distinctions, the seismic velocity must increase with depth and there must be a significant velocity contrast between layers.

A 12-channel, EG&G Geometrics Nimbus ES-1210F seismograph[2]/ 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 varied from 450 to 1,000 ft long. Elevations of the shot points and geophones were surveyed where land surface relief 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 any nearby private wells and project borings were used to verify seismic results. In total, fifty-nine 12-channel lines were run (40,080 ft). Fifty-one of these lines (33,955 ft) provided reliable data for interpretation.

A single-channel Soiltest 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 single-channel seismic lines varied from 60 to 300 ft long. Data were analyzed and interpreted according to methods developed by Mooney (1980) and Zohdy and others (1974). In total, 175 single-channel lines were run (21,770 ft), and 88 of these lines (12,350 ft) provided reliable data.

Drilling and Stratigraphic-Logging Methods

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

A 6-inch-diameter hollow-stem auger rig was used for drilling. Overburden material penetrated above the water table was brought to the surface by the rotation of the augers. Where detailed stratigraphic information was needed below the water table, a split-spoon sampler was used to collect undisturbed sediment samples ahead of the drill stem. Samples were collected according to guidelines established by the Federal Interagency Work Group (1977, Chap. 2). Seven wells were drilled to refusal, which occurred when either bedrock, compact sediments, or sediments containing cobbles larger than 6-inches were encountered. Five borings were terminated before reaching refusal because of depth limitations, equipment breakdown, or scheduling constraints. Stratigraphic logs and screened intervals of observation wells are presented in tables 9-13 (at end of report).

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

Observation-Well Installation and Development

The 12 borings were cased with 2-inch-diameter, schedule 40 PVC (polyvinyl chloride) pipe to collect water samples and to measure water levels. PVC screens with slot widths varying from 0.006 to 0.008 in. were used. All casing couplings were fastened with 3/8-inch zinc-plated steel sheet metal screws. 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 ft below ground surface to the ground surface to prevent water from infiltrating directly around the casing.

At most sites, immediately after the casing was installed, water was bailed from the observation well to aid well development. All observation wells were thoroughly developed 2 to 3 weeks after installation by surging and pumping with compressed air, using the well casing as an air-lift pump shaft, and removing at least 10 well volumes of water from each well. This procedure removed the fine materials from the screen and developed the hydraulic connection with the aquifer.

Procedures for Water-Quality Sampling and Analysis

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

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

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

HYDROGEOLOGY

Surficial Geology

Maine probably was covered by continental glaciers several times during the Pleistocene Epoch, which occurred from approximately 2,000,000 to 10,000 years B.P. (before present). The last ice sheet, known as the Laurentide Ice Sheet, advanced about 20,000 years B.P., in late Wisconsin time, and flowed southeastward and eastward beyond the present coastline and into the Gulf of Maine.

Glacial History

After the peak 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 B.P., the ice margin was approximately at the present coast of Maine (Stuiver and Borns, 1975; Smith, 1985). The weight of the ice depressed the earth's crust enough to allow the sea to follow the retreating ice margin inland. At about this time or slightly later, marine waters transgressed up the St. Lawrence lowland in Canada as far inland as Ottawa, and a residual ice cap, separate from the Laurentide Ice Sheet was created, centered over northwestern Maine (Borns, 1985). Evidence of the existence of the separate ice cap is documented by the occurrence of ice-directional features, indicative of glacial flow northwestward from the Quebec-Maine border toward the St. Lawrence River (Chauvin and others, 1985; Lowell, 1985; Lowell and Kite, 1986a,b,c). This remanent ice cap, from the Appalachian Ice Complex of the Laurentide Ice Sheet (Prest, 1984; Dyke and Prest, 1987), is responsible for most of the surficial aquifer materials in the study area.

As deglaciation continued, glaciofluvial, glaciolacustrine, and glaciomarine sediments were deposited, recording the style and pattern of glacial retreat in Maine. Most glaciomarine deltas in eastern Maine formed close to the inland marine limit (Thompson and Borns, 1985), where the ice retreat became slow enough for large volumes of sediment to accumulate. Below the marine limit, glacial landforms such as eskers, deltas, fans, and moraines 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 years B.P. (Stuiver and Borns, 1975; Smith, 1985). When the ice retreated beyond the reach of the sea, vast amounts of meltwater reworked the glacial sediment and deposited fluvial and shoreline sediments over the Presumpscot Formation.

As the ice margin retreated, the marine waters removed much of the ice volume and where the ice margin was inland of the marine limit, widespread stagnation and downwasting of ice probably occurred (Lowell and Kite, 1986b). In the study area, which is well above the marine limit, the sand and gravel deposits consist primarily of ice-stagnation sediments, ice-contact stratified drift, and glaciolacustrine sediments, as well as recent (Holocene) alluvial deposits, laid down after the ice left the area (Thompson and Borns, 1985). Thick sequences of sand and gravel interbedded with and overlain by till have been observed in stream and river cuts and noted in deep boring logs in several places (Borns and Borns, 1986; Holland and Bragdon, 1986; Lowell and Kite, 1986c; Newman and others, 1985; Prescott, 1971, 1973). The deglaciation of this area occurred when the Appalachian ice mass was physically separated from the Laurentide Ice Sheet, from approximately 12,400 years B.P. to when the region was virtually ice-free at 10,000 years B.P. (Lowell and Kite, 1986b).

Surficial Materials in the Study Area

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

Till deposits in the State generally are not more than 10 feet thick. Streamlined, till covered hills known as drumlins are more common in southern Maine, however, there are streamlined hills in the study area which are covered by till. In general, however, the thickness of till on these hills is less than the thickness of till in the drumlins of southern Maine. Examples of some streamlined hills in the study area are shown on Map 75, (plate 1), southeast of Ashland. The long axes of these hills trend northwest-southeast, parallel to the direction of flow of the last ice sheet that covered the region.

In places, ridges of sediment were deposited either in front of or beneath the ice. These ridges are termed moraines; an example is the Mars Hill moraine, north of Mars Hill (Map 76, plate 2). The moraines are comprised predominantly of till interbedded with sand and gravel.

As the ice margin retreated in Maine, meltwater streams transported and deposited quantities of sand and gravel, mainly in the valleys. Coarse sediments, transported by the streams, accumulated in channels within or beneath the ice, between the ice and adjacent valley walls, or in the sea at or near the glacier front. These "ice-contact" stratified drift deposits include such features as eskers, crevasse fillings, subaqueous fans, and kame deltas. Sediments deposited by meltwater streams in valleys beyond the ice margin are termed outwash plain deposits, and commonly display pitted surfaces as a result of the burial and subsequent melting of blocks of ice.

The study area contains much less stratified drift than southern Maine. Prominent features such as the large eskers and glaciomarine deltas that occur in central and southern Maine and below the marine limit are less common in the study area. An example of a sinuous, north-south trending esker can be found on the western side of the hill east of Grindstone (Map 76, Plate 2).

A delta is present at the north end of Aroostook State Park, just west of Spragueville (Map 76, plate 2). The delta was deposited into a glacial lake that occupied a northward-flowing stream valley and was dammed to the north, probably by the glacier. The meltwater that carried the material and built the delta had to come from the drainage area that now feeds Lamson Brook, so there must have been ice in the area to the west of Aroostook State Park to supply the meltwater. The spillway that drained the lake is about 0.5 miles southeast of Echo Lake, and is now occupied by a tributary of Clark Brook. This brook is underfit with respect to the spillway, and the spillway floor at its highest elevation is about 535 feet above mean sea level. The delta surface is about 570 feet above mean sea level; the topset-foreset contact occurs about 15 to 20 feet below this. Something dammed the spillway to hold the lake in at its higher level, however, no material remains in the spillway to account for this. Glacial debris may have obstructed the spillway and was later eroded when the lake drained, or stagnant glacial ice may have blocked the spillway which later melted allowing the lake to drain. Outwash deposits associated with the spillway occur where Clark Brook joins Prestile Stream, and can be found in that stream valley southward.

Another delta is located just north of Lindsey Lake in the northeast corner of map 76 (plate 2) near the United States-Canada border. It is an ice-contact delta that displays collapse features and kettled topography and was fed by a small esker north of the delta. The delta was deposited into a basin which, like Spragueville Lake, probably was dammed by ice. Till, interbedded with the glaciolacustrine sediments, and high-angle normal faults indicative of collapse attest to the proximity of ice when the delta was built. A filled kettle hole, within the topset beds of the delta, also indicates the proximity of ice to the delta (fig. 2).

Figure 2.--Collapsed beds in kettle hole in topset beds of delta north of Lindsey Lake, Easton, Maine.

In the St. John River Valley (Maps 84 and 85, plates 5 and 6), there are more significant sand and gravel aquifer deposits than in the southern part of the study area (Maps 75, 76, 77 and 78, plates 1, 2, 3, and 4), where there are just a few deposits in the Aroostook River Valley. A glaciolacustrine delta is present in the St. John River Valley north of Frenchville, where Gagnon Brook joins the St. John River (map 85, plate 6). Other landforms in the St. John River Valley which may be of deltaic origin, either glacial or post-glacial, are present where Thibideau Brook joins the St. John River (Map 84, plate 5), and at elevation 563 feet just east of Upper Frenchville (Map 85, plate 6).

Outwash deposits occur in the St. John River Valley but are difficult to differentiate from alluvium. These landforms can only be differentiated where the glacial deposits occur downstream from former ice-marginal positions and are traceable to a head-of-outwash deposit. Examples of ice-contact stratified drift outwash are in the Fish River and Perley Brook Valleys (Map 84, plate 5).

Complex deposits of interbedded till, sand and gravel, and fine-grained deposits can be found in several locations in the study area. In the St. John River Valley, there are several sites where this stratigraphy is represented; however, the most extensive area is from south of Van Buren to the United States-Canada border (Map 85, plate 6). In the Aroostook River Valley, this stratigraphy is present in some gravel pits between Presque Isle and Bugbee (Maps 76, 77, and 78, plates 2, 3, and 4), and in pits along the river valley from Masardis and to just north of Ashland (Map 75, plate 1).

Wetland deposits occur in swamps and bogs, and are typically underlain by till or fine grained stratified deposits. Many of the wetlands are characterized by compact peat deposits. The permeability of the wetlands is generally low, though porosity and storativity of the deposits can be high. Some large wetlands include the area north of Square Lake (Map 78, plate 4), the southwestern corner of Map 75 (plate 1), and along Presque Isle Stream west of Quaggy Joe Mountain (Map 76, plate 2).

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

Recent alluvial deposits generally consist of interbedded sand, gravel, silt, and cobble gravel, and occupy much of the flood plain of the major rivers in the study area, including the St. John and Aroostook Rivers. As previously noted, alluvial deposits of late glacial and early post-glacial age may be difficult to differentiate from glacial outwash, however, post-glacial alluvium is generally deposited at lower elevations than outwash.

Stratigraphy of Glacial Deposits

Figure 3 is a schematic diagram that shows the generalized regional stratigraphic relations of glacial deposits in Maine. In general, surficial stratigraphy in the study area is best represented by the left and central parts of the schematic figure. Not all of the units shown on this figure will necessarily be found in any one place.

Figure 3 indicates the relative age of the deposits. Bedrock is overlain by till, which is overlain by sand and gravel, in the form of ice-contact stratified drift, glacial outwash and glacial-lake sediments. The youngest surficial deposit, a thin veneer of sand and gravel overlying the glacial deposits, may represent a late outwash deposit or alluvium.

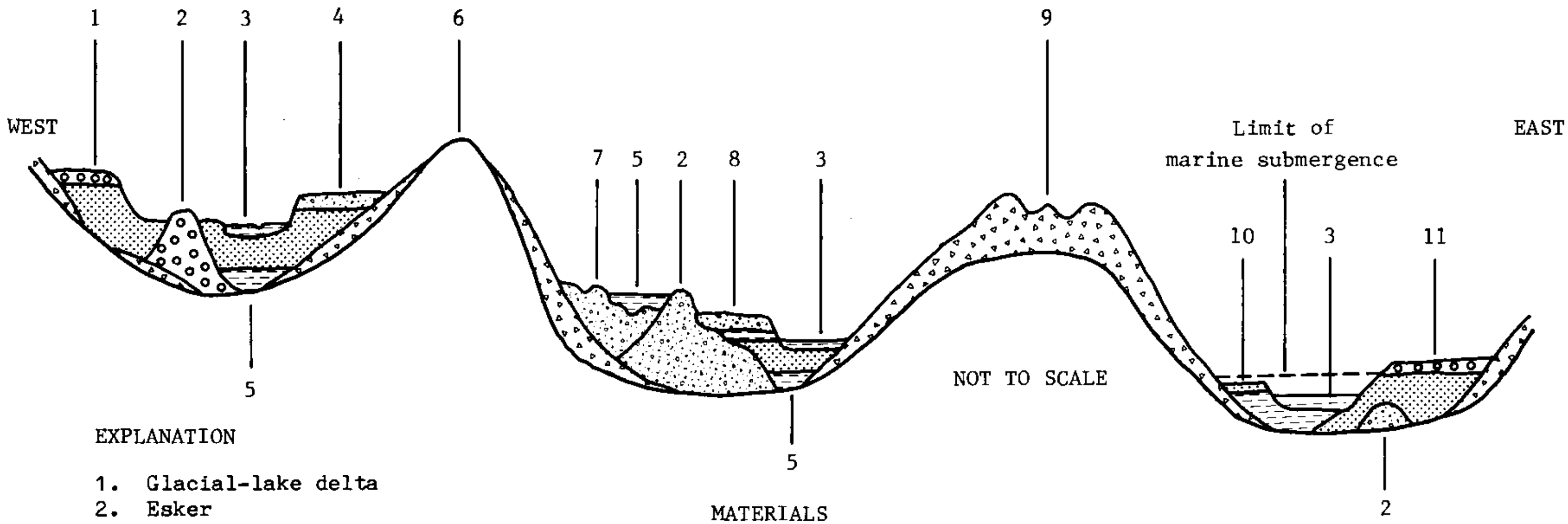
Hydrology of the Significant Sand and Gravel Aquifers

The significant sand and gravel aquifers consist of coarse glaciolacustrine deltaic sediments, ice-contact, ice-stagnation, and glacial-outwash deposits, and Holocene stream alluvium. The largest yields available are from wells in coarse-grained deposits near surface water bodies that may serve as sources of induced recharge. These aquifers are located in ice-contact stratified-drift or coarse-grained alluvial deposits--for example, the St. John River Valley sediments.

The most productive and highly-developed aquifer is located in glacial outwash deposits in Washburn (Map 78, plate 4). The largest reported single well yield in the study area, 1,710 gal/min, is from a well in the City of Presque Isle operated by a food processing company.

Significant sand and gravel aquifers are shown on the maps as areas with moderate to good potential water yield (greater than 10 gal/min to a properly constructed well), and areas with good to excellent potential water yield (greater than 50 gal/min to a properly constructed well). Areas with moderate to low or no potential water yield (generally less than 10 gal/min to a properly constructed well) are shown as surficial deposits with less favorable aquifer characteristics. These areas include regions underlain by surficial deposits such as till, alluvium, swamps, and thin glacial sand and gravel deposits. Bedrock wells shown on these maps record only the depth to bedrock of the well. The aquifer boundaries and estimated yield zones shown on plates 1-6 are based on available information and are subject to modification as additional data become available.

Major surface-water drainage-basin boundaries are identified on the maps. In general, surface-water divides coincide with ground-water divides. The horizontal direction of ground-water flow generally is away from surface-water divides and toward surface-water bodies.



EXPLANATION

1. Glacial-lake delta
2. Esker
3. Flood-plain deposits of modern river
4. Glacial-lake sand overlain by late-glacial outwash or postglacial stream-terrace alluvium
5. Fine-grained sediments deposited on bottom of glacial lake
6. Bedrock ridge
7. Kettled ice-contact deposits, locally overlain by fine-grained glacial-lake sediments
8. Alluvium on stream terrace. Terrace is developed on side of esker and locally underlain by glacial-lake sediments
9. Drumlins
10. Glacial-marine clay overlain by late-glacial outwash sand
11. Glacial-marine delta

MATERIALS

- Pebble to boulder gravel
- Sand and gravel (in varying proportions)
- Sand
- Fines (very fine sand, silt, clay)
- Till
- Bedrock

Figure 3. Generalized regional stratigraphic relations of glacial deposits.

Hydraulic Properties

Hydraulic Conductivity

Hydraulic conductivity is a measure of the volume of water that will flow through a unit area of aquifer under unit hydraulic head in a unit amount of time (Heath, 1984). Hydraulic conductivity may also be defined simply as a measure of the relative ease with which an aquifer can transmit water (Caswell, 1987). It is dependent 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 usually the most important hydraulic property of sediments for assessing ground-water flow and well yield (Caswell, 1987).

Hydraulic conductivity is best measured directly in the field on an undisturbed section of aquifer. When field measurements are impractical, the hydraulic conductivity of the aquifer material can be estimated in the laboratory. For this study, the median particle diameter (in millimeters) and the degree of sorting of representative sediment samples were determined by grain-size analyses. These analyses were performed at the USGS laboratory in Harrisburg, Pennsylvania, using a dry sieve method (Folk, 1974). The results of these analyses (table 1) were used to estimate horizontal hydraulic conductivity, using nomographs published by Masch and Denny (1966) that relate mean grain size and degree of sorting to hydraulic conductivity.

The range of horizontal hydraulic conductivities, expressed in ft/d (feet per day), are 0.000001 to 0.001 for marine clay, 0.0000001 to 0.01 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). The horizontal hydraulic-conductivities estimated for selected aquifer materials sampled in this study have much less variation, from 10 ft/d to 50 ft/d (table 1).

Transmissivity

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

Approximate transmissivity values were calculated at 11 sites from the complete stratigraphic logs of observation wells. Sediment from each interval in the saturated part of the exploration boring (tables 9-13, at end of report) was assigned a horizontal hydraulic conductivity, based on sample descriptions, grain size, and sorting (table 1). This hydraulic conductivity was multiplied by the interval thickness to obtain an interval transmissivity. The interval transmissivity values were then summed to give a total transmissivity for that part of the aquifer penetrated by the exploration boring.

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

Sample description	Observation well number	Depth of interval sampled (feet)	Median diameter (phi)[1/]	Degree of sorting[2/]	Estimated horizontal hydraulic conductivity (feet per day)[3/]
Very fine sandy silt	OW84-2	47-49	4.0	poor	10
Very fine to medium sand with silt	OW84-1	47-49	3.5	poor	11
Very fine sand with silt	OW77-2	32-34	3.5	poor	11
Fine sand	OW84-2	32-32.6	3.5	poor	11
Fine to medium sand with silt	OW77-3	28.6-29	2.7	poor	15
Medium sand	OW84-2	32.6-34	2.0	poor	17
Fine to medium sand some silt	OW77-2	27-29	2.5	moderate	19
Medium to coarse sand	OW77-4	48.1-49	1.9	poor	14
Medium to coarse sand	OW76-1	12-14	.74	moderate	50
Fine to coarse sand; fine gravel with silt	OW84-1	17-19	.1	poor	16
Coarse to very coarse sand	OW75-2	17-19	.45	poor	22
Very coarse sand	OW84-2	33-33.4	-.55	poor	24
Very coarse sand	OW77-2	22.4-22.8	-.2	poor	40

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

[2/] Sorting classified by Inclusive Graphic Standard Deviation
greater than 1.0 - poor
0.75 - 1.0 - moderate
.50 - .75 - moderately well
less than or equal to .50 - well

[3/] Masch and Denny (1966)

The transmissivities are presented in table 2. The exploration borings for three observation wells did not penetrate the entire aquifer thickness. Aquifer transmissivity at these borings was calculated based on properties of the known materials; actual transmissivity may be larger.

Table 2.-- Estimated transmissivity values of aquifers based on stratigraphic logs of observation wells
[>, greater than]

Map	Observation well number	Transmissivity, in feet squared per day
75	OW 75- 1	> 280
	OW 75- 2	210
76	OW 76- 1	840
	OW 76- 2	420
77	OW 77- 1	> 410
	OW 77- 2	800
	OW 77- 3	425
	OW 77- 4	500
84	OW 84- 1	230
	OW 84- 2	> 720
85	OW 85- 1	160

Depths to the Water Table and Bedrock Surface

Depths to the water table and bedrock surface in the significant sand and gravel aquifers were determined from seismic-refraction surveys, water level measurements, well inventory, test drilling, mapping of bedrock outcrops, and previous investigations. In the study area, the seismic velocity in unsaturated overburden materials ranges from 947 to 2,730 ft/s (feet per second), with an average velocity of 1,480 ft/s. Saturated overburden materials have velocities of 4,060 to 7,820 with an average velocity of 5,450 ft/s. Bedrock seismic velocities in the study area vary from 10,100 to 19,800 ft/s with an average velocity of 15,100 ft/s. In the significant sand and gravel aquifers, the depth to the water table differs considerably areally but typically is within 15 feet of the land surface. The greatest depth to bedrock determined by seismic-refraction is approximately 200 feet, along seismic line GDI-4, (Map 85, pl. 6) and GDI-9 (Map 84, pl 5). Well records indicate that bedrock is at a depth greater than 214 feet along the St. John River near Ft. Kent (Map 84, pl 5).

Determinations of depths to the water table and bedrock surface are necessary to provide a three-dimensional picture of aquifer geometry. Saturated thickness at selected points can be determined by subtracting the depth to water table from the depth to bedrock. Depth to bedrock data and bedrock surface profiles can be used to estimate the amount of casing required in overburden for bedrock well construction and to locate buried valleys, which may contain water-bearing sediments. A summary of the information collected with the single-channel seismographs is presented in table 14 (at end of report). Hydrogeologic sections from seismic-refraction surveys conducted with the 12-channel seismograph are presented in figures 8-13 (at end of report). The locations of 88 single-channel and 51 twelve-channel seismic-refraction lines conducted throughout the study area are shown on plates 1-6.

Estimated Well Yields

The significant sand and gravel aquifers consist of deposits that have sufficient areal extent, hydraulic conductivity, and saturated thickness to sustain a yield of 10 gal/min or more to a properly installed well. Yields available from wells constructed in the aquifers were obtained from yields reported by well drillers, well owners, and previously published studies, and from estimates based on saturated thickness, transmissivity, and areal extent of the aquifers. Aquifer transmissivity determined through pump tests was not in the scope of this study. Therefore, a method developed by Mazzaferro (1980) was used to estimate well yields in a water-table aquifer. This method is based on transmissivity (T) and saturated thickness (B), where (T X B)/750 = well yield in gallons per minute. Yields were calculated for selected observation wells (table 3).

Table 3.--Estimated well yields for selected observation wells

[>, greater than]

Map	Observation well number	Estimated well yield (gallons per minute)[1/]
75	OW 75- 1	> 3.0
	OW 75- 2	3.0
76	OW 76- 1	19.0
	OW 76- 2	10.0
77	OW 77- 1	>10.0
	OW 77- 2	35
	OW 77- 3	20
	OW 77- 4	25
84	OW 84- 1	10
	OW 84- 2	>45
85	OW 85- 1	3.0

1/ Yields calculated from the methodology of Mazzaferro (1980), where yield (gallons per minute) = TxB/750.

Areas where wells are estimated to yield more than 10 gal/min and more than 50 gal/min are shown in separate shading patterns on the maps. Areas where wells may yield less than 10 gal/min constitute the remaining unshaded portion of the map.

Although the total study area covers 2,139 mi^2 (square miles), areas mapped as significant sand and gravel aquifers include only about 111 mi^2 (5 percent) of this area. Yields exceeding 50 gal/min are obtainable in only 1.5 mi^2 (less than one percent) of the study area. The greatest yields are obtainable in areas where the deposits are coarse grained, have a thick saturated zone, or are hydraulically connected to an adjacent body of surface water that is a source of induced recharge. The largest reported well yield in the sand and gravel deposits is 1,710 gal/min from an industrial well in Presque Isle (Map 76, pl. 2). Other large well yields in the area include municipal wells in Washburn (Washburn Water Company, one well with a yield of 425 gal/min; Map 78, pl. 4) and Fort Kent (Fort Kent Water District, two wells with yields of approximately 275 gal/min each; Map 84, pl. 5).

Water-Level Fluctuations

Monthly water-level measurements at 10 observation wells in the study area are shown in table 4. Water-level measurements were made once a month from October 1986 through October 1987. Water-levels averaged over a 12-month period in all observation wells fluctuated within a range of approximately 4 to 16 feet (table 5). Hydrographs from selected observation wells are shown in figure 4.

The mean depth to water table in the 10 wells ranged from 3.51 to 36 feet below land surface over a 12-month period. In the majority of the wells, the water table is less than 10 feet from the surface. This thin unsaturated zone renders the ground water vulnerable to potential contamination originating at the land surface.

Average monthly precipitation data from National Oceanic and Atmospheric Administration Stations at Fort Kent, Van Buren, Caribou, Squa Pan Dam, Bridgewater, Presque Isle, and Houlton are compared with water-level data in figure 4. Regional recharge generally occurs in the fall and winter months, when there is little plant growth to intercept precipitation as it infiltrates the aquifer. Most water levels decline slowly but steadily between these recharge events. The 11-year record of monthly water levels from USGS observation well AR890 in Fort Kent, Maine is shown in Figure 5. Water levels have remained fairly constant during the period of record with no rising or declining trend seen.

Table 4.--Water-level data for observation wells in the study area, October 1986 through October 1987

[Depth to water in feet below land surface; --, no water level measured during this period]

Observation Well Number	Location	October 29,30,31	November 6,7	December 1,2	January 7,8	February 3,4	March 4	April 2,3	April 8,10	May 4,5,6	June 4	July 1	August 4	Aug./Sept. 31,2	October 1
OW75- 1	Ashland	9.75	--	8.70	7.08	8.71	9.41	--	2.86	8.10	10.06	10.51	11.00	11.13	10.46
OW75- 2	Masardis	6.77	--	6.90	9.42	8.33	8.76	--	4.26	6.16	7.38	8.22	9.30	9.99	9.45
OW76- 1	Presque Isle	3.70	--	3.00	3.48	3.37	3.68	--	[1]-0.78	3.34	4.21	4.29	4.54	4.85	4.42
OW77- 1	Washburn	7.63	--	5.20	6.17	5.73	3.38	--	[2] .96	6.43	8.03	7.75	8.70	9.20	7.96
OW77- 2	Ft. Fairfield	10.06	--	10.18	10.21	10.02	9.65	3.03	--	10.25	10.49	10.26	9.85	9.76	12.05
OW77- 3	Caribou	--	6.07	4.01	4.16	5.39	6.17	1.89	--	[3]--	--	--	--	--	--
OW77- 4	Ft. Fairfield	--	18.93	17.20	17.75	17.86	18.34	7.09	--	17.33	19.21	19.08	20.04	20.67	19.50
OW84- 1	St. Francis	--	10.01	9.72	8.47	8.95	9.64	2.37	--	9.79	10.44	9.23	11.42	11.84	10.82
OW84- 2	Grand Isle	--	24.41	24.18	24.47	25.06	25.63	--	15.70	22.93	24.45	24.23	25.49	25.76	25.15
OW85- 1	Grand Isle	--	37.35	37.08	37.26	37.70	38.31	22.73	--	34.48	36.34	36.29	37.70	38.13	38.23

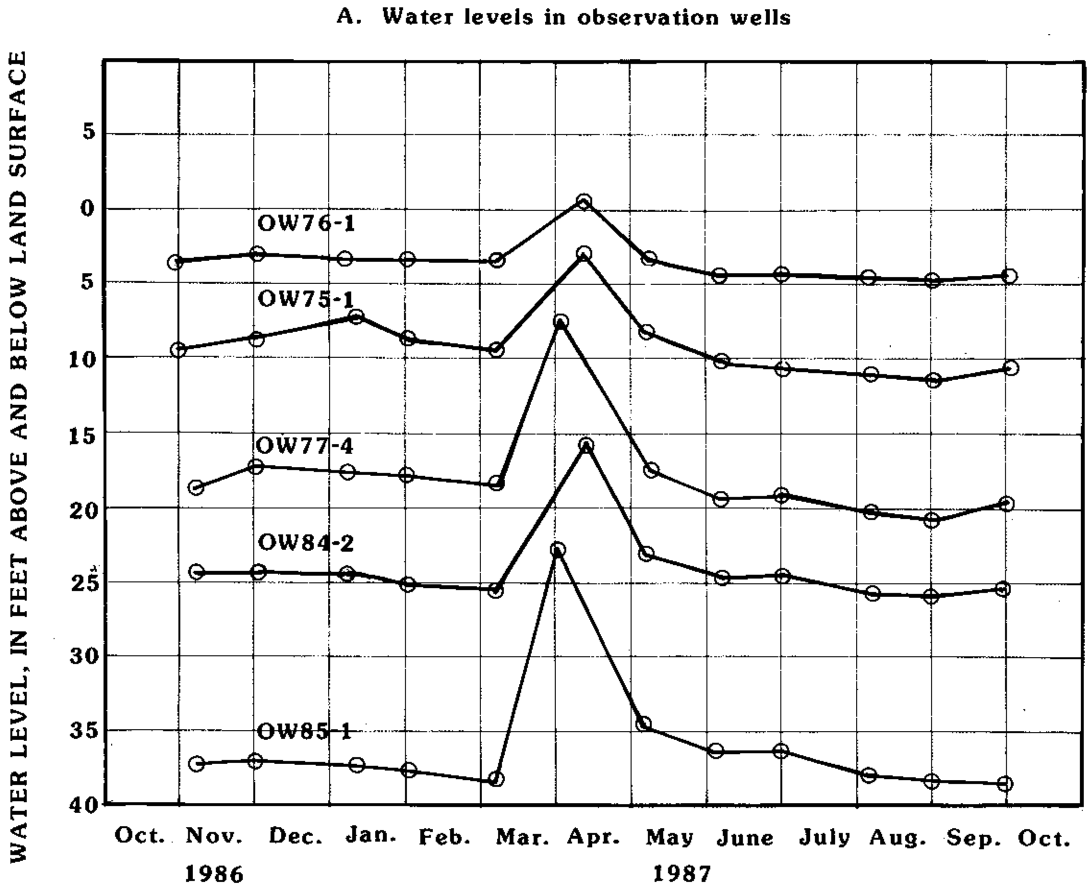
[1] Observation well and area around it were flooded by the Aroostook River.

[2] Casing was broken off at ground level.

[3] Casing was pulled up 4′ so measurements were no longer taken down the casing.

Table 5.--Statistical analysis of water-level data for observation wells in the study area, October 1986 to October 1987

Observation Well Number	Location	Number of Measurements	Mean (feet)	Standard deviation	Maximum depth to water (in feet below land surface)	Minimum depth to water (in feet below land surface)	Range of values (feet)
OW75- 1	Ashland	12	8.98	2.98	11.13	2.86	8.27
OW75- 2	Masardis	12	7.91	1.68	9.99	4.26	5.73
OW76- 1	Presque Isle	12	3.51	1.46	4.85	-.78	5.63
OW77- 1	Washburn	12	6.43	2.38	9.20	.96	8.24
OW77- 2	Ft. Fairfield	12	9.65	2.17	12.05	3.03	9.02
OW77- 3	Caribou	6	4.62	1.62	6.17	1.89	4.28
OW77- 4	Ft. Fairfield	12	17.75	3.52	20.67	7.09	13.58
OW84- 1	St. Francis	12	9.39	2.42	11.84	2.37	9.47
OW84- 2	Grand Isle	12	23.96	2.72	25.76	15.70	10.06
OW85- 1	Grand Isle	12	35.97	4.30	38.31	22.73	15.58



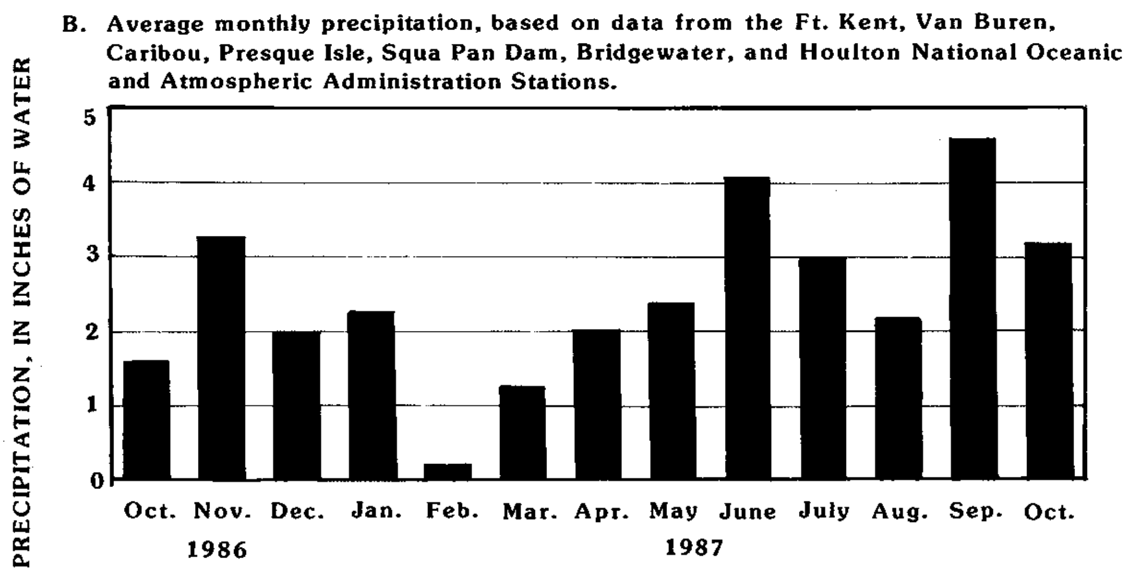


Figure 4.--Ground-water levels in selected observation wells and average monthly precipitation, October 1986 through October 1987.

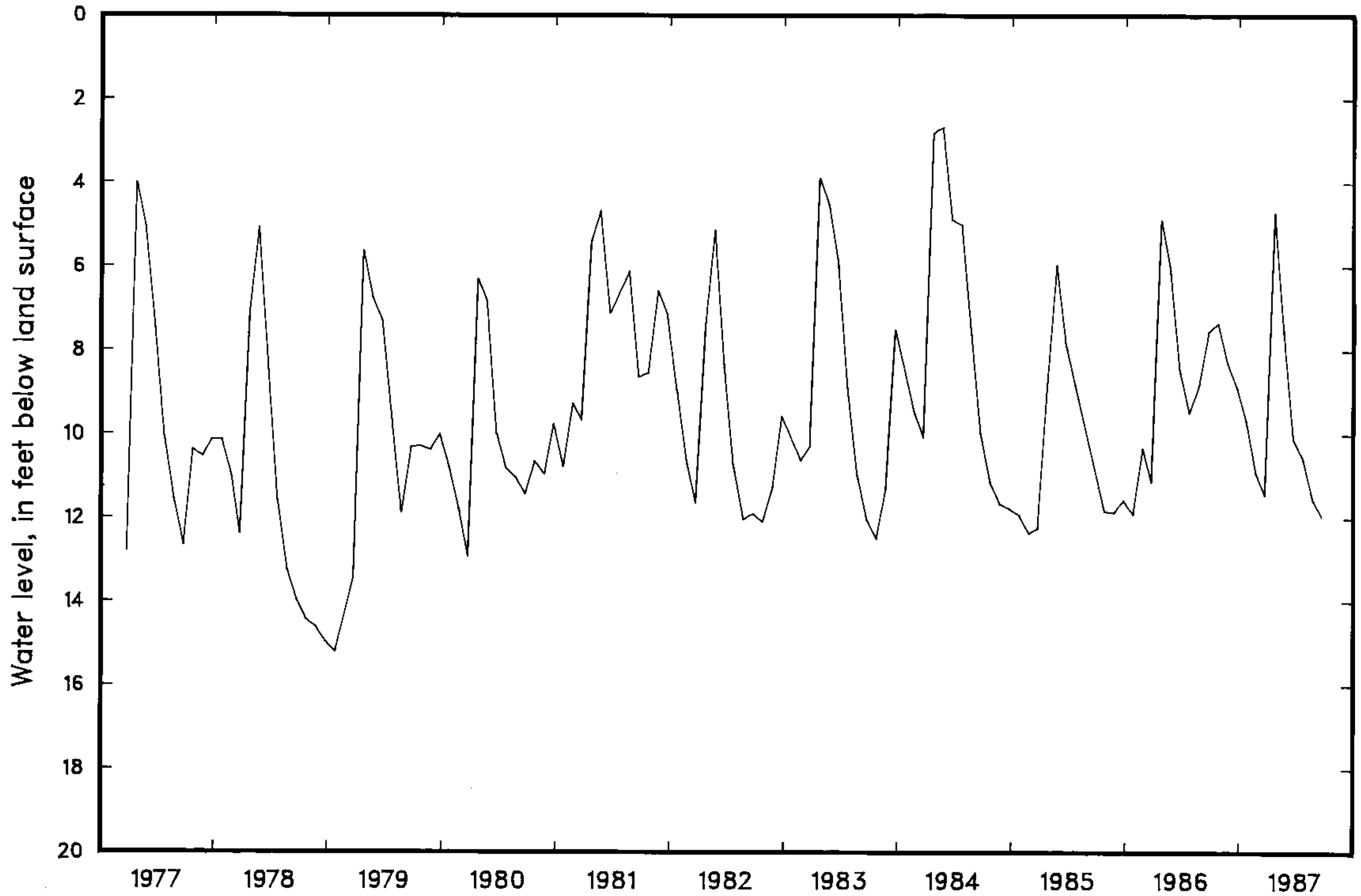


Figure 5.--Monthly water levels for U.S. Geological Survey observation well at Ft. Kent (AR890) from February 1977 through October 1987.

GROUND-WATER QUALITY

Factors Influencing Water Quality

The chemical quality of water in sand and gravel aquifers is determined by a number of factors. The primary control is the mineralogy of the sand and gravel. Most sand and gravel in the study area is derived from calcareous mudstone, sandstone, and limestone, which generally release calcium as a dominant cation to ground water. Chemical reactions that occur as water passes through the soil zone can also affect ground-water chemistry. Where the flow path of water from the recharge zone to the discharge zone is great, more time is available for the dissolution of soluble material in the aquifer (Caswell, 1987). Residence time also depends on hydraulic conductivity, hydraulic gradient, and the porosity of the unconsolidated deposits.

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

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

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

(3) Introduction of human wastes into ground water through septic tanks, disposal of septic wastes, or by spreading or landfilling of sludge from municipal sewage treatment systems;

(4) Agricultural activities, which include stockpiling and spreading of manure, spreading of commercial fertilizers, and spraying of pesticides. During 1985 and 1986, the Maine Geological Survey collected samples from 44 overburden wells within agricultural areas underlain by sand and gravel; eight of these wells had detectable concentrations of pesticides. Furthermore, six of these wells had nitrate concentrations exceeding the State drinking water standard of 10 mg/L (milligrams per liter) (Neil and others, 1987). Contamination of more than 100 wells in Aroostook County by aldicarb (Temik), an agricultural chemical used extensively for potato farming, has also been documented (unpublished data, Rhone-Poulenc Agricultural Products Company);

(5) Leaking waste-storage or disposal lagoons;

(6) Leaking fuel- or chemical-storage tanks. The DEP Bureau of Oil and Hazardous Materials Control has documented concentrations of gasoline as high as 600,000 parts per billion in a well installed in a sand and gravel aquifer (Garrett and others, 1986). Underground petroleum tank leaks were documented at 158 locations in Maine from 1979-83. In total, 76 wells were found to be contaminated, most commonly by gasoline that leaked from buried tanks and connecting pipes at retail and nonretail commercial establishments (Caswell, 1987);

(7) Spills of toxic or hazardous materials along transportation routes; and

(8) Contaminants in precipitation. In the northeastern United States "acid rain" has been reported to cause a lowering of pH and subsequent increase in aluminum and trace metal concentrations in ground water in New Hampshire and New York (Bridge and Fairchild, 1981).

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

Background Water Quality

The following discussion is based on analyses of samples collected from 11 observation and four municipal wells within the study area. Characteristics of these wells are given in table 6. Water-quality analyses of samples from these wells are provided in table 7. Data for all properties are reported in standard metric units used for these analyses. These wells are located in areas that are believed to be upgradient from sources of contaminants other than agricultural activities.

A summary of the water-quality information collected from mapped sand and gravel aquifers from previous studies in southeastern, south-central and southwestern Maine (Tolman and others, 1983; Tepper and others, 1985; Williams, Tepper, Tolman, and Thompson, 1987; Adamik and others, 1987, Weddle and others, 1988), is shown in table 8 and is compared with the data from this study area.

Because of the extensive potato farming in much of the study area, many wells could not be sited in areas where ground-water quality was not affected by agricultural chemicals and manure spreading. In previous study areas in other parts of Maine, the wells were sited to avoid any influence by man-induced contamination. Variations in water quality are attributed to natural geologic and geochemical factors and to the influence of agricultural practices on ground water. Although volatile organics were analyzed in earlier project field seasons (1981-84), they were dropped for the 1985 and 1986 seasons because previously collected samples did not yield positive results. Volatile organic pollutants are not likely to be found in wells installed for measurement of background water quality. For a study concurrent with the sand and gravel aquifer project, samples were collected from six of the observation wells in this study for pesticide analysis. None the wells sampled yielded detectable levels of agricultural chemicals (Neil and others, 1987).

Graphic summaries of selected water-quality properties and constituents are presented as box plots in figures 6 and 7. The summaries are based on analyses of water samples collected from earlier studies mentioned above and from this study area. Percentiles of some of the constituents are compared to the U.S. Environmental Protection Agency (USEPA) (1986) and Maine Department of Human Services (MDHS) drinking-water standards (1983) in figure 7. The maximum contaminant levels (MCL) are health-related and are legally enforceable. The secondary maximum contaminant levels (SMCL) apply to aesthetic qualities and are recommended guidelines.

Table 6.--Characteristics of observation and municipal wells in the study area sampled for background water quality

Observation well number	Town	Latitude	Longitude	Altitude[1]	Depth[2]	Predominant land type around well	Date sampled
OW75-1	Ashland	46°37'35"N	68°25'10"W	530	14.6	field	10-29-86
OW75-2	Masardis	46°32'12"M	68°22'38"W	537	19	field	10-29-86
OW76-1	Presque Isle	46°44'39"N	68°02'54"W	427	14	field	10-30-86
OW76-2	Presque Isle	46°42'34"N	68°01'04"W	420	20	field	10-30-86
OW77-1	Crouseville	46°45'07"N	68°05'57"W	432	23	field	10-31-86
OW77-2	Fort Fairfield	46°46'38"N	67°48'17"W	560	25	field	10-31-86
OW77-3	Caribou	46°54'18"N	67°57'41"W	446	16	gravel pit	11-06-86
OW77-4	Fort Fairfield	46°49'26"N	67°55'09"W	374	41	field	11-06-86
OW84-1	St. Francis	47°12'07"N	68°49'49"W	538	49.4	field	11-07-86
OW84-2	Grand Isle	47°16'11"N	68°05'39"W	454	42	field	11-07-86
OW85-1	Grand Isle	47°19'31"N	68°09'44"W	460	47	field	11-07-86
Municipal Wells							
Ft. Kent	Fort Kent	47°16'56"N	68°35'06"W	505	54	field	10-16-87
Church St.	Washburn	46°47'29"N	68°09'50"W	475	38	field	10-15-87
Hilt St.	Washburn	46°47'21"N	68°09'48"W	465	29	field	10-15-87
Ft. Fairfield	Fort Fairfield	46°45'45"N	67°49'07"W	363	40	field	10-15-87

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

[2] Depth of observation well in feet below land-surface datum.

Table 7.--Background water quality in sand and gravel aquifers in the study area
[all values in milligrams per liter (mg/L) except as noted;
°C, degress Celcius; us/cm, microsiemens per centimeter at 25 °C;
--, value not determined]

Observation well number	Temperature (°C)	Conductivity (us/cm)	pH values	Alkalinity as $CaCO_3$ 1/	Chloride dissolved	Nitrate + nitrite as N	Sulfate, dissolved 2/	Sodium, dissolved	Potassium, dissolved	Calcium, dissolved	Magnesium, dissolved	Hardness as $CaCO_3$	Iron, dissolved	Manganese, dissolved	Total carbon, organic 3/
OW 75-1	8.5	195	6.6	--	4.5	1.50	E13	7.8	3.2	19	4.8	67	.05	.780	17
OW 75-2	10.5	110	6.2	41 L	<0.5	0.02	E7.0	4.1	.36	10	3.1	38	4.20	.850	7.0
OW 76-1	7.0	270	6.2	72 L	15	4.00	E30	3.6	.63	34	7.2	110	.07	.120	1.0
OW 76-2	7.5	345	7.4	--	<0.5	.06	E16	13	.73	39	9.1	130	.20	.370	15
OW 77-1	7.5	390	6.7	170 L	20	1.90	E40	7.8	.77	63	6.6	180	<.03	.230	10
OW 77-2	7.0	320	7.2	--	4.0	2.50	E17	2.7	1.4	59	3.0	160	<.03	.130	8.0
OW 77-3	6.5	150	6.4	67 F	<0.5	.03	E7.0	1.4	1.1	26	1.3	70	.04	.170	5.2 U
OW 77-4	6.0	465	7.4	202 F	10	.49	E54	3.9	1.1	67	18	240	<.03	.340	2.2 U
OW 84-1	7.5	290	8.0	125 F	11	5.12	E34	29	0.41	36	5.5	110	.43	.120	40 U
OW 84-2	6.5	530	6.2	197 F	9.0	.12	E5.0	8.1	1.0	28	3.5	84	42. 5/	.770	62 U
OW 85-1	7.0	370	7.7	--	17	5.10	E34	11	2.9	58	7.9	180	.05	.290	4.0
FT. KENT	6.5	150	5.8	57 F	5.5	.40	8.9	3.6	.80	23	2.2	66	3.20	.320	2.0
CHURCH ST.	7.0	200	7.0	100 F	16	1.80	33	7.1	1.3	83	12	260	<.03	.076	9.0
HILT ST.	7.0	210	6.9	178 F	10	5.30	35	3.6	.40	78	11	240	<.03	<.005	2.0
FT. FAIRFIELD	7.5	250	7.5	202 L	8.7	.95	15	4.3	1.2	85	5.6	240	<.03	.570	<1.0
Minimum	6.0	110	5.8	41	<0.5	0.02	5.0	1.4	0.36	10	1.3	38	<.03	<.005	<1.0
Maximum	10.5	530	8.0	202	20	5.3	54.0	29.0	3.2	85	18.0	260	4.2	.850	62.0
Median	7.0	270	6.9	125	9.0	1.5	17.0	4.1	1.00	39	5.6	130	.05	.290	7.0
Mean	7.3	283	H6.5	128	8.8	1.95	23.3	7.4	1.15	47	6.7	145	0.60	.342	12.4
Standard Deviation	1.1	121	--	63	6.3	2.00	14.8	6.8	0.84	25	4.4	75	1.33	.275	16.9

1/ L - Analysis done by DEP lab with fixed end point calculation;
F - Field analysis by incremental titration
2/ E - Estimated value
3/ U - Sample analysed by the USGS lab - all others analysed by DEP lab
4/ H - Mean pH value calculated from hydrogen ion concentration
5/ This value was not used in calculating statistics. It is believed to be erroneous since the pH value of 6.2 is well above the range where iron is highly soluble in a normal ground-water environment.

Table 8.--Background water quality in sand and gravel aquifers 1981-85 study areas[1]
[All values in milligrams per liter except as noted]

	Temperature (°C)	Conductivity (microsiesmens)	pH	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	Total Organic Carbon
Number	84	84	83	80	83	82	83	84	84	84	84	84	84	83	59
Minimum	6.5	17	5.3	4	.5	.01	3.0	1.3	.3	.2	.08	1.0	.02	.005	1.0
Maximum	15.0	234	8.6	97	15.0	8.00	18.0	20.0	4.8	33.0	10.00	109	10.00	1.500	83.0
Median	9.0	65	6.6	15	2.0	.06	5.6	4.6	1.2	5.6	1.15	19	.07	.061	1.0
Mean	9.2	75	NA[2]	22	3.5	.38	6.9	5.3	1.6	8.2	1.70	27	.52	.174	5.4
Standard Deviation	1.6	45	NA[2]	20	3.1	1.10	3.3	3.3	1.0	6.8	1.61	22.5	1.54	.284	12.3

1 Tolman and others, 1983; Tepper and others, 1985; Williams, Tepper, Tolman, and Thompson, 1987; Adamik and others, 1987; Weddle amd others, 1988.

2 Not Analyzed

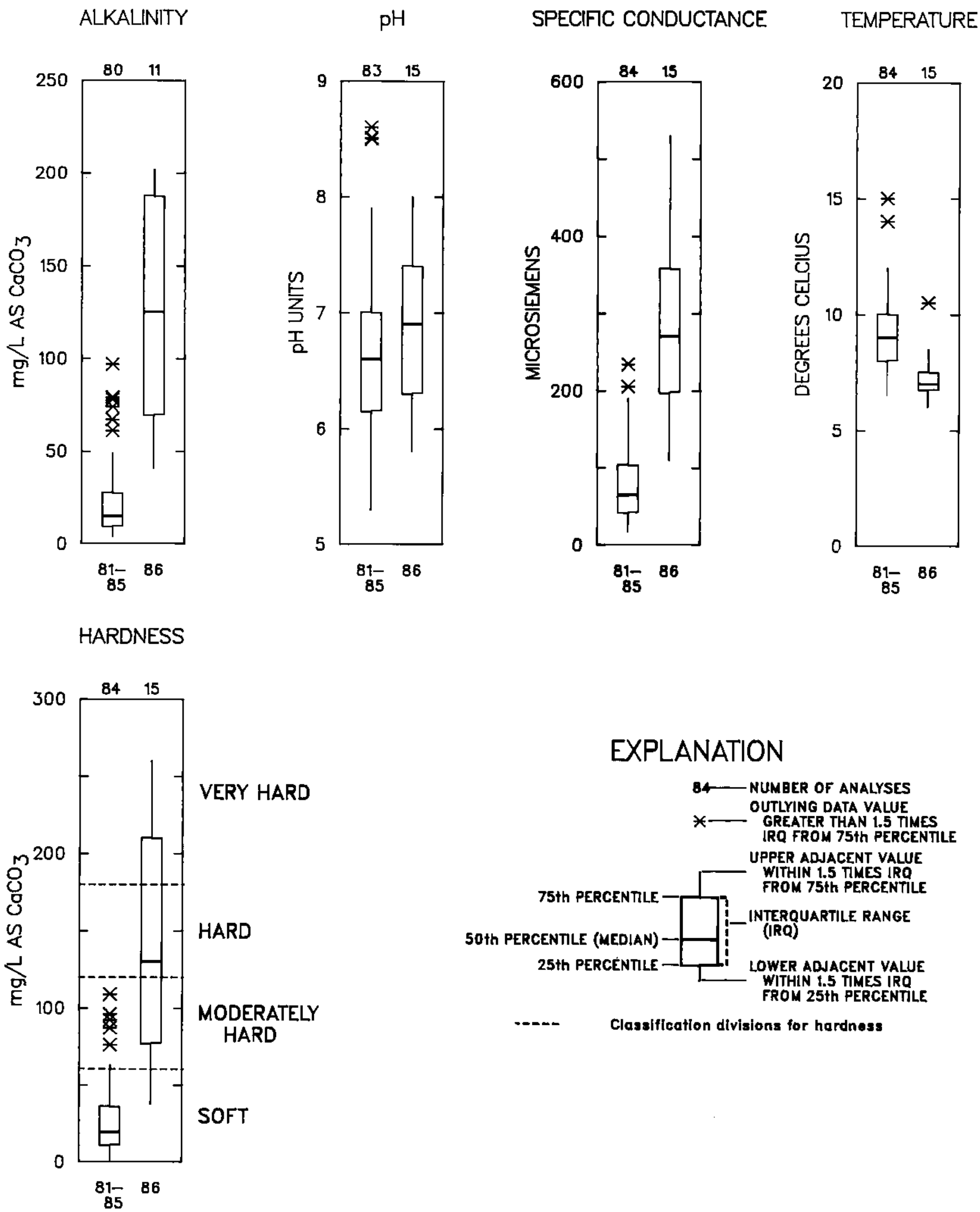


Figure 6.—Boxplots of selected water-quality properties for 1981-85 and 1986 study areas.

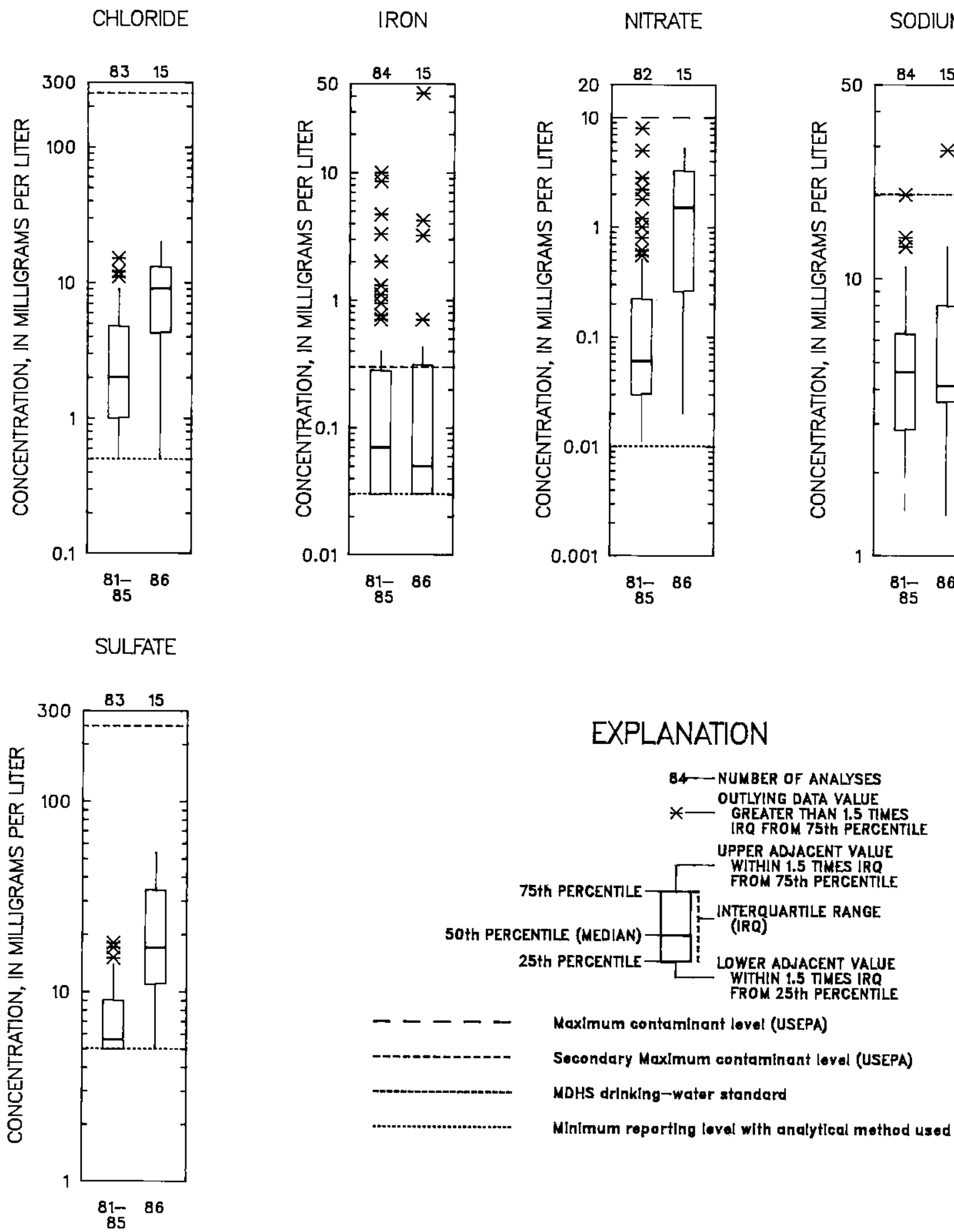


Figure 7.--Boxplots of selected water-quality constituents for 1981-85 and 1986 study areas with U.S. Environmental Protection Agency (USEPA) and Maine Department of Human Services (MDHS) drinking-water standards.

Temperature

The temperature of ground water normally has a small seasonal fluctuation and remains within a few degrees of the mean annual air temperature in a given area. In Maine, ground-water temperatures are typically between 4.4 °C and 10.0 °C (Caswell, 1987). The temperature of ground water in the study area varies from 6.0 °C to 10.5 °C, with a median of 7.0 °C (table 7). This is lower than the median ground-water temperature of 9.0 °C in wells from previous study areas (table 8, figure 6).

Specific conductance

The specific conductance (conductivity) 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 specific conductance. Dissolved inorganic salts are the source of most ionic species and make up a large part of the total dissolved solids in most natural waters.

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

Specific conductance of the water-quality samples from the study area range from 110 to 530 μS/cm, with a median of 270 μS/cm (table 7). Converting to dissolved solids (using the high-end factor of 0.75 for a worst-case estimate), a range of 83 to 398 mg/L and median of 203 mg/L is estimated for dissolved-solids concentration. The dissolved-solid concentrations in the study area are therefore below the recommended maximum level. In contrast, the specific conductance of background water-quality samples in previous study areas ranged from 17 to 234 μS/cm with a median of 65 μS/cm (table 8, fig. 6). The dissolved-solids concentration derived from specific-conductance values from previous study areas were lower, with a range of 13 to 176 mg/L and a median of 49 mg/L.

pH

The pH of water is a measure of hydrogen-ion activity (concentration). Each unit increase in the pH scale represents a tenfold decrease in hydrogen-ion activity. A pH of 7 is considered neutral, less than 7 is acidic, and greater than 7 is alkaline. The primary control on pH in ground water involves interaction of soil and rocks with gaseous carbon dioxide, bicarbonate, and carbonate ions. The pH in the background water-quality samples from the study area ranges from 5.8 to 8.0, with a median of 6.9 (table 7). This is slightly higher than pH values found in previous study areas, which ranged from 5.3 to 8.6, with a median of 6.6. The USEPA (1986) has set a recommended pH range for drinking water of from 5 to 9.

Alkalinity

Alkalinity is a measure of the capacity of a solution to neutralize acid. This capacity depends on the concentrations of carbonate (CO^{-2}), bicarbonate (HCO_3^-), and hydroxyl (OH^-). Under equilibrium conditions, pH may be used to indicate the distribution of the different carbonate species (Hem, 1985). Thus, for ground water with pH in the range found in the study area, bicarbonate is the dominant anion. Alkalinity is reported in terms of calcium carbonate ($CaCO_3$) concentration. The alkalinity concentrations within the study area range from 41 to 202 mg/L, with a median of 125 mg/L (table 7). The alkalinity concentrations in the wells in previous study areas were generally lower, with a range of 4 to 97 mg/L and a median of 15 mg/L (table 8, figure 6). This alkalinity variation is likely due to the presence of calcareous mudstone and limestone in the study area, whereas crystalline rocks of generally low carbonate content underlie previous study areas.

Chloride

Because chloride is a highly mobile ion and is not readily sorbed, it can be used to trace contamination from road salt, salt-sand storage piles, landfills, and septic tanks. The USEPA (1979) has set a SMCL of 250 mg/L for chloride. High cloride concentrations in water well contribute to the deterioration of plumbing, water heaters, and water works equipment. Elevated chloride concentrations in water may also be associated with sodium. Chloride concentrations in the background water-quality samples from the study area range from less than 0.5 to 20 mg/L, with a median concentration of 9.0 mg/L (table 7). Chloride concentrations in the wells in 1981-85 study areas were commonly lower, with a range of less than 0.5 to 15 mg/L, and a median of 2.0 mg/L (table 8, figure 7).

Nitrate Plus Nitrite

Nitrogenous compounds commonly are derived from plant and animal materials but can also be contributed by fertilizers. Nitrate is the most common nitrogen compound in ground water. Because nitrate is weakly adsorbed by soil, it is a good indicator of contamination from septic systems and waste-disposal sites. Nitrate can be converted to nitrite in the stomach; this may lead to the onset of methemoglobinemia in infants, a potentially lethal disease (National Research Council, 1977). Because of this, the USEPA (1986) established a MCL of 10 mg/L nitrate-nitrogen (NO_3-N) in drinking water.

Nitrate in similar doses, also is potentially lethal to cattle. Nitrate concentrations in the background water-quality samples from the study area range from 0.02 to 5.3 mg/L, with a median of 1.5 mg/L (table 7). This is much higher than the values in previous study areas, which ranged from less than 0.01 to 8 mg/L, with a median of 0.06 mg/L (table 8, figure 7). Nitrate from chemical and organic fertilizers is believed to cause this difference.

Sulfate

Sulfate is one of the major anions in natural waters. Sulfate can be reduced under anaerobic conditions to hydrogen-sulfide gas (H_2S). The rotten-egg odor of this gas can be detected in water at levels as low as a few tenths of a milligram per liter. The USEPA (1979) has set a SMCL for sulfate of 250 mg/L in drinking water; at levels above this, sulfate can have a laxative effect.

Sulfate concentrations in the background water-quality samples from the study area range from 5 to 54 mg/L, with a median of 17 mg/L (table 7). Samples from previous study areas have lower sulfate values, ranging from less than 3.0 to 18 mg/L, and a median of 5.6 mg/L (table 8, figure 7).

Sodium and Potassium

Sodium and potassium are among the major cations in ground water in Maine. The USEPA (1979) has not set a SMCL for potassium in drinking water. For sodium, a drinking water standard of 20 mg/L has been set by the Maine Department of Human Services (1983) to protect individuals on restricted sodium diets. These diets usually are recommended for people with heart, hypertension, or kidney problems.

Concentrations of sodium in the background water-quality samples from the study area range from 1.4 to 29 mg/L, with a median of 4.1 mg/L. Concentrations of potassium in the study area range from 0.36 to 3.2 mg/L, with a median of 1.0 mg/L (table 7). These values are similar to those found in the 1981-85 study areas. Sodium concentrations in the 1981-85 study areas ranged from 7.3 to 20 mg/L, with a median of 4.6 mg/L (table 8 and figure 7). Potassium concentrations in previous study areas ranged from 0.3 to 4.8 mg/L, with a median of 1.2 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 freshwater (Hem, 1985). Magnesium is also a common cation in ground water. The Maine Department of Human Services (1983) has not recommended any maximum limits for calcium, magnesium, or hardness in drinking water.

Concentrations of calcium, the principal cation in the background water-quality samples, range from 10 to 85 mg/L, and from 0.2 to 33 mg/L in the samples from previous study areas (tables 7 and 8). Median calcium concentrations are higher in the study area (39 mg/L) than in the previous study areas (5.6 mg/L). This may be due to the abundance of limestone in the Aroostook County area and agricultural activity.

Magnesium concentrations are also higher in the study-area samples (1.3 to 18 mg/L; median of 5.6 mg/L) than in 1981-85 samples (0.08 to 10 mg/L; median value of 1.2 mg/L) (tables 7 and 8). Again, this may be due to the differences in the underlying bedrock geology.

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

Hardness in study-area samples was calculated by Standard Method 314A (American Public Health Association, 1985) and is expressed in terms of an equivalent concentration of calcium carbonate. Water is considered soft if it contains 0 to 60 mg/L of hardness, moderately hard if it contains more than 60 mg/L, hard if it contains more than 120 mg/L and very hard if it contains more than 180 mg/L (Hem, 1985). Ground-water samples from the study area, had hardness ranging from 38 to 260 mg/L. This indicates that hardness of water in the region is variable, covering the entire hardness scale from soft to very hard. The median hardness for the study area is 130 mg/L, indicating generally hard ground water. In contrast, previous study-area wells had a median hardness of 19 mg/L (figure 6), which is considered soft.

Iron and Manganese

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

Iron concentrations in the study area samples vary from less than 0.03 mg/L to 4.2 mg/L (table 7). These values are similar to those found in previous study areas; the median iron concentration is 0.05 mg/L in the study area and 0.07 mg/L in previous study areas (table 8, figure 7). An iron concentration of 42 mg/L was found in OW84-2, however this value is believed to be erroneous since the pH value of 6.2 is well above the range where iron is highly soluble in a normal ground-water environment. As a consequence, this value was deleted from the statistical data set. The median values for iron in both the study area and in the previous study areas are within the SMCL of 0.3 mg/L for drinking water set by the USEPA (1979).

Manganese concentrations in the project area range from less than 0.005 mg/L to 0.85 mg/L, with a median of 0.30 mg/L (table 7). Previous study area samples had manganese concentrations ranging from less than 0.005 to 1.5 mg/L, with a median of 0.061 mg/L (table 8). Only one well in the study area (Washburn Water District-Hilt Street well) had a manganese concentration below the SMCL of 0.05 mg/L set by the USEPA (1979).

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

Total Organic Carbon

TOC (total organic carbon) is a bulk indicator of all organic chemicals present in water, although the TOC-measurement technique does not distinguish between toxic and nontoxic organic species. Natural organic species derived from soils can cause anomalously high concentrations. The TOC concentrations in the background water-quality samples from the study area range from less than 1 mg/L to 62 mg/L, with a median of 7.0 mg/L (table 7). Previous study-area TOC values ranged from less than 1 mg/L to 83 mg/L, with a median of 1.0 mg/L. Most of the TOC values in the study area are above the detection limit of 1.0 mg/L, but many of the values in previous study areas were below the detection limit.

SUMMARY

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

Although the study area includes 2,139 mi^2, areas mapped as significant aquifers cover only 111 mi^2 (plates 1-6). Yields exceeding 50 gal/min are estimated to be available in only 1.5 mi^2 of these significant aquifers. The highest yields are obtainable in areas of thick, coarse-grained, saturated deposits that are hydraulically connected to an adjacent body of surface water as a source of induced recharge. The largest reported well yield is 425 gal/min from the Washburn Water Company well constructed in sand and gravel deposits.

The water table in the significant sand and gravel aquifers typically is within 15 feet of the land surface. Based on well-record data, the greatest known depth to bedrock exceeds 214 feet; however, seismic line data indicate greatest depth to bedrock of approximately 200 feet.

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

The background water quality in sand and gravel aquifers in the study area has the following characteristics: the median pH is 6.9; calcium, sodium, and magnesium are the most abundant cations; bicarbonate is the dominant anion; and the water generally is hard. According to water-quality data for the study area and the prescribed drinking water standards, the regional water quality generally is suitable for drinking and most other uses. However, in some localities, concentrations of iron and manganese are sufficiently large to limit use of untreated water.

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

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Table 9-13.--Observation-well and test boring logs, Map 75, 76, 77, 84, and 85, Area [1].

Identification number: composed of three elements:

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 plates 1-6.

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.

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

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."

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

Table 9.--Observation-well log, Map 75 Area
[--, An aquifer "Thickness" value is not relevant for the "End of boring" depths]

OW 75-1. Latitude: 46°37'35" N., Longitude: 67°01'24" W.
Located on the edge of a field adjacent to the west bank of the Aroostook River and approximately .4 miles south of the Aroostook River Bridge in Ashland. Depth to water is approximately 8 feet.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Loam, fine sandy, brown	0 - 5	5
Gravel, silty, with occasional cobbles	5 - 15	10
Till, dark gray, very compacted, (end of boring)	15 -	--

OW 75-1 is screened from 9.6 to 14.6 feet below land surface with a 0.006-inch slotted schedule-40 PVC screen.

Table 9.--Observation-well log, Map 75 Area (Continued).
[--, An aquifer "Thickness" value is not relevant for the "Bedrock" depths]

OW 75-2. Latitude: 46°32'12" N., Longitude: 68°22'38" W.
Located in Masardis approximately 1.3 miles north of the Garfield Road bridge on the west side of the Aroostook River. Depth to water is approximately 9 feet.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Loam, fine sandy, dark brown	0 - 3.5	3.5
Gravel, medium, with subanglar pebbles 1/2 to 3/4 inch, some silty clay	3.5 - 7	3.5
Silt, with occasional layers of gravel	7 - 12	5
Gravel, coarse sand, brown; some clay, silt	12 - 17	5
Alternating layers .1 to .5 ft thick of: gravel, sandy, dark gray, with rounded pebbles to 5/8 inch; sand, very coarse, dark gray; sand, medium to fine, dark gray	17 - 20	3
Clay, silty, gray, moist, no layering or color changes	20 - 25	5
Till, compact, dark gray, with subangular pebbles to 3/4 inch	25 - 40	15
Till, compact, dark gray; very coarse sand with angular to subangular pebbles 1/4 to 1 inch	40 - 44	4
Till, very compact, sandy, gravelly, with subrounded pebbles 1/4 to 1 1/4 inch	44 - 72	28
Till or weathered bedrock, very difficult drilling	72 - 78	6
Bedrock	78	--

OW 75-2 is screened from 14.0 to 19.0 feet below land surface with a 0.006-inch slotted schedule 40-PVC screen.

Table 10.--Observation well, Map 76 Area
[See Table 9 for explanation of terms;
--, An aquifer "Thickness" value is not
relevant for the "Refusal" depths]

OW 76-1. Latitude: 46°44'39" N., Longitude: 68°02'54" W.
Located adjacent to a couple of small ponds and along a field access road approximately .4 miles south-southwest of Route 164 in Presque Isle and approximately 3.3 miles from the intersection of Route 164 and Route 1. Depth to water is approximately 5 feet.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Gravel, fine to medium, with angular to subangular pebbles 1/4 to 1 inch	0 - 2	2
Gravel, fine, with angular to sub-angular pebbles 1/4 to 1 inch	2 - 7	5
Gravel, fine to medium, with angular to subangular pebbles 1/2 to 1 inch	7 - 12	5
Sand, medium to coarse	12 - 15.5	3.5
Clay, silty, light gray, no varves	15.5 - 22	6.5
Clay, silty, light gray, with occasional coarse to very coarse sand	22 - 26	4
Sand, medium to coarse, with occasional fine sand	26 - 32.3	6.3
Till	32.3 - 40	7.7
Refusal (bedrock)	40 -	--

OW 76-1 is screened from 9.0 to 14.0 feet below land surface with a 0.006-inch slotted schedule 40 PVC screen.

Table 10.--Observation-well logs, Map 76 Area--(Continued)
[--, An aquifer "Thickness" value is not relevant for the "Refusal" depths]

OW 76-2. Latitude: 46°42'34" N., Longitude: 68°01'04" W.
Located along the south bank of the Aroostook River approximately 1/2 mile upstream from the Route 1 bridge in Presque Isle. Depth to water is approximately 6 feet.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Loam, fine sandy, dark brown	0 - 2	2
Sand, silty, light brown	2 - 7	5
Sand, silty, light brown, with gravel layers	7 - 17	10
Gravel, fine to medium, light brown, with angular to sub-angular pebbles 1/16 to 1 inch	17 - 22	5
Till, compact, gray, with pebbles to 1/2 inch	22 - 39	17
Refusal (bedrock)	39	--

OW 76-2 is screened from 15 to 20 feet below land surface with a 0.006-inch slotted schedule-40 PVC screen.

Table 11.--Observation-well logs, Map 77 Area
[See Table 9 for explaination of terms;
--, An aquifer "Thickness" value is not
relevant for the "Refusal" depths]

OW 77-1. Latitude: 46°45'07" N., Longitude: 68°05'57" W.
Located along the north bank of the Aroostook River in Crouseville, approximately 6 river miles upstream of the Route 1 bridge in Presque Isle. Depth to water is approximately 6 feet.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Loam, silty, brown	0 - 2	2
Sand, fine, silty, with gravel lenses	2 - 12	10
Silt, sandy, brown	12 - 17	5
Gravel, fine to coarse, with coarse to very coarse sand, with minor silt, pebbles to 1 1/4 inch	17 - 24	7
Till, tightly compacted, dark gray, with angular to subangular pebbles to 1 inch	24 - 28	4
Refusal, very tightly compacted till	28 -	--

OW 77-1 is screened from 18 to 23 feet below land surface with a 0.008-inch slotted schedule-40 PVC screen.

Table 11.--Observation-well and test-boring logs, Map 77 Area (Continued)
[--, An aquifer "Thickness" value is not relevant for the "Refusal" depths]

OW 77-2. Latitude: 46°46'38" N., Longitude: 67°48'17" W.
Located 250 feet east of the centerline of the Russell Road approximately 1.5 miles (by road) from the Fort Fairfield bridge. Depth to water is approximately 5 feet.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Loam, fine sandy, brown	0 - 1	1
Gravel, medium to coarse, silty, brown, with rounded pebbles 1/2 to 2 inches	1 - 12	11
Gravel, medium, silty, brown, with rounded to subangular pebbles 1/4 to 1/2 inch	12 - 17	5
Gravel, fine sandy, silty, brown; granules, 1/8 to 1/4 inch; pebbles average 1/2 inch	17 - 22	5
Gravel, very coarse sandy, with rounded pebbles 1/4 to 1/2 inch; trace silt	22 - 27	5
Sand, fine to medium, light brown, trace silt	27 - 32	5
Sand, very fine, silty, light brown	32 - 35	3
Till, loosely compact to compact as depth increases; angular to subangular pebbles 1/4 to 3/4 inch	35 - 39	4
Till, very compact, brownish gray, with 1/2 to 1 inch pebbles	39 - 53	14
Refusal (Till)	53 -	--

OW 77-2 is screened from 20 to 25 feet below land surface with a 0.006-inch slotted schedule-40 PVC screen.

Table 11.--Observation-well logs, Map 77 Area (Continued)
[--, An aquifer "Thickness" value is not relevant for the "Refusal" depths]

OW 77-3. Latitude: 46°54'18" N., Longitude: 67°57'41" W.
Located in a gravel pit situated 1.6 miles north along the Bowles Road and 530 feet to the east. This gravel pit is on the west side of the Little Madawaska River approximately 5 river miles upstream from its confluence with the Aroostook River in Caribou. Depth to water is approximately 4 feet.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Loam, fine sand, brown	0 - 2	2
Gravel, sandy, brown, with pebbles to 1/4 inch	2 - 7	5
Gravel, silty, light brown, with pebbles 1/4 to 1 inch	7 - 12	5
Gravel, silty, sandy, gray	12 - 17	5
Till, gray, with 1/4 to 1 inch pebbles	17 - 24	7
Sand, fine, with silt	24 - 27	3
Gravel, coarse sandy, light brown, with silt, pebbles 1/4 to 1 inch	27 - 28	1
Till, gray, with occasional angular pebbles 1/4 to 1 inch	28 - 28.5	.5
Sand, fine to medium, gray, with silt	28.5 - 32	3.5
Gravel, medium, with silt, very angular 1/4 to 1 inch pebbles	32 - 33	1
Till, silty, very fine sandy, gray, with angular pebbles 1/4 to 1 inch	33 - 37	4
Gravel, very coarse sandy, silty, gray, with rounded to subangular pebbles 1/4 to 3/4 inch	37 - 42	5
Gravel, very coarse sandy, silty, light brown, with subangular to rounded pebbles, 1/4 to 3/4 inch, some cobbles	42 - 49	7
Refusal (Bedrock)	49	--

OW 77-3 was to be installed and screened from 39 to 44 feet below land surface. However, because of a misunderstanding and mechanical problems, the driller withdrew the flights up to the 20 foot below land surface level. As a result, OW77-3 was screened from 11 to 16 feet below land surface with 0.006 inch slotted schedule-40 PVC screen. An attempt was made to drill an additional hole and install a well screen at the desired level, but mechanical problems prevented its installation.

Table 11.--Observation-well logs, Map 77 Area--(Continued)
[--, An aquifer "Thickness" value is not relevant for the "Refusal" depths]

OW 77-4. Latitude: 46°49'26" N., Longitude: 67°55'09" W.
Located in Fort Fairfield near where the Fort Fairfield-Caribou town line crosses the Aroostook River. This well is also situated approximately 250 feet south of the south bank of the Aroostook River. Depth to water is approximately 19 feet.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Loam, fine sandy, rust colored; fine sand	0 - 5	5
Gravel, medium, with pebbles, 1/2 to 3/4 inch	5 - 12	7
Gravel, fine sandy, silty, with pebbles 1/4 to 1/2 inch	12 - 17	5
Gravel, fine silty, with pebbles 1/2 to 3/4 inch, dark brown	17 - 22	5
Sand, very coarse	22 - 25	3
Sand, very fine, silty; occasional layers of silt, brown	25 - 28	3
Till, coarse sandy, with angular pebbles to 1 1/2 inch, gray	28 - 43	15
Gravel, coarse sandy, silty, with angular pebbles 1/4 to 1 inch brown	43 - 49	6
Sand, medium to coarse, silty, gray	49 - 53	4
Till, coarse sandy, silty, with angular pebbles 1/4 to 1 inch, brown	53 - 67	14
Refusal	67 -	--

OW77-4 Was to be screened from 45 to 50 feet below land surface. However, an obstruction between the well casing and the interior well of auger flights caused the screen to break as the auger was withdrawn. The water level at the time of drilling was approximately 21 feet. In order to allow for reasonable water level fluctuation, OW77-4 was screened from 36 to 41 feet below land surface with 0.008 inch slotted schedule-40 PVC screen. The well is screened in till and not in sand and gravel.

Table 12.--Observation-well and test-boring logs, Map 84 Area
[See Table 9 for explaination of terms;
[--, An aquifer "Thickness" value is not relevant for the "Refusal" depths]

OW 84-1. Latitude: 47°12'07" N., Longitude: 68°49'49" W.

Located between a potato field and the south bank of the St. John River in St. Francis. This well is also situated approximately 270 feet to the west of the St. Francis - St. John Plantation town line. Depth to water is approximately 10 feet.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Loam, fine sandy, brown; silt	0 - 7	7
Sand, silty, with gravel layers	7 - 12	5
Sand, coarse, silty, brown; fine gravel, with angular to sub-angular pebbles to 1/4 inch	12 - 25	13
Clay, silt, gray, with occasional 1/4 inch pebbles	25 - 30	5
Sand, very coarse; silt, gray; in alternating layers 1 to 2 inches thick	40 - 55	15
Clay, silt, gray	55 -102	47
End of boring	102 -	--

OW 84-1 is screened from 44.4 to 49.4 feet below land surface with a 0.008-inch slotted schedule-40 PVC screen.

Table 12.--Observation-well and test-boring logs, Map 84 Area--(Continued)
[--, An aquifer "Thickness" value is not relevant for the "End of boring" depths]

OW 84-2. Latitude: 47°16'11" N., Longitude: 68°05'39" W.
Located about 400 feet from the south bank of the St. John River in Grand Isle approximately 1.6 river miles up from the Grand Isle-Van Buren town line. Depth to water is approximately 25 feet.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Loam, fine sandy, brown; silt	0 - 7	7
Silt, brown	7 - 12	5
Gravel, coarse, silty	12 - 13	1
Sand, medium to coarse	12 - 25	13
Sand, very course, with occasional layers of brown silty clay	25 - 30	5
Sand, gradation from fine to medium to very coarse, silt near lower portion of interval, brown	30 - 40	10
Sand, medium to coarse, silty, gray	40 - 47	7
Silt, very fine sandy, brown, with occasional 1/2 inch thick layers of black organic matter	47 - 69	22
End of boring	69 -	--

OW 84-2 is screened from 37 to 42 feet below land surface with a 0.008-inch slotted schedule-40 PVC screen.

Table 12.--Observation-well logs and test-boring, Map 84 Area--(Continued)
[--, An aquifer "Thickness" value is not relevant for the "End of boring" depths]

TH 84-1. Latitude: 47°14'23" N., Longitude: 68°37'35" W.
Located approximately 1.1 river miles upstream of the St. John River border crossing bridge in Fort Kent. The boring was drilled near the edge of a field approximately 200 feet south of the St. John River. When drilling, a perched water table was encountered at 10 feet. The installed observation well was dry after pumping.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Loam, fine sandy, dark brown	0 - 2	2
Sand, medium, with silt	2 - 7	5
Sand, medium, wet, with silt	7 - 12	5
Clay, silty, grayish brown	12 - 17	5
Clay, silt, gray	17 - 42	25
End of boring	42 -	--

An observation well was installed and screened from 17.88 to 32.88 feet below land surface, but when the well was pumped, it did not recharge.

Table 13.--Observation-well logs, Map 85 Area
[See Table 9 for explaination of terms;
--, An aquifer "Thickness" value is not
relevant for the "End of boring" depths]

OW 85-1. Latitude: 47°19'31" N., Longitude: 68°09'44" W.
Located about 270 feet from the south bank of the St. John River and approximately 1.0 mile downstream from the Madawaska-Grand Isle town line. The water table is approximately 37 feet below land surface.

MATERIAL	DEPTH (feet)	THICKNESS (feet)
Loam, fine sandy, brown	0 - 2	2
Silt, very fine sandy, light brown	2 - 5	3
Silt, fine sandy, gray	5 - 16	11
Silt, fine sandy, gray, with gravel layers; angular pebbles to 1/2 inch	16 - 27	11
Silt, very fine sandy, light brown, alternating with layers of very fine sandy silt, with clay and occasional 1 inch pebbles	27 - 37	10
Sand, very fine, silty; alternating with layers of sandy silt, brown	37 - 40	3
Silt, very fine sandy, gray	40 - 53	13
Sand, very fine, silty, dark gray; with alternating layers of gray clay, silt, with occasional angular pebbes to 1/2 inch	53 -107	54
End of boring	107 -	--

OW 85-1 is screened from 37 to 47 feet below land surface with a 0.008-inch slotted schedule-40 PVC screen.

Table 14.--Depth to water and depth to bedrock based on single-channel seismic data
[>, greater than]

Aquifer map number	Seismic-line identifier[1]	US Geological Survey topographic quadrangle	Town	Length of line (feet)	Depth to water (feet) A[2]	Depth to water (feet) B[2]	Depth to bedrock (feet) A[2]	Depth to bedrock (feet) B[2]	Comments
Map 75	ASH-A	Ashland	Ashland	270	12	12	62	65	Bedrock outcrops 300 to 350 feet away.
Map 75	ASH-E	Ashland	Ashland	130	6	7	44	13	
Map 75	ASH-H	Ashland	Ashland	160	4	6	42	38	In gravel pit, 50 feet of sand and gravel removed.
Map 75	ASH-I	Ashland	Ashland	200	6	7	>124	>124	
Map 75	ASH-J	Ashland	Ashland	200	6	6	78	36	
Map 75	ASH-K	Ashland	Masardis	240	8	10	62	55	Line is 10-15 feet above Aroostook River.
Map 75	ASH-L	Ashland	Ashland	220	9	8	68	87	
Map 75	ASH-M	Ashland	Ashland	150	12	8	>88	>95	
Map 75	ASH-N	Ashland	Ashland	230	12	10	55	71	
Map 75	MAP-A	Mapleton	Mapleton	140	16	18	42	38	
Map 75	MAP-C	Mapleton	Chapman	160	5	1	43	45	
Map 75	MAP-D	Mapleton	Chapman	160	2	2	36	48	In gravel pit, 15 to 75 feet of sand and gravel removed.
Map 75	MAP-E	Mapleton	Chapman	160	9	6	>95	>94	In gravel pit, 25 feet of sand and gravel removed.
Map 75	MAP-G	Mapleton	Chapman	170	2	2	>101	>101	
Map 75	MAP-H	Mapleton	Chapman	120	4	4	>59	>62	
Map 75	MAP-I	Mapleton	Chapman	80	6	5	27	21	
Map 75	OXB-A	Oxbow	Oxbow Plt.	150	8	8	44	98	Line is 10 feet above Aroostook River.
Map 76	BRG-A	Bridgewater	Blaine	80	5	3	12	24	
Map 76	BRG-C	Bridgewater	Bridgewater	120	8	6	28	35	
Map 76	EAC-A	Easton Center	Ft. Fairfield	130	4	4	34	38	

Table 14.--Depth to water and depth to bedrock based on single-channel seismic data--(Continued)
[>, greater than]

Aquifer map number	Seismic-line identifier[1]	US Geological Survey topographic quadrangle	Town	Length of line (feet)	Depth to water (feet) A[2]	Depth to water (feet) B[2]	Depth to bedrock (feet) A[2]	Depth to bedrock (feet) B[2]	Comments
Map 76	EAS-A	Easton	Presque Isle	150	7	9	32	34	
Map 76	ECL-E	Echo Lake	Presque Isle	110	13	11	31	41	
Map 76	HOW-C	Howe Brook	T9 R3 WELS	100	5	7	33	24	
Map 76	MAR-A	Mars Hill	Mars Hill	70	3	4	16	11	
Map 76	PAC-A	Packard Lake	E Plantation	180	6	7	69	43	
Map 76	PAC-B	Packard Lake	E Plantation	80	5	6	18	24	Pond surface 4 feet below line.
Map 76	PAC-C	Packard Lake	Bridgewater	60	4	5	11	18	
Map 76	PRI-A	Presque Isle	Presque Isle	110	5	6	29	>43	
Map 76	PRI-C	Presque Isle	Mapleton	130	11	10	36	44	Water surface in adjacent pit is 8 feet below line.
Map 76	PRI-G	Presque Isle	Presque Isle	170	6	7	54	63	
Map 76	PRI-I	Presque Isle	Presque Isle	80	6	6	17	19	
Map 76	PRI-J	Presque Isle	Presque Isle	160	5	6	61	44	Standing water 2-3 feet below line.
Map 76	PRI-X	Presque Isle	Presque Isle	100	6	5	32	28	
Map 76	PRI-Y	Presque Isle	Presque Isle	110	6	5	36	41	
Map 76	WTF-A	Westfield	Mars Hill	100	8	8	31	20	
Map 76	WTF-D	Westfield	Westfield	110	3	5	37	20	
Map 76	WTF-E	Westfield	Westfield	100	6	5	27	24	Line is 15 feet above Prestile Stream.
Map 76	WTF-F	Westfield	Mars Hill	70	5	5	10	14	
Map 77	CAR-B	Caribou	Washburn	220	13	11	60	74	
Map 77	CAR-D	Caribou	Washburn	130	6	7	54	35	Standing water 10-15 feet line.
Map 77	CAR-E	Caribou	Washburn	80	6	8	18	18	
Map 77	CAR-F	Caribou	Caribou	80	5	4	22	29	
Map 77	CAR-G	Caribou	Woodland	110	6	7	37	53	

Table 14.--Depth to water and depth to bedrock based on single-channel seismic data--(Continued).
[>, greater than]

Aquifer map number	Seismic-line identifier[1]	US Geological Survey topographic quadrangle	Town	Length of line (feet)	Depth to water (feet) A[2]	Depth to water (feet) B[2]	Depth to bedrock (feet) A[2]	Depth to bedrock (feet) B[2]	Comments
Map 77	FNW-B	Ft. Fairfield, NW	Caribou	150	13	11	34	64	
Map 77	FNW-F	Ft. Fairfield, NW	Caribou	200	6	5	67	42	
Map 77	FNW-G	Ft. Fairfield, NW	Limestone	100	12	11	39	29	
Map 77	FTF-D	Ft. Fairfield, NW	Ft. Fairfield	120	7	6	16	22	
Map 77	FTF-F	Ft. Fairfield, NW	Ft. Fairfield	150	15	15	75	62	
Map 77	GWN-H	Goodwin	Ft. Fairfield	200	9	4	55	67	
Map 77	GWN-L	Goodwin	Caribou	120	9	8	33	28	
Map 77	LIM-B	Limestone	Caswell	90	11	6	20	37	Small pond 10 feet below line.
Map 77	NWS-G	New Sweden	Caribou	100	6	7	23	15	
Map 77	NWS-I	New Sweden	Woodland	90	9	7	26	25	
Map 77	NWS-J	New Sweden	Connor	220	4	7	75	67	
Map 77	VBN-A	Van Buren	Cyr	80	6	6	25	25	
Map 77	VBN-C	Van Buren	Hamlin	190	9	6	>61	>65	
Map 77	VBN-D	Van Buren	Cyr	170	9	11	78	34	
Map 77	VBN-G	Van Buren	Van Buren	90	8	8	28	43	
Map 78	POR-A	Portage	T13 R5	200	10	5	48	60	Water surface 10 feet below line.
Map 78	SKH-F	Stockholm	T16 R4	100	6	5	14	24	
Map 78	WHB-A	Washburn	Wade	100	9	8	31	20	Bedrock outcrop on opposite riverbank.
Map 78	WHB-B	Washburn	Washburn	80	0	0	10	15	Bedrock outcrop nearby.
Map 78	WHB-C	Washburn	Wade	110	7	6	26	44	
Map 78	WHB-H	Washburn	Washburn	120	19	20	56	46	
Map 78	WHB-I	Washburn	Washburn	160	11	10	71	60	
Map 78	WHB-P	Washburn	Washburn	90	7	6	21	11	
Map 78	WHB-O	Washburn	Washburn	120	6	7	30	40	

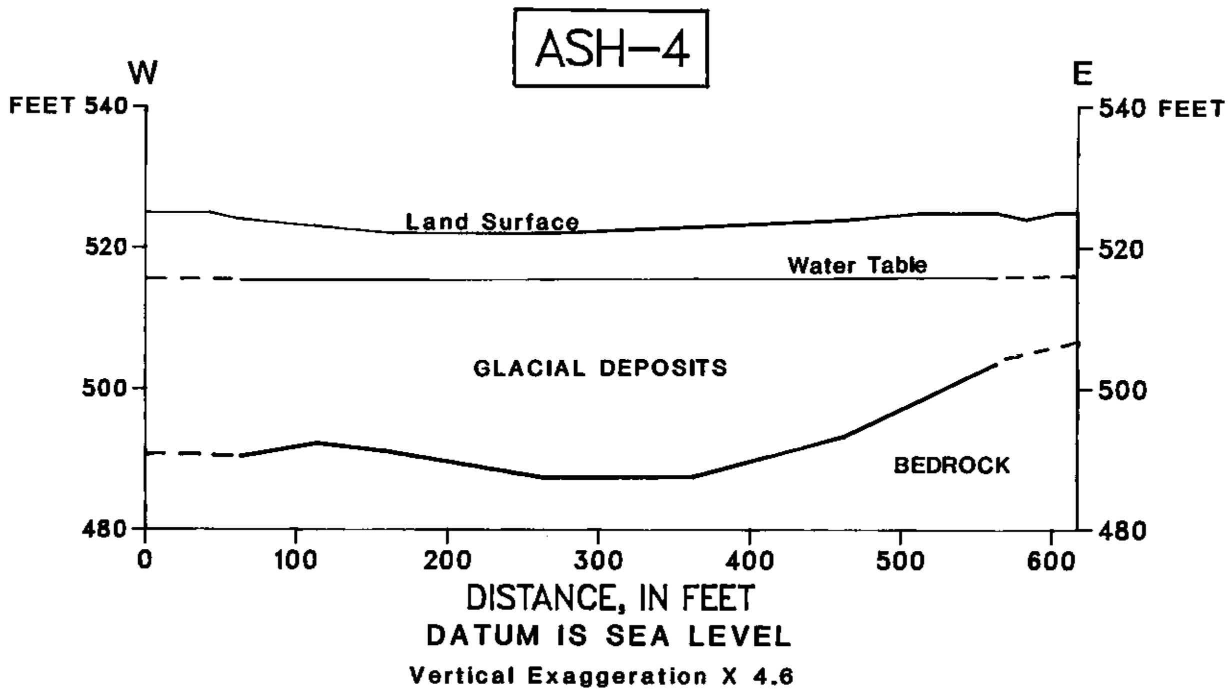
Table 14.--Depth to water and depth to bedrock based on single-channel seismic data--(Continued).
[>, greater than]

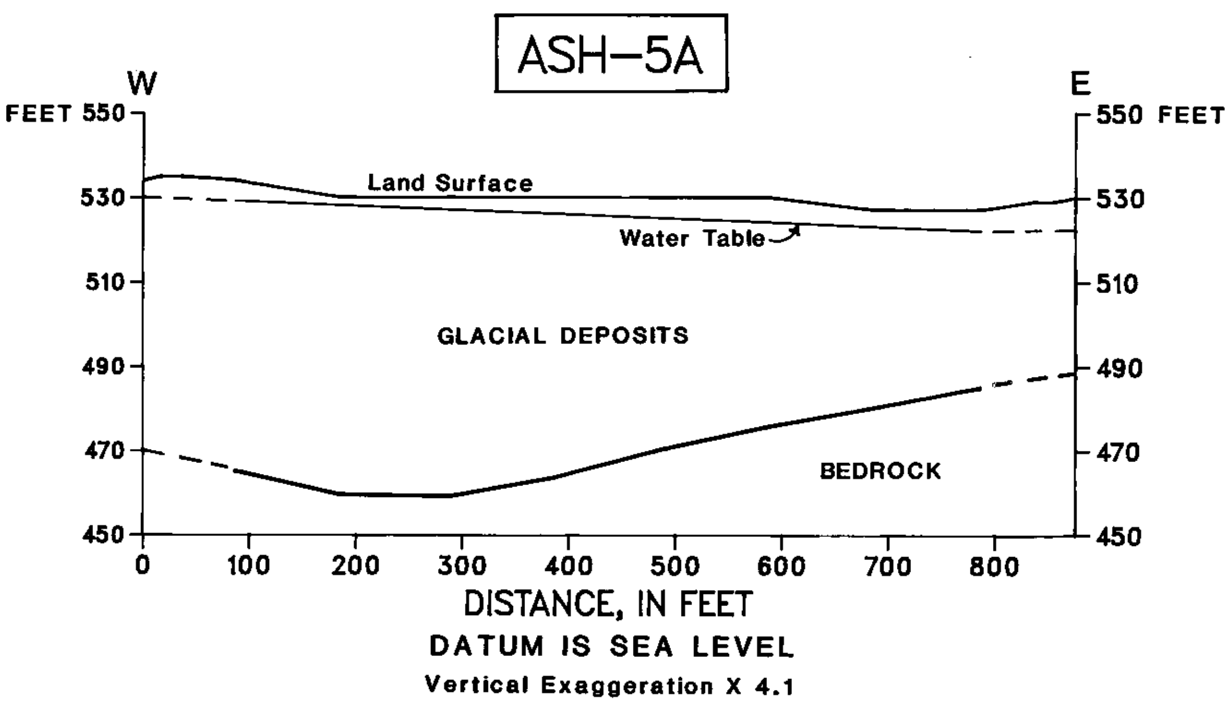
Aquifer map number	Seismic-line identifier[1]	US Geological Survey topographic quadrangle	Town	Length of line (feet)	Depth to water (feet) A[2]	Depth to water (feet) B[2]	Depth to bedrock (feet) A[2]	Depth to bedrock (feet) B[2]	Comments
Map 84	ELK-B	Eagle Lake	Wallagrass	80	5	7	22	18	Bedrock in streambed 20 feet below line.
Map 84	ELK-D	Eagle Lake	Fort Kent	290	10	6	>102	87	
Map 84	ELK-E	Eagle Lake	Fort Kent	220	14	11	61	58	
Map 84	ELK-G	Eagle Lake	St. John	180	12	6	>73	>68	
Map 84	ELK-H	Eagle Lake	Fort Kent	150	12	11	>64	>64	Bedrock outcrops nearby.
Map 84	ELK-I	Eagle Lake	Fort Kent	170	13	17	>67	>70	
Map 84	FTK-A	Fort Kent	Fort Kent	160	14	18	>67	>71	On flood plain of St. John River.
Map 84	FTK-B	Fort Kent	Fort Kent	160	19	17	58	61	
Map 84	GDI-F	Grand Isle	Grand Isle	200	9	8	35	85	
Map 84	SKH-C	Stockholm	Grand Isle	80	6	5	13	13	
Map 84	SKH-D	Stockholm	Van Buren	250	6	8	>90	>91	
Map 84	STF-A	St. Francis	St. John	160	28	28	53	56	
Map 84	STF-C	St. Francis	St. Francis	300	13	13	139	79	
Map 85	FRV-C	Frenchville	St. Agatha	100	12	10	47	30	Lake surface 15-20 feet below line.
Map 85	FRV-I	Frenchville	Madawaska	100	6	6	29	22	
Map 85	GDI-B	Grand Isle	Grand Isle	200	27	25	>92	>91	
Map 85	GDI-D	Grand Isle	Madawaska	200	24	23	>92	>91	St. John River 25-30 feet below line.
Map 85	GDI-E	Grand Isle	Grand Isle	210	13	19	76	72	
Map 85	GDI-G	Grand Isle	Madawaska	240	15	12	54	107	
Map 85	SKH-A	Stockholm	T17 R4	90	5	5	12	22	
Map 85	SQL-B	Square Lake	St. Agatha	120	6	5	26	34	
Map 85	SQL-D	Square Lake	T17 R5	90	6	5	13	19	
Map 85	SQL-H	Square Lake	T17 R4	90	2	3	11	9	

1 Location of all seismic lines is shown on plates 1-6.
2 Refers to orientation of line; A is the western end of the line, B is the eastern end of the line.

Figure 8.--12-channel seismic-refraction profiles: Plate 1, Map 75 Area

Hydrogeologic sections from seismic-refraction surveys conducted by the U.S. Geological Survey in 1986. 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.





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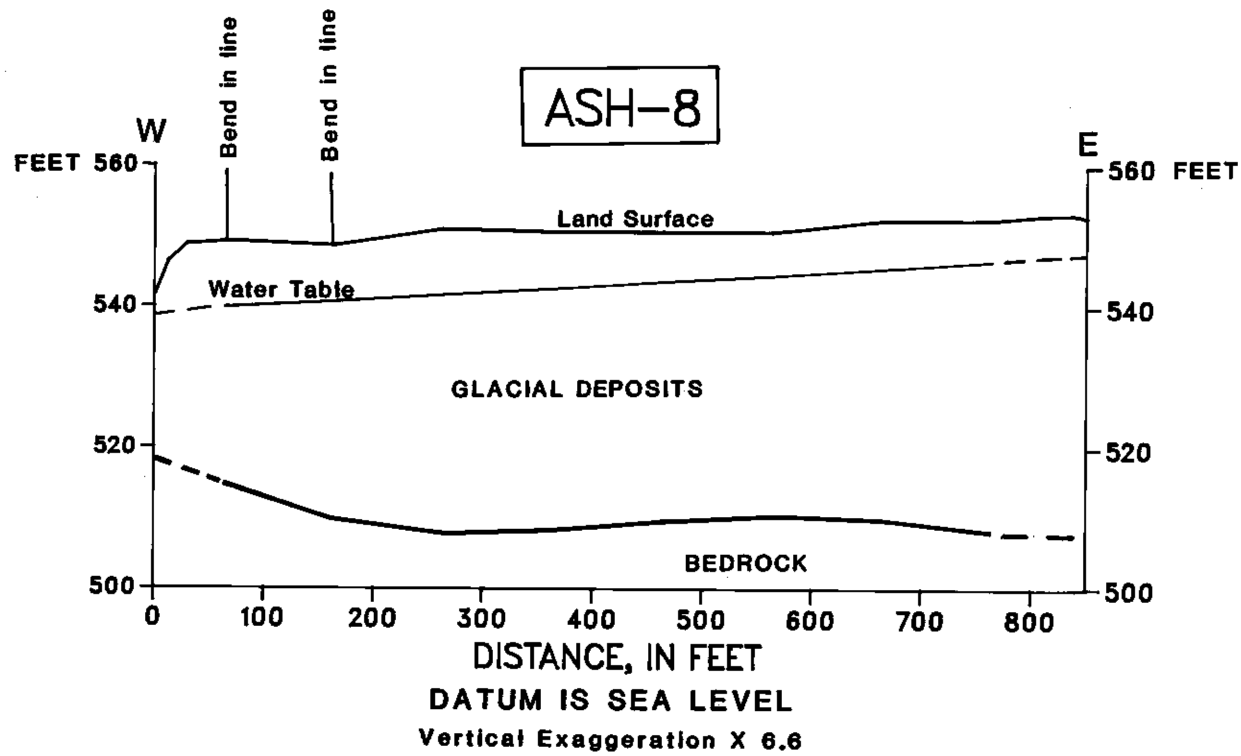

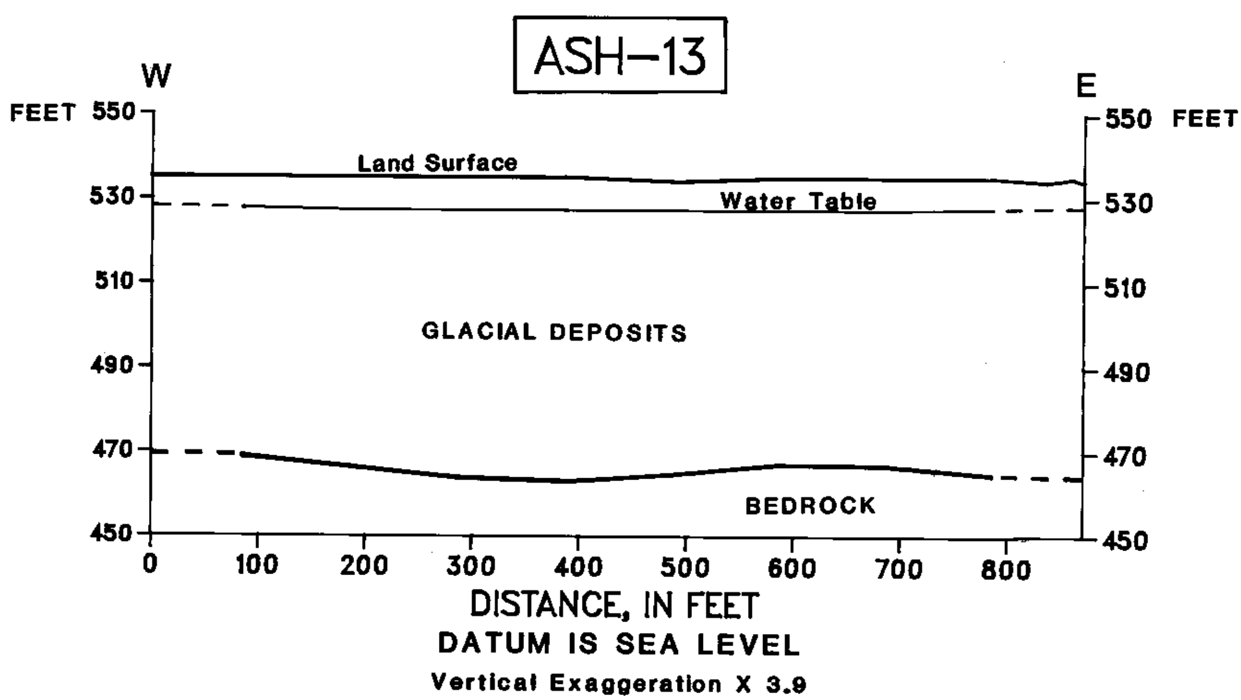

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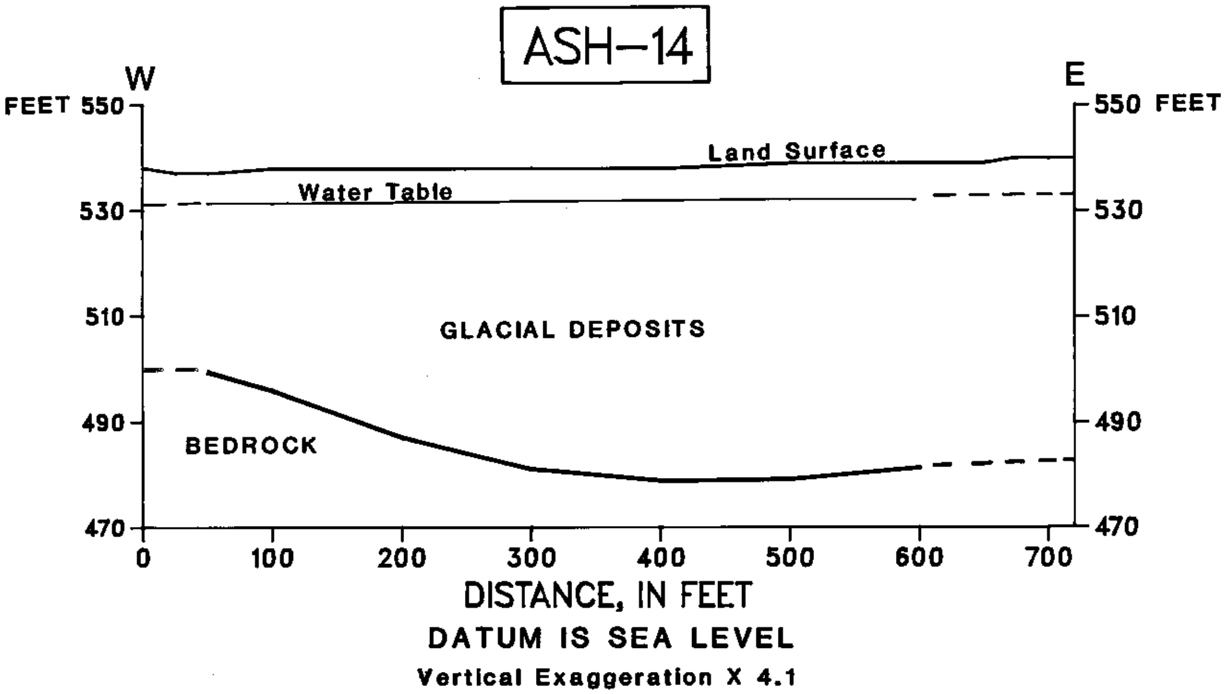


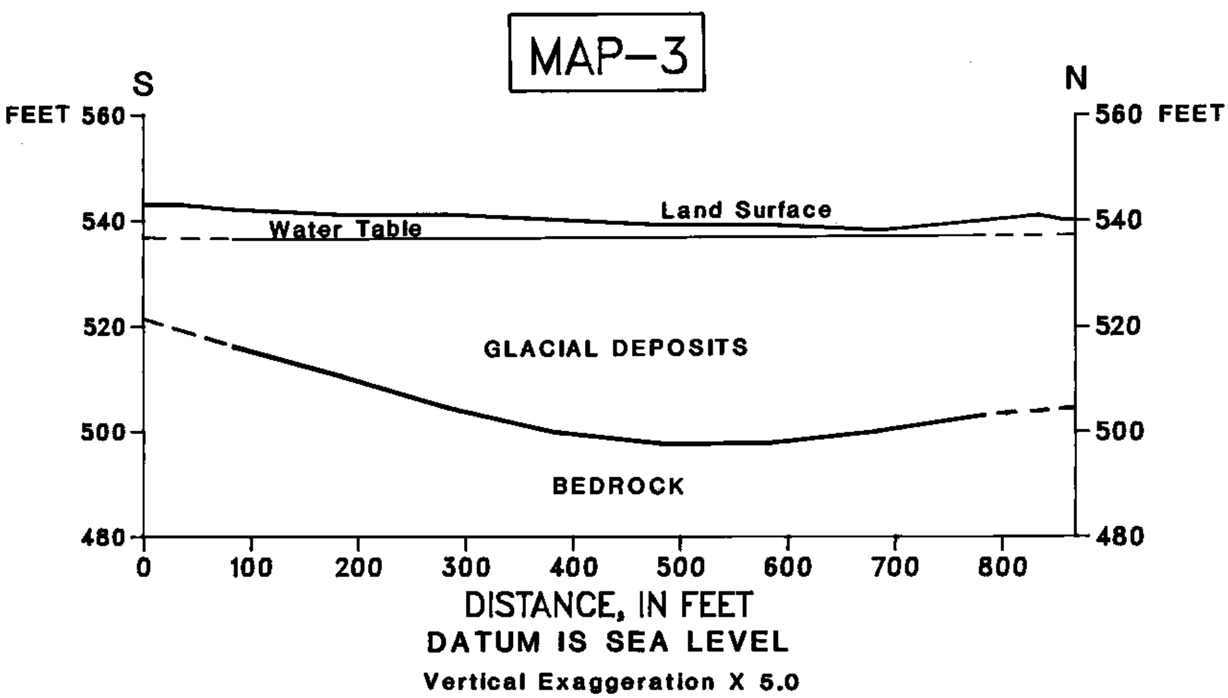
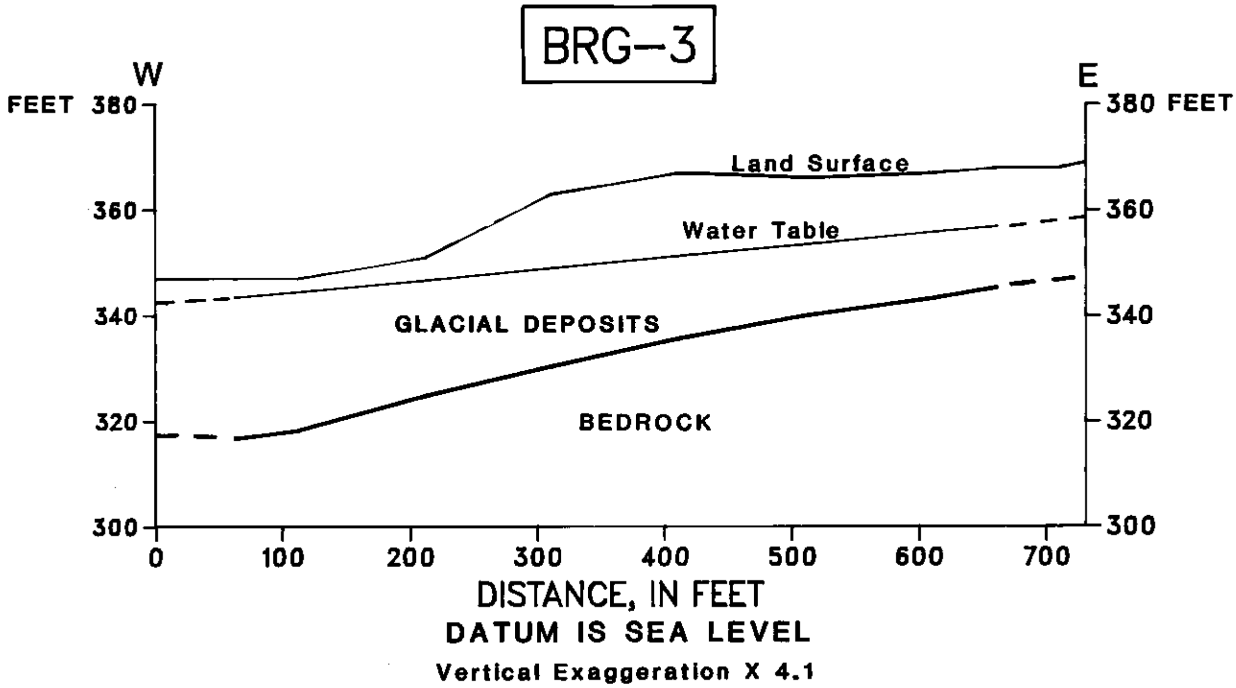
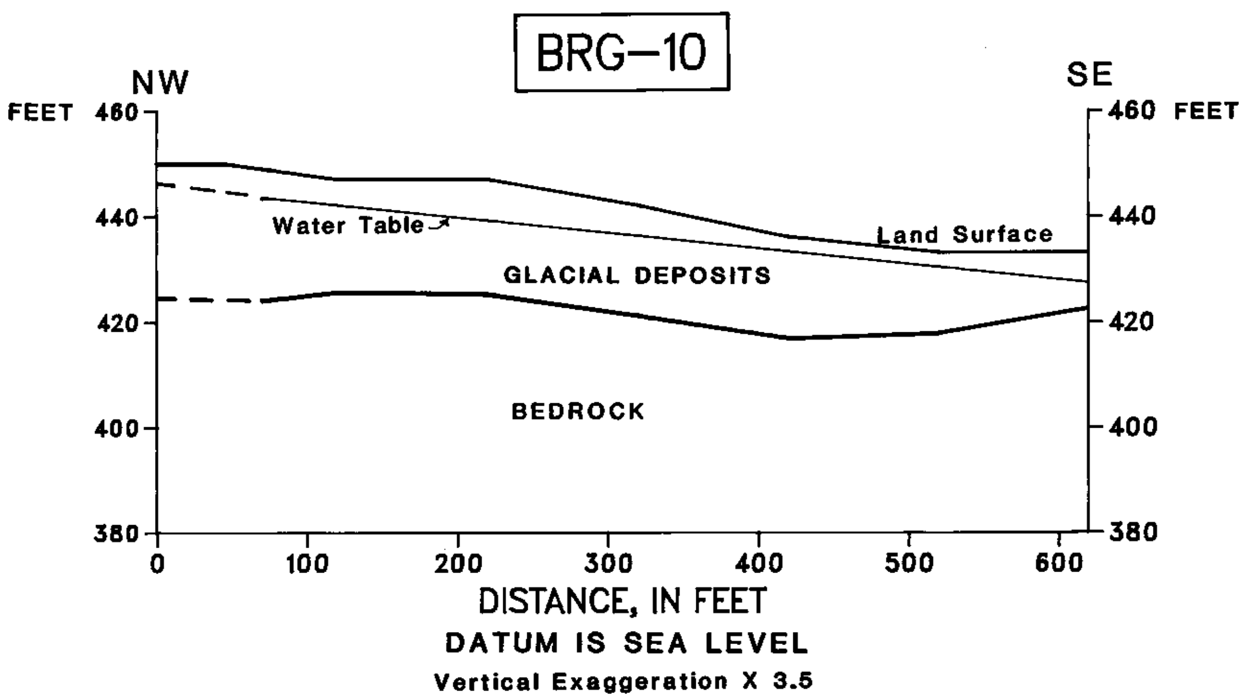


Figure 9.--12-channel seismic-refraction profiles: Plate 2, Map 76 Area

Hydrogeologic sections from seismic-refraction surveys conducted by the U.S. Geological Survey in 1986. 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 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.





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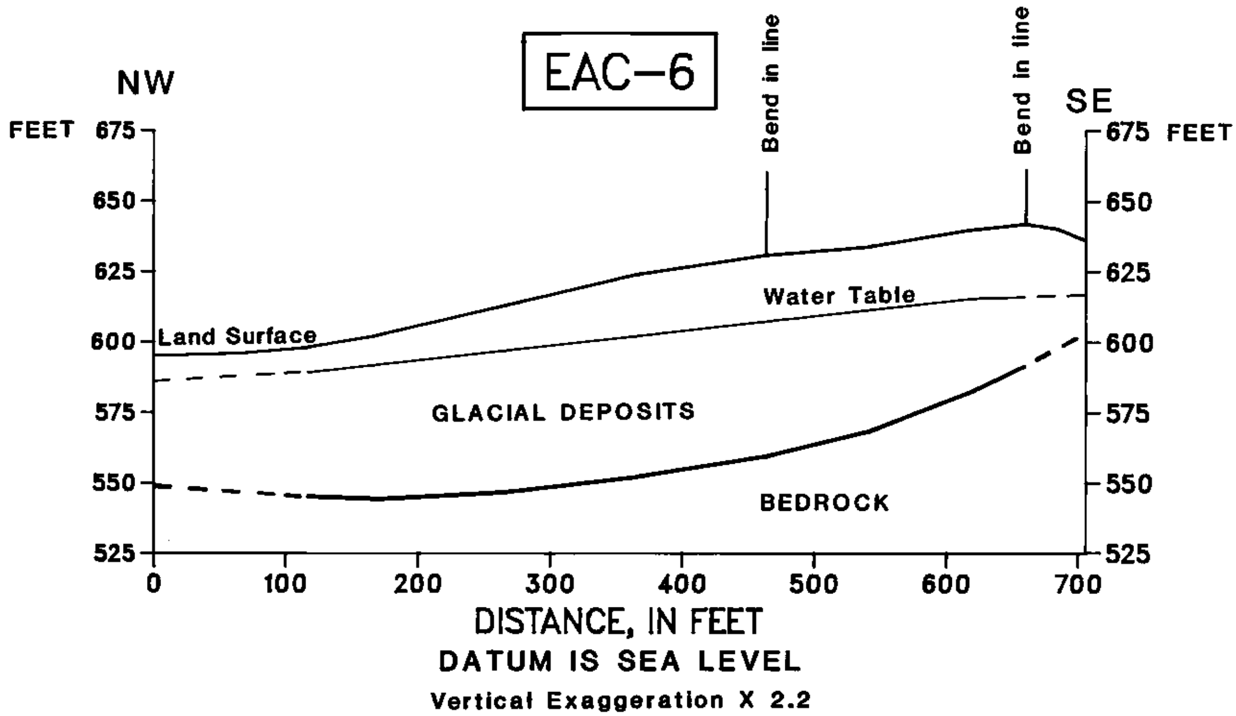

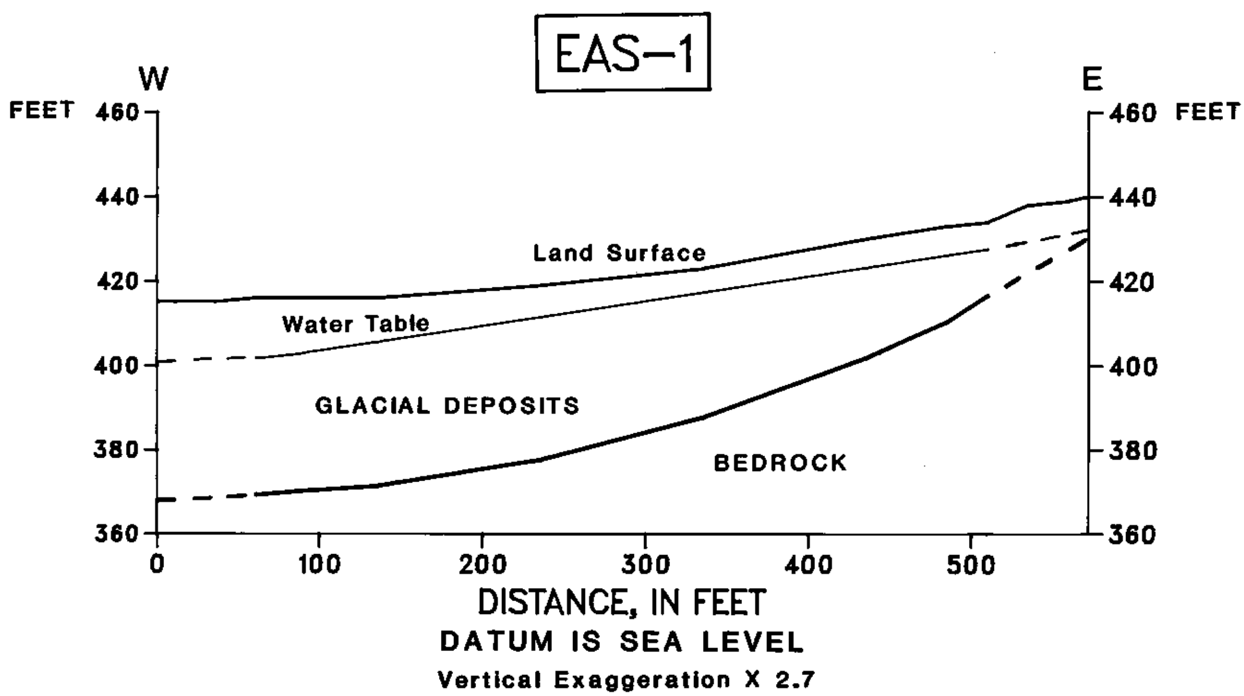

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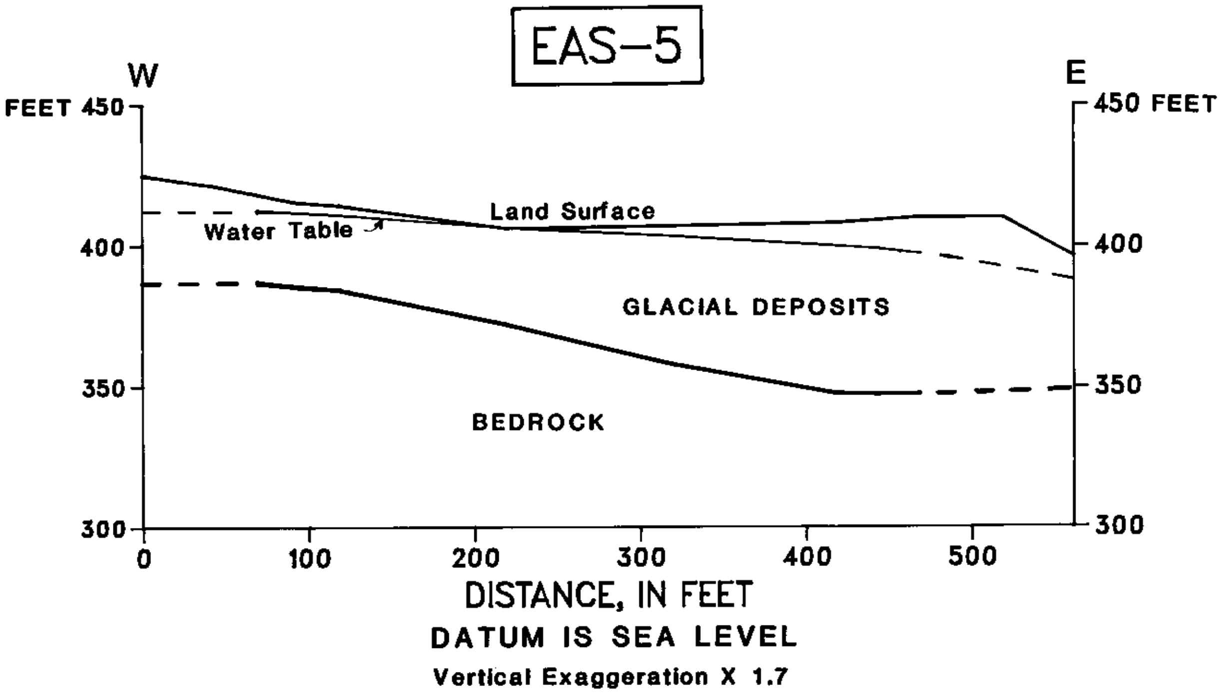

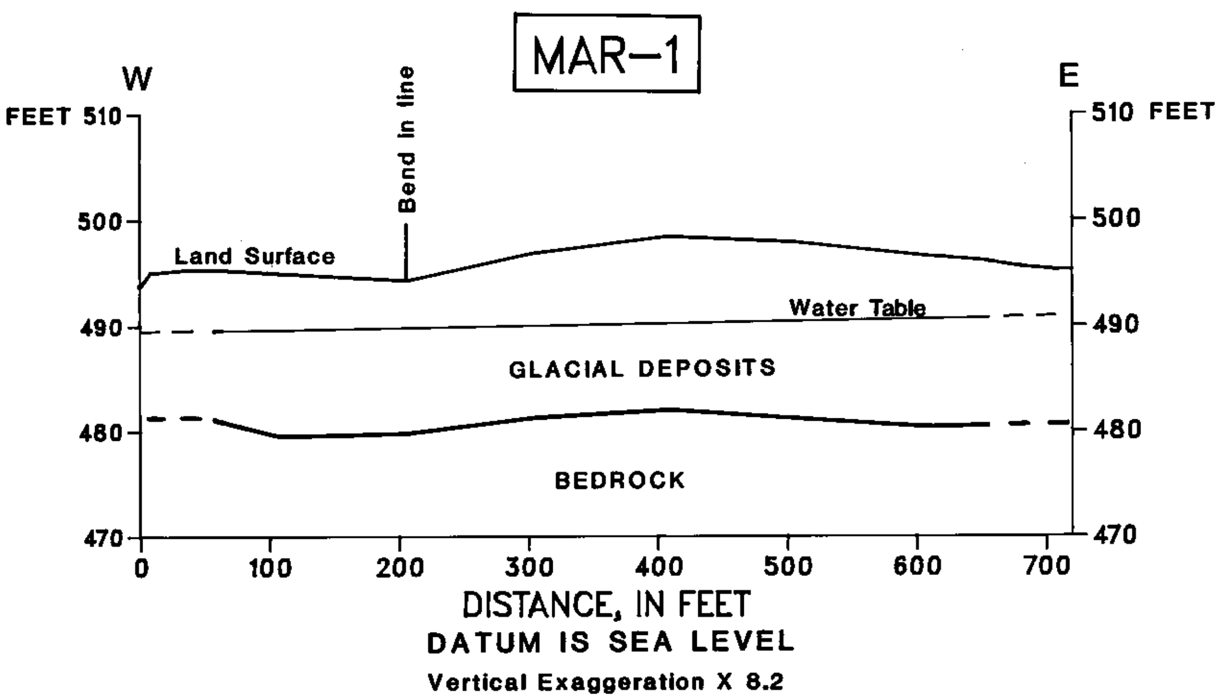

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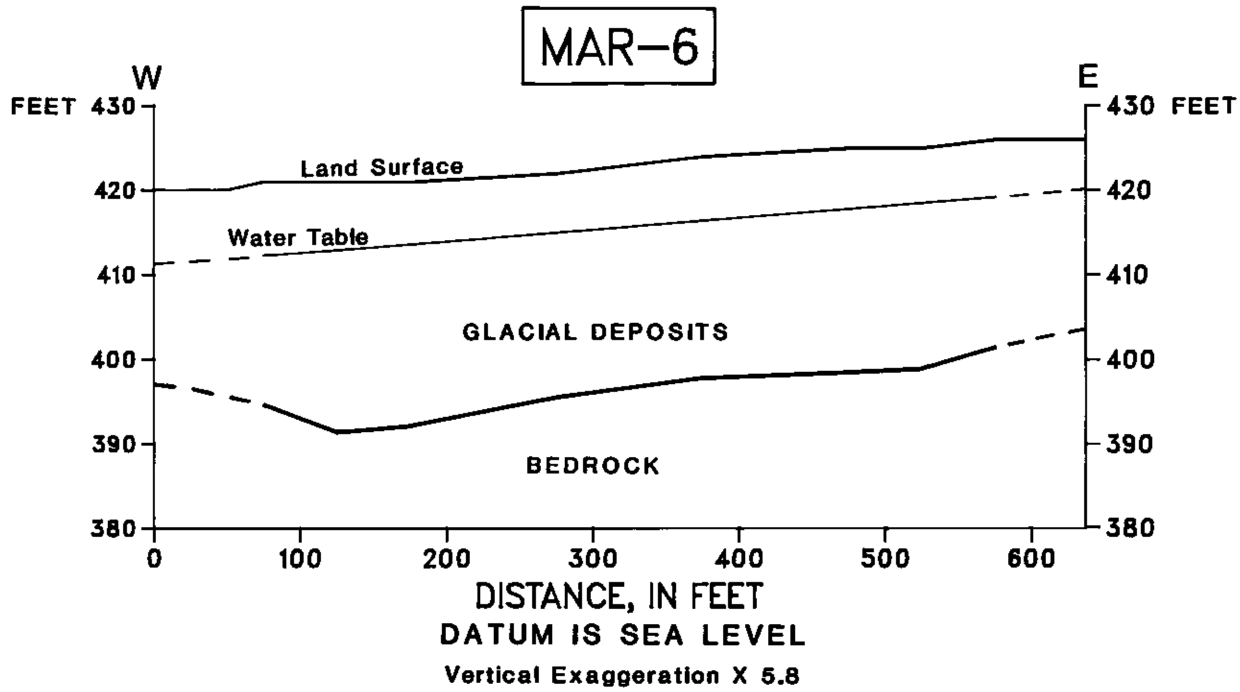

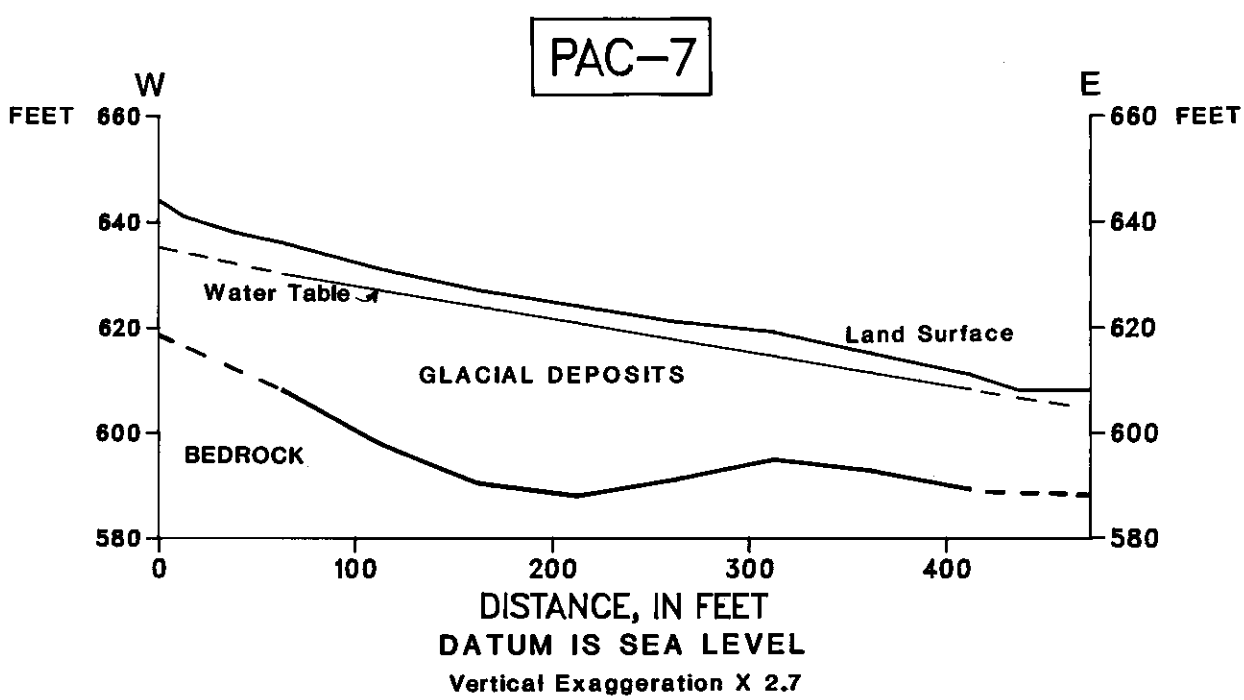

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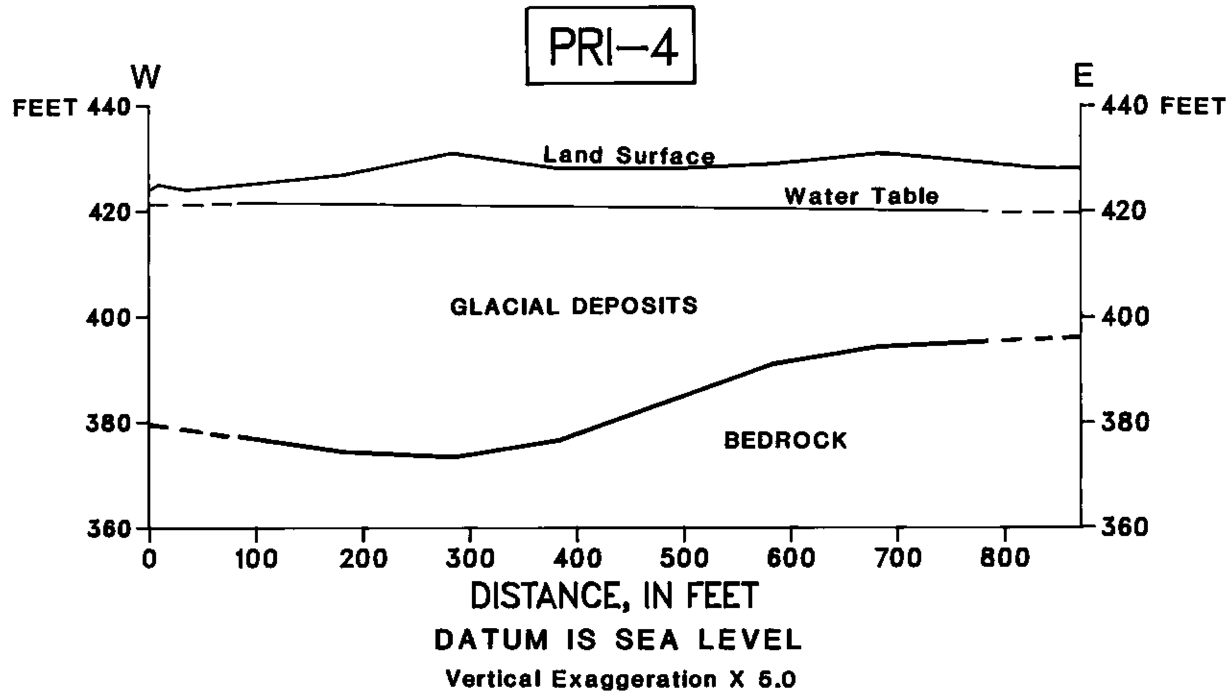

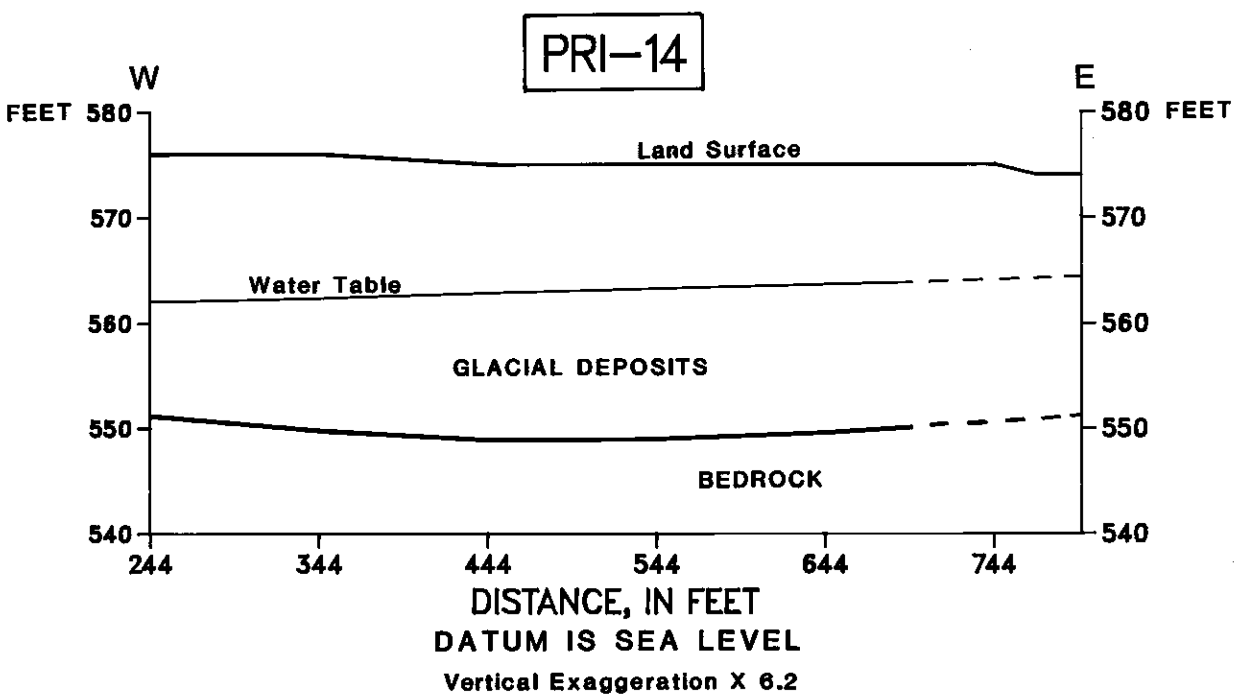

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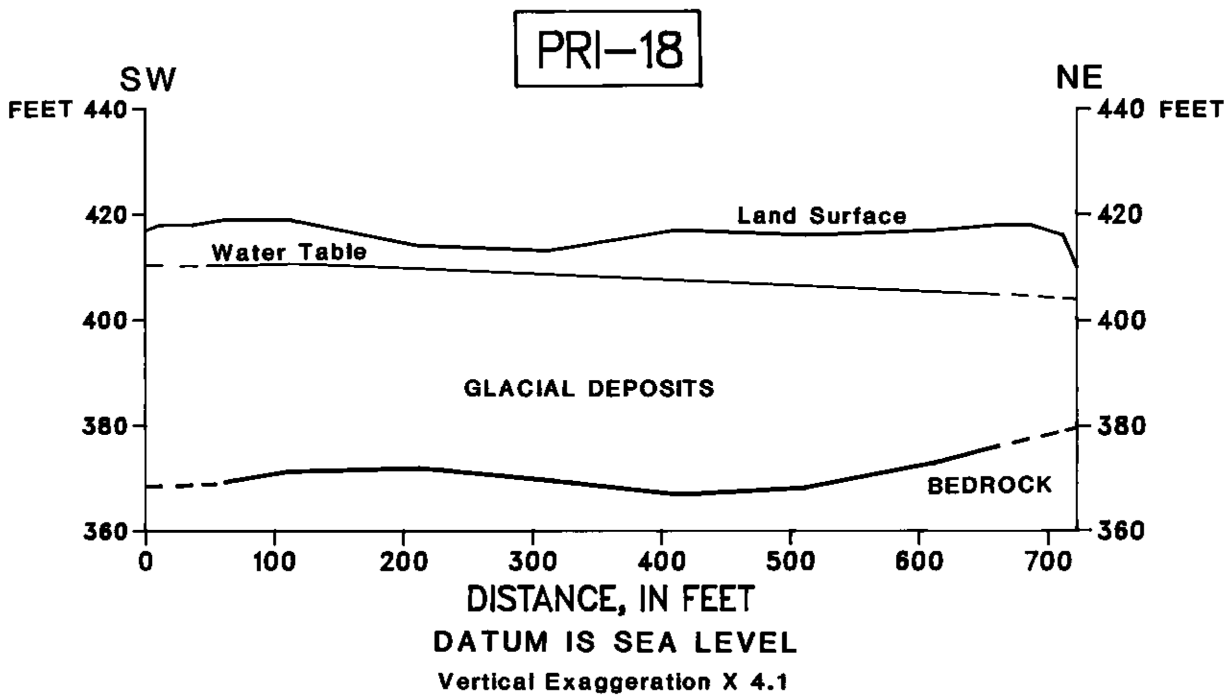

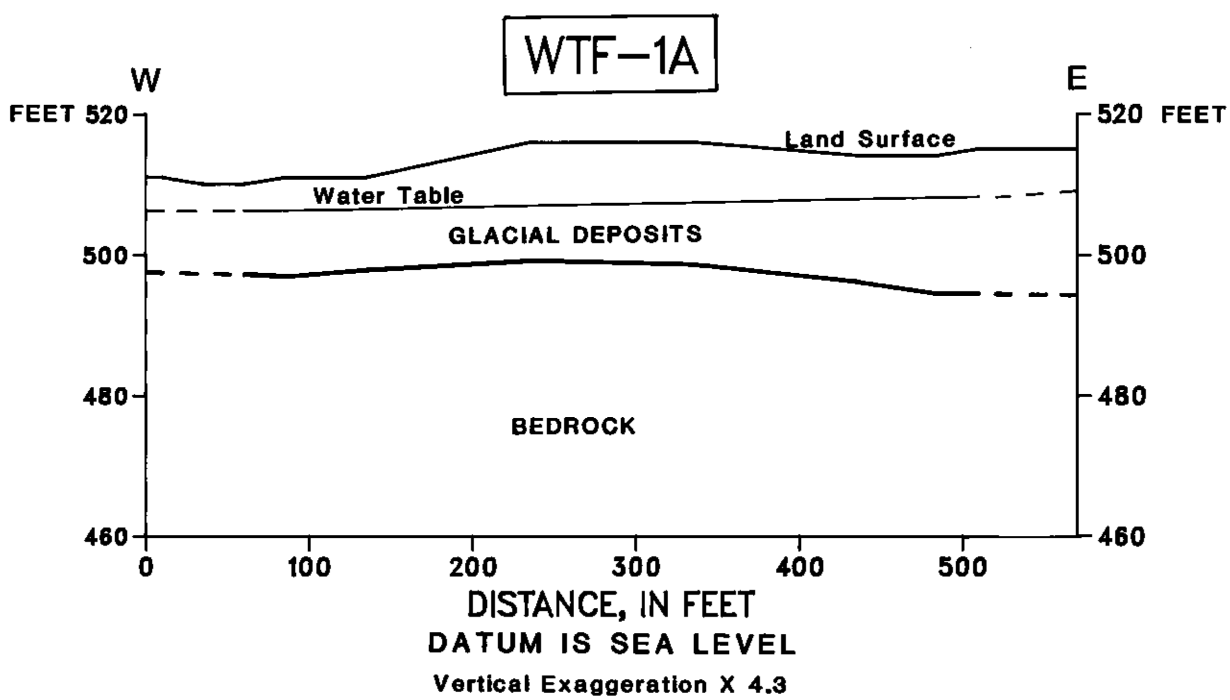

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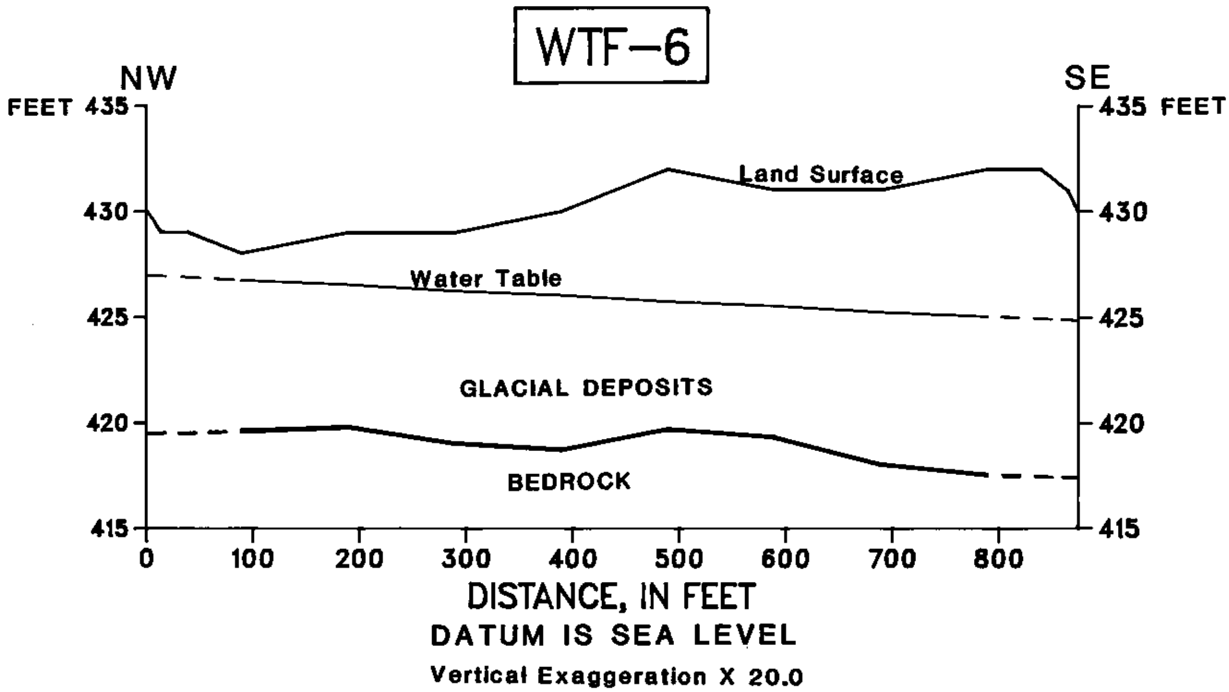
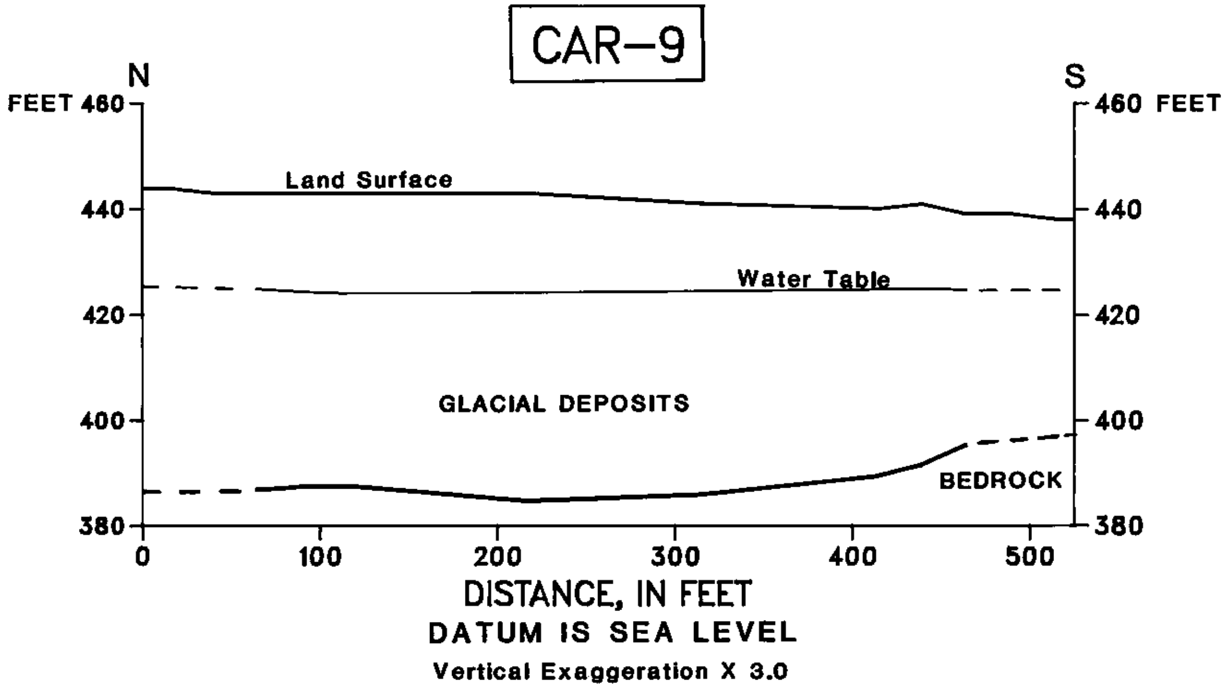
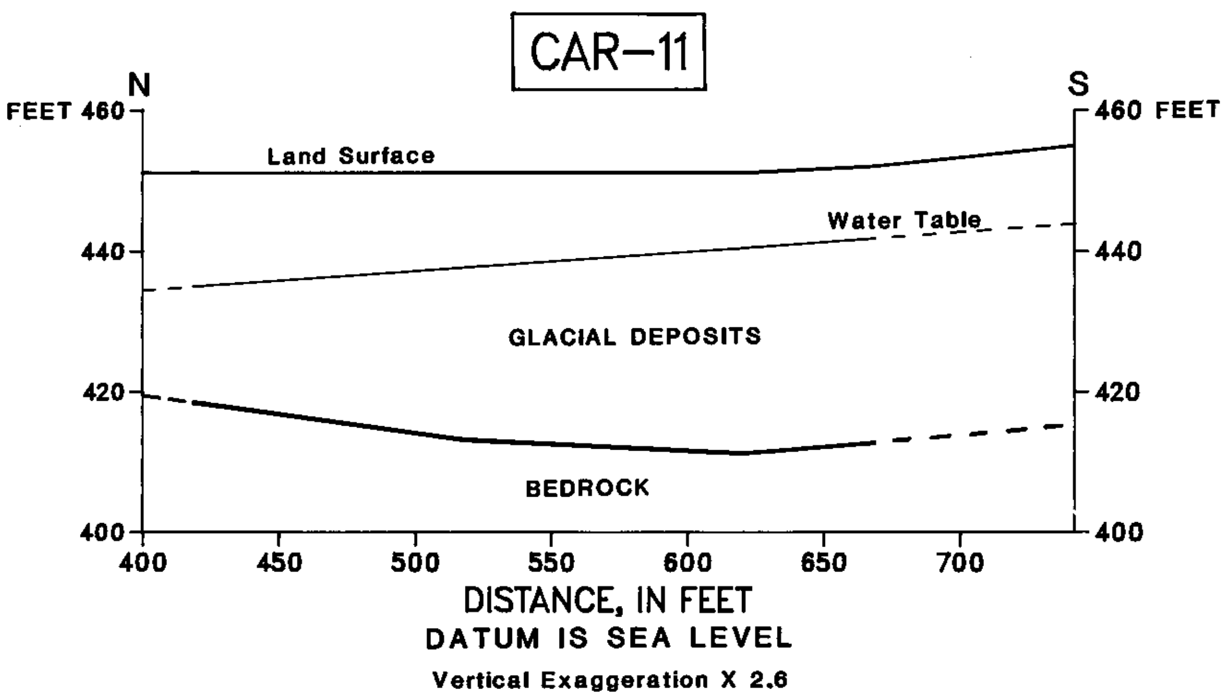


Figure 10.--12-channel seismic-refraction profiles: Plate 3, Map 77 Area

Hydrogeologic sections from seismic-refraction surveys conducted by the U.S. Geological Survey in 1986. 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 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.





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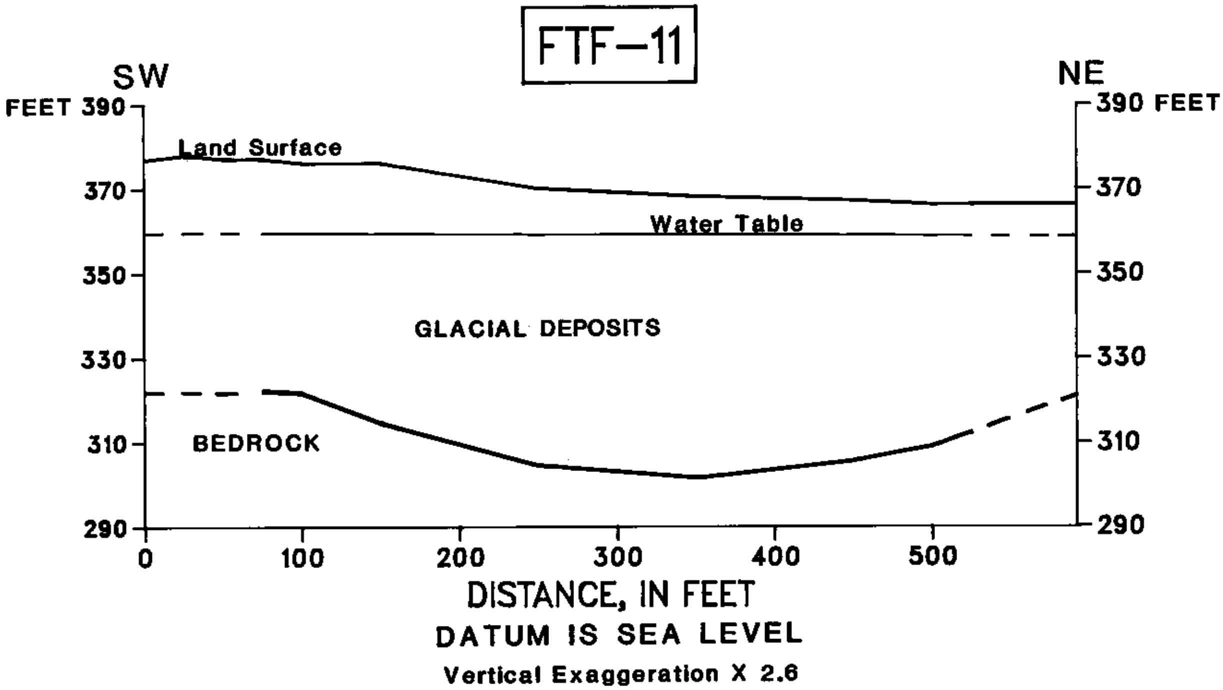

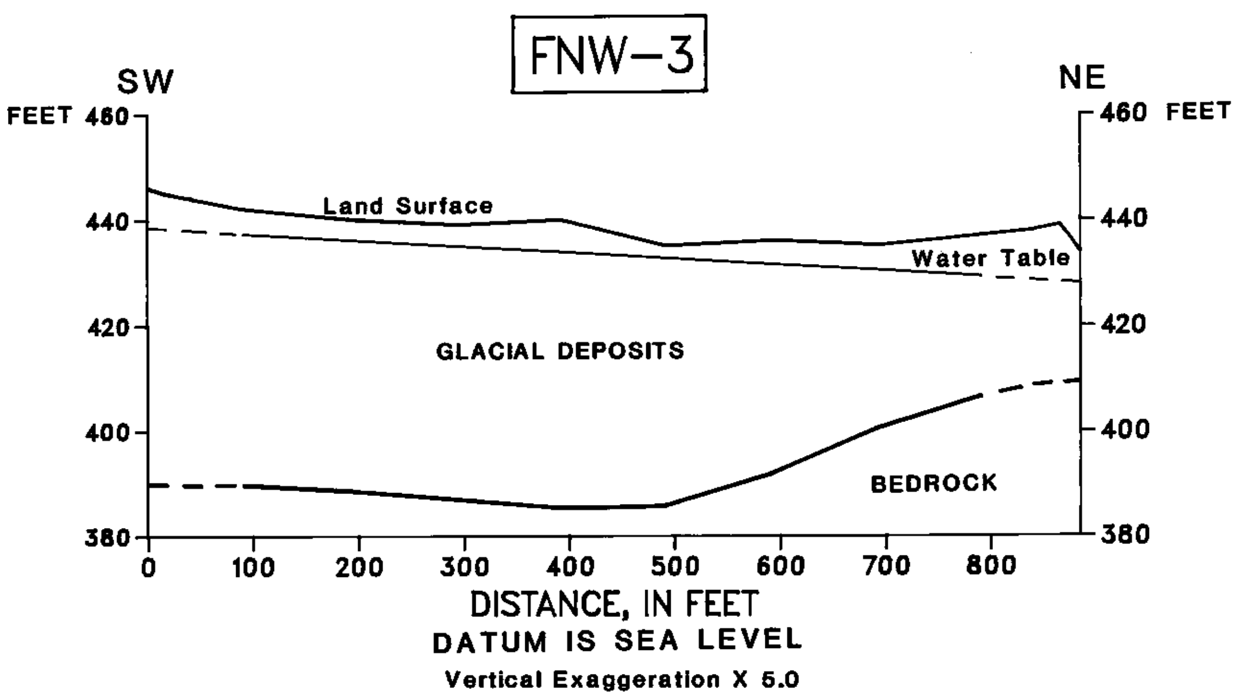

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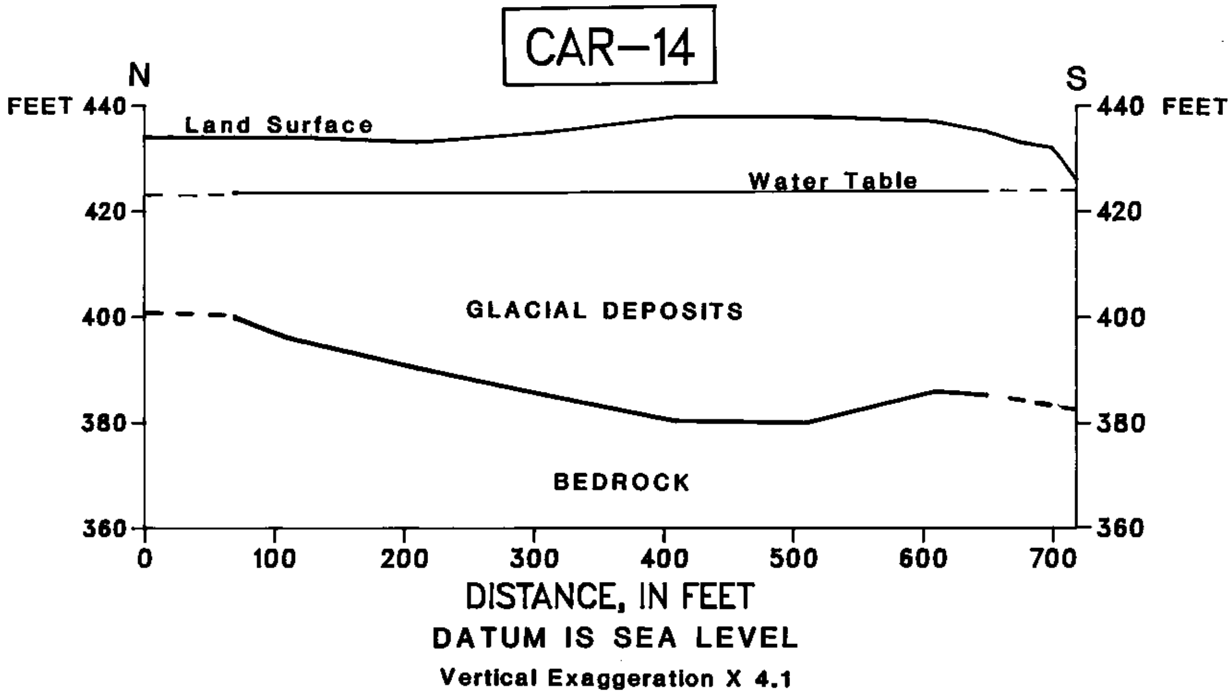

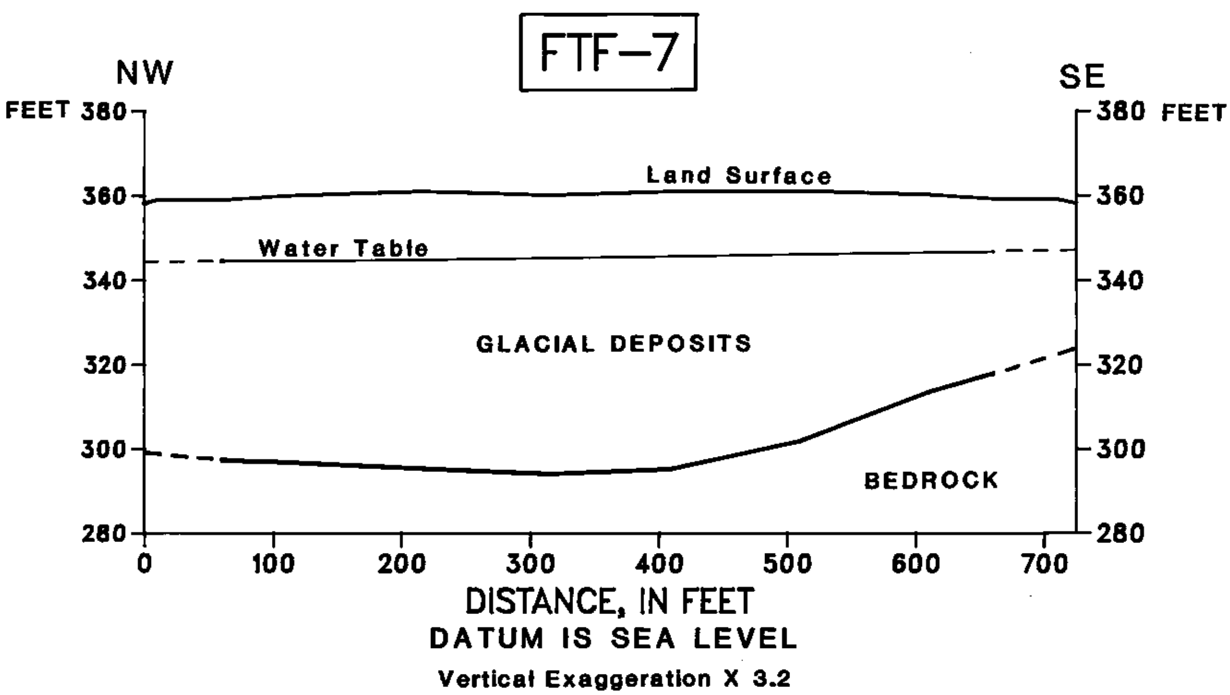

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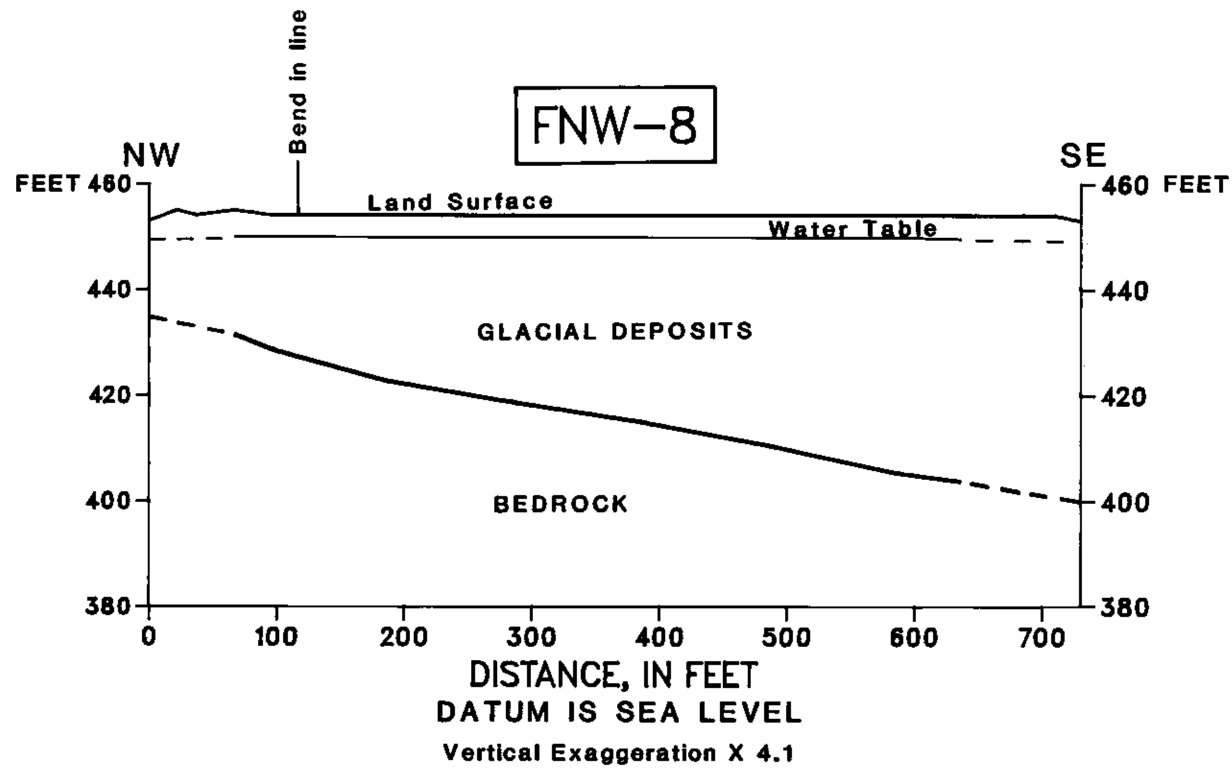

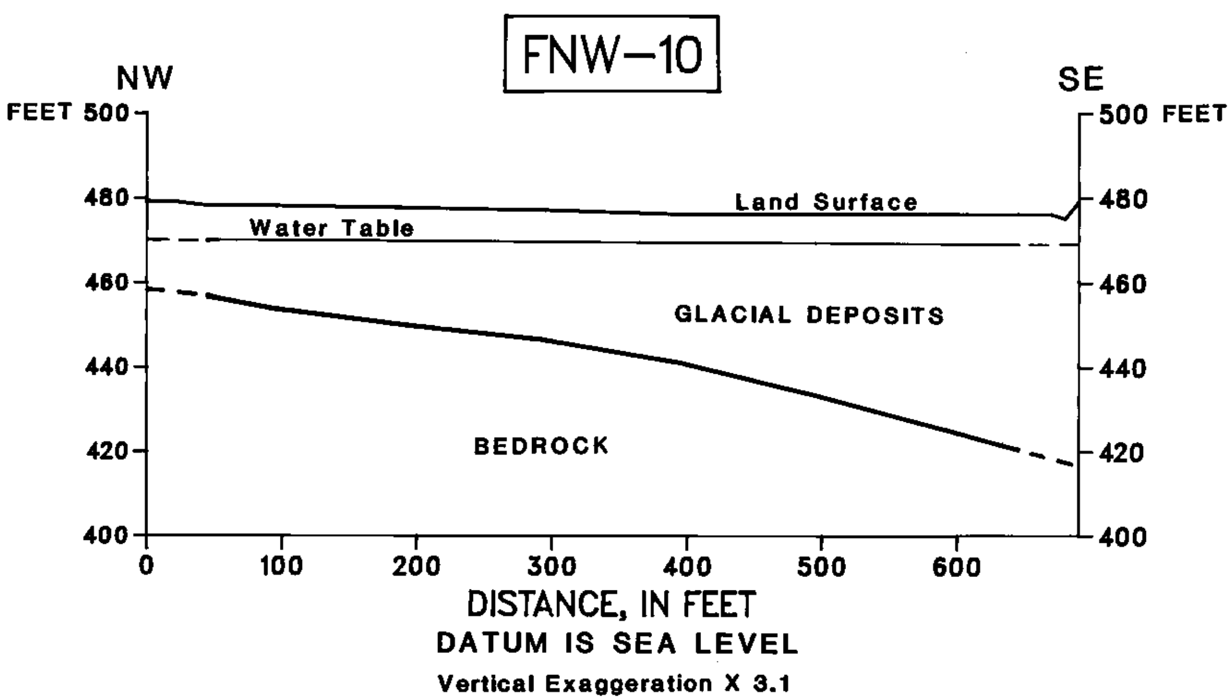

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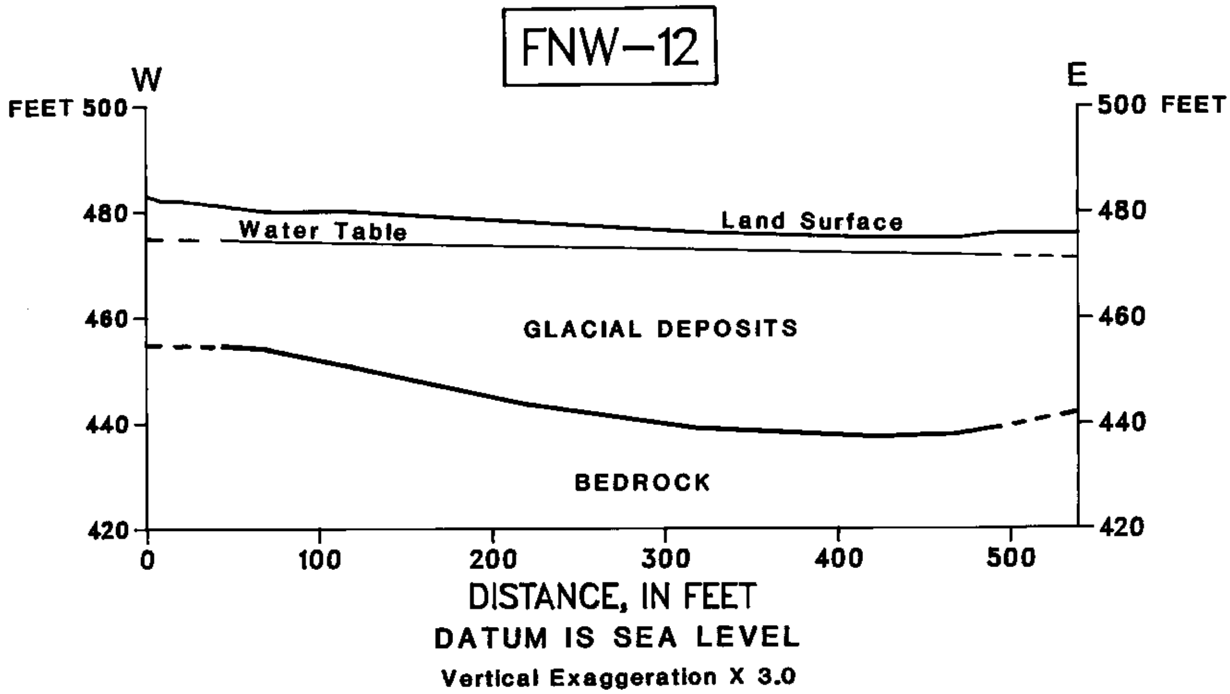

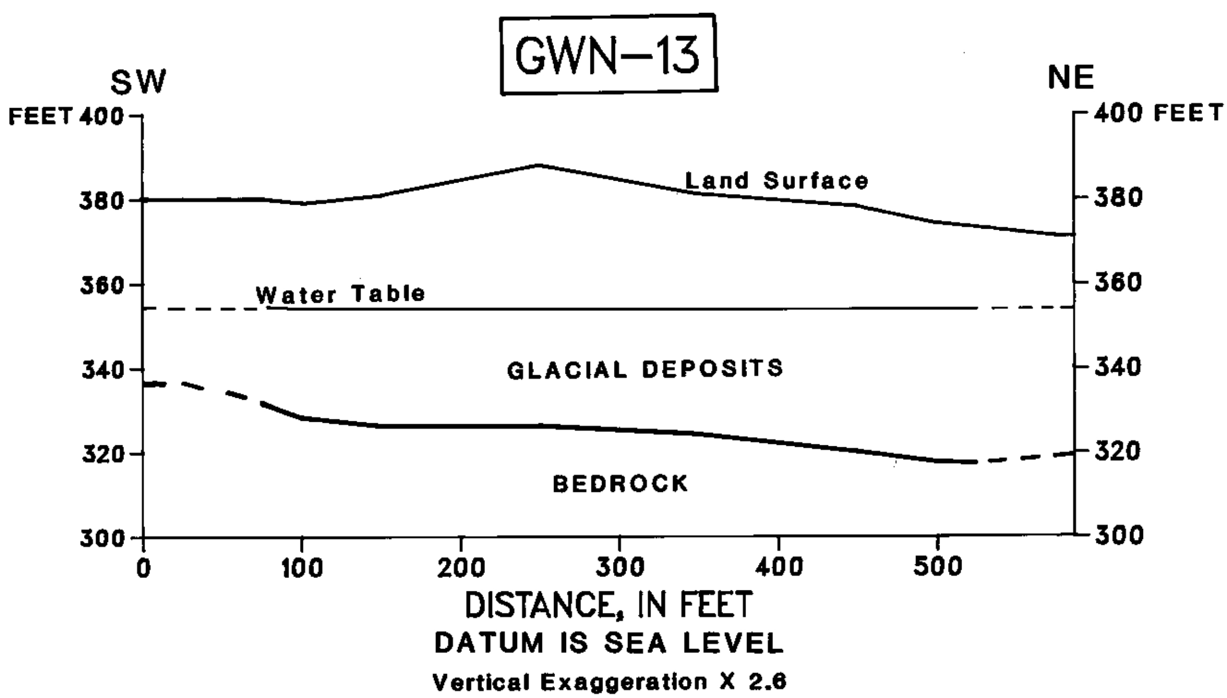

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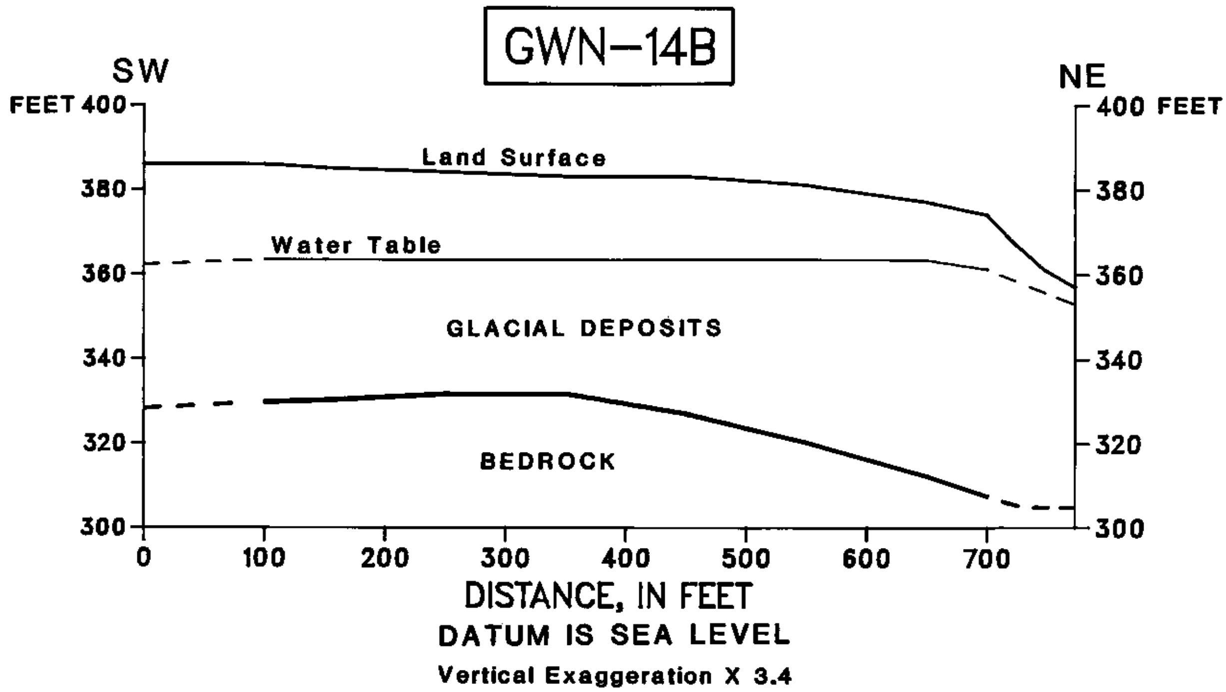

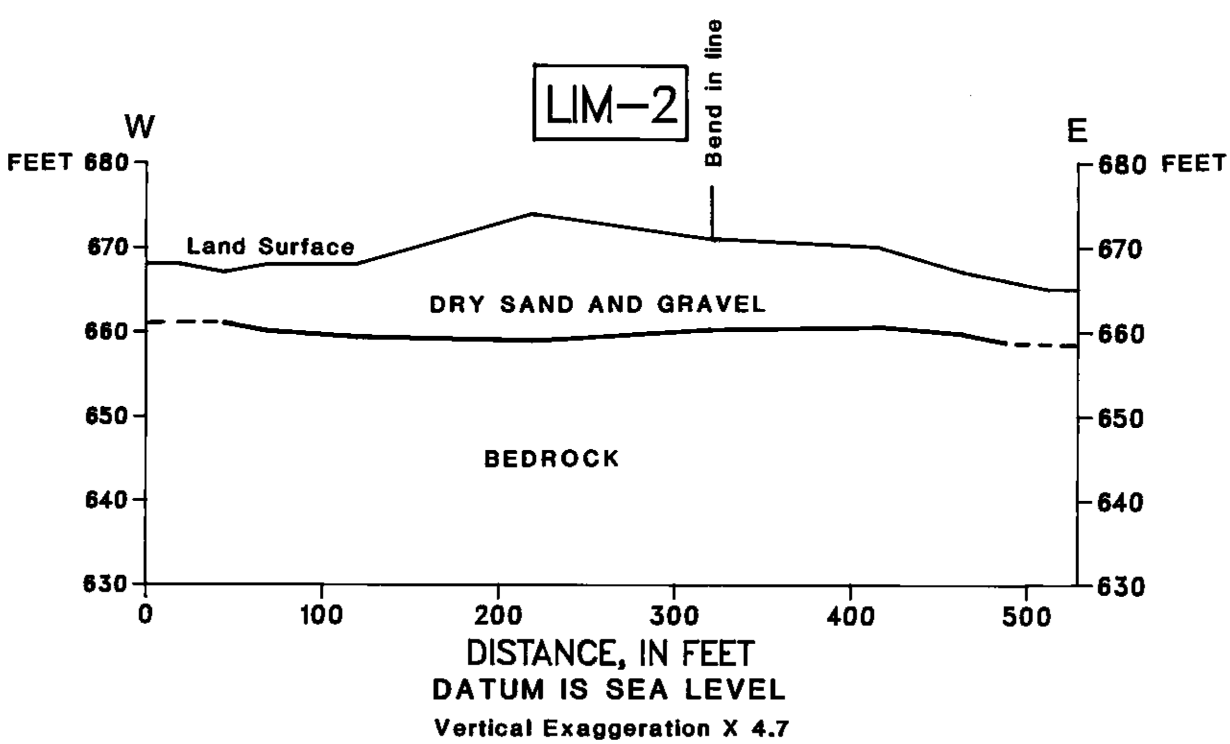

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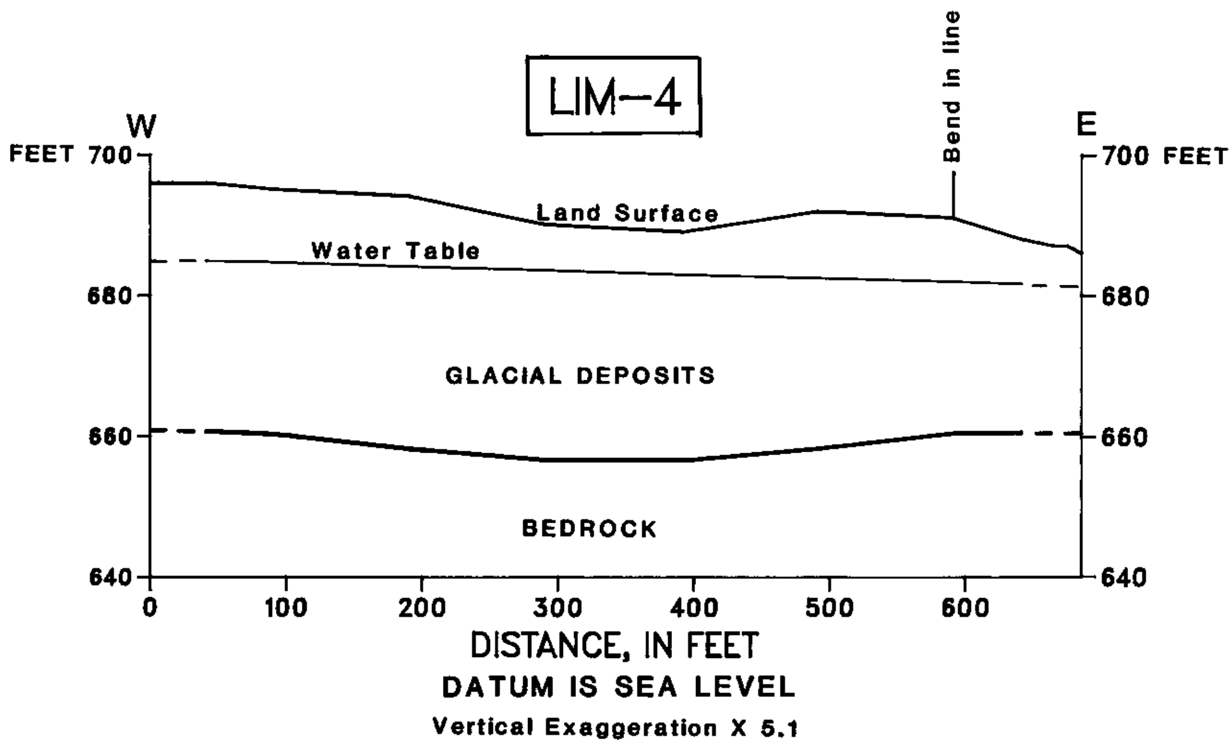

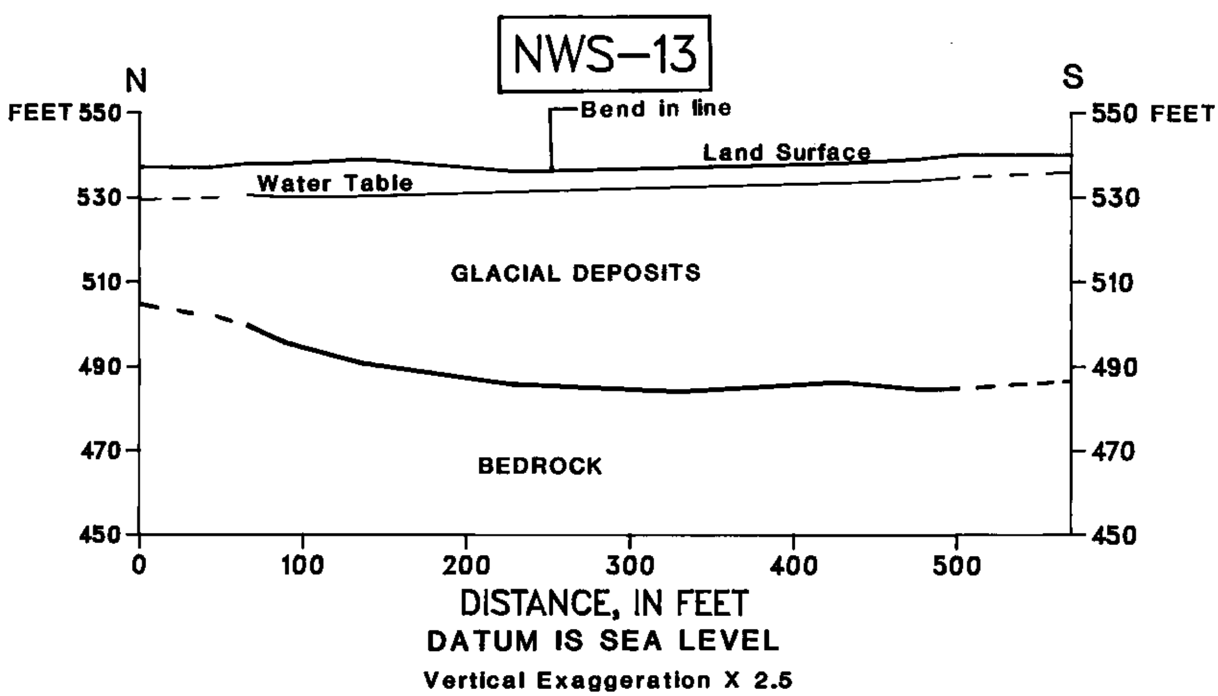

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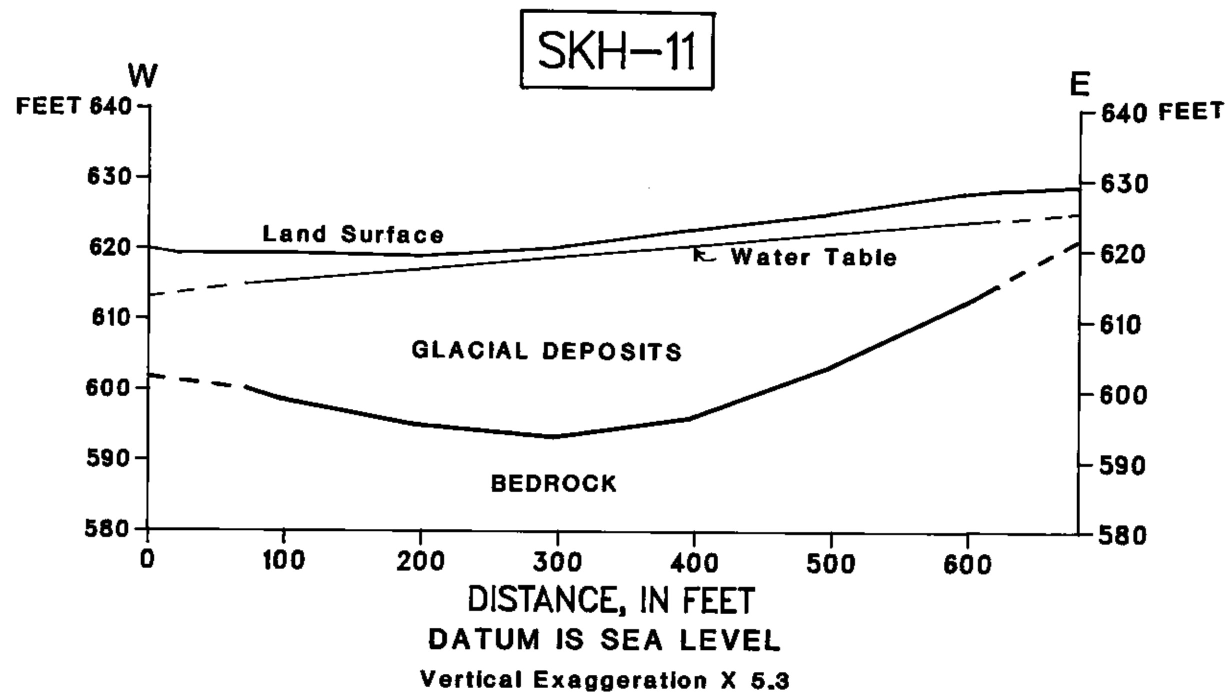


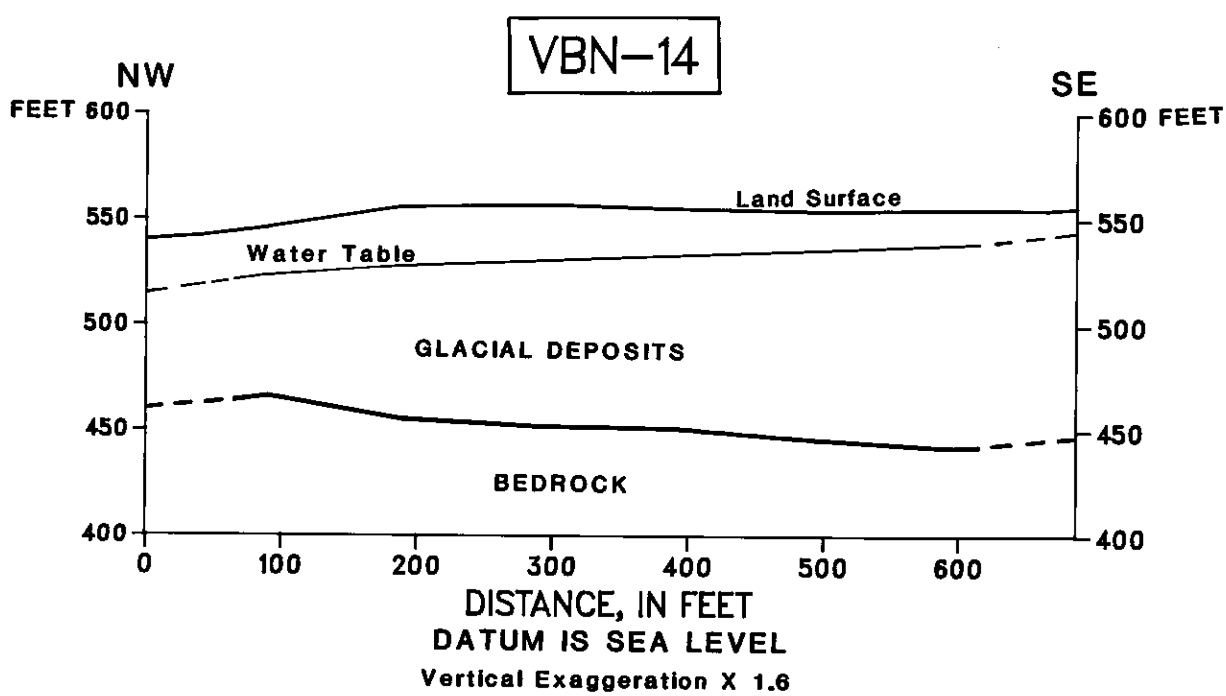
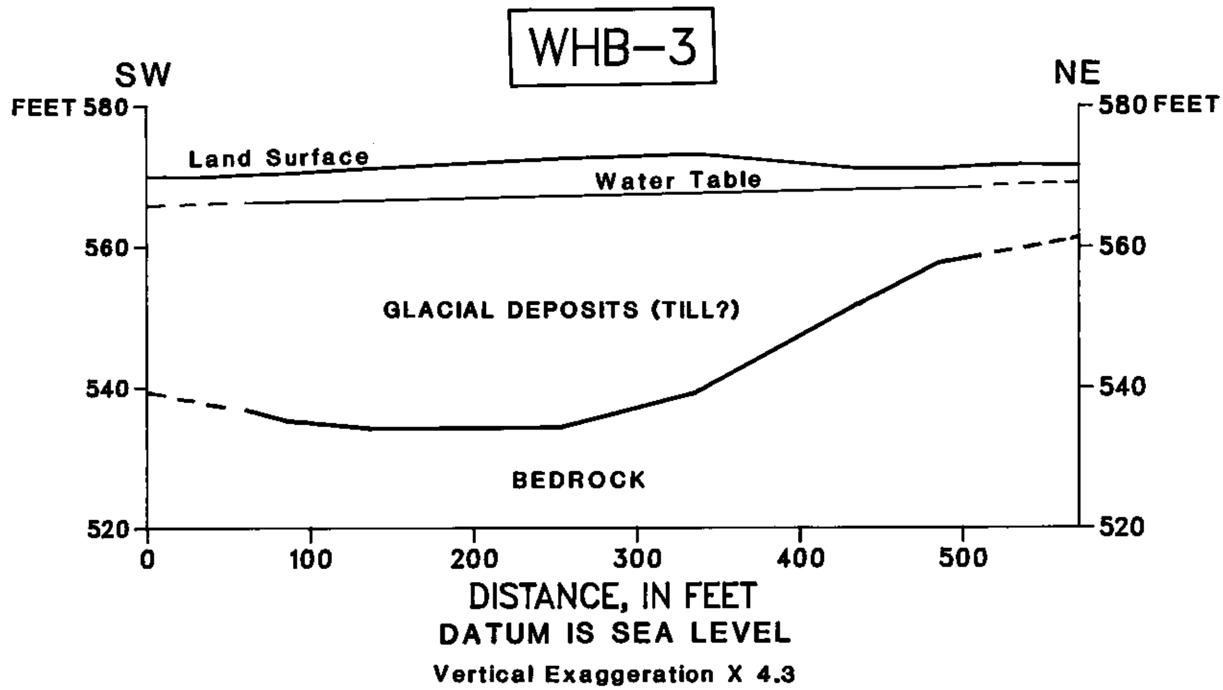


Figure 11.--12-channel seismic-refraction profiles: Plate 4, Map 78 Area

Hydrogeologic sections from seismic-refraction surveys conducted by the U.S. Geological Survey in 1986. Location of individual profiles are shown on plate 4. 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.



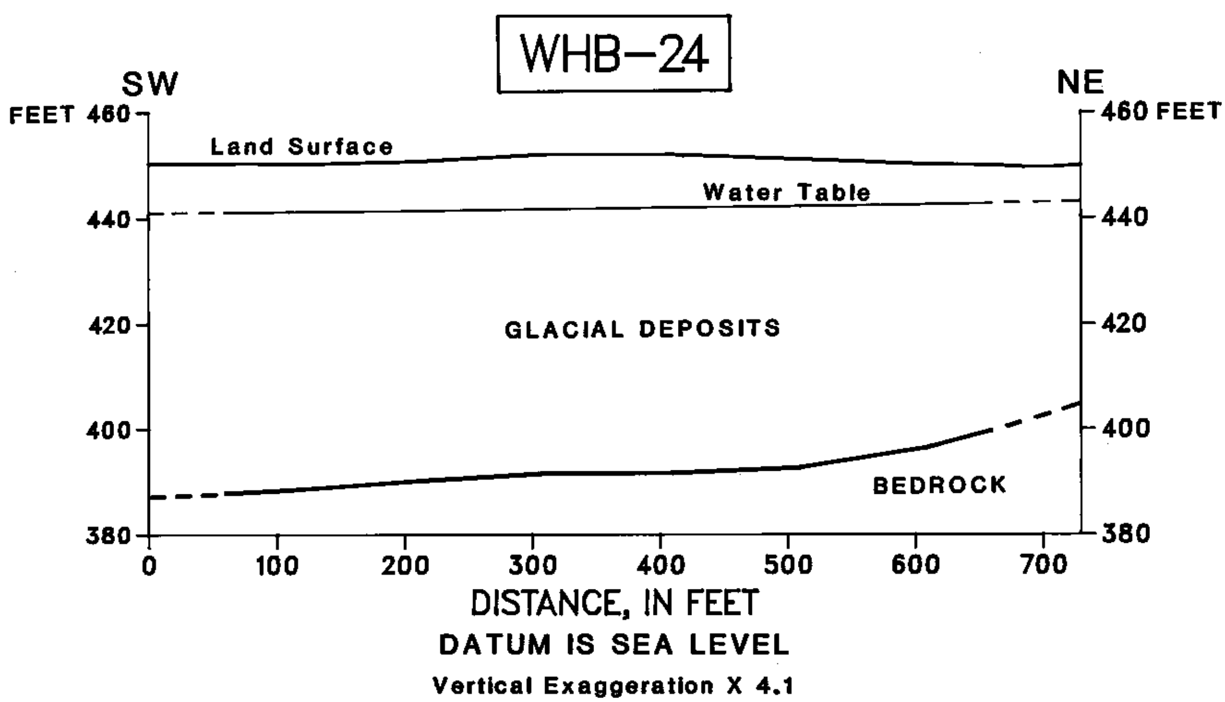
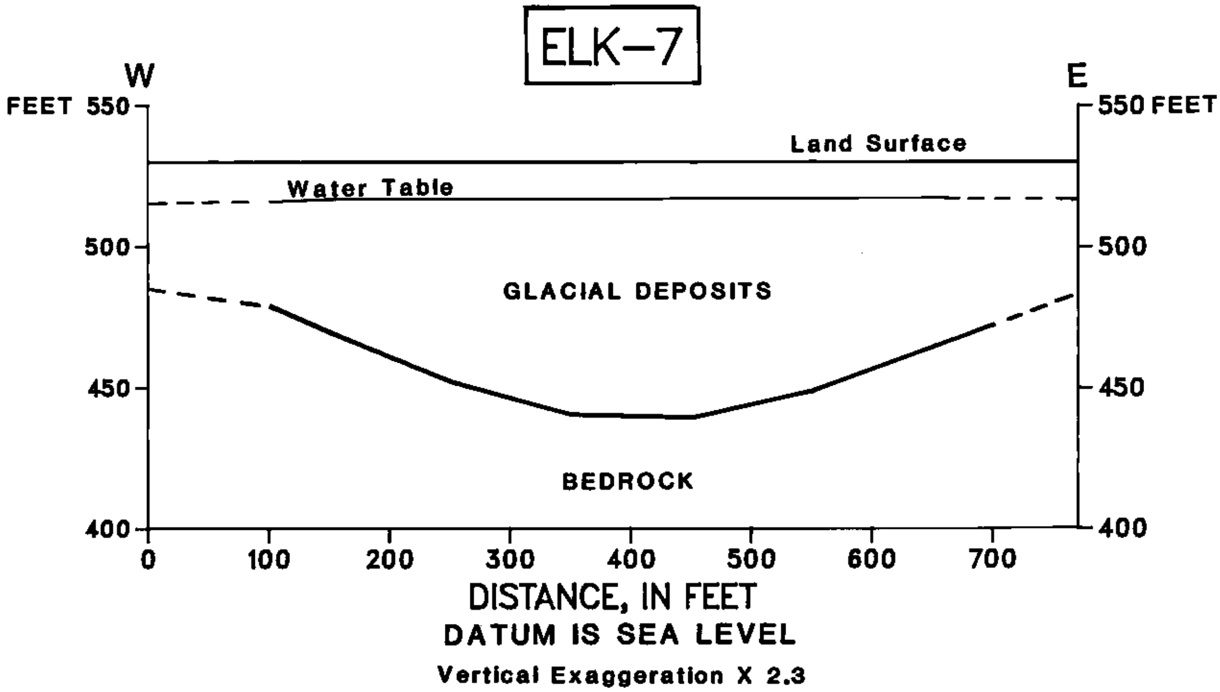
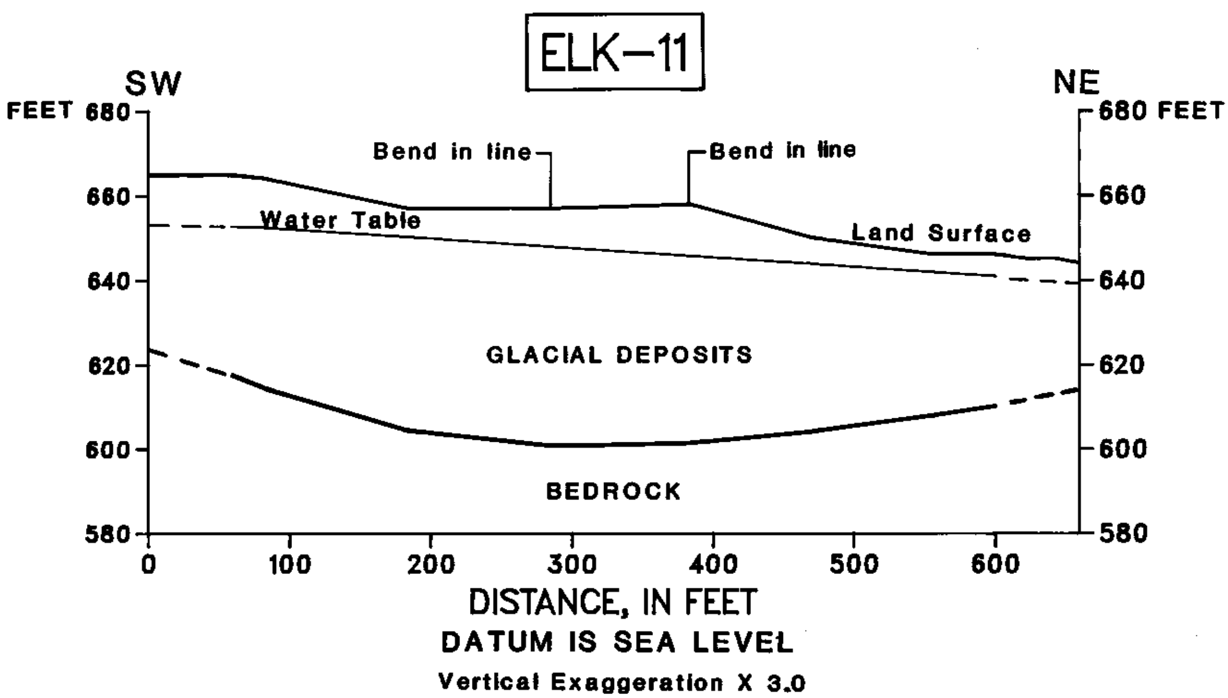


Figure 12.--12-channel seismic-refraction profiles: Plate 5, Map 84 Area

Hydrogeologic sections from seismic-refraction surveys conducted by the U.S. Geological Survey in 1986. Location of individual profiles are shown on plate 6. 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.





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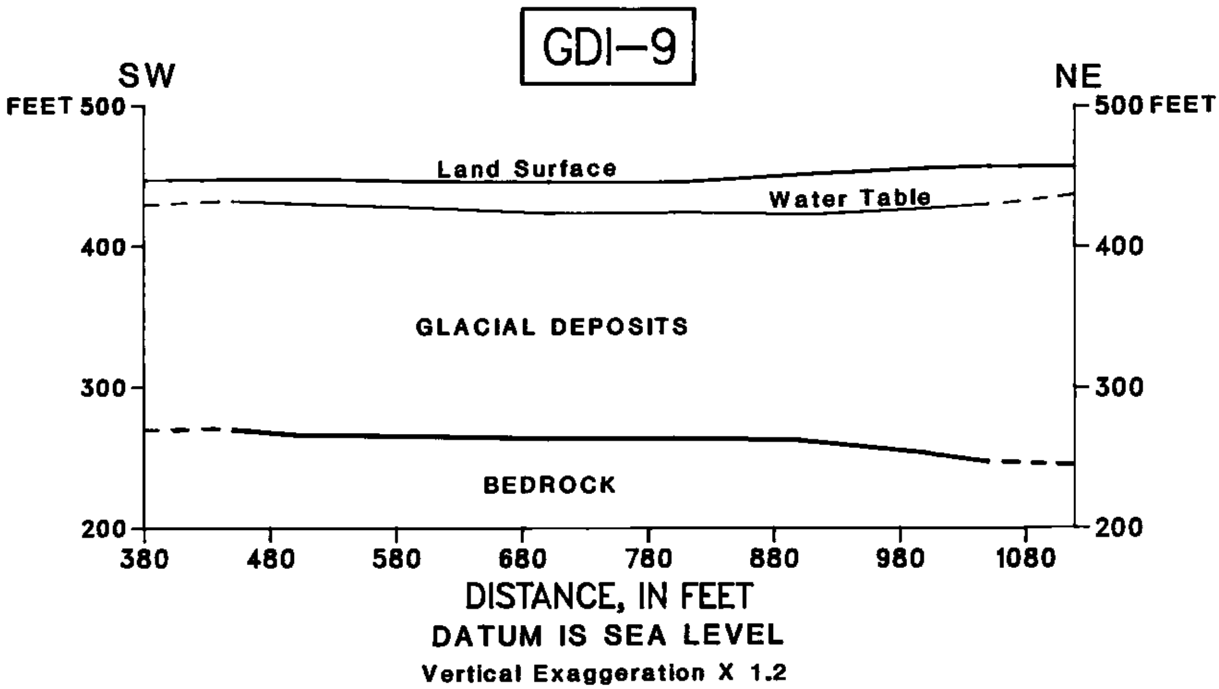

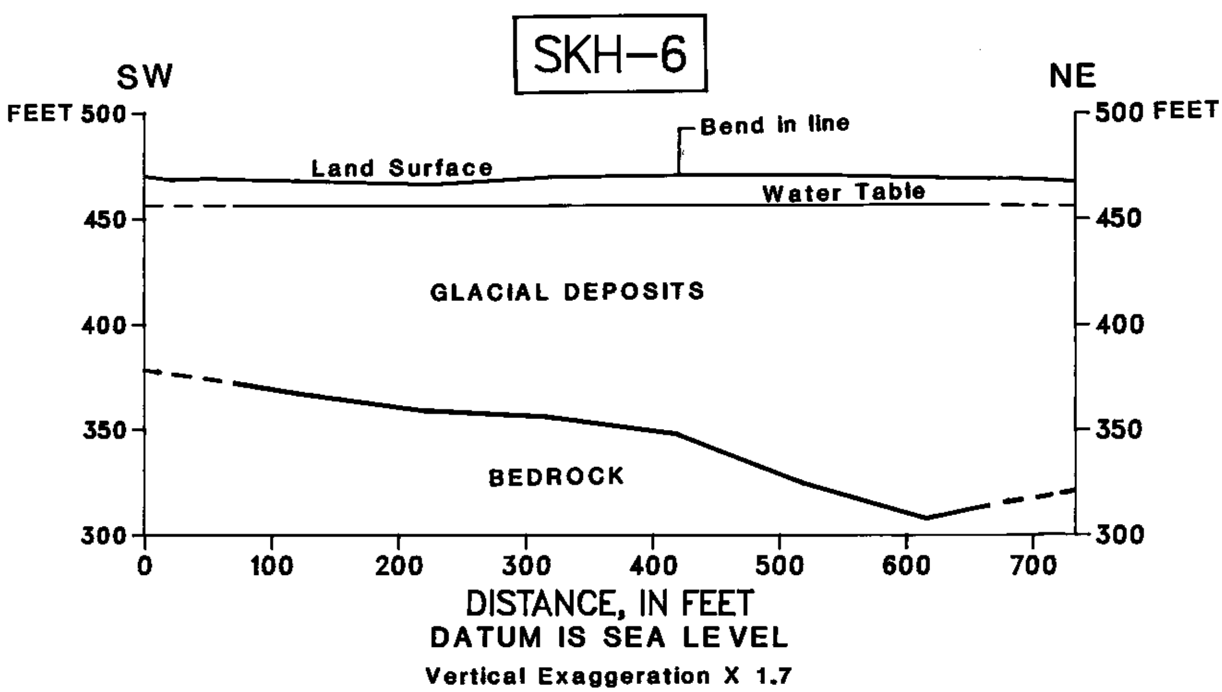

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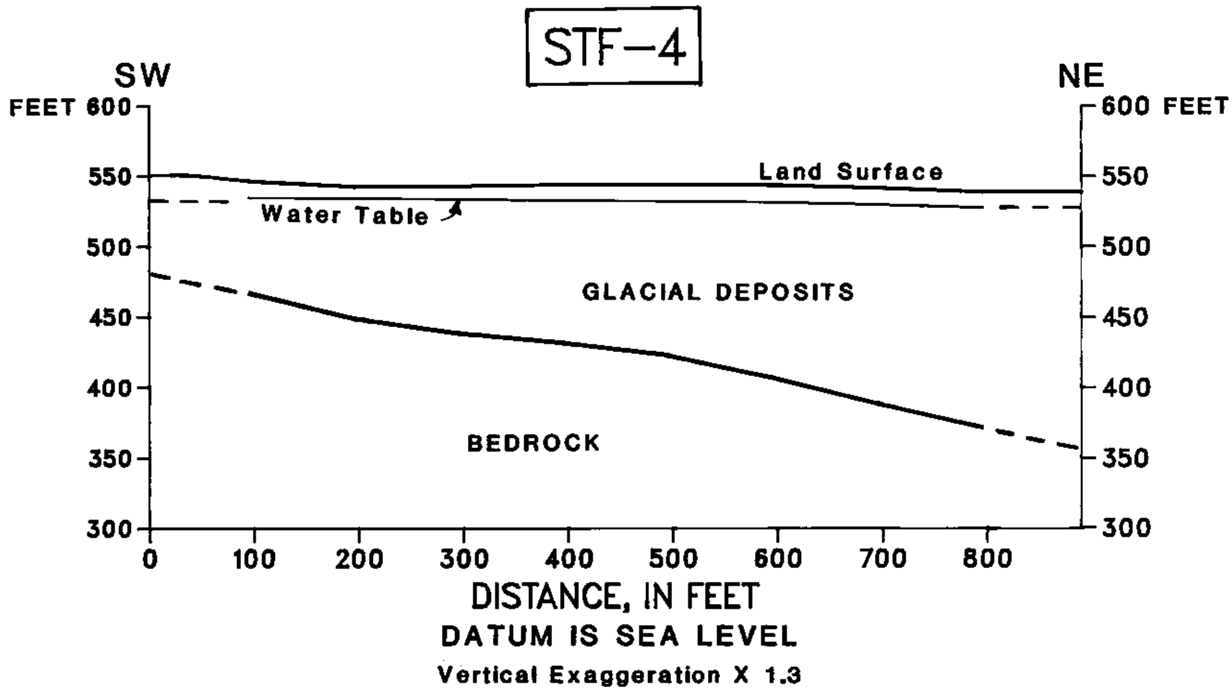

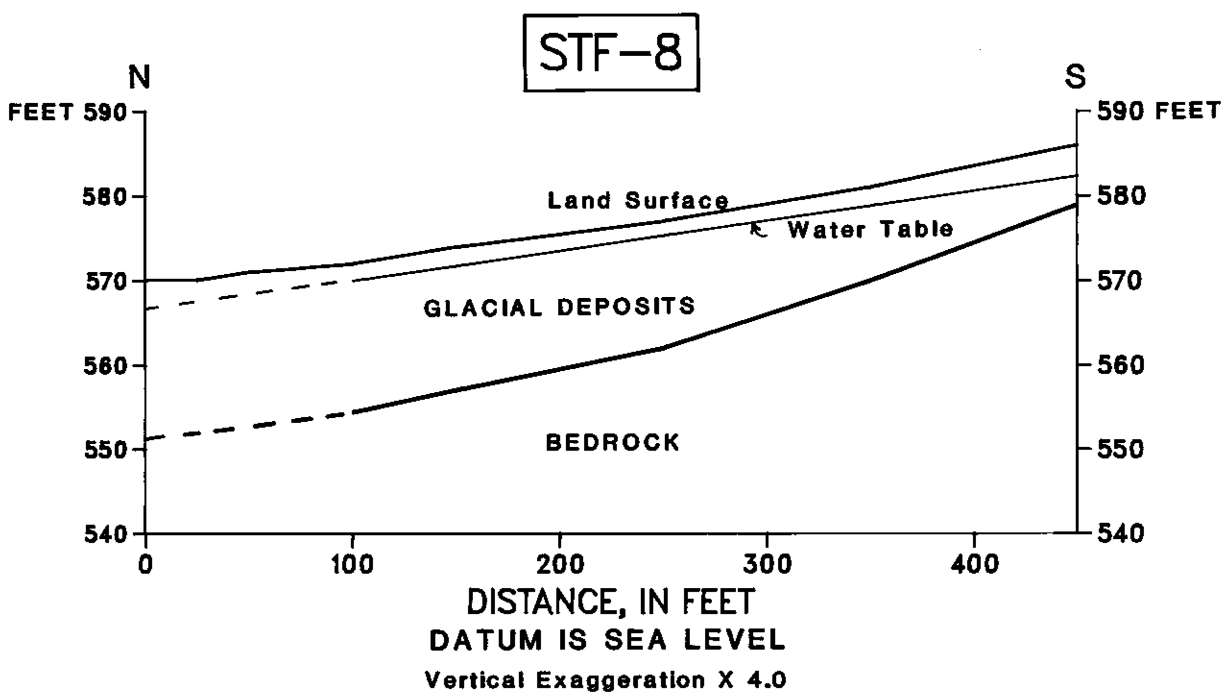

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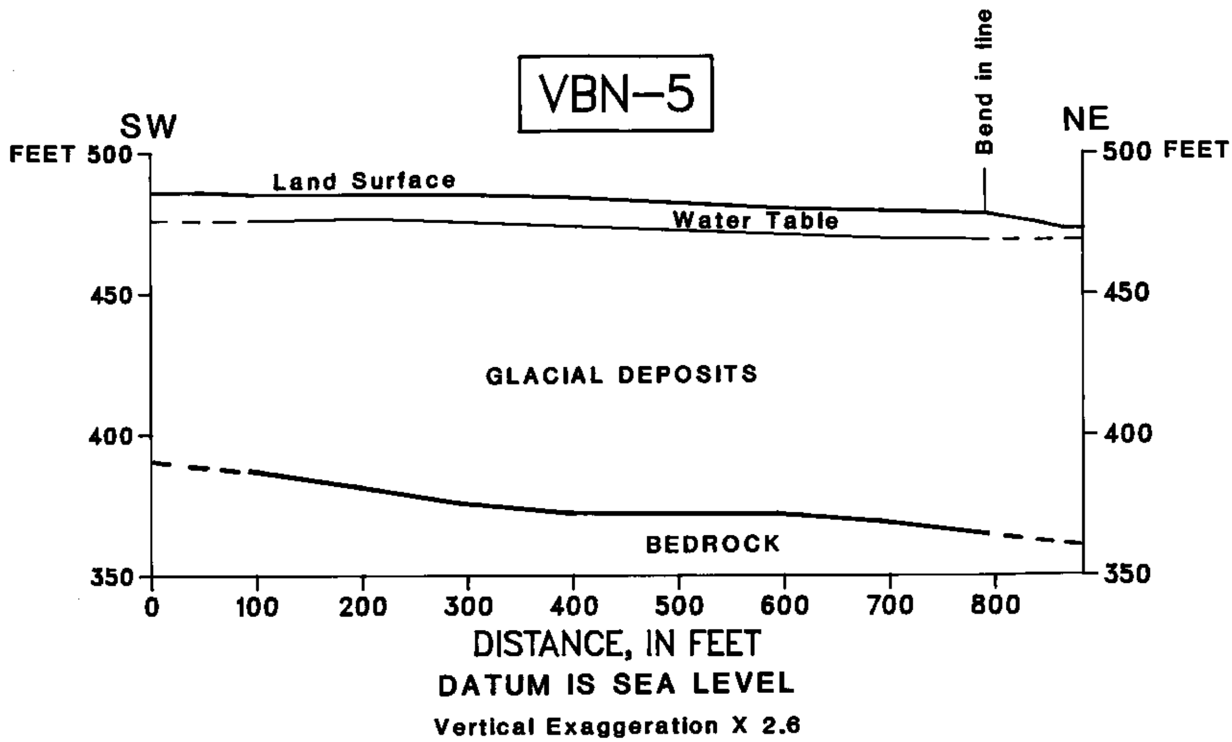

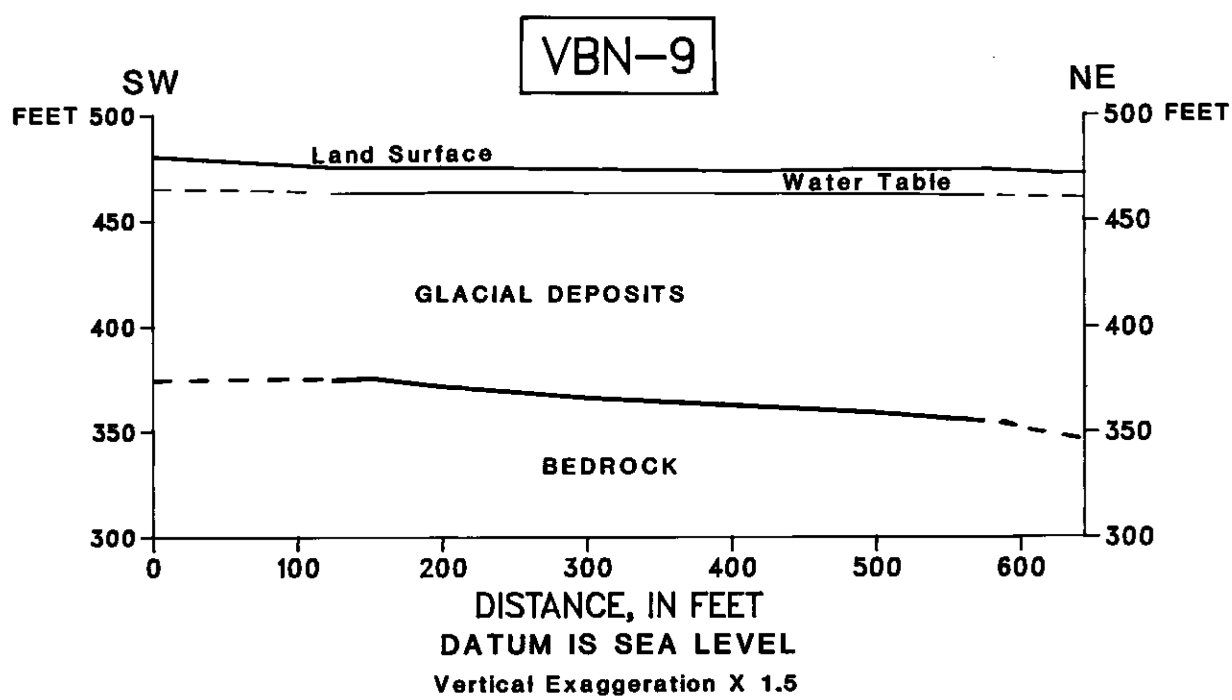

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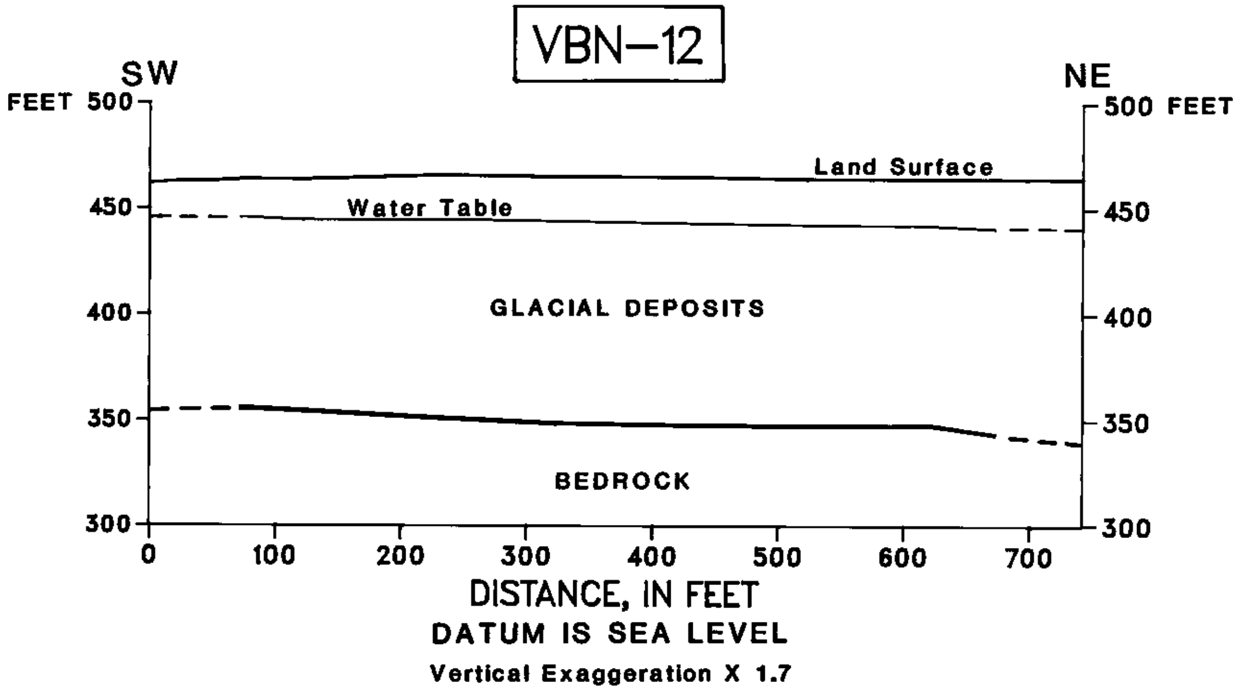
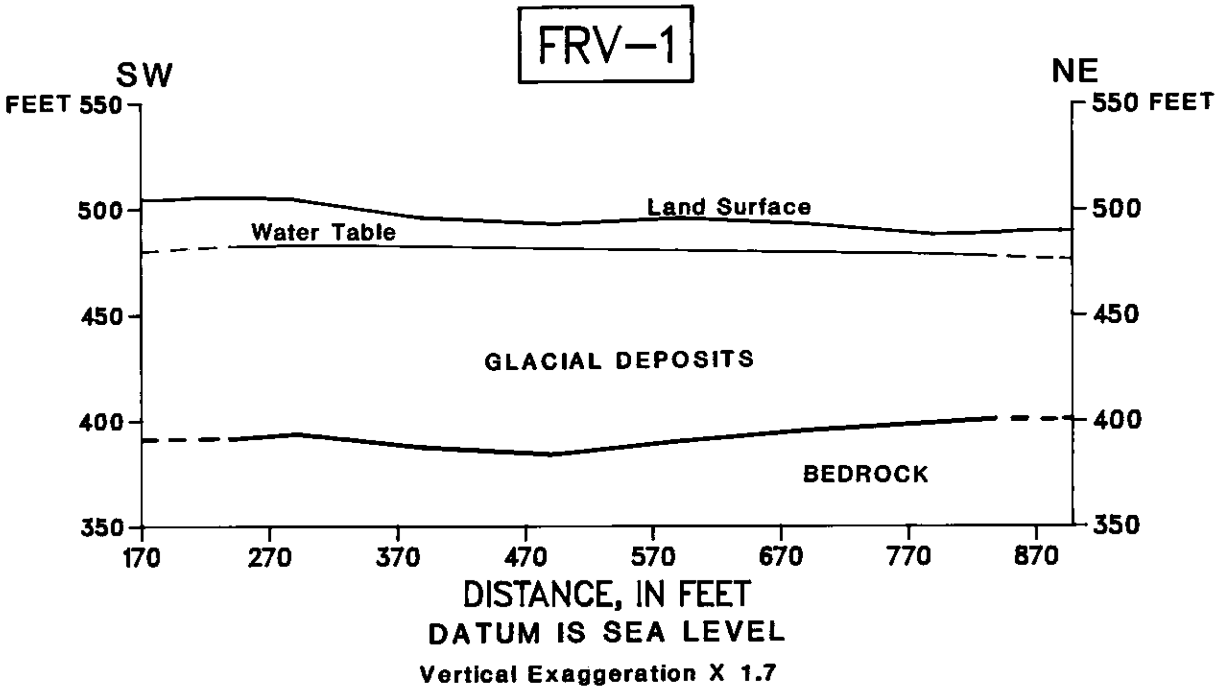
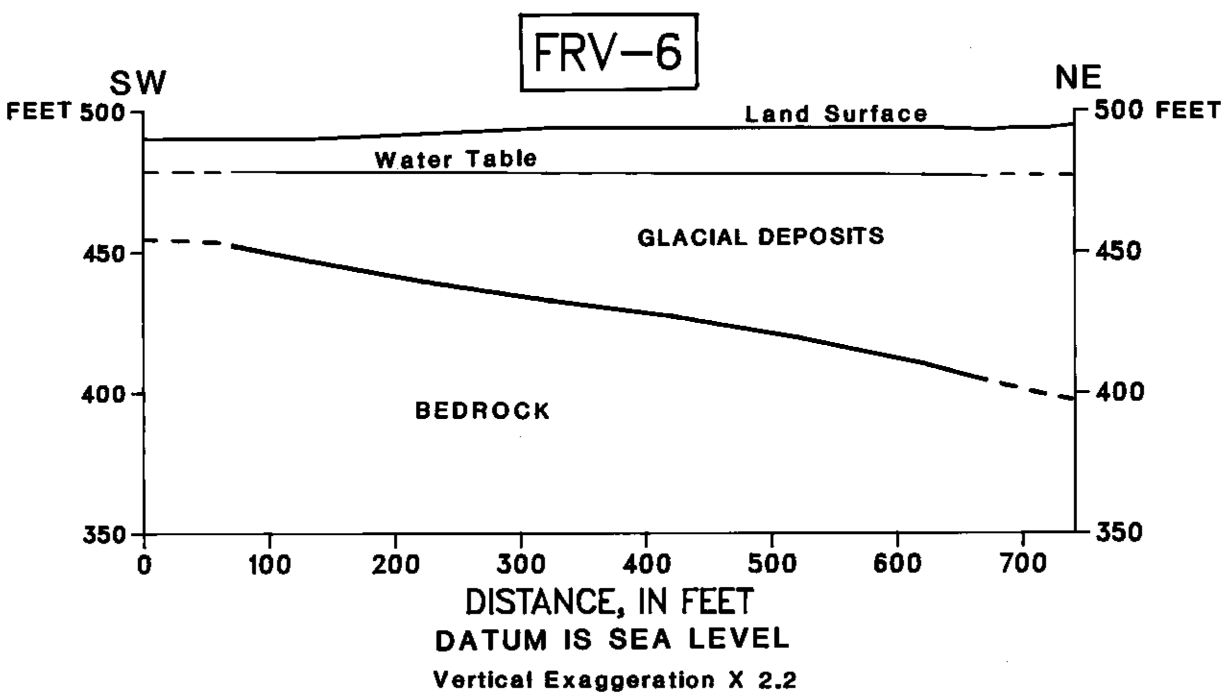


Figure 13.--12-channel seismic-refraction profiles: Plate 6, Map 85 Area

Hydrogeologic sections from seismic-refraction surveys conducted by the U.S. Geological Survey in 1986. Location of individual profiles are shown on plate 5. 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.





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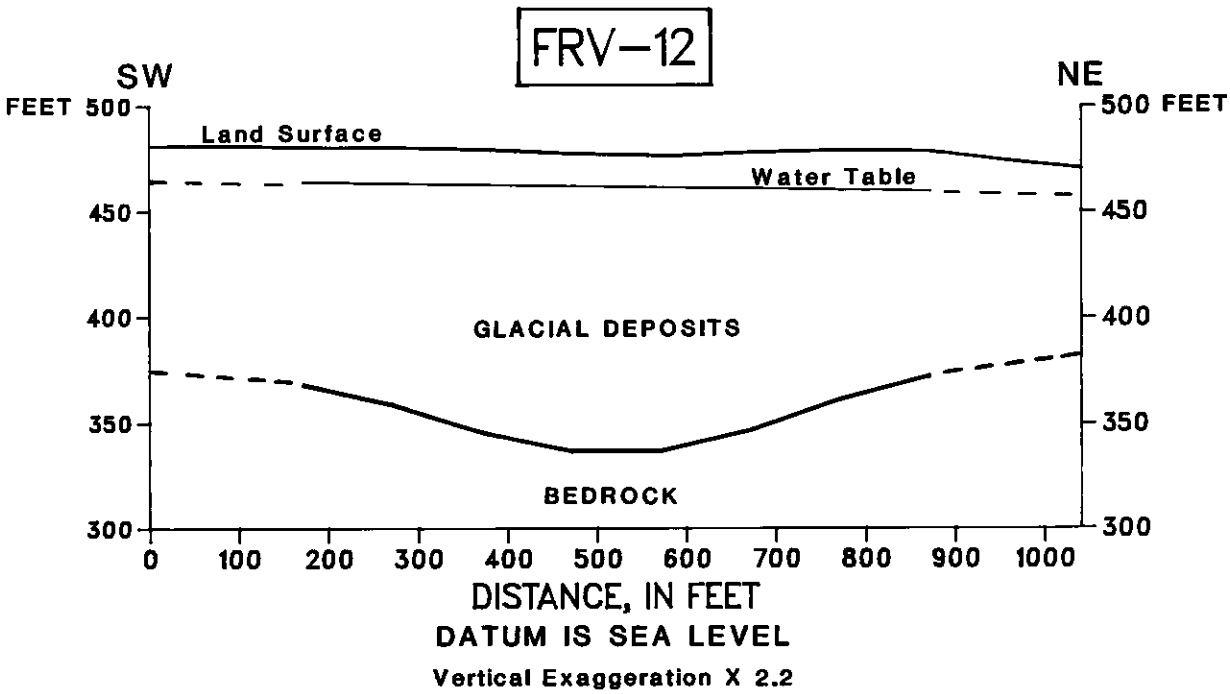

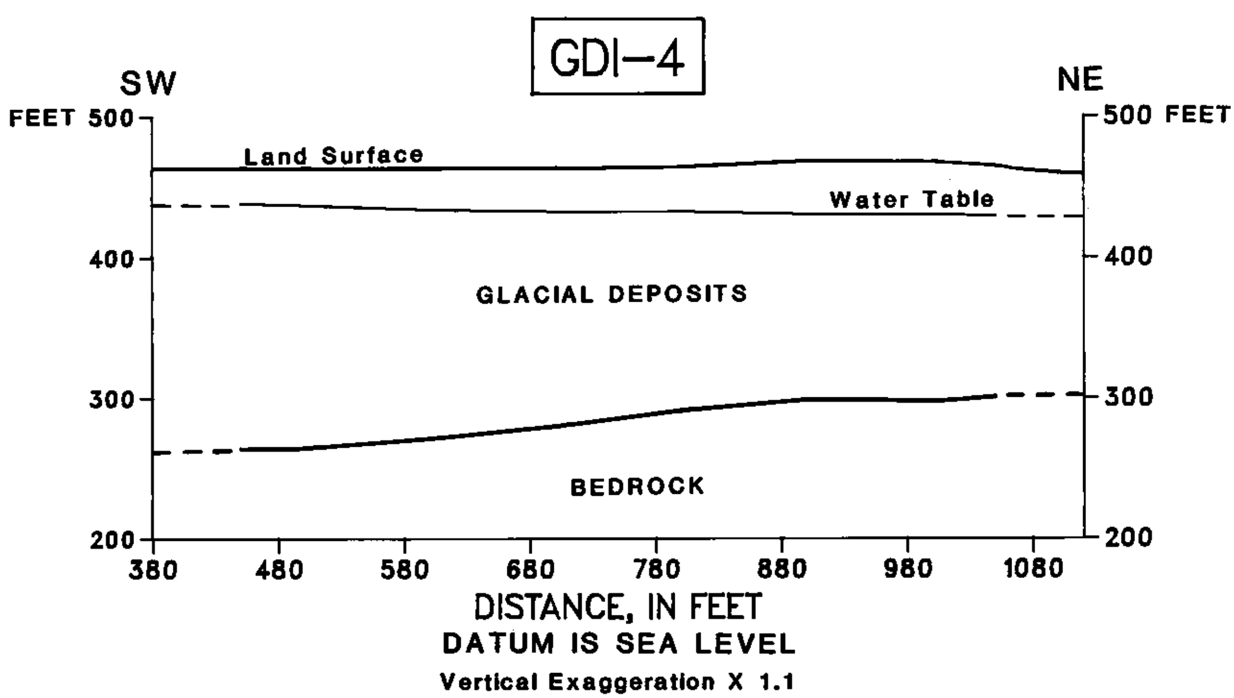

Figure 13. Continued.