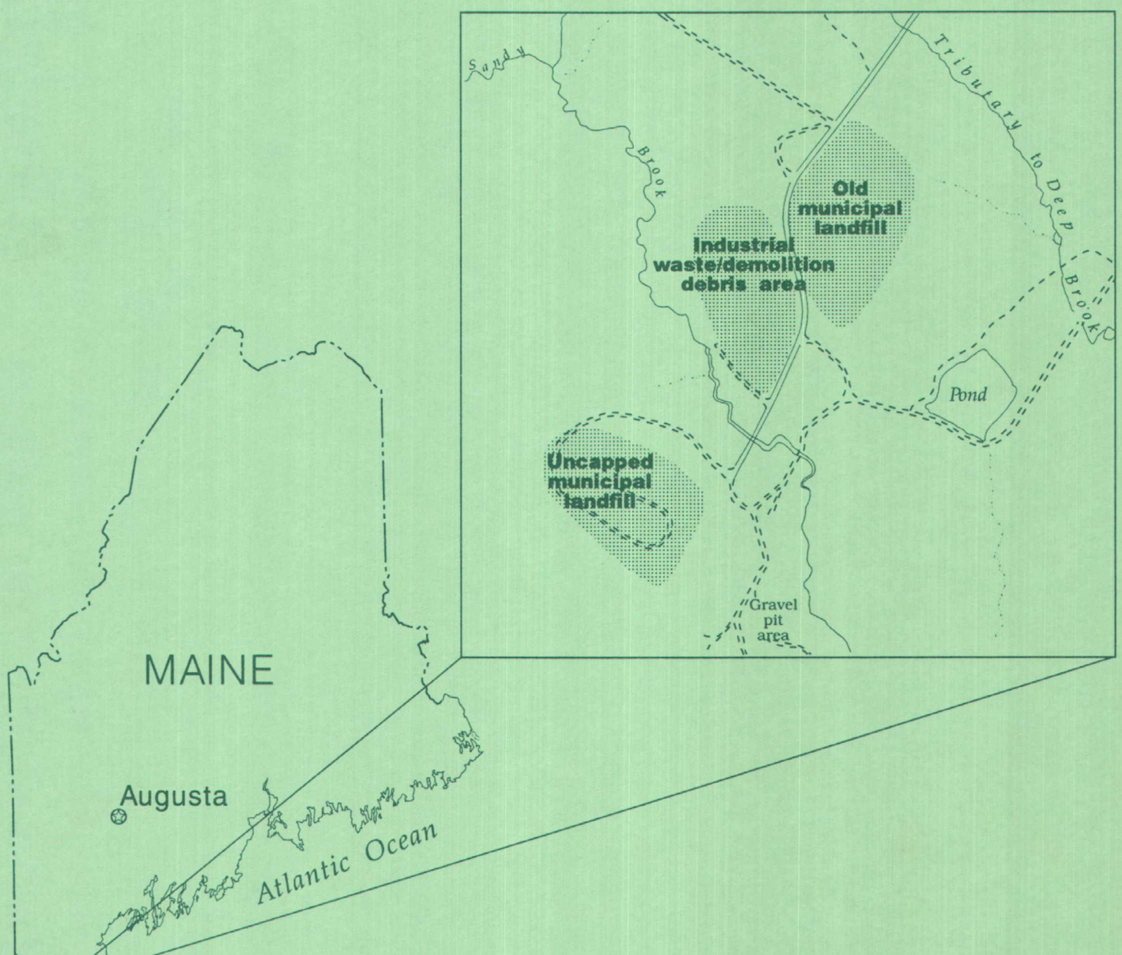
# GEOHYDROLOGY, WATER QUALITY, AND CONCEPTUAL MODEL OF THE HYDROLOGIC SYSTEM, SACO LANDFILL AREA, SACO, MAINE

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 95-4027




Prepared in cooperation with the
U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION I

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**By Martha G. Nielsen, Janet R. Stone, Bruce P. Hansen, and Joseph P. Nielsen**

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Augusta, Maine
1995

**U.S. DEPARTMENT OF THE INTERIOR**
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## TABLES



## CONVERSION FACTORS, VERTICAL DATUM, AND OTHER ABBREVIATIONS

| Multiply | By | To Obtain |
|---|---|---|
| inch (in.) | 25.4 | millimeter |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| square mile ($mi^2$) | 2.590 | square kilometer |
| acre | 0.4047 | hectare |
| gallon | 3.785 | liter |
| foot per day (ft/d) | 0.0003527 | centimeter per second |
| inch per year (in/yr) | 25.4 | millimeter per year |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second |
| gallon per minute (gal/min) | 0.06308 | liter per second |
| million gallon per day (Mgal/d) | 0.04381 | cubic meter per second |
| million gallon per year (Mgal/yr) | 3,785 | cubic meter per year |

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows °C = 5/9 (°F - 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.

**Hydraulic conductivity:** In this report, the unit of hydraulic conductivity is ft/d (foot per day), the mathematically reduced form of $(ft^3/d)/ft^2$ (cubic foot per day per square foot).

**Abbreviated water-quality units used in this report:**

| | |
|---|---|
| mg/L | milligram per liter |
| µg/L | microgram per liter |
| µS/cm | microsiemen per centimeter at 25 degrees Celsius |
| mS/m | millisiemen per meter |

# GEOHYDROLOGY, WATER QUALITY, AND CONCEPTUAL MODEL OF THE HYDROLOGIC SYSTEM, SACO LANDFILL AREA, SACO, MAINE

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## Abstract

A geohydrologic study of the Saco Municipal Landfill in Saco, Maine, was done during 1993-94 to provide a preliminary interpretation of the geology and hydrology needed to guide additional studies at the landfill as part of the Superfund Program. The Saco Landfill, which was active from the early 1960's until 1986, includes three disposal areas on a 90-acre parcel. Sandy Brook, a small perennial stream, flows from north to south through the landfill between the disposal areas. Discharge of leachate from the disposal areas to aquifers and streams has been documented since 1974. The landfill was declared a Superfund site in 1990 by the U.S. Environmental Protection Agency. Multiple lines of evidence are used in this study to indicate areas of ground-water contamination and sources of water flow in Sandy Brook.

The geohydrologic system on the east side of Sandy Brook consists of an upper water-table aquifer and a lower aquifer, separated by a thick sequence of glaciomarine silt and clay. Depths to bedrock range from 60 to more than 200 ft (feet), on the basis of data from seismic-refraction studies and drilling. The upper aquifer, which is generally less than 15 ft thick, consists of fine- to medium-grained sand deposited in a shallow postglacial marine environment. The lower aquifer, which was deposited as a series of glaciomarine fans, contains two sediment types: well-sorted sand and gravel and unsorted sediments called diamict sediments. East of Sandy Brook, the thickness of the lower aquifer ranges from 25 to 100 ft, based on drilling at the landfill. The glaciomarine silts and clays (known as the Presumpscot Formation) range from 50 to more than 100 ft thick. West of Sandy Brook, the glaciomarine silt and clay is largely absent, and fractured bedrock is very close to land surface under one of the disposal areas in the northwestern part of the property. The lower aquifer is unconfined in the southwestern side of the study area; bedrock slopes towards the south, and the aquifer thickens to 100 ft at the southwestern end of the study area.

Preliminary estimates of mean annual streamflow in Sandy Brook, based on a partial year of continuous record, indicate that runoff increases from approximately 2.1 $ft^3/s$ (cubic feet per second) upstream from the landfill to 2.7 $ft^3/s$ downstream from the landfill, although the drainage area downstream is only 11 percent greater than the drainage area upstream. A water-budget estimate based on available streamflow and climatic data indicates that Sandy Brook below the landfill gains about 80 million gallons per year from sources outside the drainage-basin boundary. Possible sources include the lower aquifer north or west of the landfill area and the fractured bedrock northwest of Sandy Brook.

Specific conductance of water in Sandy Brook increases downstream from the landfill. In September 1993, specific conductance was 184 μS/cm (microsiemens per centimeter at 25 degrees Celsius) upstream from the landfill and 496 μS/cm downstream from the landfill. Continuous monitoring of specific conductance in Sandy Brook shows that the downstream increase is less during periods of stormflow because of dilution.

Electromagnetic terrain-conductivity surveys, results of ground-water chemical analyses, and changes in streamwater quality have been used to identify areas of likely ground-water contamination. The specific conductance of ground water exceeds 2,000 μS/cm in some areas near the landfills. This compares to specific conductances of less than 200 μS/cm in water from most shallow wells that are considered to represent background water quality. Ground water in the upper aquifer east of Sandy Brook and in the lower aquifer west of Sandy Brook has been affected by leachate flowing from the landfill areas. The extent of contamination in bedrock, if any, is unknown.

Water levels measured in 16 wells were used to help determine the direction of ground-water flow. The electromagnetic terrain-conductivity surveys and stream specific-conductance data support the interpretation that water in the upper aquifer flows radially away from the two disposal areas east of Sandy Brook towards Sandy Brook and other small surface-water bodies in the area. West of Sandy Brook, ground water under the third disposal area moves in the lower aquifer northeast and southeast towards Sandy Brook, where it discharges to the stream.

## INTRODUCTION

The investigation and cleanup of hazardous-waste sites, falling under the jurisdiction of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended by the Superfund Amendments and Reauthorization Act of 1986 (commonly known as Superfund), is a time-consuming and expensive process. Remediation at each site requires a large body of information and accurate interpretive studies. Collection and interpretation of basic hydrologic and geologic data from these sites are commonly lacking, and this lack may lead to ineffective or excessively costly cleanups. With the intent of avoiding such problems, the U.S. Environmental Protection Agency (USEPA), Region I, began a program in 1992 within New England to collect and interpret basic hydrologic and geologic data at several hazardous-waste sites, before the initiation of remedial investigation and feasibility studies. This geohydrologic study of the Saco Landfill in Saco, Maine, is one such study.

The city of Saco ran several landfill operations on a 90-acre parcel from the early 1960's through 1986 (Maine Department of Environmental Protection, written commun., 1993). The property was first used as an open municipal dump during the 1960's (Area 1 on fig. 1). In 1973, the municipal dump also began accepting sludge from a nearby tannery. The sludge was deposited in open, unlined trenches within Area 1. An industrial-waste/demolition-debris area (Area 2 on fig. 1) and a sanitary landfill for municipal waste and local industrial waste, such as leather goods and wastes from shoe manufacturing (Area 3 on fig. 1), were opened in 1974. The tannery sludges were subsequently disposed of in Area 3 and within trenches in contact with the bedrock surface just north of Area 3. Area 1 was closed and capped in 1976. In 1986, Area 2 was closed and capped, and Area 1 was recapped. The municipal landfill (Area 3) is currently (1994) closed but uncapped.

Contamination of ground water and surface water at the landfill has been evident since 1974. In 1975, the municipal water supply was extended to residents along Buxton Road (Route 112) because of concerns about ground-water contamination in nearby shallow wells. Since then, several engineering firms and State and local agencies have collected data at the landfill and in surrounding areas. Many organic and inorganic contaminants have been detected in soils, ground water, and surface water at the landfill, but to date (1994) no comprehensive studies of water and contaminant movement have been done.

The U.S. Geological Survey (USGS), in cooperation with the USEPA Region I, studied the landfill area during 1993-94 in order to provide a more comprehensive geohydrologic investigation of the area.

### Purpose and Scope

The purpose of this report is to (1) describe the type and distribution of surficial geologic units at the landfill, and the depth to bedrock, (2) summarize water quality at the landfill, and (3) develop a conceptual model of ground-water and surface-water flow at the landfill and its immediate surroundings. The scope of this report includes review and analysis of water-quality and

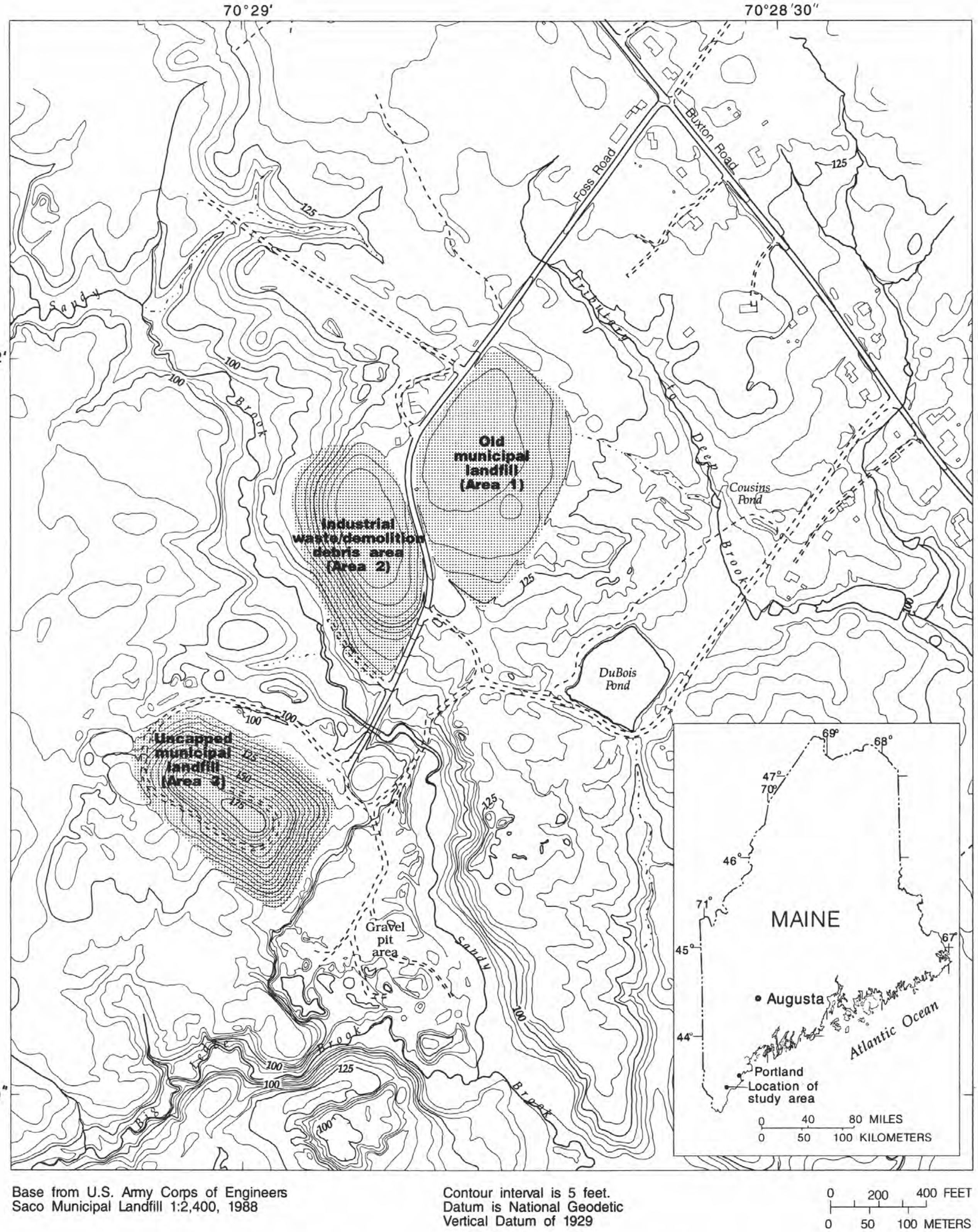



**Figure 1.** Saco Landfill study area, Saco, Maine.

geologic data collected for several studies already completed at the landfill at the behest of the USEPA, the State, and the city of Saco. The water-quality and limited geologic data collected for these studies were used in this investigation to help determine the distribution of leachate in ground water and to provide an initial geologic framework at the landfill. Geologic information and water-level data were collected from seven wells and two test borings installed for this investigation. Surface electromagnetic (EM) terrain-conductivity survey of the soils at the landfill were used to help locate leachate in ground water, and a seismic refraction survey was used to determine the depth of the bedrock surface. Bedrock and surficial geologic materials were mapped using ground surveys and aerial photo interpretation. Hydrologic data collection included stage and streamflow measurements at six streamflow sites, and water-level monitoring in 16 wells.

## Previous Investigations

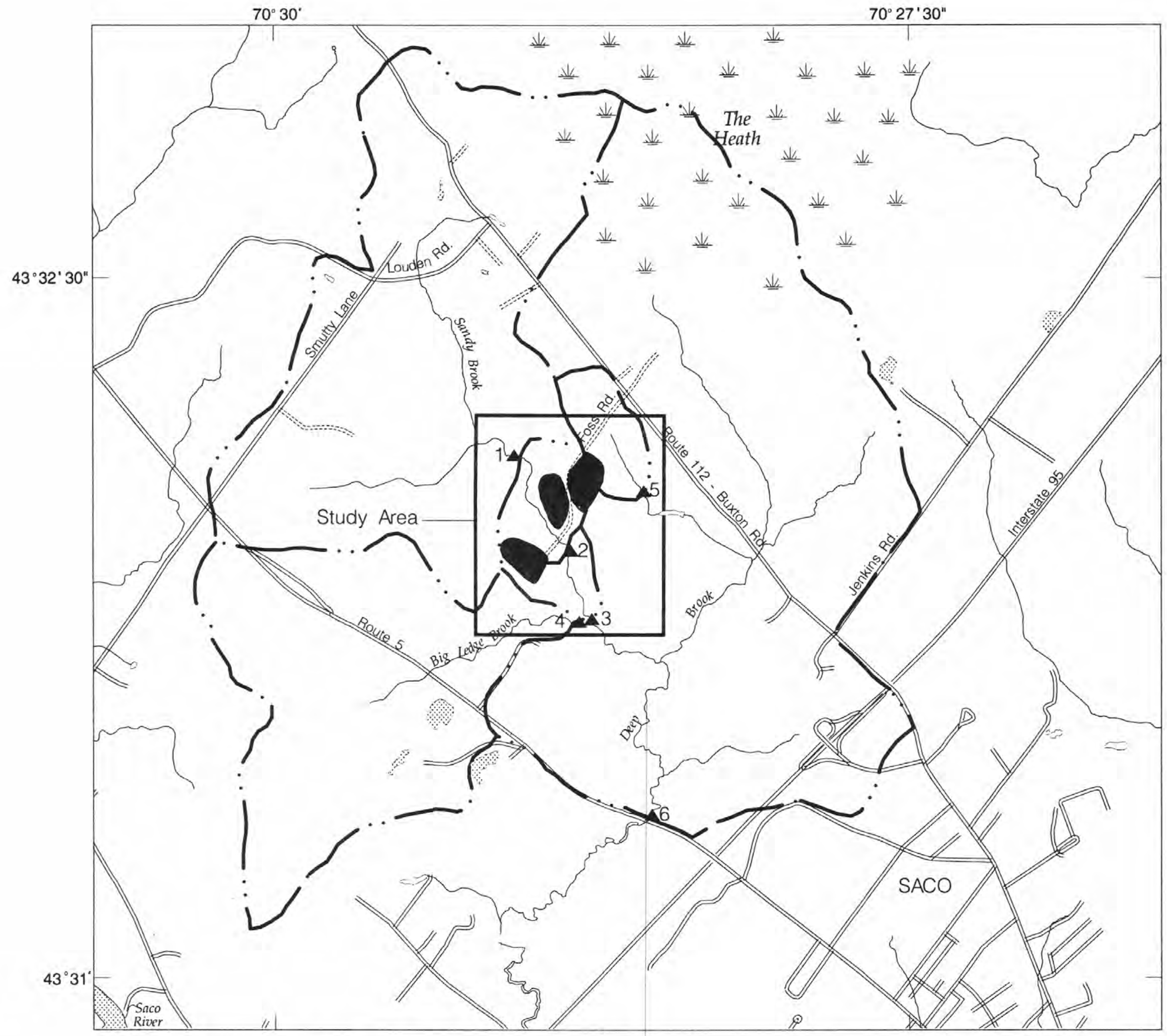
The geology, hydrology, and water quality of the study area have been the subject of many investigations. Regional studies of aquifer distributions and yields in the vicinity of the study area by Prescott (1963) and Tolman and Lanctot (1985) aided in the regional hydrologic interpretation. Caswell and Lanctot (1975) published information on yields and depths of bedrock wells, thickness of overburden, and bedrock-surface topography. Geologic and hydrologic investigations at the Saco Landfill have been done by E.C. Jordan (Atwell, 1975), the Maine Department of Environmental Protection (DEP) (R. Farrell, Maine DEP, written commun., 1980), and DuBois and King (written commun., 1984); these studies provided geologic sections and well logs. Water-quality studies of ground water and surface water have been done by E.C. Jordan (Atwell, 1975), the Maine DEP (Camp Dresser & McKee, Inc., written commun., 1983), DuBois and King (written commun., 1984), Balsam Environmental Consultants (1988), Halliburton NUS (1994), and the city of Saco (unpublished data, 1987-93). These studies provided inorganic and organic water-quality data for the study area.

## Physical Setting

The Saco Landfill lies in the coastal lowlands of southern Maine. Topography is low and undulating, shaped by long periods of glacial erosion and deposition. Land-surface altitude in the area ranges from sea level at the Saco River to about 140 ft at the Heath, a wetland 0.5 mi north of the landfill. The landfill is at an altitude of 120 to 130 ft on an uneven plain that slopes gently eastward towards the ocean, 5 mi away. The Saco River is 2.3 mi west and south of the study area. The coastal city of Saco is southeast of the landfill at the mouth of the Saco River. Sandy Brook, a small perennial tributary to the Saco River, flows through the study area (fig. 2).

The Saco Landfill lies in the southeastern end of the Saco River Valley. Deep Brook, a tributary to the Saco River, drains a 5.8-$mi^2$ area that includes the landfill (fig. 2). Sandy Brook, the primary surface-water body near the landfill, is a tributary of Deep Brook. Other streams receiving runoff from the landfill area include Big Ledge Brook, which flows into Sandy Brook, and a small unnamed tributary to Deep Brook. The Heath, situated on the divide between the Saco River drainage basin on the west and several smaller coastal stream drainage basins on the east, contains the headwaters of seven streams, two of which flow into Deep Brook.

The physiography of the region surrounding the Saco Landfill is a result of the lithology and structure of crystalline bedrock, the lithology and distribution of unconsolidated glacial sediments, and postglacial erosion and deposition. Knobby topography to the west of the Saco Landfill is underlain by relatively resistant igneous plutonic bedrock that is at or near the land surface; altitudes range from 120 to 160 ft above sea level. North, south, and east of the Saco Landfill, smoother, gently undulating topography from 100 to 140 ft above sea level forms the surface of glacial deposits. The glacial deposits are as much as 200 ft thick and completely mantle the lower lying, less resistant metasedimentary bedrock of the Cape Elizabeth Formation. Postglacial processes such as marine regression and eolian activity have slightly modified the surface of glacial deposits; the most significant effect of postglacial stream erosion is the incision of the valleys of Deep Brook, Sandy Brook, Big Ledge Brook, and the Saco River into the surface of glacial deposits. In addition, organic material has accumulated during this postglacial time in poorly drained swampy areas such as the Heath (fig. 2).




Base from U.S. Geological Survey digital data 1:24,000, 1970, Universal Transverse Mercator projection

0 0.5 1 MILE
0 1 KILOMETER

EXPLANATION

LANDFILL

WETLAND

DRAINAGE BASIN BOUNDARY

1 ▲ SURFACE-WATER STATION AND NUMBER--Station names also are listed in table 4

Surface-water stations:

| Station no. | USGS no. | Name: |
|---|---|---|
| 1 | 01067851 | Sandy Brook above landfill, near Saco, ME |
| 2 | 01067852 | Sandy Brook at landfill, near Saco, ME |
| 3 | 01067853 | Sandy Brook below landfill, near Saco, ME |
| 4 | 01067855 | Big Ledge Brook near Saco, ME |
| 5 | 01067859 | Unnamed tributary to Deep Brook, near Saco, ME |
| 6 | 01067861 | Deep Brook near Saco, ME |

**Figure 2.** Location of the Saco Landfill study area and associated drainage basins and surface-water stations near the Saco Landfill, Saco, Maine.

## Water Use

The city of Saco obtains its municipal water supply from the Saco River. In 1993, the privately owned water company served 10,786 residential year-round households and 1,235 seasonal households in Saco and nearby Biddeford. In 1993, the water company supplied 950 Mgal to residential customers (Jerry Mansfield, Saco Biddeford Water Company, oral commun., 1993). A public-water-supply line extends past the east side of the Saco Landfill, serving residents on Buxton Road up to its intersection with Louden Road. To the north and west of the landfill, residents depend on private wells that terminate in fractured crystalline bedrock or sandy surficial materials. At least one residence on Buxton Road continues to use a private well for water supply, even though public water is available.

The public sewer system serving the city of Saco does not extend to the residents on Buxton Road or any other road within 1 mi of the landfill. Residents on all sides of the Saco Landfill use onsite septic systems for wastewater disposal.

## Acknowledgments

The authors thank Mike Bolduc and other employees of the city of Saco, Rebecca Cleaver of Halliburton NUS Corp. in Wilmington, Mass., and Mary Kate Dwire, Maine Department of Environmental Protection, for providing reports and data collected at the Saco Landfill. Marc Loiselle and other employees of the Maine Geological Survey provided geologic reports and expertise, and Claude DuBois provided access to the gravel pit in the study area.

# DATA COLLECTION

Data collected by the USGS for this report include geologic data for the study area and surrounding area, geophysical data, and hydrologic and water-quality data for surface water and ground water at the landfill.

## Geologic Data

Geologic data were collected by field reconnaissance, aerial-photo interpretation, drilling, and review of available geologic reports. Field reconnaissance included inspection of all outcrops and gravel pits within a 2-mi radius of the landfill. Aerial photos taken on May 29, 1962, obtained from the Maine Geological Survey, were viewed stereoscopically to aid in the interpretation of the geology. Wells and test holes were drilled with an 8-in. hollow-stem auger drill rig, and sediment samples were collected with a 2-in. split-spoon sampler at regular intervals (see Appendix 1). All available geologic reports for the southern part of Maine were reviewed.

## Geophysical Data

Geophysical data were collected by use of surface and borehole geophysical methods. Surface geophysical methods included seismic refraction and electromagnetic (EM) terrain conductivity. EM induction borehole logs were obtained at three wells. All geophysical methods make use of the fact that different rock and sediment types have different physical properties. The physical properties of interest for this study were seismic velocity, electrical conductivity, and the rate of natural gamma radiation from earth materials.

### Seismic Refraction

The seismic-refraction method makes use of refracted waves of seismic energy and is based on the time required for energy generated at a point source to travel through the ground to receivers (geophones). The velocity of sound travelling through the various geologic layers can be calculated, and this velocity is used to predict the structure and depth of the various geologic layers in the subsurface.

Seismic-refraction data at the Saco Landfill were collected by use of a 12-channel signal-enhancement seismograph. The distance between the first and last geophone in each of the 19 seismic lines was either 550 or 220 ft, which corresponds to a spacing between geophones of 50 or 20 ft, respectively. Small two-component explosive charges were used as a source of seismic energy. These explosive charges were buried 3 to 4 ft below land surface at selected shotpoints. Altitudes and locations of all geophones and shotpoints were recorded. The seismic-refraction data were interpreted by computer-modeling techniques that incorporate delay-time and ray-tracing procedures (Scott and others, 1972; Scott, 1977).

The use of the seismic-refraction method requires the assumption of a layered earth in which the velocity of seismic energy increases with depth in each successive layer. Where this condition is met, seismic energy originating from a sound source travels downward into the ground until it meets a refracting surface. The energy refracted along this surface continually generates seismic waves that travel upward to land surface, where they may be detected by a series of geophones. In some cases, thin, intermediate-velocity layers cannot be detected. Descriptions of seismic-refraction theory and interpretation methods are given in Redpath (1973), Dobrin (1976), Mooney (1981), and Haeni (1988).

### Electromagnetic Surveys

Electromagnetic (EM) surveys were done during July and August 1993. Apparent terrain conductivity was measured by use of the Geonics EM34-3[1], which consists of a transmitter and transmitting antenna (coil), a receiver and receiving antenna (coil), and 33-, 66-, and 131-ft-long connecting cables. Apparent terrain conductivity is a function of the relative contributions of conductivity from all material within the depth of penetration of the instrument. The depth of investigation is dependent primarily on the antenna spacing and the orientation of the antennas, and to a lesser degree, the operating frequency. The effective depth of exploration for this instrument at various antenna spacings and orientations (McNeill, 1980a) is given in table 1.

**Table 1.** Effective exploration depths for electromagnetic terrain-conductivity antenna spacings for the horizontal and vertical orientations

| Intercoil spacing, in feet | Effective exploration depth, in feet | |
|---|---|---|
| | Horizontal dipole | Vertical dipole |
| 33 | 25 | 50 |
| 66 | 50 | 99 |
| 131 | 99 | 197 |

In general, when the antennas are in the horizontal dipole orientation, the instrument is most sensitive to near-surface layers. When the antennas are in the vertical dipole orientation, the instrument is most sensitive to deeper materials (0.4 times the intercoil spacing), and near-surface materials have little effect on the instrument. The three coil spacings and the unique response of each antenna orientation give this technique a limited depth-sounding capability. Six measurements can be made at each site and interpreted to define vertical changes in subsurface electrical properties. Lateral changes in electrical conductivity can be delineated by making a series of measurements in a grid or along a profile. A detailed description of this instrument and its operation is given in the manufacturer's series of technical notes (Geonics, Ltd., 1980; McNeill, 1980a, b). A description of the applications of the EM techniques to ground-water contamination studies are given by Greenhouse and Slaine (1983), Grady and Haeni (1984), and Haeni (1986).

EM terrain-conductivity measurements were made to delineate areas of ground water suspected to have high conductivity as a result of leachate contamination, primarily adjacent to the landfills. Additional measurements were made in areas near the landfill thought to represent natural, uncontaminated conditions. In general, measurement sites (stations) correspond to a 100-foot grid, which was established so the location of EM measurements could be plotted and successive measurements could be made at the same location. Stations were located by use of a hipchain and compass and a detailed site map and aerial photographs. The EM data, consisting of more than 1,200 apparent terrain-conductivity measurements, are discussed later in this report. Measurements were not made in the area between Area 2 and Sandy Brook because leachate contamination has been well documented there.

### Electromagnetic Induction Logging

In addition to its use as a tool to help map high-conductivity zones in shallow ground water, EM induction can be a valuable tool for the vertical delineation of contaminated zones in sandy aquifers (Williams and others, 1993). EM induction logs were obtained in three of the wells drilled by the USGS. The EM tool, which is slowly lowered down a well, measures by induction the electrical conductivity of the formation material and the water adjacent to the borehole. Wells chosen for logging were a minimum of 2 in. in diameter, penetrated the lower aquifer, were located where contamination levels were largely unknown, and had a long cased length to provide the best vertical profile of the aquifer materials. A borehole logger with single-conductor logging cable was used for this survey. Digital data from each 0.1-foot interval were recorded. Two coils are contained in the

[1] The use of trade or product names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

logging tool, one transmitting and the other receiving. The transmitter coil is energized with alternating current that causes very small currents to be induced in the medium near the well bore; the receiver coil detects these currents. By comparing the EM field induced in the receiver coil caused by the currents induced in the earth with those currents caused by the transmitter coil itself, a measure of the conductivity of the nearby earth can be obtained. The coil spacing in the logging tool minimizes the effects of borehole-fluid conductivity. Detailed descriptions of the theory, application, and analysis of borehole geophysics for ground-water investigations can be found in Keys (1990).

## Hydrologic and Water-Chemistry Data

Six surface-water measuring stations were established in and around the Saco Landfill in July 1993 (fig. 2) to study the surface-water hydrology of the landfill area. Two continuous-record stations where streamflow was measured continuously were established on Sandy Brook, one upstream and one downstream from the landfill (stations 1 and 3). In addition, four partial-record stations where streamflow was measured several times a quarter were established: on Sandy Brook at the landfill between the two continuous-record stations (station 2), on Big Ledge Brook (station 4), on an unnamed tributary to Deep Brook (station 5), and on Deep Brook (station 6). All data were collected according to methods adopted by the USGS and are described in Carter and Davidian (1968) and in Rantz and others (1982).

Data collected at the continuous-record stations consists of continuous measurements of stream stage and periodic measurements of streamflow. Stage was recorded at 15-minute intervals by use of an electronic data logger attached to a pressure transducer. The streamflow measurements were used to develop a rating curve at each station, which gives the streamflow associated with a given stage. In order to provide a stable and sensitive relation between stage and streamflow, 45-degree, sharp-crested V-notch weirs were installed at each station. The daily mean streamflow was computed as the arithmetic mean of the streamflows associated with the recorded stages for each day. At both continuous-record stations, daily mean streamflow was estimated for periods when either ice formed on the weir causing an unknown shift in the rating curve or equipment failed, resulting in the loss of stage record. Data for periods of questionable or missing data were estimated from data for the other continuous-record station on Sandy Brook or from another station, and streamflow measurements and weather records. Temperature and specific conductance also were monitored continuously at the two continuous-record stations.

Data collected at the partial-record sites consisted of periodic measurements of stage and streamflow. For the Big Ledge Brook and Deep Brook partial-record stations (stations 4 and 6), stage-discharge rating curves were used to calculate streamflow from stage readings on days when streamflow measurements were not made. The middle station on Sandy Brook (station 2) and the unnamed tributary to Deep Brook (station 5) lacked a stable control needed to develop a reliable rating curve. Specific conductance, dissolved oxygen, and water temperature were measured once every 2 weeks in the streams at the gaging stations from September 2, 1993, through February 23, 1994. In addition, specific conductance and water temperature were measured in late January and late February at each station.

Data used in the description of ground-water hydrology consisted of water-level data collected by the USGS and Halliburton NUS. At the beginning of this investigation, 39 monitoring wells were identified at the Saco Landfill (Halliburton NUS, 1994). The USGS installed seven additional 2-inch-diameter wells, five of which were subsequently used for water-level monitoring. Water levels in 10 monitoring wells at the Saco Landfill were measured monthly from October 1993 through February 1994. The altitudes of the wells with respect to sea level were surveyed by Owen Haskell, Inc., in November 1993 (Halliburton NUS, 1994). In addition, six wells were equipped with pressure transducers, and water-level data were collected at 1-hour intervals from September 1993 through February 1994. Water levels measured by Halliburton NUS from April 26, through May 4, 1993, also were used in the investigation.

Ground-water-chemistry data collected during previous and ongoing investigations were used in this study. All known information about methods of sample collection, preservation, and quality-assurance/quality-control (QA/QC) procedures for the sources used are given below, along with the source of the information:

E.C. Jordan, 1975—No reference for sample-collection methods was found (Atwell, 1975).

Maine Department of Environmental Protection, 1980—No reference for sample-collection methods was found (Camp, Dresser, and McKee, written commun., 1983).

DuBois and King, 1984—Wells were purged one day before samples were collected. Organic constituents were sampled by use of a polyvinyl chloride bailer; inorganic constituents were sampled by use of a peristaltic pump. Samples were filtered and preserved in the field. QA/QC samples were run in the laboratory, no reference to field QA/QC procedures was found. Specific conductance and pH were measured in the field (NUS Corporation, 1987).

Balsam Environmental Consultants, 1988—Wells were purged just before samples were collected. Samples were collected with a precleaned bailer. Metals samples were filtered in the field. QA/QC samples consisted of field blanks and duplicates. Samples were chilled until delivery to the laboratory and were analyzed within 48 hours of collection. Specific conductance and pH were measured in the field.

Halliburton NUS, April 1993—Wells were purged one day before sampling, and samples were collected by use of a positive-displacement pump or a bailer; the pump or bailer was cleaned between each well. All filtering was done in the field. QA/QC samples consisted of split samples, field blanks, and laboratory-spiked samples. Specific conductance and pH were measured in the field (Halliburton NUS, 1994).

Halliburton NUS, December 1993—Wells were purged just before samples were collected. Samples were collected by use of a low-flow-rate peristaltic pump and clean tubing for each well. All filtering was done in the field. QA/QC samples consisted of split samples, field blanks, and laboratory-spiked samples. Specific conductance and pH were measured in the field (Halliburton NUS, 1994).

City of Saco, 1987-94—Samples were collected by use of a bailer from wells purged from 1 to 48 hours before samples were collected. Samples were filtered in the laboratory, where pH and specific conductance measurements were made. As of June 1994, samples are still being collected (Brian Greene, city of Saco, oral commun., 1994).

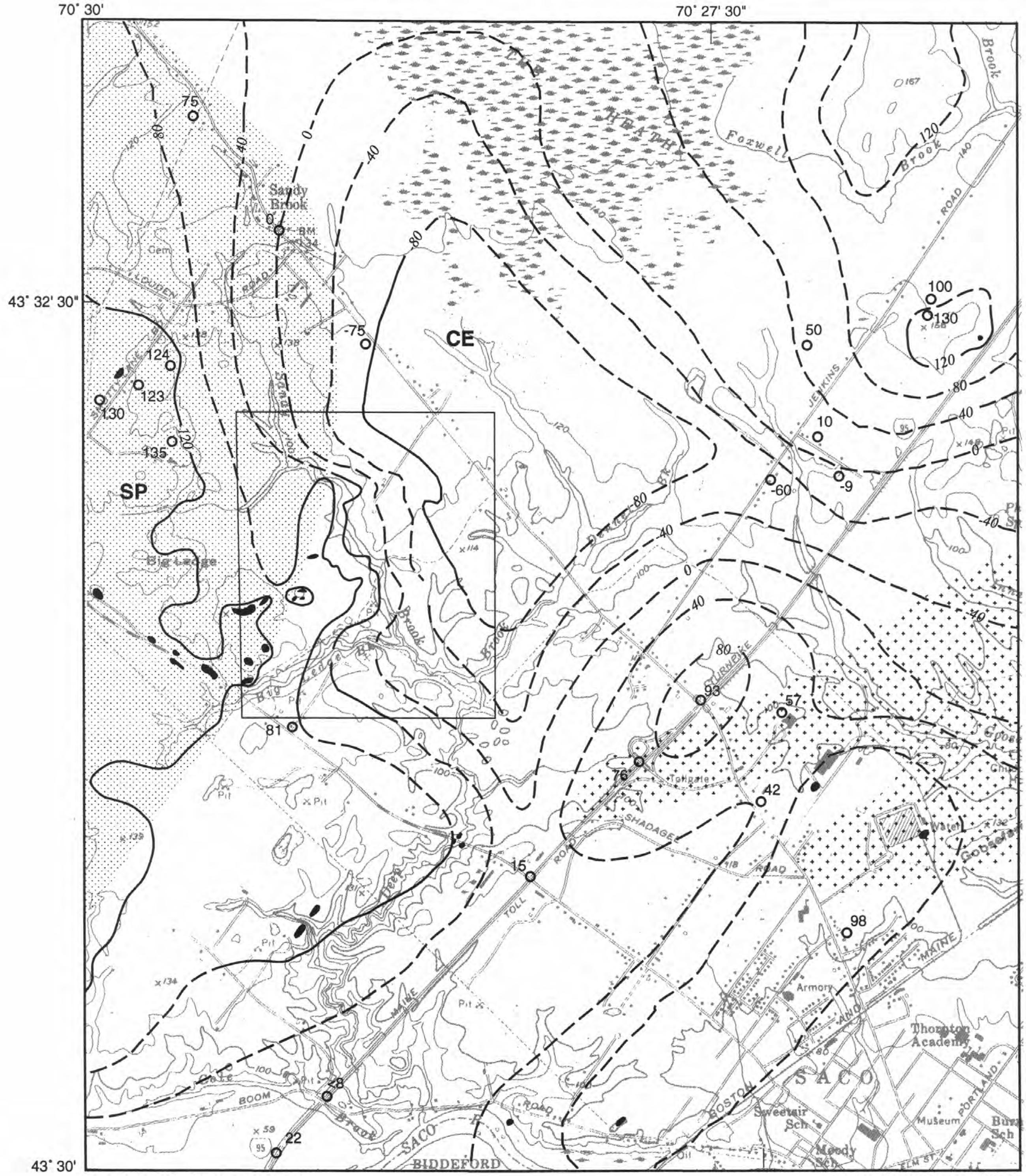
# GEOHYDROLOGY

An understanding of the geometry and distribution of geologic materials, their function as aquifers or confining units, and the distribution of hydraulic head and streamflow in a system is needed to understand the hydrologic system. The following description of geology at the Saco Landfill includes a discussion of the bedrock and unconsolidated glacial deposits. Several of these units are saturated and comprise three aquifers at the landfill. Spatial and temporal changes in water levels in the two surficial aquifers along with spatial and temporal patterns of surface runoff help in understanding the whole hydrologic system in the study area.

## Geology

### Bedrock

The bedrock geology of the Saco area has been mapped by Hussey (1971; 1985). Two basic types of rock underlie the region surrounding the Saco Landfill study area (fig. 3). The western part of the area is underlain by igneous rock of the Saco Pluton of Hussey (1971). The Saco Pluton is Carboniferous (345-280 million years ago) in age and is an intrusive body, 3 to 4 mi in diameter, within older metasedimentary rocks of the Cape Elizabeth Formation to the east. The Saco Pluton is composed of dark gray, medium- to coarse-grained rock ranging in composition from diorite to gabbro. Minerals present include plagioclase, light green hornblende, and brown biotite (the latter two minerals are commonly altered to secondary chlorite); quartz and augite are minor minerals.




Base from U.S. Geological Survey, Old Orchard Beach topographic quadrangle, 1:24,000, 1970

Geology from Hussey (1971)
Bedrock contours modified from Caswell and Lanctot (1975) by J.R. Stone and B.P. Hansen (1994)

0 .5 1 MILE

0 .5 1 KILOMETER

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

**EXPLANATION**

**SACO LANDFILL AREA**

SP **IGNEOUS ROCK**--Diorite and gabbro of the Saco Pluton

CE **METASEDIMENTARY ROCK**-- Phyllite and schist of the Cape Elizabeth Formation; shaded area is schist of the Scarboro Formation.

*120* **BEDROCK CONTOUR**--Shows altitude of bedrock surface. Dashed where approximately located. Contour interval is 40 feet. Datum is sea level

**BEDROCK OUTCROP**

o 124 **LOCATION OF WELL OR TEST BORING THAT REACHED OR PENETRATED BEDROCK**--Number is altitude of bedrock surface in feet above or below (-) sea level

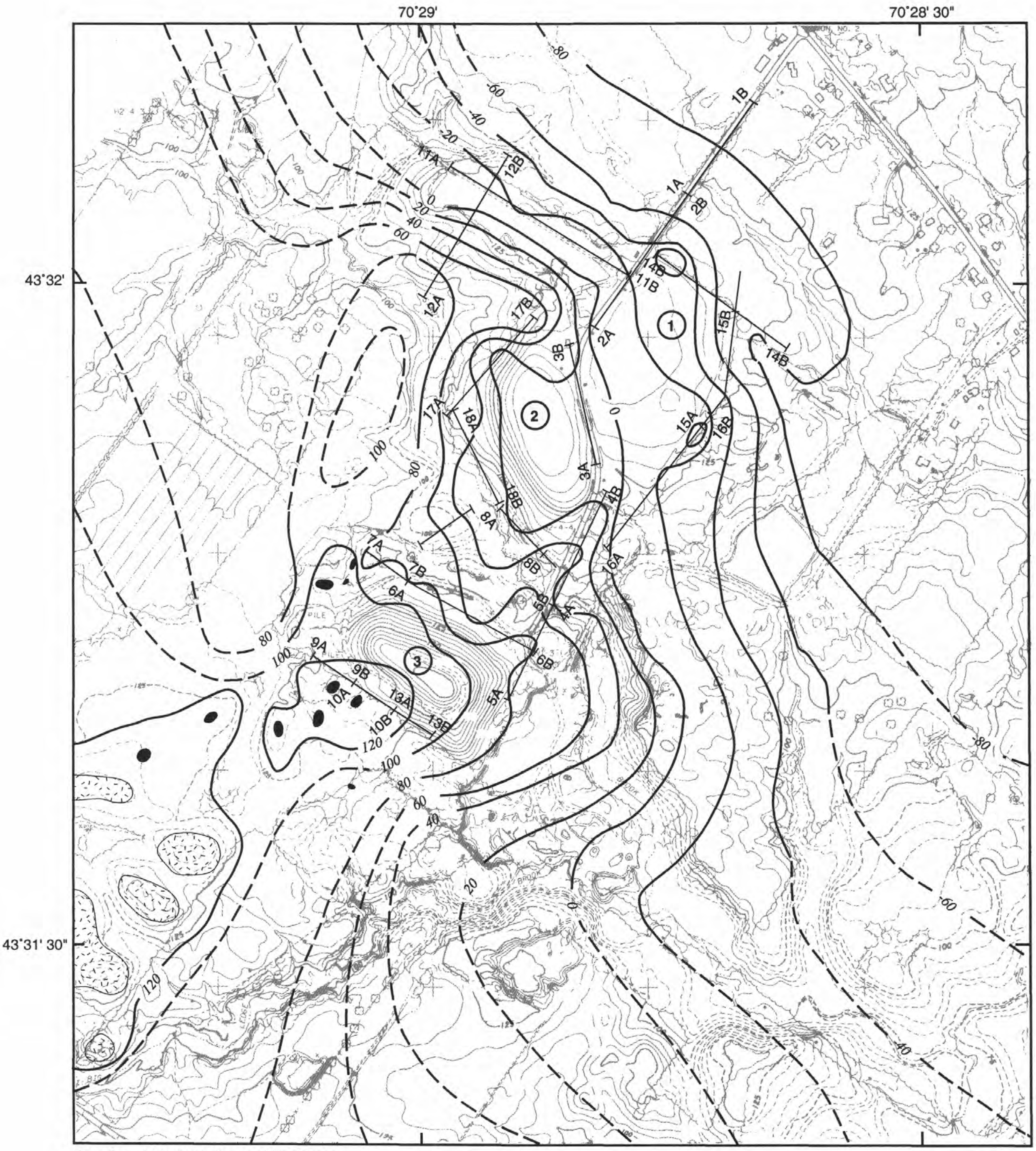
**Figure 3.** Bedrock geologic units and bedrock-surface contours in the region surrounding the Saco Landfill area, Saco, Maine.

The presence of a contact-metamorphic zone, where the country rock has been "cooked" by the heat of the intruding magma, around the outer edge of the oval-shaped pluton is likely at least on the east side, although such a zone has not been shown on published geologic maps. Bedrock presently exposed at the Saco Landfill (uncovered during previous landfill excavations) is dark, fine-grained hornfels typically found in contact-metamorphic zones. Several outcrops in the wooded area to the west of the Saco Landfill also are fine-grained hornfels. The entire area west of Sandy Brook in the Saco Landfill area where the bedrock surface lies above 0 to 20 ft in altitude (fig. 3) is probably underlain by extremely hard, dense, fine-grained hornfelsic facies of the contact-metamorphosed zone.

The Saco Pluton is relatively resistant to weathering and erosion; hence, the pluton stands in higher relief in the landscape than do the less resistant metasedimentary rocks to the east (fig. 3). The Saco River crosses the pluton along several major northwest- and northeast-trending fracture zones. These same fracture trends are evident as joint sets seen on aerial photographs and in small stream segments within the Biddeford Granite (Paleozoic age) to the immediate southeast (Hildreth, 1990). A nearby northeast-southwest-trending segment of the Saco River crossing the Saco Pluton flows along the Nonesuch River Fault, a major regional right-lateral strike-slip fault 3 mi north of the Saco Landfill (Hussey, 1971). Several small stream segments in the eastern part of the pluton follow a fracture set trending north to north-northeast and a second set trending east-northeast to east. Similar orientations were measured on subvertical fractures in outcrops of the pluton along Route 5 in Saco.

To the east of the Saco Pluton, the area is underlain by metasedimentary rocks belonging to the Casco Bay Group, which range in age from Precambrian to Ordovician (Hussey, 1985). Within the area shown in figure 4, the underlying bedrock is the Cape Elizabeth Formation; a small area on the east side is underlain by the Scarboro Formation, which is lithologically similar to the Cape Elizabeth Formation but lies stratigraphically above it. The Cape Elizabeth rock units in this area are on the northwestern limb of the Saco syncline; the area underlain by the Scarboro Formation is in the axis and at the nose of this northeast-plunging fold.

The metasedimentary rocks are less resistant to weathering and erosion than are the igneous rocks of the Saco Pluton; hence, they lie at lower altitudes in the present landscape. Some stratigraphic units within the formation, probably those containing quartzite beds, are more resistant than others; these resistant units form the northeast-southwest trending outcrop and shallow-rock areas. Breaks in these outcrop belts probably are due to northwest-trending joints and fractures. The deep bedrock valley (fig. 3) at and to the north and east of the Saco Landfill may reflect the presence of a fracture zone as well as a weakening in the phyllite near the edge of




Base from U.S. Army Corps of Engineers
Saco Municipal Landfill 1:2,400, 1988

0 500 1,000 FEET
0 100 200 METERS
CONTOUR INTERVAL 5 FEET
National Geodetic Vertical Datum 1929

## EXPLANATION

- OUTCROP OF COARSE-GRAINED DIORITE OF THE SACO PLUTON
- OUTCROP OF FINE-GRAINED HORNFELS WITHIN THE CONTACT-METAMORPHOSED ZONE AROUND THE SACO PLUTON
- —— 80 —— **BEDROCK CONTOUR**--Shows altitude of bedrock surface. Dashed where approximately located. Contour interval is 20 feet. Datum is sea level
- 2A ├──┤ 2B **LOCATION OF SEISMIC-REFRACTION LINE FROM WHICH DEPTHS TO BEDROCK WERE OBTAINED**
- (2) **LANDFILL IDENTIFICATION NUMBER**

**Figure 4.** Distribution of bedrock units and bedrock-surface topography in the Saco Landfill area, Saco, Maine.

the pluton. The deep bedrock valley may have been a former course of the Saco River around the Saco Pluton if the valley continues southeastward to Saco Bay. No well or test-boring data were available to confirm the continuation of this valley; however, the presence of a west-to-east-trending bedrock valley offshore from the mouth of Goosefare Brook with a midvalley depth of about -180 ft is indicated by seismic-reflection data from Saco Bay (Kelley and others, 1989). The bedrock contours shown in figure 4 are based in part on a map by Caswell and Lanctot (1975) and in part on more recent well and test-boring data.

The distribution of bedrock units and bedrock-surface topography in the Saco Landfill study area are shown in figure 4. On the west side of the area, bedrock is dark, coarse-grained igneous rock ranging in composition from diorite to gabbro. Exposures of this rock can be seen along Smutty Lane and Route 5 to the north and west of the study area (fig. 3). Fractures in these outcrops are predominantly subvertical, trend northward and east-northeastward, and are spaced 10 to 20 ft apart with local closely spaced fracture zones. Some fractures are filled with vein quartz. Beneath Area 3 and extending for about 1,200 ft west-southwest of it, the bedrock is dark, dense, very fine grained contact-metamorphosed rock that is hornfelsic in composition. A glacially smoothed and striated surface of this bedrock is exposed beneath glaciomarine sands just north of Area 3; although no open fractures were evident on this rock surface, several subvertical fractures trending N. 20° W. to N. 15° E. were measured on an outcrop in the wooded area to the west of Area 3.

Bedrock in the eastern half of the Saco Landfill area is not exposed at land surface but is inferred from regional geologic maps to be metasedimentary rock of the Cape Elizabeth Formation. Exposures of this rock within 1 to 3 mi of the study area are thinly layered, calcareous, quartz-muscovite phyllite locally interlayered with thin beds of micaceous quartzite; muscovite is altered to chlorite because of high-grade metamorphism. Layering in these rocks is vertical to near vertical, and strike directions are N. 40° to 60° E.

The altitude of the bedrock surface at the Saco Landfill (fig. 4) was interpreted from the seismic data and a small amount of bedrock-outcrop and test-well data. The interpreted bedrock altitude ranges from less than 80 ft below sea level at the north end of line 1 to 135 ft above sea level along line 10. The bedrock surface is irregular and undulating and generally decreases in altitude from southwest to northeast. The locations of the 19 seismic-refraction lines are shown on figure 4, and geohydrologic sections interpreted from seismic-refraction data are shown in Appendix 2.

In general, the seismic-refraction data indicate the presence of three seismic horizons along most of the seismic profiles. In the first layer, seismic velocity ranges from 800 to 1,500 ft/s and is representative of unsaturated unconsolidated deposits. In the second layer, seismic velocity ranges from 4,450 to 6,100 ft/s and is representative of saturated, stratified, unconsolidated deposits. The data indicate that these deposits range from 0 to 220 ft in thickness. In the third layer, seismic velocity ranges from 12,000 to 34,000 ft/s, which is indicative of bedrock.

In many locations in New England, a layer of till overlies the bedrock surface. Till has a seismic velocity ranging from 6,500 to 8,000 ft/s. Drilling logs at the Saco Landfill (Appendix 4) indicate that till is at least 19 ft thick at USGS test hole 93-9. Seismic data did not indicate the presence of this intermediate-velocity layer. The nondetection of an intermediate layer may be the result of either too large a geophone spacing or a "blind zone." A blind zone (Soske, 1959; Sander, 1978) occurs when seismic velocity increases with depth in a layer, but the velocity contrast or layer thickness is too small to cause a return of first-arrival energy to land surface. This problem cannot be overcome by any change in the layout of the geophones or shotpoints. If this intermediate layer is present, the computed depth to bedrock at that location will be in error, and the actual depth to bedrock will be greater than shown. This error, however, probably will be less than 50 percent of the total indicated depth to bedrock (Redpath, 1973).

Seismic lines 9, 10, and 13 (southwest of Area 3) were interpreted as overlying only unsaturated unconsolidated deposits over bedrock. A thin saturated layer probably exists, at least seasonally, along these lines.

Within the study area, depths to bedrock that are interpreted from seismic data generally are considered to have an error of ±15 percent. Errors are caused by blind zones, velocity inversions, and lenses of different velocity deposits within average velocity zones. In some cases, the altitudes of layers at the meeting points of two lines do not match exactly (Appendix 3). This inconsistency probably is due to variable geologic conditions and the unique location of the shotpoints, which do not sample geologic conditions common to both lines. This condition is particularly noticeable where seismic lines 2 and 14 meet; the shot point for line 14 is 200 ft to the west of the common point and the shot point for line 2 is 450 ft south.

### Unconsolidated Deposits

The surficial geology of the Portland-Saco area has been mapped by Smith (1977) and Retelle (1991) and placed in a regional context on the "Surficial Geologic Map of Maine" (Thompson and Borns, 1985a). The present-day bedrock surface has been produced by millions of years of differential erosion, but its final form was produced by the scouring effects of Pleistocene glaciations during the last 2 million years.

Glacial till deposits (shown as **tb** in fig. 5) laid down beneath glacial ice overlie the bedrock surface in many places in southwestern Maine. The glacial till deposits are commonly relatively thin and consist of a compact, unsorted mixture of stones in a fine-grained matrix of sand, silt, and clay; the color and texture of particular till deposits differ from place to place and are related to the type of bedrock in northerly adjacent areas from which the till was derived. In the Old Orchard Beach quadrangle, till is generally compact and ranges in color from dark olive gray to dark olive brown (Retelle, 1991). Most of the till at the surface and beneath glaciomarine deposits is unweathered and was laid down during the late Wisconsinan glaciation. A more weathered till also is present locally at depth and is believed to have been laid down during an earlier glaciation (Thompson, 1982; Thompson and Borns, 1985a; Weddle and others, 1989).

The glacially scoured and till-draped bedrock surface in this region is overlain by extensive glaciomarine deposits. These sediments range from a few feet to more than 200 ft in thickness and include coarse-grained and fine-grained sedimentary facies (**mp** and **mf** in fig. 5). Sometime between 17,000 and 15,000 years ago, the late Wisconsinan ice sheet began to retreat from its terminal position on the Continental Shelf, where its terminus was in contact with the sea. Sea level during the time of glaciation was at least 395 ft below its present level (Fairbanks, 1990). Continental deglaciation was accompanied by a rise in sea level. By about 14,000 years ago, the glacier margin had retreated to the vicinity of the present coastline (Smith, 1985; Thompson and Borns, 1985b), and because the land was depressed isostatically by about 650 ft, the region was inundated by the sea with water depths of 100 to 300 ft. The altitude of the marine limit in the Saco region is marked by an ice-marginal glaciomarine delta at an altitude of 262 ft about 4 mi to the west of the Saco Landfill (Hunter, 1990). Retreat of the grounded ice margin through the coastal zone in the glaciomarine environment probably was fairly rapid (Smith, 1982; Smith and Hunter, 1989).

During this retreat, substantial deposits of coarse-grained, stratified meltwater deposits and local diamict (unstratified) sediments were laid down on the sea floor as subaqueous fans and fan complexes (**mf** in fig. 5). Successive end moraines were formed where a number of these fans were built along particular stands of the ice margin (grounding lines) and where minor oscillations of the margin occurred. The end moraines are composed predominantly of coarse-grained stratified materials but have more internal deformation and overlying diamict sediment than simple fan deposits. Submarine fan deposits consist of coarse gravel and sand with local diamict sediment in ice-proximal (northerly) parts, and grade to finer gravels and sand within short distances in distal (southerly) directions. The distal sandy beds interfinger with fine-grained marine silt and clay. Commonly, a coarse-grained facies of one submarine fan sequence is overlain by a sandier facies of the next sequence to the north. Detailed descriptions of various sedimentary facies that make up the coarse-grained glaciomarine deposits are given in Thompson (1982), Retelle and Bither (1989), and Smith and Hunter (1989).

Fine-grained glaciomarine deposits consisting of massive to finely laminated, gray to dark-bluish gray silty clay with minor amounts of fine sand (**mp** in fig. 5) are ubiquitous in the Saco area; thickness ranges from 10 to 140 ft. This material locally interfingers with the coarse-grained facies, but mostly overlies it. Glaciomarine silty clay deposits in coastal Maine compose the Presumpscot Formation referred to by Bloom (1960; 1963) and many later investigators. The marine silty clay settled out in relatively quiet, deep water while the ice margin retreated farther to the north. Deposition of the fine-grained sediment by underflow currents coming from the nearby ice sheet resulted in the filling of deeper areas on the sea floor with greater thicknesses of sediment, thus masking the irregular relief on the surface of the coarse-grained ice-contact deposits; only locally do the coarse-grained deposits protrude through the marine silt and clay and are exposed at the present-day surface (see fig. 5). Deposition of the Presumpscot Formation in the deep-water glaciomarine environment in the Saco area probably continued until approximately 13,000 years ago (Belknap and others, 1989).

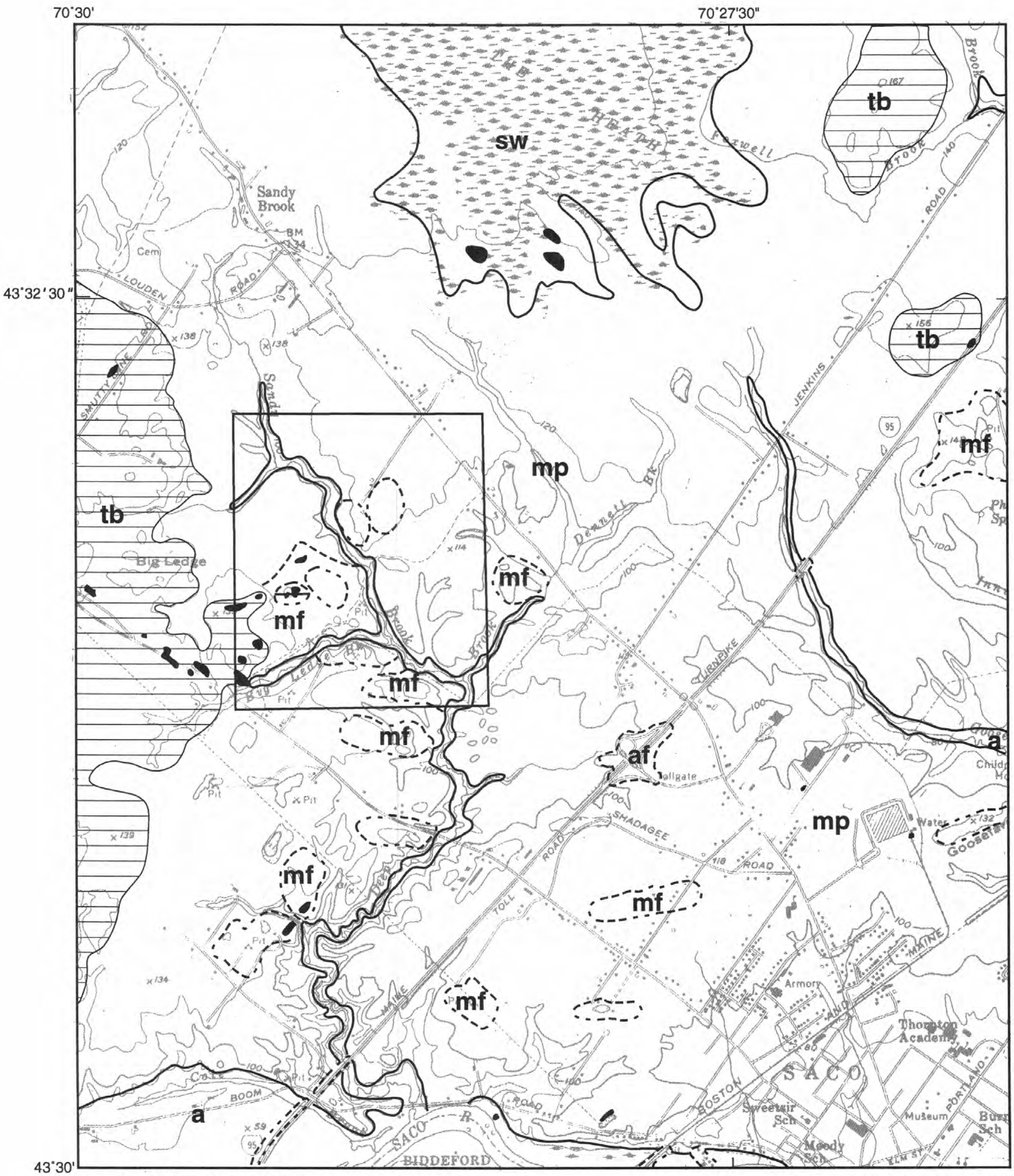
As the rate of glacio-isostatic rebound of the Earth's crust exceeded the rate of eustatic sea-level rise, relative sea level in the area declined. A sandy facies of the Presumpscot Formation was laid down in the shallow marine environment as shoreline regression progressed southeasterly through the area. This facies consists of massive to stratified, generally well-sorted, brown to gray-brown fine to medium sand that locally grades downward to finely laminated fine sand and silt; it is typically 5 to 20 ft thick and gradationally overlies the fine-grained silt and clay facies. Locally, the surface of the shallow marine facies has either erosional or depositional features indicative of particular sea-level stands. In the Biddeford and Saco area several former shorelines are recorded (Hildreth, 1990; Retelle, 1991). In the town of Old Orchard Beach, sandy spit deposits, which mark a projection of beach sands into open water, mark a sea-level stand at an altitude from 100 to 130 ft above present sea level during which the Landfill area was covered by about 10 ft of water and the shoreline extended to the southern end of the Heath.

During the time of this 130-foot sea-level stand, nearshore processes (predominantly wave reworking) redistributed marine sand as spits, bars, and beaches. Particular sea-level stands were relatively brief, as sea level lowered rapidly; the coastal zone (up to 25 mi inland in southwestern Maine) was completely emergent by 11,500 years ago (Smith, 1985). Sea level continued to lower to levels below the present shoreline; by about 9,500 years ago, the rates of uplift and eustatic sea-level rise were balanced, and a low stand was reached at a depth of 180 to 197 ft below present sea level (Belknap and others, 1986; Shipp and others, 1989). When the sea fell below the present level, streams incised deeply into the surface of the exposed glaciomarine deposits. Following the low stand, sea level slowly rose to its present position. A record of sea-level rise in Saco Bay is summarized in Kelley and others (1989).

Postglacial deposits in the Saco area (units **af**, **a**, and **sw** in fig. 5) include flood-plain alluvium and swamp deposits. Flood-plain alluvium is relatively thin (commonly less than 5 ft thick) and is present on erosional surfaces where postglacial streams have incised glacial deposits. In low-lying areas, such as the Heath, deposits of organic muck and peat accumulated after the sea had retreated from the area.

## Geohydrologic Units

All geologic units described previously are saturated with ground water to some extent. This includes the fractured bedrock, the till, the coarse-grained and overlying fine-grained glaciomarine sediments, and the surficial sandy deposits. The most significant of these, in terms of their use as water-bearing deposits, are the




Base from U.S. Geological Survey, Old Orchard Beach quadrangle 1:24,000, 1970

0 .5 1 MILES

0 .5 1 KILOMETERS

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Geology modified from M.J. Retelle (1991)

## EXPLANATION

*POSTGLACIAL DEPOSITS*

**af** **ARTIFICIAL FILL**-- Compacted fill, generally quarried from glacial deposits, used beneath highway embankments; bodies of artificial fill at the Saco Landfill are compacted trash mixed with sand and gravel; two fill areas are capped with clay quarried from nearby glaciomarine deposits.

**a** **FLOOD-PLAIN ALLUVIUM**-- Sand, gravel, and silt with minor amounts of organic material on modern flood plains; generally less than 5 ft thick along Sandy Brook, Big Ledge Brook, Deep Brook, and Goosefare Brook; deposits may be thicker along the Saco River. Alluvium generally overlies thicker glacial sediment.

**sw** **SWAMP DEPOSITS**-- Peat and muck with lesser amounts of fine-grained inorganic sediment in the poorly-drained wetland area of "The Heath". Unit overlies thick, fine-grained glaciomarine deposits.

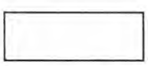
*GLACIAL DEPOSITS*

**mp** **GLACIOMARINE DEPOSITS, FINE-GRAINED**-- Lower part of unit (10-140 ft in thickness) is massive to finely laminated, gray, silty clay with minor amounts of fine sand and sparse fossil marine mollusk shells and ice-rafted dropstones; deposited in the deeper water glaciomarine environment, distal from the ice margin. Where sediment has been oxidized in the upper part of section, the color is dark olive gray. This unit is the Presumpscot Formation of Bloom (1960). Upper part of unit (5-25 ft in thickness) is finely laminated to massive, silty, fine to medium sand, locally pebbly, containing fossil shells; deposited in the shallow glaciomarine environment during regression of the sea. Unit includes lithofacies association MM of Smith and Hunter (1989).

**mf** **GLACIOMARINE DEPOSITS, COARSE-GRAINED**-- Well- to poorly-sorted gravel and sand and nonsorted diamict sediment deposited as fans and end moraines in contact with the glacier margin on the sea floor at successive grounding-line positions during ice retreat. Deposits are coarse grained and poorly sorted in ice-proximal (northerly) parts; beds generally dip in southerly directions and are finer-grained and better sorted farther from (distal to) the ice-margin position; in distal parts, submarine fan deposits interfinger with finer-grained glaciomarine sediment. Unit includes lithofacies associations DPF, SF, and SEM of Smith and Hunter (1989). Shown only where at or near the land surface; deposits are more extensive below unit **mp**.

**tb** **GLACIAL TILL AND SHALLOW BEDROCK**-- Areas of numerous bedrock outcrops and shallow bedrock, mantled by thin glacial till and glaciomarine deposits.

### MAP SYMBOLS


Saco Landfill area (figures 4 and 6)


Contact between map units, dotted where approximately located


Bedrock outcrops; shown only where mapped in the field

**Figure 5.** Surficial geology in the region surrounding the Saco Landfill area, Saco, Maine.

fractured bedrock and the coarse-grained glaciomarine deposits. The landfill and surrounding area straddle the boundary between a deep, productive glacial aquifer to the south and east (coarse-grained glaciomarine deposits) and a fractured bedrock aquifer to the west (Tolman and Lanctot, 1985).

The fractured bedrock of the Saco Pluton and the Cape Elizabeth Formation is used extensively as a water-supply source in this area, primarily for individual residential wells. Many of the residences in the vicinity of the Saco Landfill are supplied by bedrock wells, except on Buxton Road, where residences are connected to the Saco-Biddeford public water-supply system. Seventeen wells within approximately 2.5 mi of the Saco Landfill have been reported to the Maine Geological Survey (MGS) by well drillers. Yields in these wells range from 0.5 to 40 gal/min; the median yield is 5 gal/min. Depths to bedrock at these wells range from 2 ft to more than 150 ft. The fractured bedrock is recharged by direct precipitation and infiltration where soils are thin and bedrock is near the surface; recharge passes through the overlying sediments where they are saturated. None of the observation wells installed at the landfill penetrate bedrock. Data regarding the hydraulic conductivity of bedrock aquifers are scarce. Because of the unknown size and density distribution of subsurface fractures in the bedrock, estimation of transmissivity or hydraulic conductivity of the bedrock aquifer would be difficult.

The distribution of surficial materials in the Saco Landfill area was mapped by use of all available information from well- and test-boring logs, test-pit descriptions, and exposures in existing sand and gravel excavations (fig. 6). The map units describe the texture of surficial materials at the surface as well as in the subsurface. Geologic sections shown in figure 7 also illustrate the vertical relations among various sedimentary facies within the glacial deposits overlying bedrock.

Glacial till is not exposed at the surface in the Saco Landfill area. It is inferred to be present beneath glaciomarine deposits in many places and is generally less than 20 ft thick. Till was found beneath glaciomarine deposits and on top of bedrock at wells 93-2, 93-3, and 93-9; interpretation of this material as till was based mostly on the difficulty of drilling through the material rather than analysis of samples. Therefore, lithologic description of glacial till within the study area must be taken from regional descriptions. Retelle (1991, p. 2) describes till in the Old Orchard Beach quadrangle as "a generally fine-grained matrix with a mixture of sand, silt and clay, and clasts of varying composition (metamorphic and igneous) and size, ranging from pebbles to boulders * * * generally compact and [ranging] in color from dark olive gray to dark olive brown."

The till may transmit water to and from the bedrock aquifer, but it is not a significant water-bearing unit in the study area. The till is not discussed further in this report.

Coarse-grained glaciomarine deposits (units **gd** and **sf**) that make up the lower aquifer include beds of gravel, mixed sand and gravel, sand and lenses or layers of diamict sediment. Two sedimentary facies of these deposits have been delineated in the map (fig. 6) and geologic sections (fig. 7): a coarser-grained gravel and diamict facies (unit **gd**) and a finer grained sand and pebbly sand facies (unit **sf**). These materials are present at or near the land surface in the study area west of Sandy Brook, where they are 10 to 80 ft thick. To the east of Sandy Brook, coarse-grained materials are present beneath fine-grained glaciomarine deposits in most places and are of varied thickness. At well 93-2, sand and gravel is 30 ft thick beneath 165 ft of fine-grained sediment; at well 93-4, sand, gravel, and diamict sediment is 70 ft thick beneath 105 ft of fine-grained sediment. At test boring 93-9, no coarse-grained glaciomarine sediments were found; marine silt and clay directly overlies till at this locality. Because the thickness and distribution of these deposits are highly varied, their subsurface extent as shown on the map and geologic sections is more inferential than that of the surface units. Coarse-grained glaciomarine deposits are presently exposed in a small excavation about 200 ft east of Area 3; this pit exposes the core of a marine fan, which was probably part of the fan/end-moraine complex formerly excavated beneath Area 3 during landfill operations. In the northernmost extent of the pit, several feet of diamict sediment overlie deformed sand and gravel beds. Within a few tens of feet further south in the pit face, sand beds interfinger with thin beds of oxidized marine silt and clay. Well 93-6, approximately 100 ft northwest of the pit scarp, was drilled through 26 ft of sandy diamict sediment and gravel overlying bedrock.

The coarse-grained glaciomarine fan sediments are referred to as the "lower aquifer" in this report because they are stratigraphically below the fine-grained sediments of the Presumpscot Formation (unit **fm** in fig. 6), which functions as a confining unit. Where the overlying Presumpscot Formation is absent and the glaciomarine fan deposits are unconfined, the term "lower aquifer" remains (fig. 8). The ability of this aquifer to transmit water is dominated by the more highly permeable sand and gravel facies. Water flow within the aquifer is much slower in the unsorted sediments. Tolman and Lanctot (1985) indicate that this aquifer is highly productive, an interpretation most likely based on data from the sand and gravel sediments. The lower aquifer probably is recharged where fan deposits protrude through the overlying fine-grained sediments, though some recharge may come from the underlying bedrock. Hydraulic conductivities for this aquifer have not been published, but they may be quite varied because of the mixture of clean, coarse sand and gravel and unsorted diamict fan deposits.

The distribution of the lower aquifer coincides with the map units **fm/sf**, **sf**, and **gd** (fig. 6). The lower aquifer is confined where the unit **fm** is above it (for example, under Area 1) and unconfined where **fm** is absent (for example, southeast of Area 3). Saturated thicknesses range from less than 10 ft, where the aquifer is unconfined and bedrock is near the surface, to more than 100 ft (see fig. 7). In the vicinity of well 93-6 (at seismic shotpoint 6B, figs. 4 and 6), these sediments were dry.

<u>Fine-grained glaciomarine deposits</u> (units **fm** and **ss**) include two sedimentary facies as delineated in figures 6 and 7. The silt-clay facies (unit **fm**) is composed of massive to thinly laminated silt, clay, and minor amounts of fine sand; its color is gray to dark-bluish gray, except in upper sections where it is above the water table and has been oxidized; there, it is brownish gray and has numerous dark-brown iron/manganese-stained joints and desiccation cracks, giving it a blocky structure. This material is present only locally west of Sandy Brook in the immediate Saco Landfill area as thin beds interfingering with marine fan deposits. To the east of Sandy Brook, marine silt and clay deposits are an extensive unit, 25 to 150 ft in thickness, overlying coarse-grained deposits. Borehole geophysical logs from wells 93-1 and 93-2 (fig. 9) show a significant increase in EM conductivity in the marine silt and clay at a depth of 40 to 50 ft below land surface; this increase is interpreted to be a result of connate salty water in the lower part of the section, whereas recharge from precipitation has introduced freshwater into the upper part of the deposit. A decrease in natural gamma counts in the marine silt-clay at a depth of 60 to 70 ft below land surface is attributed to a slight coarsening in overall texture (more fine sand and less clay) in the lower part of the section.

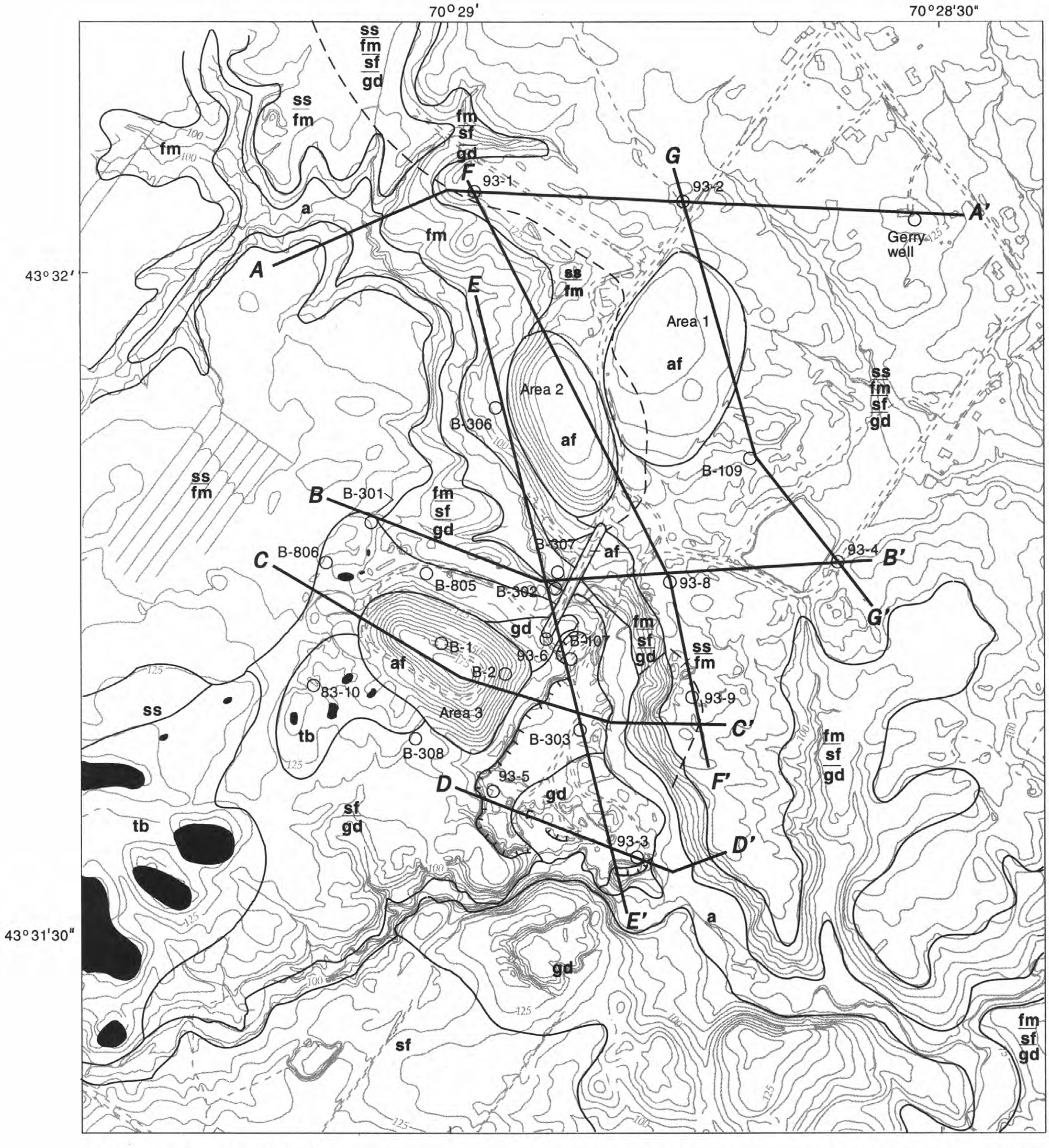
Less significant than the lower aquifer in terms of water supply, but important in terms of contaminant migration, are the fine-grained glaciomarine unit and the overlying sandy sediments of the Presumpscot Formation (**ss** on fig. 6). The fine-grained glaciomarine unit of the Presumpscot Formation functions as a regional confining unit, separating the lower aquifer in the marine fan deposits from shallower ground water overlying the fine-grained unit. This silt and clay deposit has been the subject of much scrutiny because it causes many geotechnical engineering problems across its geographic range. It is prone to landslides, it undergoes unpredictable compaction and settlement beneath engineered structures, and it is prone to frost heaving near the surface (Andrews, 1987). Published hydraulic conductivities for the glaciomarine silt and clay unit range from 4 x $10^{-5}$ to 1 x $10^{-3}$ ft/d (Andrews, 1987; Brutsaert, 1987; and Holland and Tolman, 1987).

The borehole EM conductivity logs may be used to calculate a vertical hydraulic conductivity of the confining unit. In wells 93-1 and 93-2, a zone of lower EM conductivity can be seen in the upper part of the silt/clay confining unit, which extends approximately 50 ft into the deposit (fig. 9). Because the vertical hydraulic gradient between the upper and lower aquifers is downward, this zone of lower EM conductivity may be due to vertical flushing of water through the confining unit. If it is assumed that the present hydraulic gradient near wells 93-1 and 93-2 has persisted over a long period of time (10,000 years), a vertical hydraulic conductivity of the confining unit may be calculated by use of Darcy's law:

$$K_v = \frac{vn}{dh/dl} \quad ,$$

where

$K_v$ is vertical hydraulic conductivity;
$v$ is average linear velocity;
$n$ is porosity; and
$dh/dl$ is the vertical hydraulic gradient.




Base from U.S. Army Corps of Engineers
Saco Municipal Landfill 1:2,400, 1988

0 500 1,000 FEET

0 100 200 300 METERS

CONTOUR INTERVAL 5 FEET

National Geodetic Vertical Datum of 1929

Geology by J.R. Stone (1994)

# EXPLANATION

*POSTGLACIAL DEPOSITS*

**af** — **ARTIFICIAL FILL**--Includes road embankment and graded landfill bodies and their clay caps. Arficial and "disturbed" material less than 1 ft thick is present over much of the mapped area especially where sand and gravel have been extracted. Mapped bodies of artificial fill overlie surrounding glacial or postglacial deposits.

**a** — **FLOOD-PLAIN ALLUVIUM**-- Composed of sand and silt, locally gravel, with some organic material on flood-plain surfaces of Sandy Brook and Big Ledge Brook; unit overlies thicker glaciomarine deposits.

*GLACIOMARINE DEPOSITS*

Gravel, diamict, sand, silt, and clay that were deposited in layers and are classified into four textural units on the basis of grain-size distribution, sedimentary structures, and mode of deposition; these units comprise lithofacies as defined by Smith and Hunter (1989) and Retelle and Bither (1989). The texture of glaciomarine deposits is described throughout their whole vertical extent either as a single textural unit or as two or more units in various orders of superposistion, referred to as "stacked units. " Contacts between subsurface textural units are not mapped with as great accuracy and detail as those at the surface. All units of glacial stratified deposits overlie glacial till and (or) bedrock that is not included in the stacked unit.

**gd** — **GRAVEL AND DIAMICT FACIES OF GLACIOMARINE PROXIMAL-FAN DEPOSITS**-- Layers of fine to coarse gravel with lesser amounts of sand within gravel beds; locally includes sand beds as separate layers. Material may be well to poorly sorted, deposited by meltwater streams that issued from ice tunnels on the sea floor. Unit also includes layers and lenses of diamict sediment that are composed of a nonsorted mixture of stones, gravel, and sand commonly in a fine-grained, silty matrix; diamict layers resulted from resedimentation of water-laid materials by mass-flow processes. Bedding in gravels is commonly distorted and faulted because of over-riding by ice, slumping, and postdepositional collapse.

**sf** — **SAND FACIES OF GLACIOMARINE DISTAL-FAN DEPOSITS**-- Well to poorly sorted, fine to coarse sand and pebbly sand, commonly planar cross-bedded, sometimes massive. This facies interfingers with **gd** facies in proximal parts and **fm** facies in distal parts; it commonly overrides the **gd** facies. Sand was deposited by meltwater currents on the sea floor farther away from mouths of ice tunnels where flow velocities were decreased. Bedding may be locally deformed by slumping and ice-rafted boulders are common.

**ss** — **SAND FACIES OF GLACIOMARINE DEPOSITS**-- Massive to stratified, well sorted, brown to gray-brown fine to medium sand; locally grades downward to finely laminated fine sand and silt. Unit is generally 5 to 20 ft thick and gradationally overlies **fm** facies. This sand was deposited as the sea became shallower during the postglacial regresssion.

**fm** — **SILT-CLAY FACIES OF GLACIOMARINE DEPOSITS**-- Composed of silt and clay and lesser amounts of fine sand, in massive to thinly laminated beds; locally may contain fossil shells, lenses of coarser material, and dropstones. These fine-grained sediments settled out in deep glaciomarine waters; the facies may interfinger with distal marine fan deposits and commonly overlies the ice-proximal deposits.

**STACKED UNITS**

sf / gd — **Distal-fan sand facies** / **Gravel and diamict facies**

fm / sf / gd — **Silt-clay facies** / **Distal-fan sand facies** / **Gravel and diamict facies**

ss / fm / sf / gd — **Marine sand facies** / **Silt-clay facies** / **Distal-fan sand facies** / **Gravel and diamict facies**

ss / fm — **Marine sand facies** / **Silt-clay facies**

*GLACIAL TILL AND SHALLOW BEDROCK*

**tb** — Areas of numerous bedrock outcrops and shallow bedrock locally mantled by thin glacial till and (or) fine-grained glaciomarine sediment. Glacial till consists of nonsorted, nonstratified, compact mixture of grain sizes ranging from clay to large boulders; matrix is largely fine sand containing up to 25 percent silt and clay; deposited beneath glacial ice. Till forms a thin blanket overlying the bedrock surface in most places and generally underlies glaciomarine sediment but is not included in the stacked units.

**MAP SYMBOLS**

**CONTACT BETWEEN SURFACE MAP UNITS**

**CONTACT BETWEEN SUBSURFACE MAP UNITS**

**A——A′ LOCATION OF CROSS-SECTION LINE, SECTION SHOWN IN FIGURE 7**

**EXCAVATION SCARP**

**BEDROCK OUTCROP**

**93-8 ○ LOCATION OF WELLS AND TEST BORINGS, LOGS OF WHICH WERE USED IN MAPPING**

**Figure 6.** Surficial materials of the Saco Landfill area, Saco Maine.

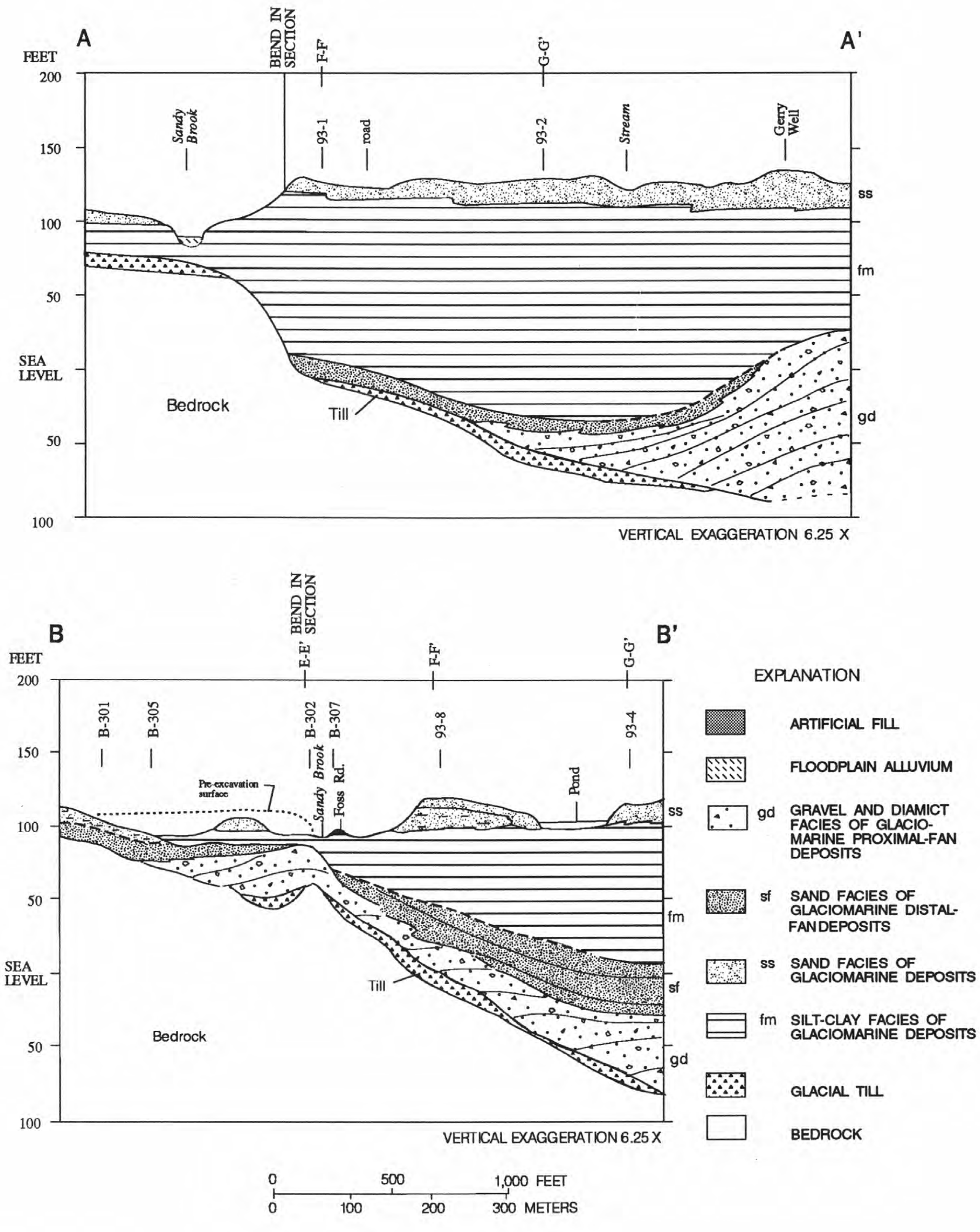



**Figure 7.** Geologic cross sections *A-A'* through *G-G'* for the Saco Landfill area, Saco, Maine. (See figure 6 for location of section lines.)

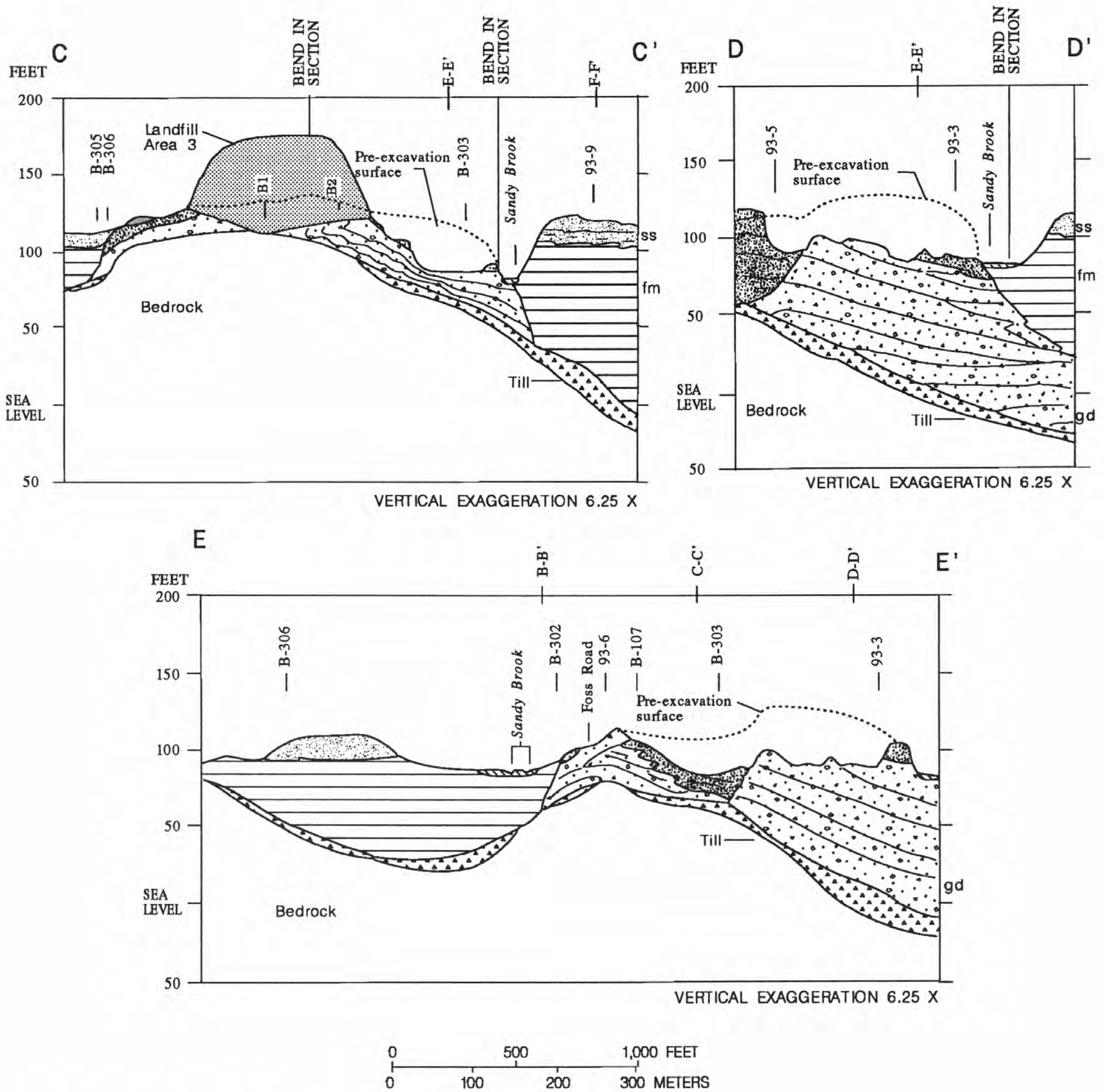



**Figure 7.** *Continued.*

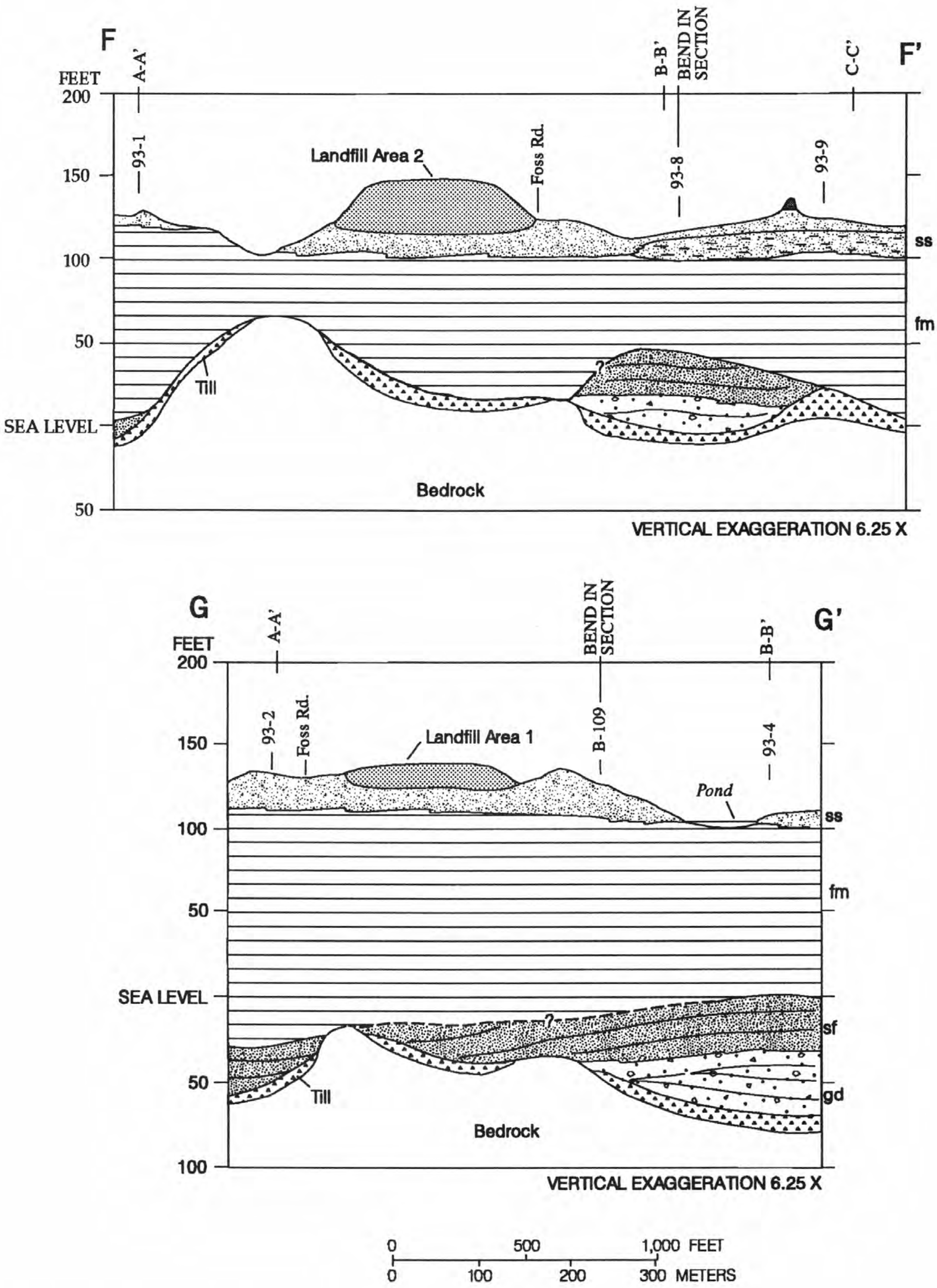



**Figure 7.** *Continued.*

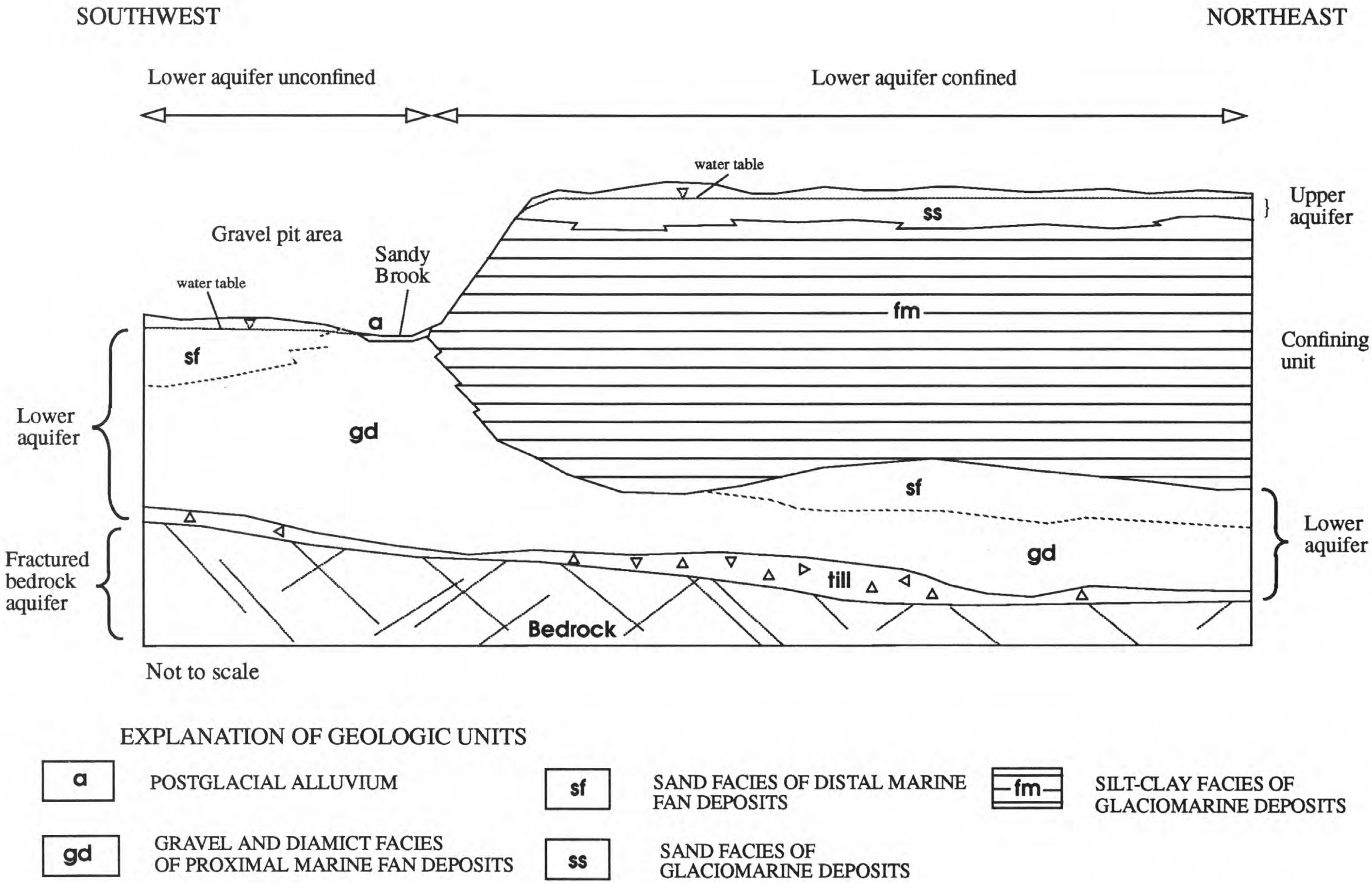



**Figure 8.** Relation between the geologic units and the upper and lower aquifers in the Saco Landfill area, Saco, Maine. (Additional information on geologic units shown in figure 6.)

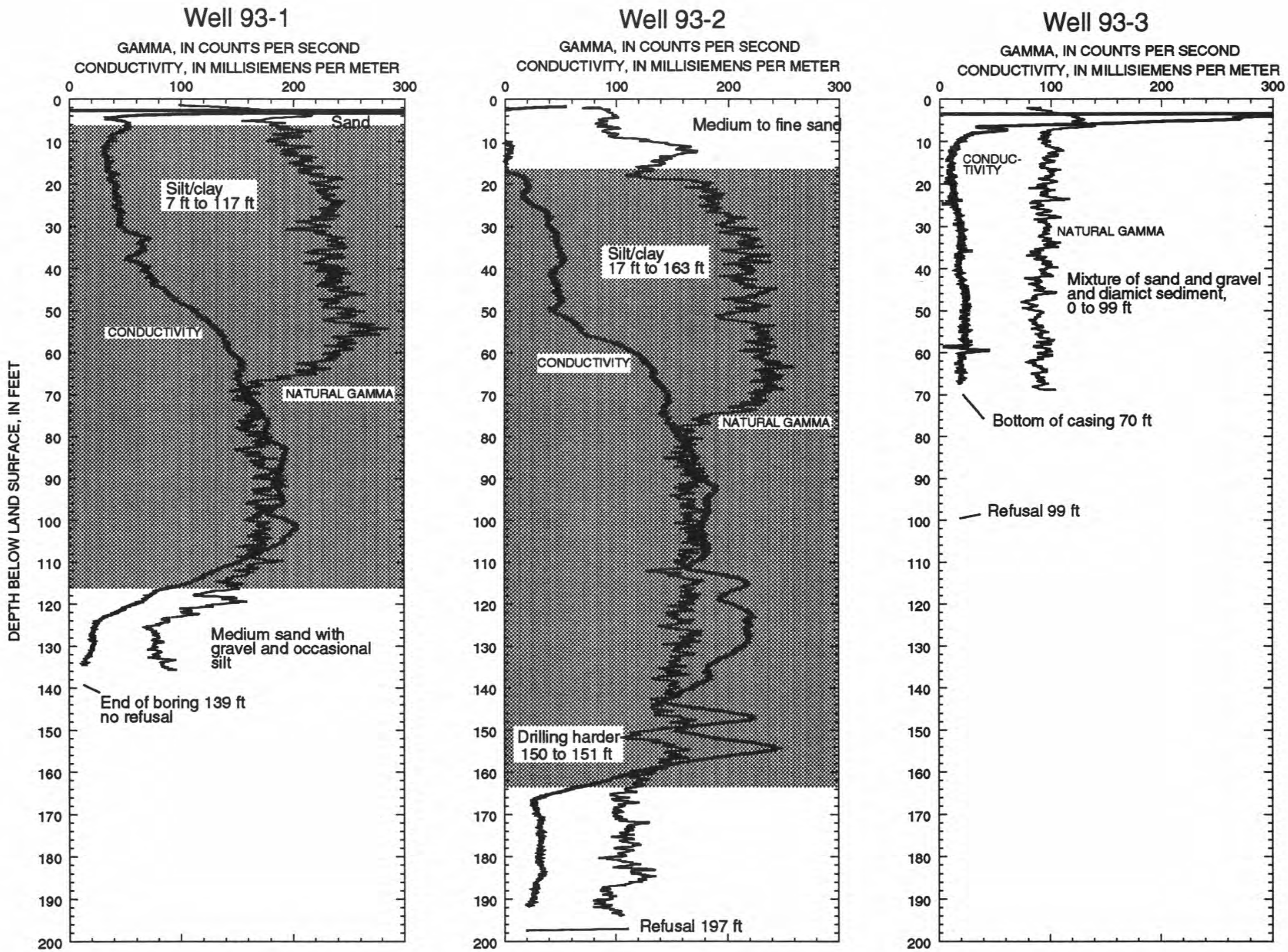



**Figure 9.** Borehole electromagnetic conductivity and natural-gamma logs for wells 93-1, 93-2, and 93-3, near the Saco Landfill area, Saco, Maine.

In 1993, the vertical hydraulic gradient between wells 93-1 and 93-2 was 0.2. If the freshwater has moved 50 ft in 10,000 years, the average linear velocity during that time period is 0.005 ft/yr. By use of an estimated porosity of 0.4 for the silt/clay sediments (Freeze and Cherry, 1979, p. 37) a gradient of 0.2, and the average linear velocity of 0.005 ft/yr, the resulting vertical hydraulic conductivity near these wells is $2.7\times10^{-5}$ ft/d. This falls within the range of hydraulic conductivity for unweathered marine clay (Freeze and Cherry, 1979) but is slightly lower than the previously published hydraulic conductivities presented above.

The sandy facies of fine-gained glaciomarine deposits (unit **ss**) consists of massive to layered, fine to medium sand; locally, thinly laminated fine sand and silt can be found in lower sections. This material, which makes up the upper 5 to 25 ft of the glaciomarine deposits in many parts of the study area, is exposed in shallow excavation scarps north of Area 2 near well 93-1 and in the vicinity of test boring 93-9 (fig. 6).

The upper sand facies of the Presumpscot Formation is saturated to some degree over most of its areal extent and is referred to as the "upper aquifer" in this report. This sometimes silty sand overlies most of the fine-grained facies, except where it has been removed by erosion after the sea level fell or by excavation. In the areas investigated for this study, the water table in this aquifer ranges from 2 to 10 ft below land surface. Because of its shallow water table, this aquifer has been a convenient source of water; historically, rock-lined dug wells in this aquifer have been used for residential water supplies. The shallow water table, however, also makes this aquifer susceptible to contamination from road salt, private septic systems, agricultural chemicals, and other sources. Saturated thicknesses range from 0 to about 15 ft; in areas where the saturated thickness is minimal at best, the aquifer can dry out completely during drought, further limiting the usefulness of the aquifer as a drinking-water source. Hydraulic conductivities for this aquifer have not been published; however, published hydraulic conductivities for silty sand range from 0.3 to 30 to ft/d (Freeze and Cherry, 1979, p 29).

Where **fm** is the surficial unit, mainly on areas of relatively steep slopes (fig. 6), there is no surficial aquifer as such. Water may flow through the soil, especially if the land surface slopes towards a surface-water body and the upper aquifer is at a height above the surface-water body. Just as water flows over a dam, ground water in the upper aquifer flowing towards Sandy Brook flows over the break in slope and onto the slope, flowing within the shallow soil or in shallow fractures in the silt/clay unit towards the recent alluvium and Sandy Brook. Areas where this may be occurring are on both sides of Sandy Brook upstream from Area 2 and the northeast side of Sandy Brook downstream from Area 2 (see fig. 6).

<u>Postglacial alluvium</u> (unit **a**) generally less than 5 ft thick overlies glacial deposits on flood-plain surfaces along Sandy Brook and Big Ledge Brook. These surfaces are erosional, incised as much as 50 ft into the glacial deposits. The alluvium is mostly sand and silt, but it may contain gravel where the streams have cut into coarse-grained materials, especially on the west side of Sandy Brook between Areas 2 and 3.

All the aquifers previously discussed (the fractured bedrock, the lower fan-deposits aquifer, and the upper sandy aquifer) are recharged to some extent by direct precipitation. In the humid parts of North America, precipitation that infiltrates the soil may be available for ground-water recharge. Evaporation from the soil and transpiration by plants use part of the water; the remainder recharges the near-surface water table. Regional estimates of recharge to surficial aquifers range from 18 to 20 in/yr (Knox and Nordensen, 1955; Morrisey, 1983; Tepper and others, 1990).

## Hydrology

### Precipitation

Average annual precipitation in Portland, Maine, is 44.3 in., and precipitation occurs fairly evenly throughout the year; mean monthly precipitation generally differs less than an inch from month to month (fig. 10). The monthly data show a weak bimodal distribution, with slightly greater precipitation in the spring and autumn and less in the summer and winter months. August has the lowest monthly average (2.87 in.) and November the greatest (5.17 in.). Precipitation usually falls as snow during January, February, and March, and the average annual water equivalent in the snowpack at the beginning of March is 3.4 in. (Hayes, 1972). This precipitation stored as snow and ice is converted to surface runoff and ground-water recharge during spring melt. Average annual runoff in the Saco area is approximately

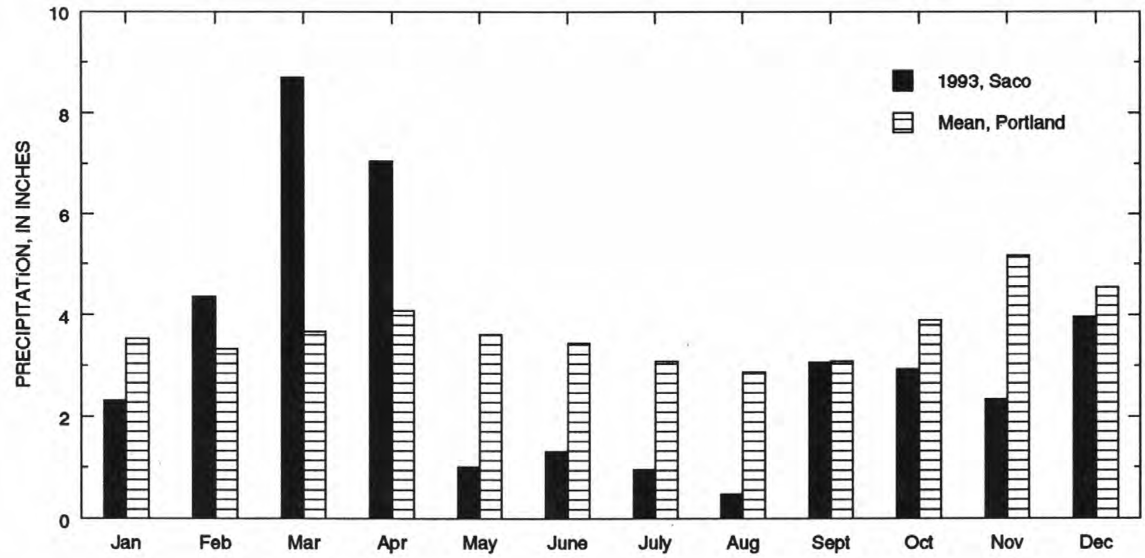



**Figure 10.** Mean monthly precipitation at Portland International Jetport, 1962-92, and monthly precipitation at the sewage-treatment facility, Saco, Maine, 1993.

20 in/yr (Knox and Nordensen, 1955). In addition to the long-term records for Portland, daily precipitation data for 1993 are available from the Saco sewage-treatment facility (fig. 10), approximately 3 mi to the south of the landfill area. After a wet spring in 1993, precipitation in Saco was below normal from May through August; precipitation was about normal from September through December.

## Ground Water

The lithology, stratigraphy, and geographic distribution of water-bearing geologic units at the Saco Landfill control the movement of contamination in the soils and ground water. Water-level measurements and topographic control provide data used to show the directions of ground-water flow.

Water levels measured during the spring of 1993 (measured by Halliburton NUS) and water levels measured during the following summer, autumn, and winter for this investigation were used to construct water-table maps. Ground-water levels have been measured in and around the landfill areas since 1975; however, because no accurate altitudes for land surface and water levels at individual wells were determined until 1993 (table 2), the usefulness of these historical data is limited. Water levels in 20 wells (6 new wells installed for this study and 14 existing wells) were monitored from April 1993 to February 1994 (table 3). The upper sandy aquifer above the glaciomarine confining unit and the lower aquifer were both monitored. The locations of the wells and streamflow stations where water-level data were collected during the investigation are shown in figure 11. Well-screen settings range from shallow (3 to 8 ft) to deep (172 to 174 ft), and screen lengths range from 2 to more than 20 ft. Altitudes of the surface-water bodies determined as part of this investigation were used as points of reference in constructing ground-water-level maps. All the wells shown in figure 11 are water-table wells screened in the upper aquifer, except for wells 93-1, 93-3, 93-4, 93-5, B-301, B-302, and B-307, which are screened in the lower aquifer. Wells 93-1, B-307, and 93-4 are the only wells screened in the confined part of the lower aquifer.

Two water-table maps were constructed, one for late April/early May 1993 and one for October 1993, from available water-level data and the topographic map of the area shown in figure 1. These two periods illustrate the seasonal high and low water-table positions. A comparison of the water-table maps for April/May (fig. 12) and October (fig. 13) shows a 2- to 6-ft decline in the water table in the upper aquifer east of Sandy Brook, and a 5- to 8.5-ft decline in the area west of Sandy Brook and north of Area 3. The difference in the water table between April and October in the lower aquifer southeast of Area 3 is comparatively small (approximately 1 to 2 ft).

**Table 2.** Data for wells completed in surficial materials at the Saco Landfill, Saco, Maine

[Well No.: Locations of wells are shown in figures 11, 18, or 1A. Total depth: Depths measured by Halliburton NUS (1994), except for 93-series wells. Screened interval: Original logs at Halliburton NUS (1994), except for 93-series wells, which are in Appendix 1. Altitude: Altitudes are in feet above sea level. --, data unavailable; E, screened interval or original elevation estimated (Halliburton NUS, written comm., 1993)]

| Well No. | Date of well installation | Total depth (feet) | Screened interval (feet below land surface) | Land-surface altitude, 1993 | Bottom altitude of well | Aquifer in which screen is set |
|---|---|---|---|---|---|---|
| 83-1 | Nov. 21-22, 1983 | 11.0 | 8.0-11.0 | 88.3 | 77.5 | Lower |
| 83-2 | Nov. 21-22, 1983 | 12.0 | [1]12.0-12.0 | 92.5 | 80.5 | Lower |
| 83-3 | Nov. 21-22, 1983 | [2]10.0 | 7.0-10.0 | -- | -- | Lower |
| 83-4 | Nov. 21-22, 1983 | 86.4 | 80.4 | 3.0-6.0 | 6.0 | Upper |
| 83-5 | Nov. 21-22, 1983 | 8.0 | 6.0-8.0 | 83.8 | 76.0 | Lower |
| 83-6 | Nov. 21-22, 1983 | 9.0 | 7.0-9.0 | 86.9 | 78.0 | Upper |
| 83-8 | Nov. 21-22, 1983 | 97.9 | 81.7 | 13.2-16.2 | 16.2 | Upper |
| 83-9 | Nov. 21-22, 1983 | 16.5 | 14.5-16.5 | 111.6 | 95.0 | Upper |
| 83-10 | Nov. 21-22, 1983 | 7.5 | 6.5-7.5 | 124.4 | 117.0 | Lower |
| 83-12 | Nov. 21-22, 1983 | 15.5 | 14.5-15.5 | 88.6 | 73.0 | Upper |
| 83-13 | Nov. 21-22, 1983 | 9.0 | 7.5-9.0 | 92.4 | 83.5 | Upper |
| 83-14 | Nov. 21-22, 1983 | 9.0 | 7.0-9.0 | 88.1 | 79.0 | Upper |
| 83-15 | Nov. 21-22, 1983 | 8.0 | [1]8.0-8.0 | 93.9 | 86.0 | Upper |
| 83-16 | Nov. 21-22, 1983 | 8.5 | [1]8.5-8.5 | 95.1 | 86.5 | Upper |
| 85-2 | 1985 | 16.5 | Unknown | 135.8 | 119.5 | Upper |
| 85-4 | 1985 | 5.5 | Unknown | 127.6 | 122.0 | Upper |
| 85-6 | 1985 | 18.0 | Unknown | 135.7 | 117.5 | Upper |
| 93-1 | Sept. 8, 1993 | 136.0 | 134-136 | 126.9 | -9.0 | Lower |
| 93-2 | Sept. 13, 1993 | 194.0 | 172-174 | 130.5 | -63.5 | Lower |
| 93-3 | Sept. 8, 1993 | 70.0 | 68-70 | 87.1 | 17.0 | Lower |
| 93-4 | Sept. 14, 1993 | 186.0 | 134-136 | 109.5 | -76.5 | Lower |
| 93-5 | Sept. 15, 1993 | 49.0 | 27-29 | 90.3 | 41.5 | Lower |
| 93-6 | Sept. 15, 1993 | 18.0 | 16-18 | 105.9 | 87.9 | Lower |
| 93-7 | Dec. 6, 1993 | 14.0 | 12-14 | 133.2 | 119.0 | Upper |
| B-101 | April 3, 1975 | [2]16.0 | Unknown | E 135 | E 119 | Upper |
| B-102 | April 4, 1975 | [2]11.5 | Unknown | E 130 | E 118.5 | Upper |
| B-103 | April 4, 1975 | [2]15.0 | Unknown | -- | -- | Upper |
| B-104 | April 9, 1975 | 11.0 | 4.5-11.0 | 124.5 | 113.5 | Upper |
| B-105 | April 2, 1975 | [2]16.5 | Unknown | -- | -- | Upper |
| B-106 | April 8, 1975 | [2]18.0 | 8.0-18.0 | E 126 | E 108 | Upper |
| B-109 | April 7, 1975 | 11.5 | 4.0-11.5 | 126.3 | 115.0 | Upper |
| B-110 | April 7, 1975 | 13.0 | 4.0-13.0 | 121.7 | 108.5 | Upper |
| B-111 | April 8, 1975 | 7.5 | 3.0-7.5 | 124.0 | 116.5 | Upper |
| B-113 | April 8, 1975 | [2]8.0 | 3.0-8.0 | E 118 | E 110 | Upper |
| B-202 | Feb. 16, 1977 | 10.0 | Unknown | 128.2 | 118.0 | Upper |
| B-301 | Dec. 9, 1983 | 19.5 | E 10.0-19.5 | 105.9 | 86.5 | Upper |
| B-302 | Dec. 9, 1983 | 34.0 | E 9.0-34.0 | 95.4 | 61.5 | Lower |
| B-303A | Dec. 14, 1983 | 24.5 | 19.0-24.5 | 85.8 | 61.5 | Lower |
| B-303B | Dec. 14, 1983 | 7.5 | 4.0-7.5 | 85.8 | 78.5 | Lower |

**Table 2.** Data for wells completed in surficial materials at the Saco Landfill, Saco Maine--*Continued*

| Well No. | Date of well installation | Total depth (feet) | Screened interval (feet below land surface) | Land-surface altitude, 1993 | Bottom altitude of well | Aquifer in which screen is set |
|---|---|---|---|---|---|---|
| B-304 | Dec. 14, 1983 | [2]29.0 | 9.0-29.0 | -- | -- | Lower |
| B-305A | Dec. 16, 1983 | 37.0 | 32.0-37.0 | 115.0 | 78.0 | Lower |
| B-305B | Dec. 16, 1983 | 14.0 | 9.0-14.0 | 115.0 | 101.0 | Upper |
| B-306 | Dec. 18, 1983 | 42.0 | 8.0-42.0 | 98.2 | 56.0 | Confining unit and lower aquifer |
| B-307 | Dec. 22, 1983 | 38.5 | E 20.0-38.5 | 91.9 | 53.5 | Lower |
| B-308 | Dec. 23, 1983 | 13.5 | E 9.0-13.5 | 123.4 | 110.0 | Lower |
| C-2 | Oct. 2, 1990 | 8.5 | 3.5-8.5 | 129.7 | 121.0 | Upper |
| C-3 | Oct. 2, 1990 | 19.0 | 9.0-19.0 | 117.8 | 99.0 | Upper |
| C-4 | Oct. 2, 1990 | 4.5 | 4.5-9.5 | 127.2 | 122.5 | Upper |
| C-5 | Oct. 2, 1990 | 9.0 | 4.0-9.0 | 128.7 | 119.5 | Upper |
| CC | Unknown | 23.0 | Unknown | 92.5 | 69.5 | Lower |
| BB | Unknown | 7.5 | Unknown | 111.8 | 104.5 | Lower |
| City's 9 | Unknown | 5.5 | Unknown | 112.1 | 106.5 | Lower |
| City's 9A | Unknown | 5.5 | Unknown | 108.2 | 102.5 | Lower |
| CIty's 18 | Unknown | 19.0 | Unknown | 111.2 | 92.0 | Upper |

[1] Open-bottomed casing.
[2] Depths taken from original logs (well could not be located and was assumed destroyed).

**Table 3.** Water-level data for selected wells at the Saco Landfill, Saco, Maine, April 1993 to February 1994

[Well No.: Locations of wells are shown in figure 11. Measurements are instantaneous field measurements unless otherwise noted. --, indicates missing data]

| Well No. | Water-level altitude, in feet above sea level, on measurement date | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | April 29, 1993 | Oct. 6, 1993 | Oct. 20, 1993 | Nov. 4, 1993 | Dec. 2, 1993 | Dec. 20, 1993 | Jan. 25, 1994 | Feb. 23, 1994 |
| 83-2 | 86.7 | 84.09 | 84.04 | 84.34 | 84.53 | 84.61 | 84.62 | 85.20 |
| 83-6 | 84.3 | 82.98 | 82.99 | 83.07 | 83.12 | 83.22 | 83.13 | 83.44 |
| 83-10 | 124.5 | [1]<116.00 | 116.95 | 119.94 | 123.59 | 123.52 | 122.42 | -- |
| 85-2 | 128.2 | 124.50 | 124.56 | 124.74 | 125.49 | 126.38 | 126.32 | 126.88 |
| 85-4 | 127.3 | 125.19 | 125.23 | 125.71 | 126.10 | 126.24 | -- | 126.51 |
| 85-6 | 131.6 | 125.56 | 124.55 | 125.81 | 127.19 | 128.61 | 127.83 | 127.89 |
| 93-1 | -- | 95.11 | 95.12 | 95.22 | 95.42 | 95.64 | 95.67 | 95.74 |
| 93-2 | -- | 95.12 | 91.42 | -- | 87.95 | -- | -- | -- |
| 93-3 | -- | 82.95 | -- | 83.01 | [2]83.20 | 83.20 | 83.19 | 83.37 |
| 93-4 | -- | 83.80 | 83.91 | 84.03 | [2]84.17 | 84.24 | 84.24 | 84.43 |
| 93-5 | -- | 83.48 | -- | 83.60 | [2]83.84 | [2]83.80 | 83.77 | 83.96 |
| 93-7 | -- | -- | -- | -- | -- | 131.11 | 131.00 | 131.09 |
| B-104 | 122.2 | 119.74 | 119.87 | 120.65 | 121.58 | 121.86 | 120.82 | 121.67 |
| B-109 | 122.7 | 120.64 | 120.71 | 121.01 | 121.36 | 121.76 | 122.19 | 121.88 |
| B-110 | 118.8 | 116.03 | 117.22 | 118.07 | 118.50 | 118.45 | 118.05 | 118.69 |
| B-111 | 121.8 | -- | -- | 117.93 | -- | 119.15 | 119.60 | 119.95 |
| B-301 | 98.0 | 93.19 | 93.06 | [2]93.24 | 94.00 | [2]94.61 | 94.11 | 94.87 |
| B-306 | 91.1 | 87.62 | 87.61 | 87.95 | 87.92 | 88.14 | 88.18 | 88.63 |
| B-307 | 84.9 | 82.67 | 82.64 | -- | 82.85 | -- | 82.89 | 83.23 |
| C-5 | 125.6 | 124.02 | 124.58 | [2]125.78 | 126.89 | [2]127.08 | 125.77 | 126.28 |

[1] Well was dry. Bottom of well is at an altitude of 116.0 ft.
[2] Daily average from continuous data recorder.

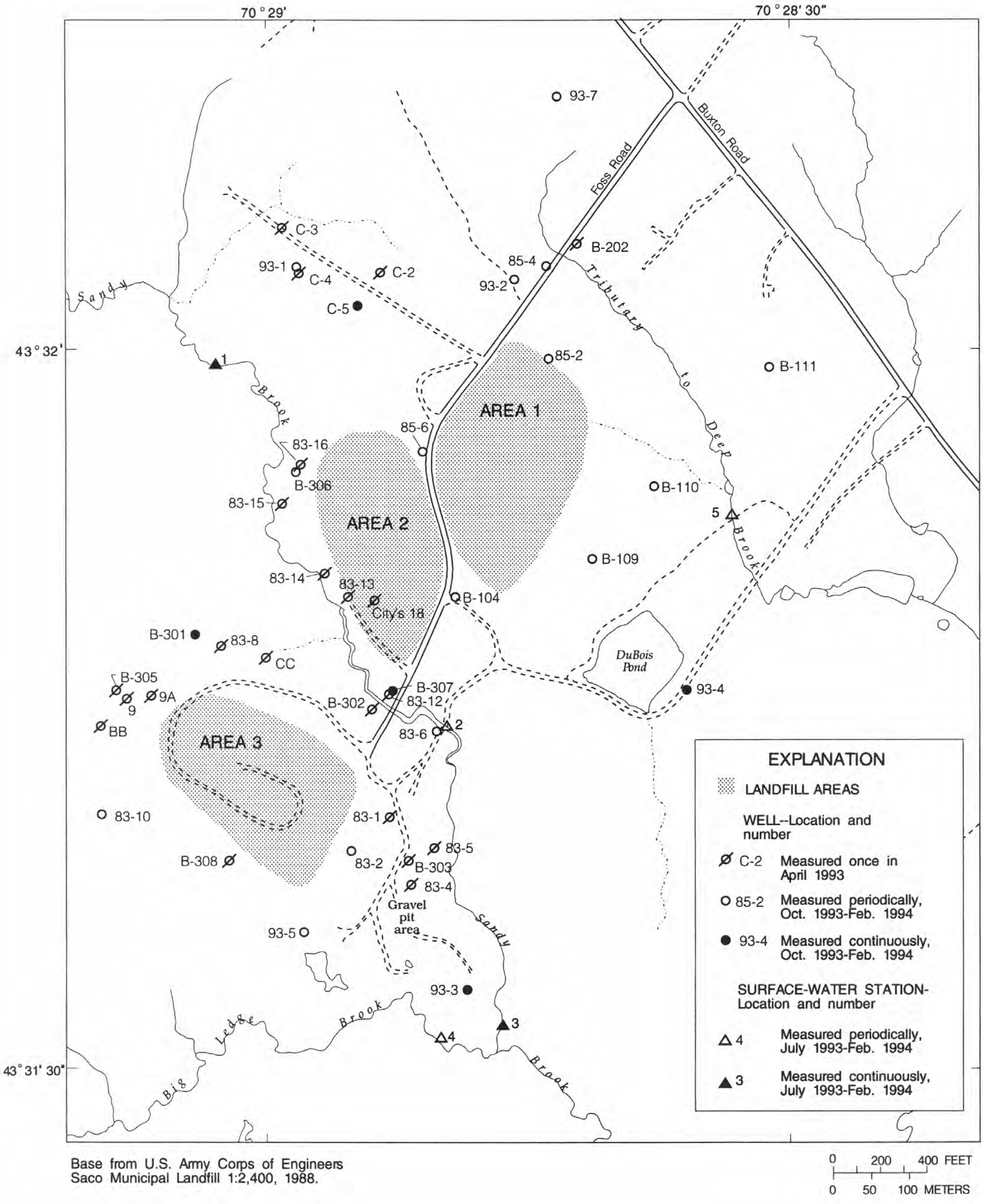



**Figure 11.** Wells and surface-water stations near the Saco Landfill used for water-level measurements, April 1993-February 1994. (Discharge measurements made periodically at all surface-water stations.)

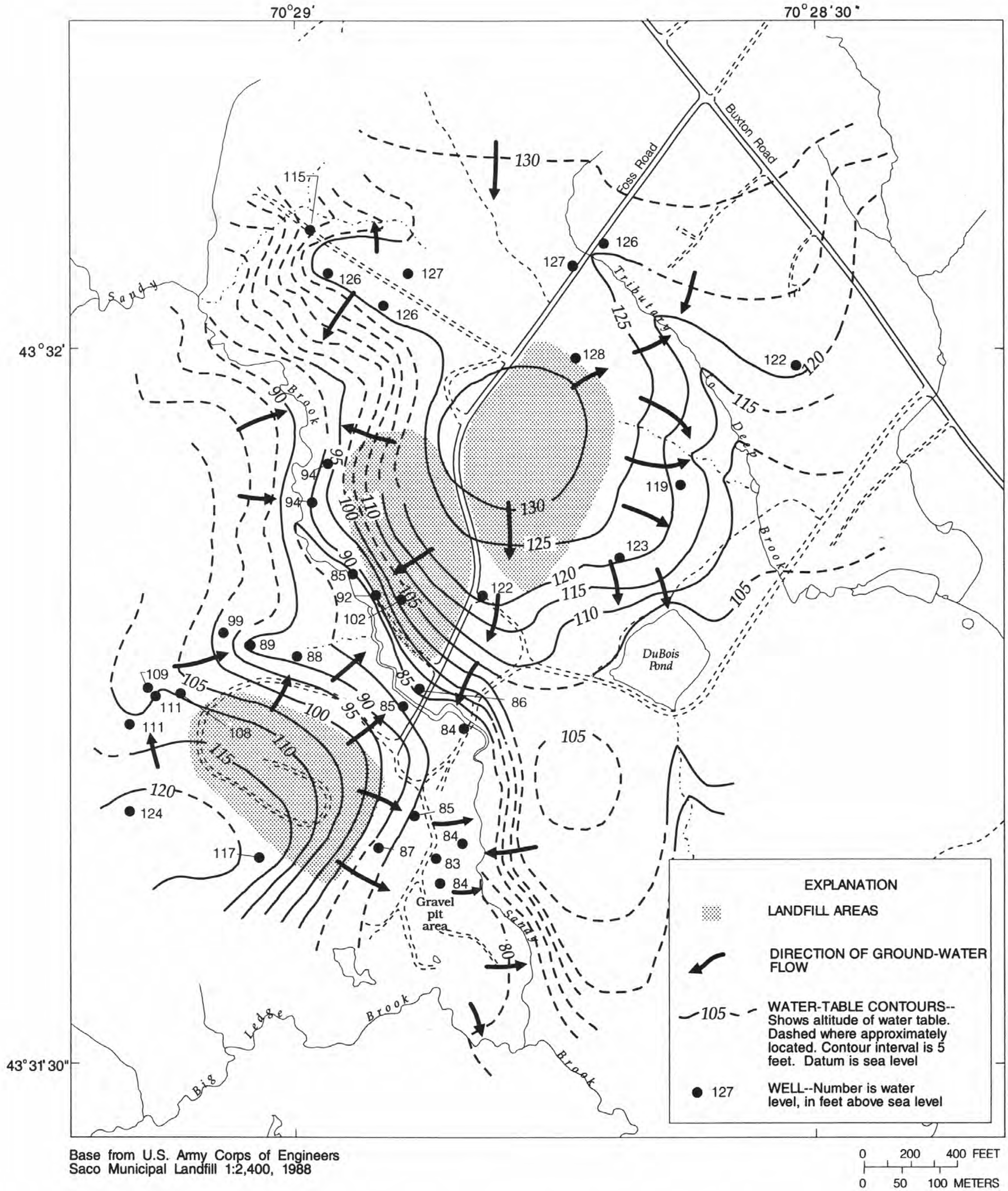



**Figure 12.** Water-table altitude and ground-water-flow directions in the vicinity of the Saco Landfill, Saco, Maine, April 28-May 4, 1993.

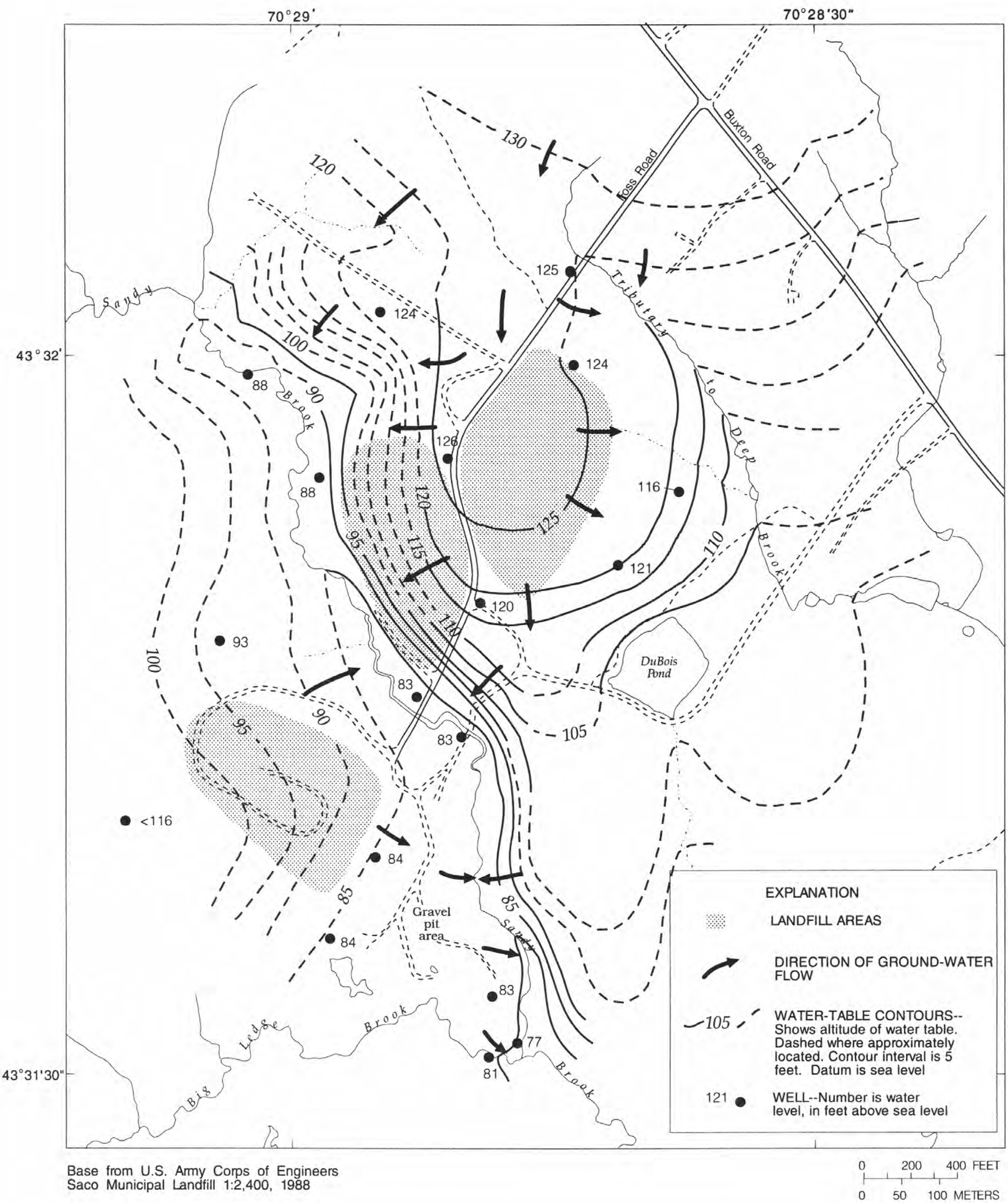



**Figure 13.** Water-table altitude and ground-water-flow directions in the vicinity of the Saco Landfill, Saco, Maine, October 1993.

Although data for the confined part of the lower aquifer are sparse, a tentative potentiometric-surface map was prepared for this report (fig. 14). The potentiometric-surface map is the same as the water-table map for October in the gravel pit area, where the aquifer is unconfined. Within the unconfined part of the aquifer, vertical gradients are unknown but must be upwards locally near Sandy Brook, where ground water discharges. Gradients may be downward in the gravel pit area close to landfill Area 3. Water levels in the three confined-area wells indicate a regional gradient sloping from the north-northwest to southeast, towards the Saco River or Deep Brook. There is a downward gradient across the confining unit between the upper unconfined aquifer and the lower aquifer on the east side of Sandy Brook. The downward gradient is 0.21 ft/ft near well 93-1 and 0.14 ft/ft near well 93-4.

Water-level data collected continuously from September 1993 through February 1994 at six wells (fig. 15) show short-term fluctuations in water levels in the aquifers. Wells B-307 and 93-4 (confined conditions), and wells 93-3 and 93-5 (unconfined conditions) are screened in the lower aquifer. Wells B-301 and C-5 are shallow-aquifer wells. In the upper aquifer, the water level in well C-5 changed approximately 3 ft for the period of record and responded quickly to rainfall events (fig. 15). Water levels in each of the 93-series wells changed less than 1 ft, but they also responded quickly to rainfall events, including the confined-area well (93-4). The response of water levels in well B-301 is slower and the magnitude of change is less than that seen in the other wells. Its somewhat long screened interval (estimated at 10 ft), which integrates head changes along its length, may dampen the changes in water levels in the well in response to water-level fluctuations in the aquifer. This well also has at least one thin clay bed along the screened interval. Because of equipment failures at well B-307, data were insufficient to allow meaningful interpretation.

## Surface Water

Surface-water runoff from the Saco Landfill flows into three separate streams in the Deep Brook Basin: Sandy Brook, Big Ledge Brook, and a small unnamed tributary to Deep Brook (fig. 1). Of the three streams, Sandy Brook receives the largest proportion of runoff from the landfilled areas. Part of Area 3 drains into Big Ledge Brook. The unnamed tributary to Deep Brook receives drainage from the eastern side of Area 1. Drainage areas for each subbasin are given in table 4.

Streamflow data were collected at the two continuous-record stations on Sandy Brook from July 17, 1993, through February 22, 1994[2] (Appendix 3). Daily mean streamflow at the upstream station ranged from a low of 0.10 $ft^3/s$ on many days in August and September to a high of 9.8 $ft^3/s$ on December 21. At the downstream station the daily mean streamflow ranged from 0.34 $ft^3/s$ on October 26 to 13 $ft^3/s$ on December 21. The mean streamflow for the entire period was 0.86 $ft^3/s$ at the upstream stage and 1.32 $ft^3/s$ at the downstream station. During this period, streamflow in southern Maine was generally normal[3] as indicated by nearby streamflow stations with long-term periods of record, except for July and September, when streamflows were below normal, and December, when streamflows were above normal (U.S. Geological Survey, 1993-94).

Streamflow at both continuous-record stations was characterized by periods of extended, consistent base flow interspersed with brief high flows caused by runoff (fig. 16). Streamflow at both gages responded very quickly to even moderate amounts of rainfall, increasing sharply with rainfall and returning quickly thereafter to pre-rainfall flows. This general pattern is indicative of a basin without a significant surface-water storage (as shown by the quick response to rain events) and with a large amount of ground-water discharge (as shown by the consistent base flow). Base flow changed gradually during the period, generally increasing from July through December, decreasing slightly in late December, and remaining stable from January into February (fig. 16). The increase and decrease of the base flow corresponded very closely to changes in the local water-table altitude recorded at several wells at the landfill (fig. 15). The base flows were consistently higher at the downstream station than at the upstream

[2] The USGS is continuing to collect continuous-streamflow data at these two stations and will have 1 year of data at the completion of this investigation. These data can be obtained from the USEPA Region I in Boston, Mass., until 1996, when they will be available from the USGS office in Augusta, Maine.

[3] Above-normal streamflows are defined as those within the upper 25th percentile of all streamflow records for a given month. Normal streamflows are defined as those within the middle 50 percent of all streamflow records, and below-normal streamflows are those within the lower 25th percentile of all streamflow records for that month.

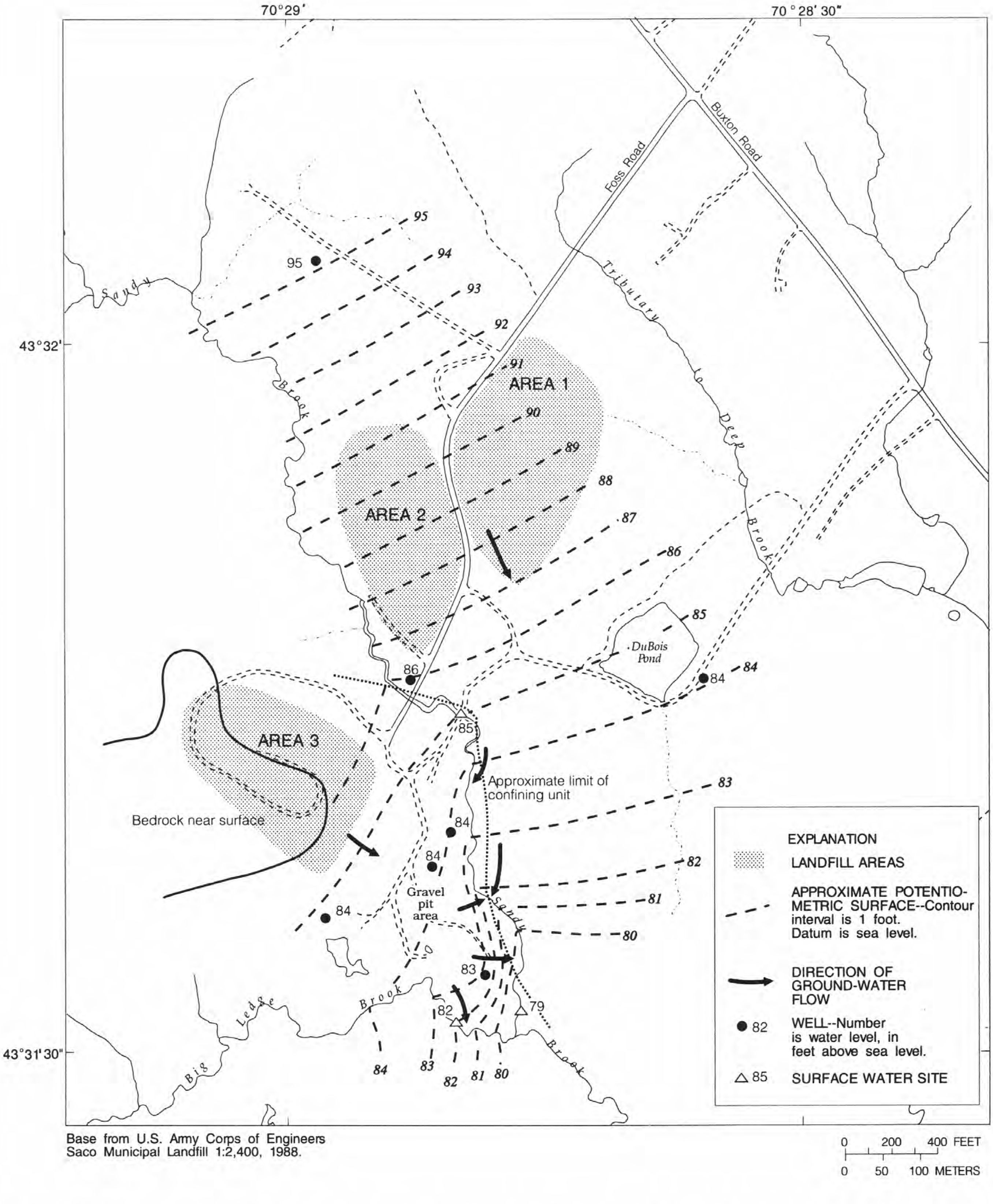



**Figure 14.** Potentiometric surface of lower aquifer and ground-water-flow directions near the Saco Landfill, Saco, Maine, October 1993.

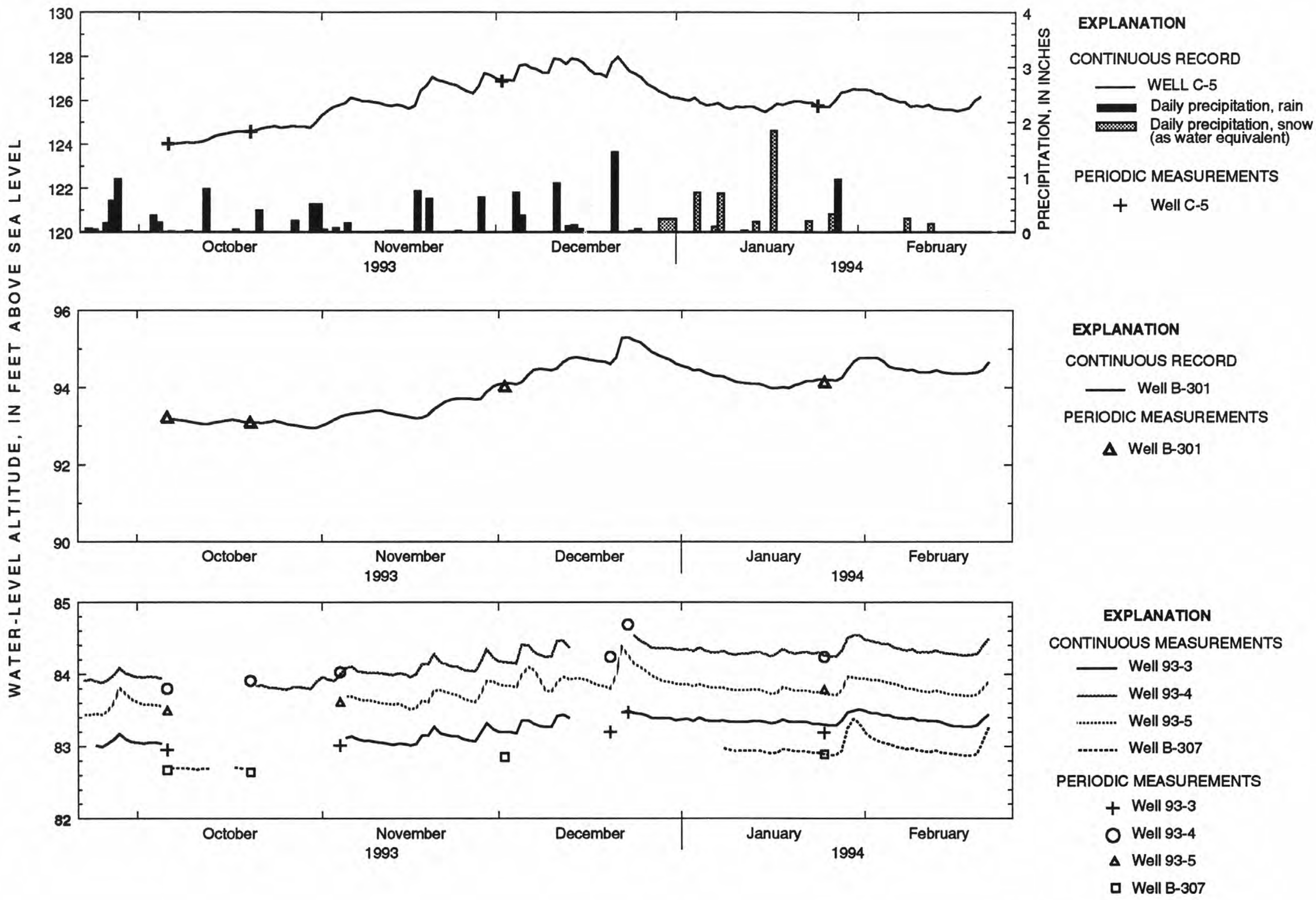



**Figure 15.** Water-level hydrographs for wells near the Saco Landfill and precipitation at the Saco sewage-treatment plant, Saco, Maine, September 1993-February 1994.

**Table 4.** Information on surface-water stations near the Saco Landfill, Saco, Maine

[Station No.: Station locations shown in figures 2 and 18. SW, Surface water; SD, sediment. Flow data: C, continuous flow data July 1993 to February 1994; N, no flow data; P, periodic flow data July 1993 to February 1994. Water-quality data: F, water-quality parameters measured in field: specific conductance, water temperature, dissolved oxygen; I, inorganic chemistry data; O, organic chemistry data. Acronymns: USGS, U.S. Geological Survey; USEPA; U.S. Environmental Protection Agency. ft, foot; mi$^2$, square mile; --, no information]

| Station No. | Name | Altitude (feet above sea level) | Drainage area (mi$^2$) | Flow data | Water-quality data | Remarks |
|---|---|---|---|---|---|---|
| **USGS Stations:** | | | | | | |
| 1 | Sandy Brook above landfill, near Saco | 89.8 | 1.28 | C | F, I, O | Same as SW/SD-7, [1]01067851 |
| 2 | Sandy Brook at landfill, near Saco | 85.1 | 1.37 | P | F | [1]01067852 |
| 3 | Sandy Brook below landfill, near Saco | 78.8 | 1.42 | C | F | [1]01067853 |
| 4 | Big Ledge Brook near Saco | | .82 | P | F | [1]01067855 |
| 5 | Unnamed tributary to Deep Brook, near Saco | [2]106 | .08 | P | F | [1]01067859 |
| 6 | Deep Brook near Saco | 66.5 | 4.38 | P | F | [1]01067861 |
| **City of Saco and USEPA Stations:** | | | | | | |
| SW/SD-1 | -- | [2]126 | -- | N | I, O | -- |
| SW/SD-2 | -- | [2]118 | -- | N | I, O | -- |
| SW/SD-3 | -- | [2]107 | -- | N | -- | -- |
| SW/SD-4 | -- | [2]85 | -- | N | I, O | ([3]) |
| SW/SD-5 | -- | [2]81 | -- | N | I, O | -- |
| SW/SD-6 | -- | [2]83 | -- | N | O | -- |
| SW/SD-7 | -- | 89.8 | 1.28 | C | F, I, O | ([3]) Same as USGS station 1 |
| SW-6 | -- | [2]81 | -- | N | I | ([3]) |
| SW-17 | -- | [2]87 | -- | N | I | ([3]) |
| SW-26 | -- | [2]107 | -- | N | I | ([3]) |

[1]USGS station number.
[2]Estimated from 5-foot contour map.
[3]Sampled quarterly by the City of Saco.

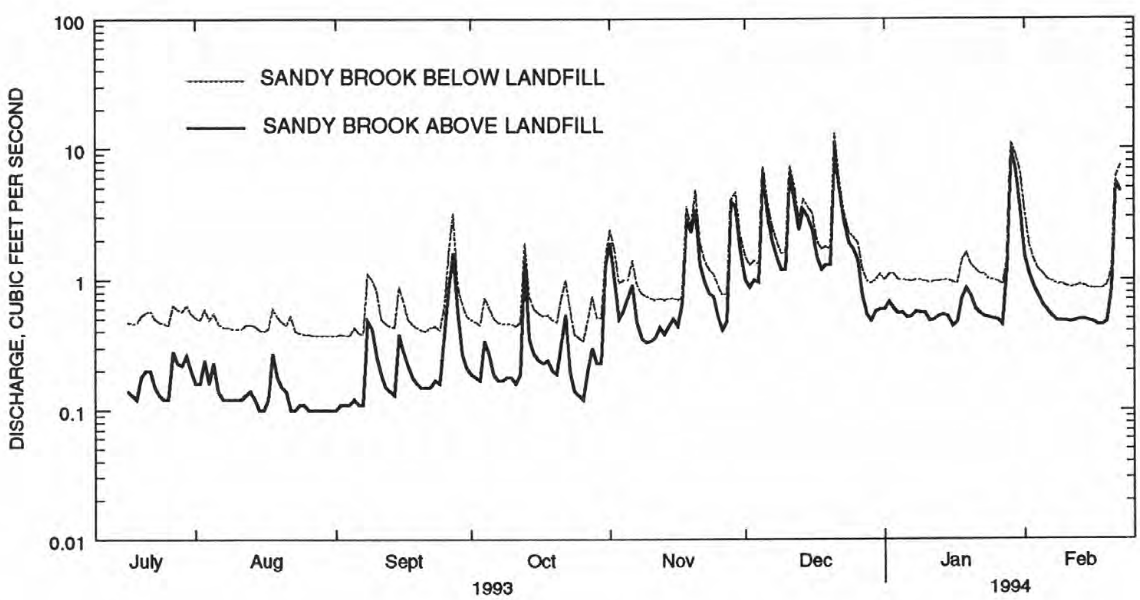



**Figure 16.** Continuous-record gaging stations on Sandy Brook above and below Saco Landfill, Saco, Maine, July 1993-February 1994.

station. This difference, which was higher than might be expected on the basis of the difference in drainage area alone, indicates that a greater amount of ground water is discharged into Sandy Brook between the two stations than is discharged upstream from the upstream station, on a per-square-mile-of-drainage-basin basis.

Streamflow measurements made at the four miscellaneous stations during the same period showed a similar temporal pattern of base flow as the two continuous-record stations, an indication that the seasonal pattern of ground-water discharge is similar throughout the Deep Brook Basin (Appendix 1). Measurements made at the partial-record station (station 2) between the two continuous-record stations were somewhat difficult to evaluate. On several occasions, the measured streamflow at this station was less than the concurrent streamflow at the upstream station on Sandy Brook (station 1). This apparent loss of flow may be due to errors associated with the measurements made at station 2, where channel conditions are not conducive to accurate streamflow measurement, or it may be due to underflow in the gravelly bed in this segment of Sandy Brook.

At the time of the preparation of this report (spring 1994), 8 months of streamflow data were available, not enough to allow for a rigorous analysis of streamflow conditions. In particular, without a complete year of daily streamflow data at the continuous-record stations, traditional statistical techniques (such as mean monthly streamflow, mean annual streamflow, low-flow statistics, or high-flow statistics) are difficult to apply. For example, the available data do not cover the period of high streamflow associated with spring runoff. Streamflow characteristics and surface-water/ground-water interaction are probably somewhat different during the spring than during the period of available data. Nevertheless, some statistical analysis of the available data was done to provide a general overview of the streamflow conditions at the landfill. All analytical results should be considered provisional and subject to unknown error due to the extremely short period of record.

Analyses of streamflows at surface-water stations having short periods of streamflow record typically require some record-extension technique through comparison with another similar station or stations having long-term records. Identification of a long-term station having statistical characteristics similar to Sandy Brook was difficult because few data have been collected on small streams in Maine. Records from the streamflow-gaging station on the Little Androscoggin River near South Paris (station number 01057000, drainage area 73.5 $mi^2$, period of record 1916-24, 1932-94) were the most comparable of the existing stations in the Maine data-collection network.

Estimated flow-duration curves for the Sandy Brook continuous-record stations were developed by use of techniques outlined in Searcy (1959) (fig. 17). The relatively steep slope of the upper and middle sections of the curves is an indication of the large range in streamflow in Sandy Brook. The flattening of the curves at the lower end (high percentage exceeded) shows the effects of ground-water storage in the basin. Although the curve was not extended beyond 95 percent because of data limitations, the curve would likely continue to flatten in this part of the graph. The upper ends of the curves (low percentage exceeded) are questionable because spring runoff data were not available for the analysis. If high-water events are typically caused by snowmelt rather than rainfall, the upper ends of the curves may be flatter than shown in figure 17. The difference between the two curves at the lower end is an indication of the large amount of ground-water inflow to Sandy Brook between the two stations. The decreasing distance between the curves with decreasing percentage illustrates that as streamflow increases, the amount of ground-water inflow relative to direct runoff decreases, and the relation between streamflows at the two stations becomes closer to the ratio of the drainage areas with gaging stations. Estimated mean annual streamflows also were calculated for the Sandy Brook continuous-record stations by use of the relation developed for the flow-duration analysis between the Sandy Brook stations and the Little Androscoggin River station (table 5).

A streamflow hydrograph can be separated into two components: direct runoff, the flow entering the stream during and immediately following rainfall or snowmelt; and base flow, the sustained flow composed largely of ground-water inflow. To provide a more direct comparison of streamflow with ground-water levels at the landfill, the daily streamflow data for the two Sandy Brook stations for July 13 through November 31 were separated into their direct runoff and base flow components according to techniques outlined in Rutledge (1993). Although hydrograph separation sometimes requires considerable subjective judgement, it nevertheless provides valuable qualitative

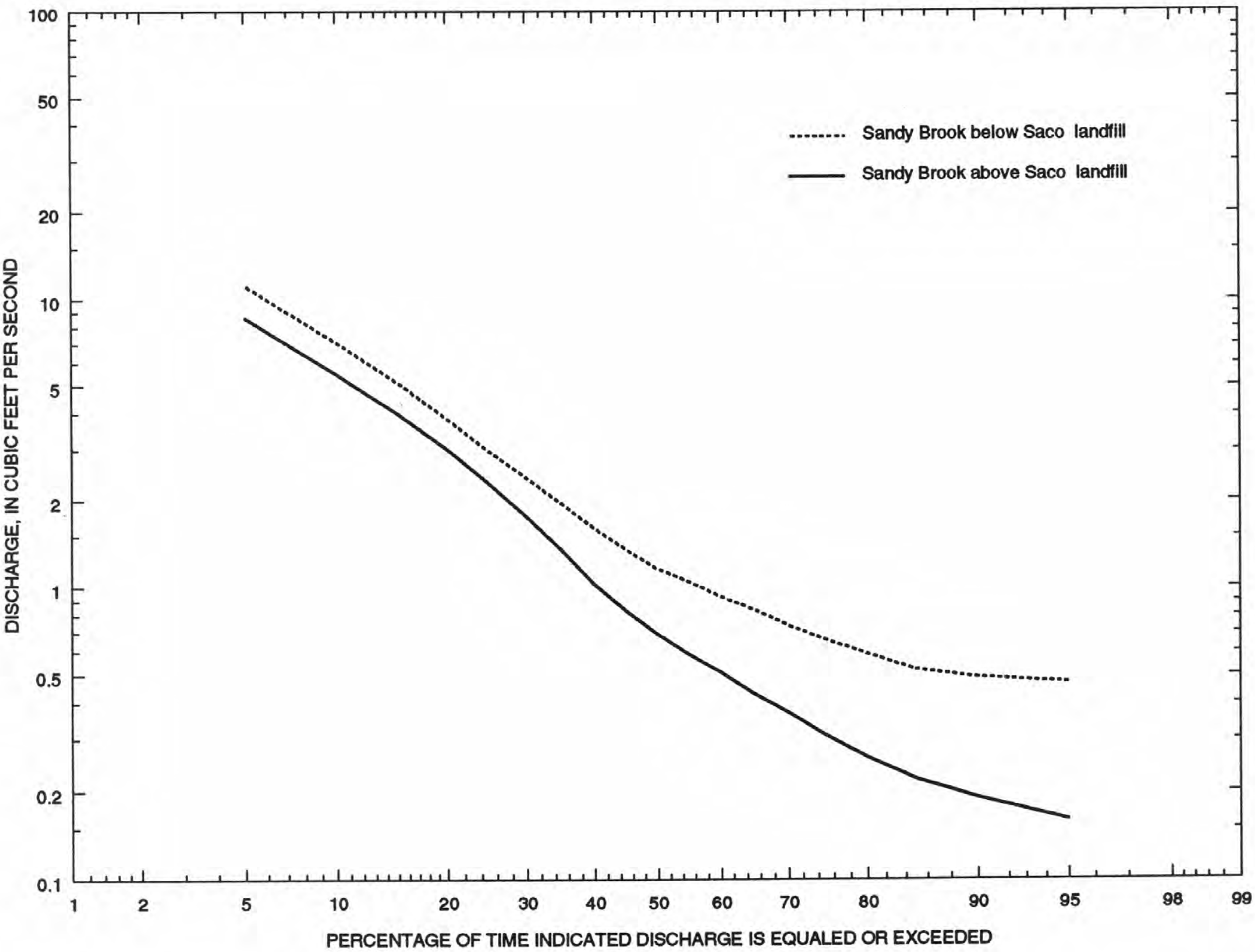



**Figure 17.** Estimated flow-duration curves for Sandy Brook above the Saco Landfill and Sandy Brook below the Saco Landfill, Saco, Maine.

**Table 5.** Mean annual streamflow for the Little Androscoggin River near South Paris, Maine, and estimated mean annual streamflow for Sandy Brook

[$ft^3/s$, cubic foot per second; $mi^2$, square mi; $(ft^3/s)/mi^2$, cubic foot per second per square mile]

| Streamflow-gaging station | Mean annual streamflow ($ft^3/s$) | Drainage area ($mi^2$) | Mean annual streamflow per square mile [$(ft^3/s)/mi^2$] |
|---|---|---|---|
| Little Androscoggin River near South Paris | 138 | 73.5 | 1.88 |
| Sandy Brook above landfill near Saco | [1]2.1 | 1.28 | [1]1.64 |
| Sandy Brook below landfill near Saco | [1]2.7 | 1.42 | [1]1.90 |

[1]Estimated from data for the Little Androscoggin River near South Paris.

information. By comparison to the Sandy Brook stations, the measurements at the four partial-record stations were separated into those representing base-flow conditions and those representing direct runoff. The measurements of base flow were then averaged to provide estimates of average base flow at these stations for the period of data collection (table 6).

Stations 1, 2, 5, and 6 have similar base flow rates, ranging from 0.12 to 0.16 $(ft^3/s)/mi^2$. Stations 1, 2, and 5 each drain areas underlain by the silt/clay layer and upper sandy facies of the Presumpscot Formation (figs. 5 and 6). Ground-water discharge in these basins is from the upper aquifer. The basin upstream from station 4, on Big Ledge Brook, is underlain by sand and gravel on the south and shallow bedrock and till on the north. Discharge to this stream is from the lower aquifer. Its low base flow rate indicates that the valley of Big Ledge Brook is not incised deeply enough into the sand and gravel of the lower aquifer to make the brook a strong discharge point for the lower aquifer. The base flow rate for station 3, Sandy Brook below the landfill, is much higher than that for the other stations. This stream segment also receives discharge from the lower aquifer, which is apparently focused within the segment of Sandy Brook between station 2 and the confluence of Sandy Brook and Big Ledge Brook.

**Table 6.** Estimated base flow for selected stations near Saco, Maine, July 13-November 31,1993

[Station No.: Locations shown in figures 2 and 11. $(ft^3/s)/mi^2$, cubic foot per second per square mile. USGS, U.S. Geological Survey]

| Station No. | Streamflow-gaging station name and No. | Base flow $[(ft^3/s)/mi^2]$ |
|---|---|---|
| 1 | Sandy Brook above landfill near Saco, 01067851 | 0.12 |
| 2 | Sandy Brook at landfill near Saco, 01067852 | .15 |
| 3 | Sandy Brook below landfill near Saco, 01067853 | .33 |
| 4 | Big Ledge Brook near Saco, 01067855 | .05 |
| 5 | Unnamed tributary to Deep Brook near Saco, 01067859 | .15 |
| 6 | Deep Brook near Saco, 01067861 | .16 |
| -- | Little Androscoggin River near South Paris, 01057000 | .11 |

## WATER QUALITY

As ground water flows through or under a landfill, it may pick up chemical constituents and undergo changes in its redox potential. As advection carries the dissolved chemical constituents beyond the landfill, they may be diluted, undergo chemical reactions, and (or) be discharged into a surface-water body. The presence, relative concentrations, or absence of organic and inorganic chemical constituents commonly associated with landfills may indicate the directions of ground-water flow. Downstream changes in various chemical constituents and properties such as specific conductance may indicate areas where leachate possibly is discharged to streams.

Collection of water-quality data at the Saco Landfill began in 1975, when 13 monitoring wells were installed and several water samples were collected from these wells and from surface-water bodies near the landfill (Atwell, 1975). Additional monitoring wells were added between 1980 and 1993. Water samples were collected for determination of organic and inorganic chemicals in 1983 and 1987 (NUS Corporation, 1987) and twice in 1993 (Haliburton NUS, 1994). The city of Saco has sampled 26 wells and surface-water stations quarterly since 1991 for the inorganic constituents magnesium ($Mg^{2+}$), calcium ($Ca^{2+}$), sodium ($Na^+$), chloride ($Cl^-$), nitrate ($NO_3^-$), ammonium ($NH_4^+$), total iron (Fe), total chromium (Cr(tot)), and hexavalent chromium ($Cr^{+6}$), specific conductance[4], and pH. All sampling locations are shown in figure 18.

As a quality-assurance check on the available water-quality data, a linear regression was done between specific conductance and total cations, expressed as the sum of positive milliequivalents per liter. The deviation from the resultant regression line was calculated for each sample, data for samples more than two standard deviations away from the regression

[4] Specific conductance refers to the ability of water to conduct an electrical current. The specific conductance of water increases as the amount of dissolved ionic species increases. Specific conductance is therefore a general measure of the total dissolved ionic species in solution. Organic chemicals, which are commonly uncharged or only weakly charged, do not contribute significantly to specific conductance. Therefore, it is useful primarily as an indicator of the concentration of inorganic species in solution.

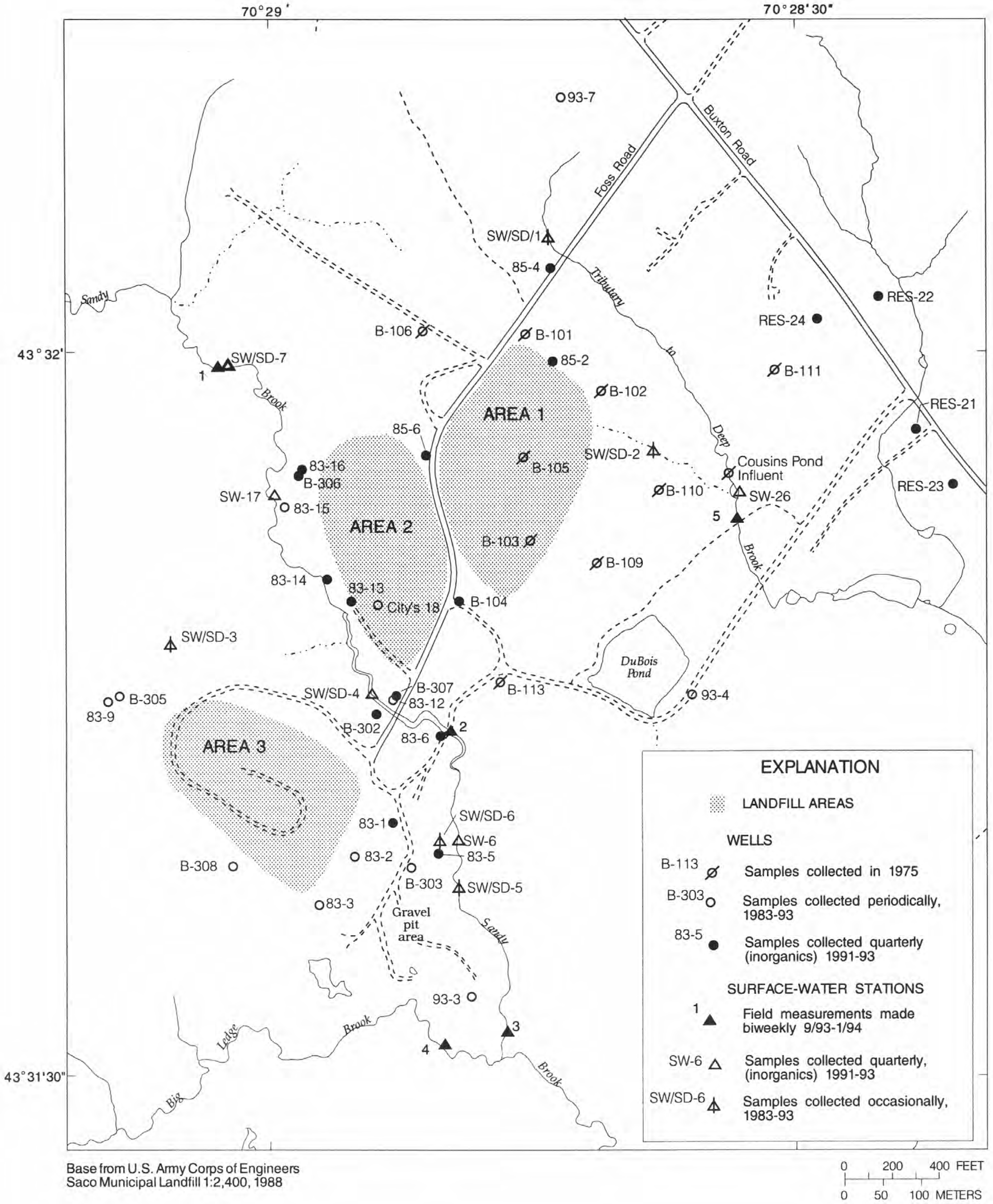



**Figure 18.** Locations where ground water and surface water were sampled for organic or inorganic chemical constituents near the Saco Landfill, Saco, Maine, 1975-93.

line were omitted from subsequent statistical analysis. The remaining data were used to calculate median concentrations of constituents at each sampling point.

### Ground Water

Shallow wells upgradient from the landfilled areas should represent natural[5] or background conditions. The upper aquifer is composed of glacial deposits consisting of silty to clean fine- to medium-grained sand. Water flowing through these deposits, which are derived from igneous and metamorphic rocks, is likely to dissolve minor amounts of $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, and $HCO_3^-$ (Freeze and Cherry, 1979). The total concentration of dissolved ionic species for natural conditions may be as high as 100 mg/L (which would correspond to a specific conductance as high as 185 µS/cm, based on the ratio from Hem, 1989, p. 67). The natural amount of total dissolved ions in the lower aquifer may be greater because of longer flow paths, longer contact time with aquifer materials, and greater amounts of chloride ions from possible interactions with the confining clay layer.

The water in wells 85-4, 93-7, B-106, B-111, B-305, RES-21, RES-22, RES-23, and RES-24, which are upgradient from or parallel to the hydraulic gradient crossing the landfill areas, should be unaffected by the landfill (fig. 18). All these wells except for RES-21 and RES-22 are screened in the upper aquifer. Although water in the vicinity of these wells should not be affected by the landfill, other factors may affect the water chemistry at these locations and increase the concentrations of dissolved ions above natural levels. One example is septic waste from homes on Buxton Road. Most of these homes have private septic systems. Household septic wastes may contain concentrations of $Na^{+}$, $Cl^{-}$, $Ca^{2+}$, $NO_3^-$, and $HCO_3^-$ higher than natural background levels (Fair and Geyer, 1954; Sawyer and McCarty, 1967). The septic systems discharge water to the upper aquifer, which may then increase the concentration of these ions and the specific conductance of the water. Another example is the road salt applied to nearby roads during the winter to control snow and ice. During snowmelt, the salty runoff percolates into the upper aquifer, contributing sodium and chloride to the ground water (Church and Friesz, 1993). Another example might be ions leached from manure. Manure can leach nitrogen species, $Na^{+}$, $K^{+}$, $Ca^{2+}$, and $Cl^{-}$ to ground water and surface water. A local natural source of sodium and chloride ions is the silt/clay layer of the Presumpscot Formation.

Of the wells upgradient from the landfill, wells 85-4, B-106, RES-23, and RES-24 appear to be most representative of natural water quality in the upper aquifer (table 7). Wells 93-7, B-111, and B-305 may be affected to some degree by one or more of the human activities discussed earlier, because samples from these wells all had higher concentrations of $Na^{+}$, $Cl^{-}$, $Ca^{2+}$, or $NO_3^-$. Water quality of wells RES-21 and RES-22, each more than 90 ft deep, may be affected by the glaciomarine clay, which is known to contain elevated concentrations of sodium chloride that remain from the time of its marine deposition.

Fifteen wells are located within or directly adjacent to the landfill areas (fig. 18). Water from these wells may be affected by landfill leachate. Several of these wells no longer exist, but water-quality data for these wells from the mid-1970's are included in this analysis (table 7). These 15 wells are the destroyed wells B-101, B-102, B-103, and B-105; the existing wells B-104, 83-12, 83-13, 83-14, 83-15, 83-16, B-306, 85-2, 85-6, B-308; and the well labeled "city's 18."

Leachate generated from municipal landfills contains elevated concentrations of many dissolved inorganic constituents, including $K^{+}$, $Na^{+}$, $Ca^{2+}$, $Cl^{-}$, $HCO_3^-$, $SO_4^{2-}$, Fe (total)[6], and $NH_4^+$ (Freeze and Cherry, 1979). Magnesium also is contained in landfill leachate, but at concentrations lower than for the ions listed above. Although actual concentrations differ considerably at different locations, two studies of leachate-plume chemistry in glacial aquifers on Long Island, N.Y. (Kimmel and Braids, 1980; Wexler, 1988) are used here for general comparisons. Concentrations of constituents found in the leachate plumes at these New York landfills are shown in table 8.

[5] In this report, natural refers to water-quality conditions unaffected by any human activity, and background refers to water-quality conditions that may be affected by humans but are not affected by the landfill.

[6] Iron concentration is high in leachate plumes because iron in the waste pile and, more significantly, in the aquifer materials, is reduced and made soluble by anaerobic conditions resulting from the biodegradation of organic wastes (Wexler, 1988).

**Table 7.** Summary of data for selected inorganic chemical analyses of ground water from the Saco Landfill, Saco, Maine, 1975-93

[Well No. and surface-water station No.: Locations are shown in figure 18. µS/cm, microsiemen per centimeter at 25 degrees Celsius. <, actual value is less than value shown. --, indicates that no samples were analyzed for that constituent]

| Well No. and surface-water station No. | Total number of samples | Year of most recent sample | Median specific conductance (µS/cm) | Median concentration of indicated constituent, in milligrams per liter | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Sodium | Calcium | Magnesium | Chloride | Iron, total | Nitrogen, nitrate (as N) | Nitrogen, ammonia (as N) |
| **Monitoring Wells** | | | | | | | | | | |
| 83-1 | 16 | 1993 | 85 | 7.03 | 8.50 | 1.86 | 10.0 | 1.64 | 0.50 | 0.50 |
| 83-2 | 3 | 1987 | 854 | 40.0 | 31. | 10.2 | 99.0 | 83.0 | .50 | 11.4 |
| 83-3 | 2 | 1987 | 187 | 14.0 | 13.5 | 3.76 | 8.76 | 4.76 | .87 | 2.55 |
| 83-5 | 13 | 1993 | 713 | 53.0 | 35.0 | 13.6 | 71.5 | 30.0 | .50 | 15.9 |
| 83-6 | 15 | 1993 | 150 | 15.0 | 5.88 | 2.04 | 17.0 | 20.0 | .53 | 1.30 |
| 83-9 | 4 | 1993 | 92 | 7.6 | 16.4 | 3.50 | 6.38 | .09 | < .05 | .16 |
| 83-12 | 1 | 1988 | 712 | 68.0 | 87.0 | 45.0 | -- | 33.0 | -- | -- |
| 83-13 | 9 | 1993 | 2,300 | 275 | 161 | 48.3 | 410 | 14.3 | .50 | 20.5 |
| 83-14 | 13 | 1993 | 8,150 | 2,000 | 141 | 75.5 | 3,060 | 49.0 | .54 | 21.8 |
| 83-15 | 1 | 1988 | 540 | 27.0 | 21.0 | 18.0 | -- | 4.80 | -- | -- |
| 83-16 | 12 | 1993 | 2,270 | 300 | 108 | 81.9 | 575 | 21.0 | .53 | 1.30 |
| 85-2 | 9 | 1993 | 440 | 9.9 | 50.9 | 11.9 | 10.0 | 13.2 | .50 | 4.90 |
| 85-4 | 7 | 1993 | 105 | 9.9 | 6.10 | 2.00 | 19.0 | 1.90 | .59 | .50 |
| 85-6 | 13 | 1993 | 243 | 13.8 | 30.0 | 7.31 | 10.0 | 2.90 | .50 | 1.55 |
| 93-3 | 1 | 1993 | 462 | 11.7 | 55.7 | 11.5 | -- | < .08 | -- | -- |
| 93-4 | 1 | 1993 | 385 | 55.6 | 16.9 | 4.58 | -- | < .07 | -- | -- |
| 93-7 | 1 | 1993 | 442 | 49.7 | 14.3 | 6.51 | -- | < .01 | -- | -- |
| B-101 | 7 | 1975 | 800 | -- | -- | -- | -- | 67.0 | .10 | -- |
| B-102 | 5 | 1975 | 4,200 | -- | -- | -- | -- | 405 | .35 | -- |
| B-103 | 5 | 1975 | 7,000 | -- | -- | -- | -- | 760 | .55 | -- |
| B-104 | 20 | 1993 | 1,280 | 115 | 92.9 | 36.5 | 100 | 168 | .71 | 3.65 |
| B-105 | 4 | 1975 | 2,750 | -- | -- | -- | -- | 300 | .10 | -- |
| B-106 | 6 | 1975 | 56 | -- | -- | -- | -- | 40.5 | .70 | -- |
| B-109 | 7 | 1975 | 5,500 | -- | -- | -- | -- | 340 | .32 | -- |
| B-110[1] | 8 | 1993 | [1]52 | [1]64.7 | [1]19.7 | [1]19.7 | -- | 114 | 1.20 | -- |
| B-111 | 7 | 1975 | 130 | -- | -- | -- | -- | 6.45 | 5.00 | -- |
| B-113 | 5 | 1975 | 110 | -- | -- | -- | -- | 130 | .70 | -- |
| B-302 | 16 | 1993 | 592 | 41.3 | 47.5 | 25.9 | 49.5 | 27.0 | .50 | 1.10 |
| B-303 | 3 | 1987 | 1,520 | 209 | 119 | 22.6 | 222 | 39.9 | .10 | 1.65 |
| B-305 | 3 | 1993 | 105 | 14.0 | 15.0 | 5.30 | 25.0 | .03 | 2.52 | .41 |
| B-306 | 12 | 1993 | 1,410 | 216 | 120 | 38.2 | 383 | 1.92 | 1.90 | 9.76 |
| B-307 | 13 | 1993 | 710 | 47.0 | 58.0 | 24.0 | 83.0 | .89 | .50 | .17 |
| B-308 | 1 | 1993 | 162 | 9.50 | 18.4 | 2.11 | -- | .07 | -- | -- |
| City's 18 | 1 | 1993 | 2,950 | 364 | 167 | 47.3 | -- | 50.6 | -- | -- |
| **Residential Wells** | | | | | | | | | | |
| RES-21 | 10 | 1993 | 922 | 191 | 7.07 | 6.12 | 120 | .09 | .46 | .50 |
| RES-22 | 13 | 1993 | 766 | 166 | 7.59 | 4.90 | 99.0 | .05 | .50 | .27 |
| RES-23 | 12 | 1993 | 203 | 19.4 | 10.0 | 3.98 | 27.0 | .20 | 1.20 | .20 |
| RES-24 | 13 | 1993 | 72 | 6.40 | 4.12 | 1.25 | 8.50 | .06 | .42 | .21 |

**Table 7.** Summary of data for selected inorganic chemical analyses at the Saco Landfill, Saco, Maine, 1975-93—*Continued*

| Well No. and surface-water station No. | Total number of samples | Year of most recent sample | Median specific conductance (µS/cm) | Median concentration of indicated constituent, in milligrams per liter | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Sodium | Calcium | Magnesium | Chloride | Iron, total | Nitrogen, nitrate (as N) | Nitrogen, ammonia (as N) |
| **Surface-Water Stations** | | | | | | | | | | |
| SW/SD-1 | 1 | 1993 | 202 | 20.3 | 9.09 | 1.46 | -- | <.22 | -- | -- |
| SW/SD-2[1] | 4 | 1993 | [1]1,330 | [1]35.7 | [1]28.6 | [1]8.24 | -- | 50.0 | 0.60 | -- |
| SW/SD-3 | 1 | 1993 | 115 | 3.5 | 15.6 | 1.54 | -- | <.13 | -- | -- |
| SW/SD-4 | 20 | 1993 | 160 | 14.5 | 10.0 | 2.53 | 24.0 | .88 | .62 | 0.44 |
| SW/SD-5 | 2 | 1993 | 458 | 24.0 | 13.0 | 3.40 | 46.0 | 1.60 | .52 | 1.25 |
| SW/SD-6 | 1 | 1993 | 713 | 57.9 | 47.2 | 11.4 | -- | 10.4 | -- | -- |
| SW/SD-7 | 15 | 1993 | 140 | 12.9 | 8.78 | 2.26 | 20.8 | .69 | .63 | .23 |
| SW-6 | 13 | 1993 | 160 | 20.8 | 16.0 | 2.75 | 25.0 | 1.40 | .62 | .50 |
| SW-17 | 16 | 1993 | 143 | 16.6 | 9.51 | 2.35 | 24.0 | .75 | .71 | .50 |
| SW-26 | 8 | 1993 | 202 | 22.7 | 11.0 | 3.44 | 33.0 | .54 | 1.35 | .50 |
| Cousin's Pond influent | 3 | 1975 | 110 | -- | -- | -- | -- | < .03 | 1.52 | -- |

[1]The most recent sample in 1993 is the only sample to include sodium, calcium, and magnesium. For well B-110, the specific conductance of that sample was 601 µS/cm, and for SW/SD-2, it was 354 µS/cm.

**Table 8.** Ranges in concentrations of inorganic chemical constituents and in specific conductance for ground water affected by landfill leachate on Long Island, New York

[mg/L, milligram per liter; µS/cm, microsiemen per centimeter at 25 degrees Celsius; <, actual value is less than value shown; ~, about]

| Constituent | Range in concentrations in leachate plume | |
|---|---|---|
| | Data from Kimmel and Braids (1980) | Data from Wexler (1988) |
| **Cations (mg/L)** | | |
| Sodium | 39-860 | 8 - 500 |
| Potassium | 11-110 | 1.4 - 330 |
| Calcium | 45-565 | 8.5 - 210 |
| Magnesium | 26-55 | 1.9 - 83 |
| Ammonium, as N | 0-43 | 0.11 - 291 |
| **Anions (mg/L)** | | |
| Chloride | 29-300 | 16 - 650 |
| Sulfate | 19-150 | < 1 - 36 |
| Bicarbonate | 59-2700 | 79 - 2540 |
| Nitrate (as N) | 0.05-2.2 | < 0.01 - 0.65 |
| Iron, total | 0.1-440 | 0.05 - 155 |
| Specific conductance (µS/cm) | ~400-2,000 | ~200 - 5,500 |

Water samples from most of the wells in and near the landfill areas in Saco had concentrations of constituents within the range of concentrations reported by Kimmel and Braids (1980) and Wexler (1988). High specific conductances and elevated ammonium and iron (the latter two indicating reducing conditions) were found at wells 83-13, 83-14, 85-2, and B-110. The highest median concentrations of calcium were found at wells near Area 2 (B-306, 83-16, 83-14, and 83-13, and city's 18). High concentrations of calcium may be attributable to leachate derived from construction debris, which includes concrete and gypsum board. The water sampled from wells near Area 2 also had relatively higher sodium and chloride concentrations than did samples from wells near Area 3 and (or) Area 1, indicating a possible source of sodium chloride within the landfill. A few of the water samples did not exhibit signs of leachate contamination. These samples were from wells, notably wells 85-6 and B-308, that apparently are upgradient from the adjacent landfills. The water-table maps (figs. 12, 13 and 14), indicate that 85-6 is in an area of ground-water mounding. Local recharge is probably the cause of the low median concentrations of the measured constituents at this well.

Many of the monitoring wells installed at the Saco Landfill are downgradient from the landfill areas (wells B-110, B-109, 83-1, 83-2, 83-5, B-303, B-113, B-307, B-303, B-302, and possibly 93-3). Water samples from most of these wells did not have constituent concentrations as high as those from the wells directly in or adjacent to the landfills, but they did have similar relative concentrations of constituents. Wells downgradient from Area 3 include B-302, B-303, 83-2, 83-1, 83-5, and 93-3. Water samples from all these wells except 83-1 and 93-3 had high median iron concentrations and specific conductances greater than 600 µS/cm, indicating that they may have been affected by leachate (fig. 19). Well 83-1 is possibly screened above the leachate plume, which flows to the southeast; also possible, however, is that a bedrock high near the eastern corner of Area 3 splits the leachate plume into two segments: one moving eastward towards Sandy Brook above the gravel pit area and the other moving southward through the gravel pit towards Sandy Brook. In either case, the water sampled at 83-1 appears to be dominated by recharge near the well itself. Well 93-3 is screened much deeper than the others, but may still be in the direct path of the leachate plume; it will be discussed more fully later in this report. Wells B-109, B-110, B-113 (destroyed) and B-307 are or were downgradient from Areas 1 and 2. Water from wells B-109 and B-113 was last sampled in 1975; the samples from both showed signs of leachate contamination at that time. In 1975, water from well B-110 did not have high specific conductance, but it did have high concentrations of iron. Recent (1993) sampling indicates elevated specific conductance (601 µS/cm), which is probably from migration of leachate-affected water towards the well since 1975. Constituent concentrations in water from well B-307 were somewhat elevated and indicative of oxidized conditions (low concentrations of iron and ammonia), indicating that leachate has had some affect on ground water at that well.

A few of the wells sampled do not fit clearly into the categories discussed above. Some are difficult to categorize as clearly upgradient or downgradient from the landfill areas, and others are screened in the confined part of the lower aquifer. Water from wells B-305 and 83-9 (northwest of Area 3) seems to be unaffected by leachate, despite being adjacent to an area that reportedly received tannery sludges directly on the bedrock surface (NUS Corporation, 1987). Although there is considerable uncertainty in the water-table maps in that area (figs. 12 and 13), these wells appear to be upgradient from the reported sludge-disposal areas. (Wells 83-8 and B-301, downgradient from the sludge-disposal area, were not sampled.) Wells 93-3 and 93-4 are the only wells from which the lower-aquifer water was sampled below a depth of 30 ft. The potentiometric surface map show that wells 93-3 and 93-4 are in different flow paths, so their water chemistry cannot be compared directly. Neither area appears to be clearly affected by landfill leachate. Specific conductance and calcium are moderately high in well 93-3, but this effect could be from either leachate or a natural source, such as mineral dissolution.

A map showing the distribution of median specific conductances (fig. 19) measured during 1975-93 shows areas where specific conductance was consistently higher than background. Water from most wells upgradient from the landfill areas had median specific conductances less than 200 µS/cm, which is probably the local background level. An area of elevated ground-water specific conductance east of Area 1 extends towards the unnamed tributary to Deep Brook and extends around to the southeast towards DuBois Pond[7]. Several of the wells in this area no longer exist or have not been sampled since 1975. Recent (1993) data from well B-110 indicate that elevated levels of specific conductance persist in this area. A second area of elevated specific conductance is to the west and south of Area 2. Water samples collected from wells in this area by the city of Saco since 1987 have consistently shown very high specific conductance (greater than 2,000 µS/cm).

The data presented do not show a large downstream increase in specific conductance in Sandy Brook. During the summer and early autumn of 1993, specific conductance measured in the stream by the USGS just downstream from Area 2 at station 2 was higher than that measured upstream at station 1, especially during low flow (see table 10). During this same period, a leachate recirculation system installed at Area 2 was not working (Mike Bolduc, city of Saco, oral commun., 1993). Once the leachate recirculation system was repaired, the downstream rise in specific conductance at station 2 diminished. Two other areas of high-conductivity ground water are downgradient from Area 3 (fig. 19). One is to the northeast, where ground water in well B-302 has specific conductances above

[7] Names assigned to ponds in this report (DuBois Pond and Cousin's Pond) do not constitute official geographic names.

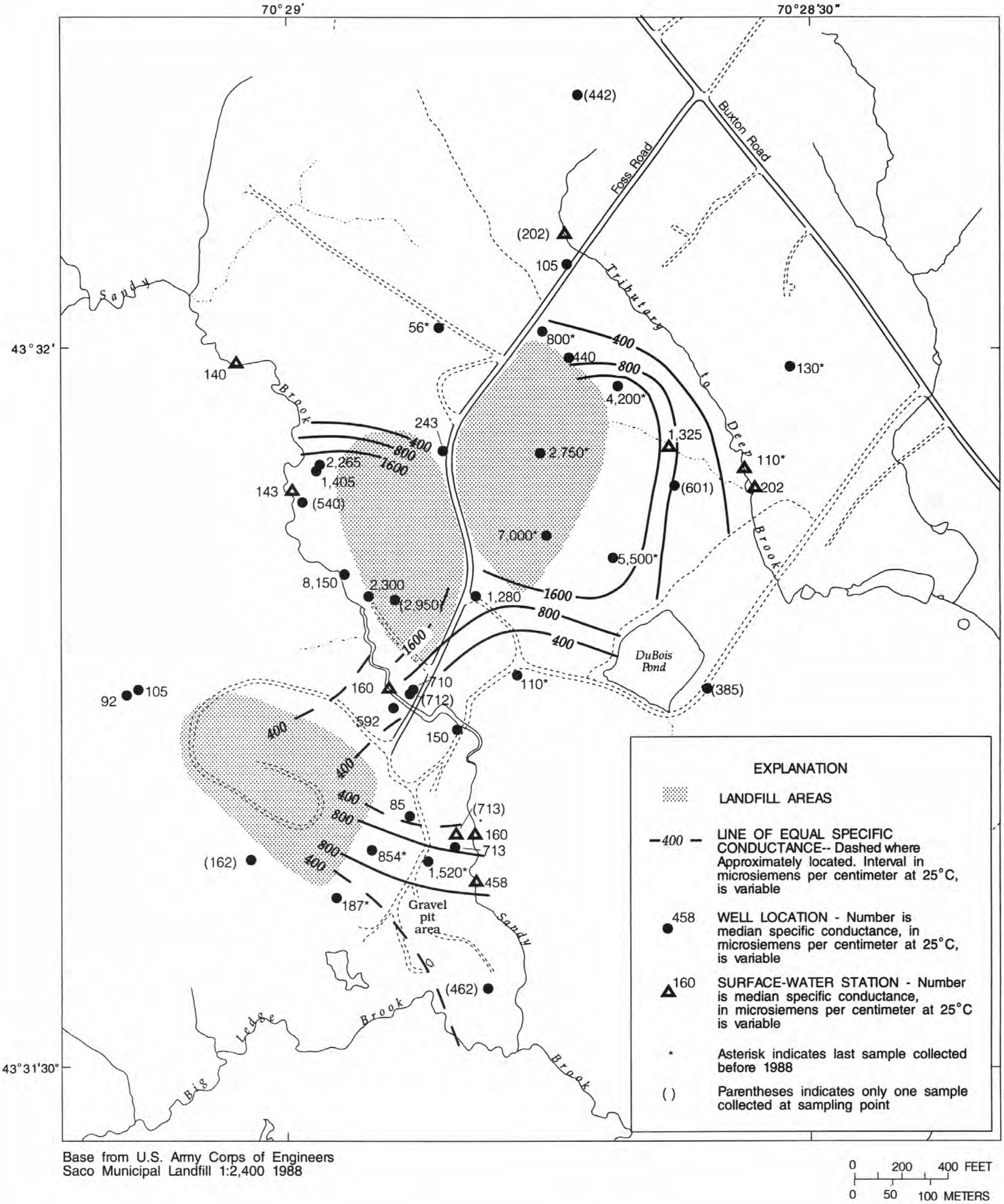



**Figure 19.** Distribution of median specific conductance for ground-water and surface-water sampling locations, Saco Landfill, Saco, Maine, 1975-93.

background. Because this well is the only one sampled in this vicinity, the water-chemistry data cannot accurately delineate the extent of this plume. Another zone of high specific conductance is southeast of Area 3 (fig. 19). Analysis of water samples from shallow wells and springs in the northern part of the gravel pit area has consistently indicated high-conductivity, leachate-enriched ground water. Some of this ground water discharges to Sandy Brook, as indicated by large increases in specific conductance as the stream flows past this area. The southern extent of this plume is not well defined. Well 93-3 was sampled in 1993; the water had a specific conductance of 462 µS/cm, which is somewhat above the local background level. The screen in this well is much deeper than screens in the other wells sampled in the gravel pit area, and the specific conductance measured may be due to mineral dissolution in the lower aquifer.

In general, the organic-chemistry data corroborate the inorganic chemistry data with respect to the flow of water affected by leachate. More than 38 organic chemicals have been detected in water near the Saco Landfill (table 9). A combined total of 24 surface-water stations and wells were sampled during 1983-93; at 17, one or more organic chemicals were detected. Water at few of the stations and wells has been sampled more than once, so median concentrations cannot be calculated. Wells B-104, 83-5, and 85-2 have been sampled the most often, and detections of various organic chemicals have been consistent. The most organic chemicals have been detected in samples from well B-104, although many also have been detected at well 83-5 and the recently sampled well B-110. Sampling points where organic chemicals were not detected include SW/SD-1, SW/SD-7, B-306, B-308, 93-3, 93-4, and 83-9.

Most of the detections of organic compounds have been in water samples from wells east of Sandy Brook, near Areas 1 and 2, but this may be a function of the wells selected for sampling rather than of the overall distribution of chemicals. Detections in wells B-304 and 83-5 show that Area 3 is also a likely source of organic chemicals. The detections of organic compounds in water samples from well B-304 in 1983 have three possible explanations: leachate has migrated to the south of Area 3 towards Big Ledge Brook, dissolved or free-phase organic chemicals entered the source area for that well but inorganic leachate did not, or the analysis is in error or represents sample cross-contamination. The uncertainty as to the southern and western extent of the leachate plume in the gravel pit area, as well as uncertainty in ground-water flow directions in that area, leave the possibility that leachate has, at one time, migrated under the western side of the gravel pit area towards Big Ledge Brook.

Terrain-conductivity measurement was another method used to identify possible zones of contamination in the unconsolidated deposits. Because of the shallowness of the clay layer to the east of Sandy Brook and the shallow bedrock to the west of Sandy Brook, the most useful data are from the 33-ft-spacing data, which are the data principally discussed in this report. The data-collection stations are shown in figure 20, and data are given in Appendix 4. The data were collected during a period when the water table was low. Measurements made when the water table is high may be different from those made for this study. Contamination in the area directly between Area 2 and Sandy Brook is well documented (Halliburton NUS, 1994), and additional measurements in that area were not made.

Terrain conductivities measured in areas thought to represent background conditions (where the magnitude of terrain conductivity is unrelated to the presence of high-conductivity ground water) are varied and range from -6 to 12 mS/m (millisiemens per meter) for data collected by use of 33-foot antenna spacing and horizontal dipole antenna orientation. Variations in background terrain conductivities result from topographic, hydrologic, and lithologic differences, and structural sources of interference such as metal fences and power lines. The greatest variations in background levels of apparent terrain-conductivities are related to different geologic environments. Southwest of Area 3, where nonconductive bedrock is at or near land surface, background apparent terrain conductivity ranges from -5 to 3 mS/m. In the gravel pit southeast of Area 3, where deposits are mostly coarse-grained, background apparent terrain conductivity ranges from 1 to 3 mS/m. In the areas surrounding areas 1 and 2, where thick fine-grained deposits are overlain by thin sandy deposits, background apparent terrain conductivity ranges from 4 to 8 mS/m. At stations 15.05 to 15.09 (in a field north of the study area (fig. 20) and along the access road to the gravel pits east of the landfill), where conductive fine-grained deposits are very near the land surface, background apparent terrain-conductivity ranges from 8 to 12 mS/m. The Saco Landfill area is characterized by a bedrock surface that decreases in altitude from southwest to northeast. Conductivity values, starting 200 to

**Table 9.** Organic compounds detected in ground water and surface water at the Saco Municipal Landfill, Saco, Maine, 1983-93

[Year of sample collection: Camp Dresser & McKee, Inc., sampled stations SW/SD-1, SW/SD-2, SW/SD-4, SW/SD-5, SW/SD-6, SW/SD-7, well B-109, and leachate seep in gravel pit; Dubois and King sampled wells 83-5, B-304, B-306, B-307; Balsam Environmental sampled wells 83-5, 83-9, 83-12, B-104, 83-15, 83-13, and surface-water station SW/SD-4; Halliburton NUS sampled wells 83-5, City's 18, B-104, 85-2, 83-12, and 83-13 and surface-water stations SW/SD-1 through SW/SD-7 in April 1993; Halliburton NUS sampled wells 93-3, 93-4, 93-7, B-104, B-110, B-306, B-308, 83-5, 85-2, and 85-6 in December 1993. nd, not detected; tr, trace; --, not analyzed]

| Chemical | Year of sample collection | | | | |
|---|---|---|---|---|---|
| | Camp Dresser & McKee, Inc., 1983 | Dubois and King, 1983 | Balsam Environmental, 1987 | Halliburton NUS, April 1993 | Halliburton NUS, December 1993 |
| **Volatile organic compounds** | | | | | |
| Acetone | SW/SD-5<br>SW/SD-6 | -- | nd | City's 18 | nd |
| Benzene | -- | B-307 | B-104<br>83-5 (tr) | 83-5 (tr)<br>City's 18 (tr) | 83-5<br>B-110 |
| n-Butyl benzene | -- | -- | -- | -- | B-104 |
| Carbon disulfide | -- | -- | nd | 83-5<br>B-104 (tr)<br>85-2 (tr)<br>83-12 (tr) | nd |
| Chlorobenzene | -- | -- | nd | 85-2 (tr) | 85-6<br>85-2<br>B-110 |
| Chloroethane | -- | -- | 83-5<br>B-104 | 83-5<br>City's 18<br>SW/SD-6 | 83-5<br>B-104 |
| Cyclohexanemethanol | -- | -- | -- | B-104 | -- |
| Dichlorodiflouromethane | -- | -- | -- | -- | B-110(tr) |
| 1,1 Dichloroethane | -- | B-304<br>B-307 | B-104 | B-104 | B-104 |
| 1,2 Dichloroethane | -- | B-304 | nd | nd | nd |
| Ethylbenzene | -- | B-304 | 83-5 | SW/SD-2 (tr) | 85-2<br>B-104(tr) |
| Freons | -- | B-304 | -- | -- | -- |
| Isopropyltoluene | -- | -- | -- | -- | B-104 |
| Isopropylbenzene | -- | -- | -- | -- | B-110(tr) |
| Methylbenzene | -- | -- | -- | B-104 | nd |
| Methylene chloride | SW/SD-4 (tr) | -- | nd | nd | 85-2 |
| Methyl ethyl ketone (2-Butanone) | SW/SD-5<br>SW/SD-6<br>Leachate seep | -- | B-104 | B-104<br>83-13 | nd |
| Methyl isobutyl ketone | SW/SD-6<br>Leachate seep | -- | nd | nd | nd |
| n-propylbenzene | -- | -- | -- | -- | B-104 |
| Tetrachloroethylene | -- | B-304<br>B-307 | nd | nd | -- |
| Tetrahydrofuran | SW/SD-6 | -- | nd | -- | -- |
| Toluene | SW/SD-5<br>SW/SD-6<br>leachate seep | B-307 | B-104 | B-104<br>85-2 (tr) | B-104<br>85-2 |

**Table 9.** Organic compounds detected in ground water and surface water at the Saco Municipal Landfill, Saco, Maine, 1983-93--*Continued*

| Chemical | Year of sample collection | | | | |
|---|---|---|---|---|---|
| | Camp Dresser & McKee, Inc., 1983 | Dubois and King, 1983 | Balsam Environmental, 1987 | Halliburton NUS, April 1993 | Halliburton NUS, December 1993 |
| Trichlorobenzene | -- | -- | -- | -- | B-104 |
| 1,1,1 Trichloroethane | -- | -- | B-104 | nd | nd |
| Trichloroethlyene | Leachate seep | B-304 | nd | nd | nd |
| Trimethylbenzene | -- | -- | -- | -- | B-104 |
| Vinyl chloride | -- | -- | B-104 (tr) | nd | nd |
| Xylenes | -- | B-307 | B-104<br>83-5 | B-104 (tr) | B-104 |
| **Semivolatile organic compounds** | | | | | |
| Bis-(2-Ethylhexyl) pthalate | -- | -- | nd | 85-2 | 93-7(tr) |
| Creosols (methyl phenol) | SW/SD-2<br>B-109 | -- | nd | B-104 | B-104 |
| Cyclotrisiloxane | -- | -- | -- | 83-13 (tr) | -- |
| Diacetone alcohol | -- | -- | -- | 83-13 | nd |
| Dichlorobenzenes | -- | -- | nd | 85-2 (tr)<br>SW/SD-2 (tr) | 83-5 (tr)<br>85-2<br>B-110 |
| Napthalene | -- | -- | nd | nd | B-104(tr) |
| Pentanones | -- | -- | -- | B-104<br>83-12 | nd |
| Phenols | nd | -- | B-104 | B-104<br>City's 18 | nd |
| 2-Propanol | -- | -- | -- | 83-13 (tr) | -- |
| Unidentified semivolatile organic compounds | -- | -- | -- | 83-5<br>City's 18 | B-104 |

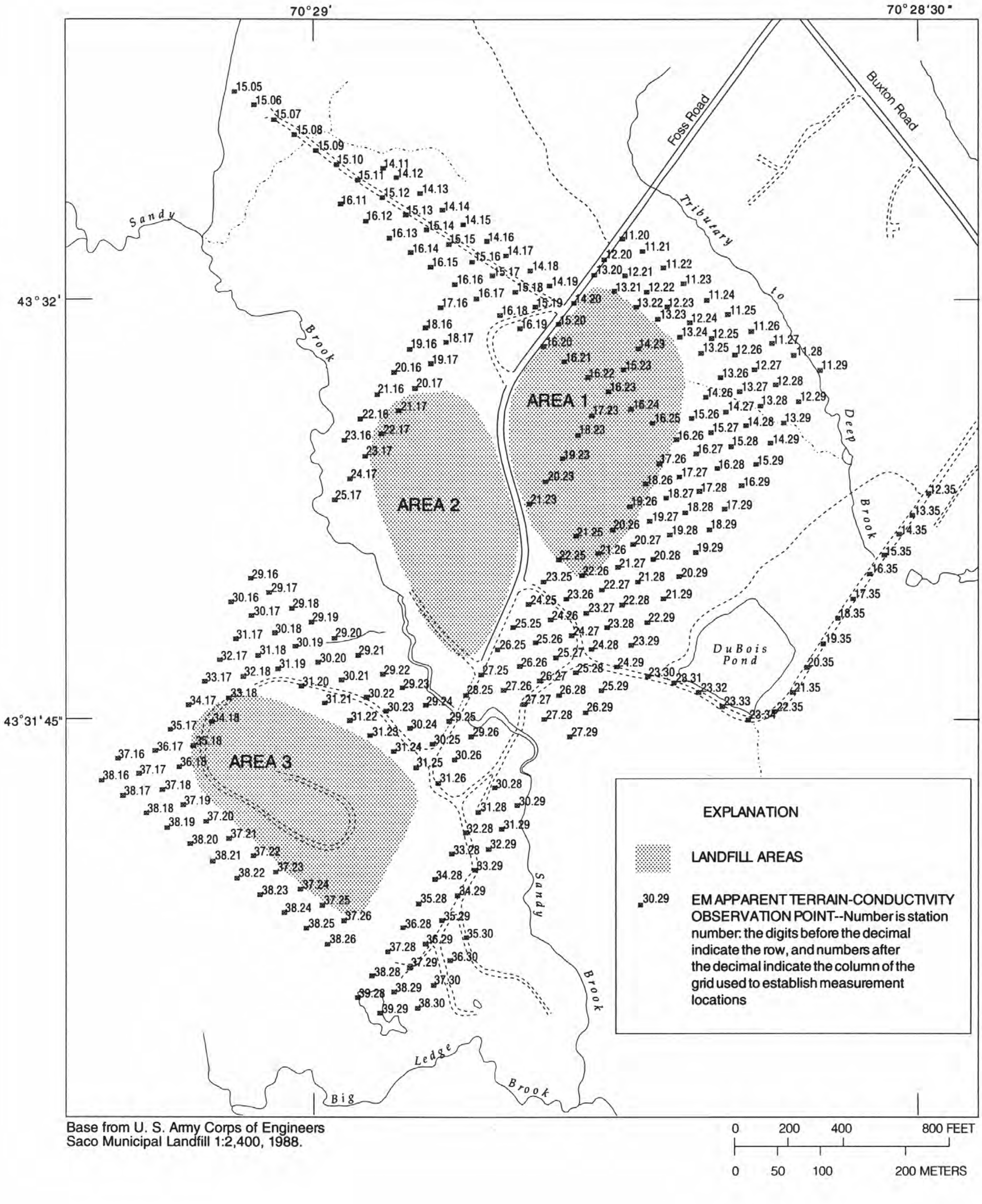



**Figure 20.** Data-collection stations for electromagnetic terrain-conductivity survey at the Saco Landfill, Saco, Maine.

300 ft east of Sandy Brook and proceeding to the southwest, appear to progressively decrease as a result of the progressively higher bedrock surface. This effect is most apparent in measurements made with the 66- and 131-foot antenna spacings (Appendix 3).

Anomalous patterns of apparent terrain conductivities indicate areas underlain by high-conductivity ground water or high-conductivity soils. These areas of high conductivity are shaded in figures 21 and 22. The absence of strong anomalies for the 66- and 131-foot antenna spacing and vertical-antenna-orientation data for the landfill areas east of Sandy Brook (Appendix 3), indicates that most of the high-conductivity ground water adjacent to this area is fairly close to land surface.

Areas of high apparent terrain conductivity are described as follows:

- At Area 1, an area of high conductivity (8 to 20 mS/m) extends from the landfill to the unnamed tributary to Deep Brook to the northeast and also to the east and southeast towards DuBois Pond.
- At Area 2, a small area of high conductivity (9 to 33 mS/m) on the western side extends westward or southwestward toward Sandy Brook. East of this landfill, an area of high conductivity (9 to 32 mS/m) extends southward toward Sandy Brook.
- Southeast of Area 3, an area of high conductivity (5 to 11 mS/m) extends east and northeastward toward Sandy Brook. The 33-ft spacing, vertical-dipole-orientation data (fig. 22) indicates that this area of high conductivity is more extensive at depth than the area indicated by the horizontal-dipole data (fig. 21).
- On the northeastern side of Area 3, an area of high conductivity (5 to 10 mS/m) that extends toward Sandy Brook is difficult to interpret because of the complex geologic conditions. In this area, clay deposits (high conductivity) begin and thicken to the north and the bedrock surface (low conductivity) rises in altitude from north to south, creating highly contrasting conditions within a short distance.

Relatively low conductivity (0 to 2 mS/m) just northeast of Area 3 indicates the presence of a bedrock high and the absence of high-conductivity ground water in this area. The presence of a shallow bedrock surface is supported by seismic and drilling data (fig. 4). Southeast of Area 3, in the gravel pit area, the terrain-conductivity data for the 66- and 131-foot spacings do not show any trends of increasing conductivity with depth. This could be a result of either no change with depth (that is, the plume extends the entire depth of the aquifer) or clean water at depth; more likely it is the latter, but this would have to be corroborated with sampling or borehole-conductivity logging.

West of Area 3, bedrock is at or near land surface and accounts for the low and negative apparent terrain conductivities (-5 to 2 mS/m). However, a small area of slightly higher apparent terrain conductivity (2 to 4 mS/m) within this area may be underlain by high-conductivity ground water.

Relatively high terrain conductivities (8 to 15 mS/m) in two areas are interpreted to represent the effect of the silt/clay layer being close to or at land surface. These two areas are (1) 800 to 1,000 ft north of Area 2 along an access road to the landfill and (2) approximately 1,000 ft east-southeast of Area 1 along another access road, near DuBois pond.

A comparison of figures 22 and 19 shows that the areas of anomalously high apparent terrain-conductivity generally coincide with areas where ground-water samples have had high specific conductance values. The match is especially good east and south of Area 1. The zones of high specific conductance in ground water shown northeast and southeast of Area 1 are corroborated by the terrain-conductivity measurements, which may better indicate the extent of contamination than the specific conductance values. Northeast of Area 3, the apparent terrain-conductivity measurements indicate a larger area of high-conductivity aquifer materials and (or) ground water than the ground-water data indicate. As stated earlier, the terrain-conductivity measurements may be a result of leachate-enriched ground water or clay content in the aquifer materials themselves. In some cases, the two data sets do not completely agree; data are insufficient to determine the true extent of leachate contamination. For example, southeast of Area 3, the apparent-terrain-conductivity measurements do not show the anomalously high zone extending south into the gravel pit area, as is indicated in figure 19.

The results of the terrain-conductivity survey may also help to find areas of contamination that were not detected in any ground-water data, because of the

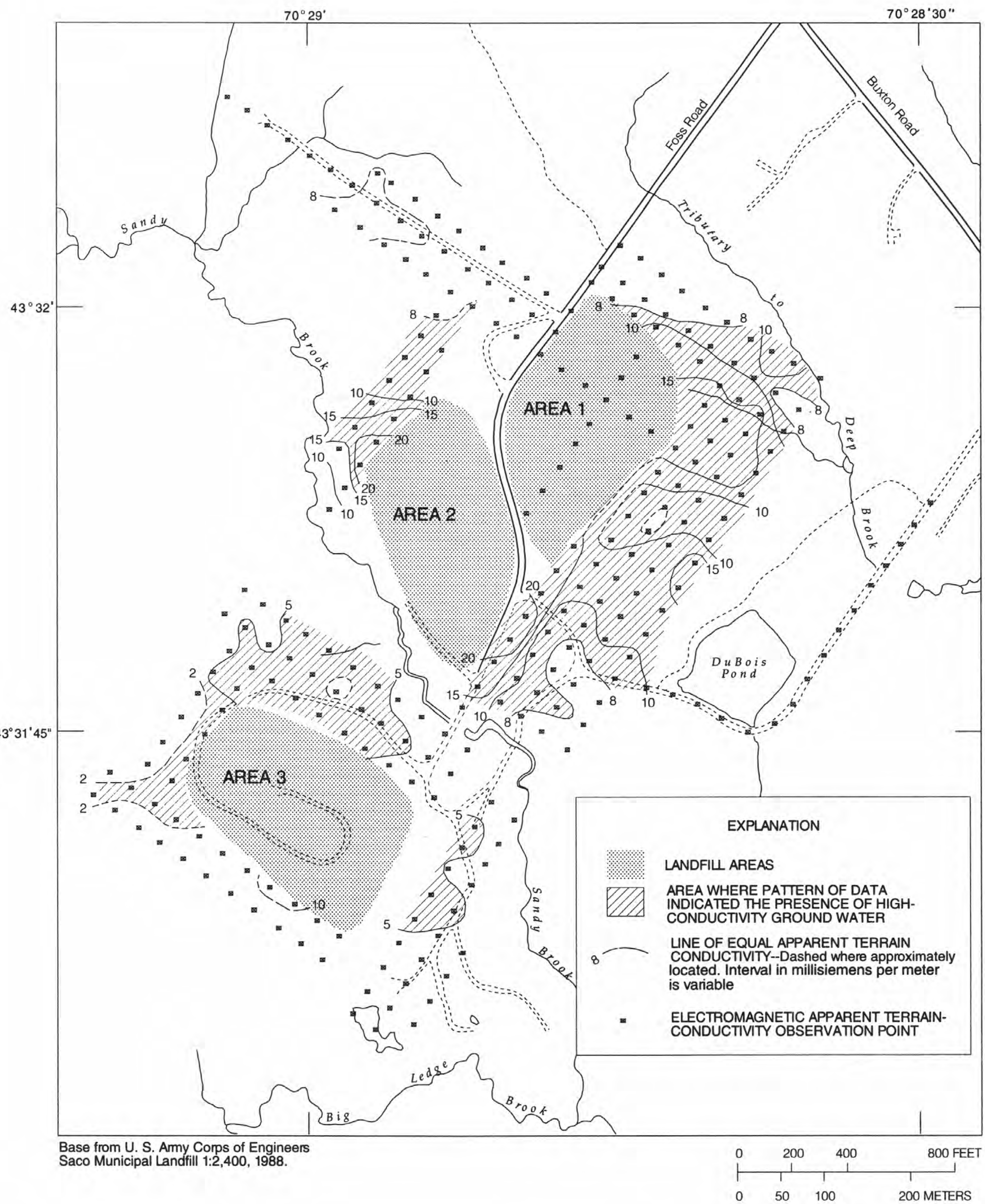
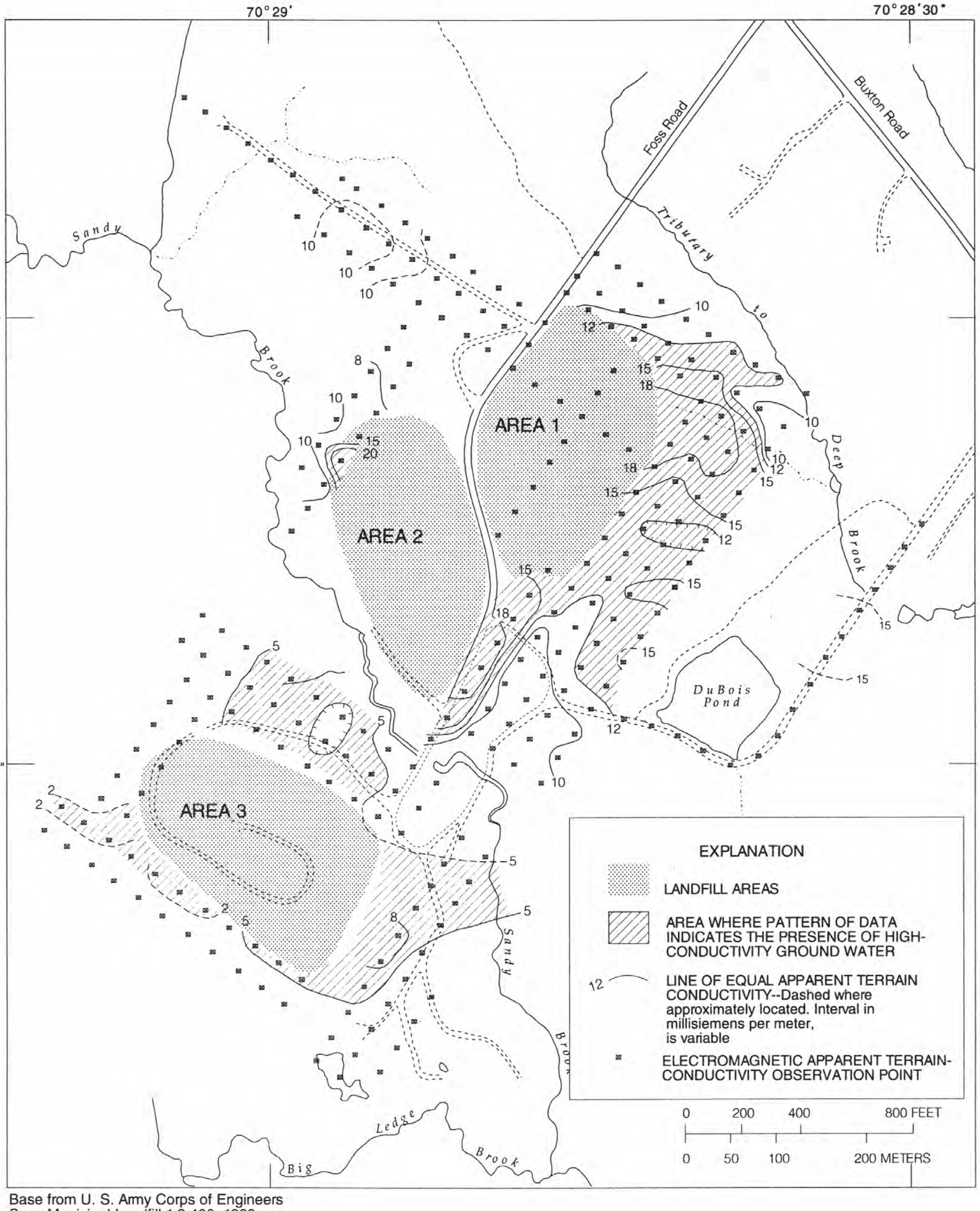



**Figure 21.** Results of electromagnetic terrain-conductivity survey, 33-foot spacing, horizontal dipole orientation, at the Saco Landfill, Saco, Maine, July 1993. (High-conductivity ground water is interpreted to be in areas where the apparent terrain conductivity is higher than background for that location.)




Base from U. S. Army Corps of Engineers
Saco Municipal Landfill 1:2,400, 1988.

**Figure 22.** Results of electromagnetic terrain-conductivity survey, 33-foot spacing, vertical dipole orientation, at the Saco Landfill, Saco, Maine, July 1993. (High-conductivity ground water is interpreted to be in areas where the apparent terrain conductivity is higher than background for that location.)

placement of monitoring wells. Figure 22 shows an area of anomalously high terrain conductivity on the northwest side of Area 3.

As described earlier, EM induction logging provided profiles of the electrical conductance of water and earth materials in three wells (fig. 9). Borehole logging was intended to help indicate whether the deeper parts of the lower aquifer within the study area had been contaminated. Because the logging tool measures the combined electrical conductance of the water and geologic materials, the EM-induction measurements cannot be directly translated into the specific conductance of the water surrounding the borehole. No obvious spike in EM conductivity is seen within the sand and gravel zones of each log that would indicate a high-conductivity leachate plume (fig. 9) in these zones. Logs for wells 93-1 and 93-2 (fig. 9) show the zone that is known to be silt and clay, on the basis of sampling during drilling. EM conductivity in these zones is much higher than in the coarse-grained zones because of the clay content and the probable connate water, which is common in the Presumpscot Formation elsewhere in the State (Snow and others, 1990). The gradual rise in EM conductivity in well 93-3 at depths below 20 ft may be from mineral dissolution in the aquifer or possibly from low-concentration leachate, because well 93-3 is downgradient from Area 3. A spike in EM conductivity in the upper 10 ft of this well corresponds to a thin clay layer, which can be seen as a rise in the natural gamma log. The EM-conductivity logs below the silt/clay layer in wells 93-1 and 93-2 do not exhibit any high-conductivity zones that might indicate contamination of the ground water.

## Surface Water

Since 1975, surface-water bodies near the landfill have been known to be affected by leachate from the landfill (Atwell, 1975). Almost all of the water-quality sampling efforts to date have included samples from Sandy Brook, the unnamed tributary to the northeast of Area 1, or various leachate seeps and leachate-enriched springs. Chemical analyses for samples from 11 locations sampled several times since Atwell's study (1975) were reviewed for this report (table 7). Of the 11 locations for which inorganic chemical data are available, 5 are sampled quarterly by the city of Saco (table 4).

Water samples from locations upstream from the landfill on Sandy Brook (fig. 18) and upstream from any leachate seeps on the unnamed tributary to Deep Brook (stations SW/SD-7, SW-17, and Cousin's Pond influent) have median specific conductances and dissolved-ion concentrations similar to those in ground water at the background wells (table 7) and may be considered to represent ambient conditions in the study area. Median specific conductance increases downstream along Sandy Brook, from 143 µS/cm at SW-17 to 160 µS/cm at SW/SD-4, 160 µS/cm at SW-6, and 458 µS/cm at SW/SD-5. Because streamflows increase downstream (table 5; Appendix 1), some of the ground-water inflow must have a higher specific conductance than the ambient water in the stream.

The USGS collected specific-conductance, water-temperature, and dissolved-oxygen data at the six streamflow stations from September 1993 to February 1994 to investigate the changes in water chemistry in the surface water. Water-temperature and specific-conductance data were collected continuously at the two continuous-record streamflow stations on Sandy Brook and every 2 weeks at the four partial-record stations (table 10).

During the early autumn (September and early October), when flows were low and the stream was sluggish, dissolved-oxygen concentrations at the Sandy Brook stations ranged from 5.8 to 6.1 mg/L. (A concentration of 6 mg/L at stream temperatures of 12°C is about 56 percent of saturation.) As streamflow increased during the autumn, dissolved-oxygen concentrations increased to greater than 90 percent of saturation. This pattern of increasing dissolved oxygen with increased streamflows was observed at the other stations, and may be the result of either a decrease in biological activity in some of the streams or a decrease in low-dissolved-oxygen ground water entering the stream relative to the total flow.

Specific conductance was lowest (108 to 184 µS/cm) at the upstream Sandy Brook station (fig. 23). Specific conductance increased downstream on Sandy Brook, a trend that agrees with previously collected data (table 7). Specific conductances on Big Ledge Brook and the unnamed tributary to Deep Brook were within the range found on Sandy Brook.

At each station, specific conductance changed over time. Relatively high specific conductances in streamwater were found during September and October,

**Table 10.** Field measurements of water-quality characteristics at surface-water stations at the Saco Landfill, Saco, Maine, September 1993-February 1994

[Station No.: Location of stations are shown in figure 2. Station 01067851 is the same as SW/SD-7. USGS, U.S. Geological Survey. µS/cm, microsiemen per centimeter at 25°C; °C, degree Celsius; ft³/s, cubic foot per second; mg/L, milligram per liter. --, indicates measurement not made]

| Station No. | USGS No. | Specific conductance (µS/cm) | Discharge (ft³/s) | Water temperature (°C) | Dissolved oxygen (mg/L) |
|---|---|---|---|---|---|
| **9/02/93** | | | | | |
| 1 | 01067851 | 184 | -- | 16.4 | 5.9 |
| 2 | 01067852 | 406 | 0.32 | 18.0 | 5.8 |
| 3 | 01067853 | 496 | -- | 13.0 | 6.4 |
| 4 | 01067855 | 262 | .04 | 11.6 | 6.6 |
| 5 | 01067859 | 316 | .01 | 15.9 | 6.1 |
| 6 | 01067861 | 365 | .58 | 16.4 | 8.1 |
| **9/21/93** | | | | | |
| 1 | 01067851 | 178 | 0.14 | 9.1 | 8.8 |
| 2 | 01067852 | 323 | .31 | 9.6 | 7.2 |
| 3 | 01067853 | 461 | .38 | 8.7 | 5.6 |
| 4 | 01067855 | 261 | .03 | 8.8 | 7.6 |
| 5 | 01067859 | 316 | .01 | 9.7 | 8.9 |
| 6 | 01067861 | 338 | .56 | 8.4 | 9.9 |
| **10/06/93** | | | | | |
| 1 | 01067851 | 180 | 0.20 | 7.1 | 8.5 |
| 2 | 01067852 | 288 | .24 | 8.6 | 10.8 |
| 3 | 01067853 | 388 | .45 | 7.9 | 6.5 |
| 4 | 01067855 | 254 | .04 | 8.5 | 7.6 |
| 5 | 01067859 | 262 | .04 | 9.2 | 10.2 |
| 6 | 01067861 | 286 | 1.00 | 8.2 | 9.0 |
| **10/20/93** | | | | | |
| 1 | 01067851 | 173 | 0.21 | 7.9 | 7.4 |
| 2 | 01067852 | 263 | .18 | 7.7 | 9.6 |
| 3 | 01067853 | 406 | .47 | 7.9 | 4.8 |
| 4 | 01067855 | 240 | .04 | 7.9 | 7.8 |
| 5 | 01067859 | 277 | .01 | 8.4 | 7.6 |
| 6 | 01067861 | 284 | .88 | 8.0 | 9.6 |
| **11/04/93** | | | | | |
| 1 | 01067851 | 164 | 0.58 | 5.5 | 11.3 |
| 2 | 01067852 | 210 | .61 | 4.9 | 10.9 |
| 3 | 01067853 | 292 | 1.35 | 5.8 | 9.2 |
| 4 | 01067855 | 139 | .49 | 4.1 | 12.6 |
| 5 | 01067859 | 226 | -- | 5.7 | 10.4 |
| 6 | 01067861 | 209 | -- | 5.4 | 11.8 |

| Station No. | USGS No. | Specific conductance (µS/cm) | Discharge (ft³/s) | Water temperature (°C) | Dissolved oxygen (mg/L) |
|---|---|---|---|---|---|
| **12/02/93** | | | | | |
| 1 | 01067851 | 138 | 0.87 | 0.5 | 12.4 |
| 2 | 01067852 | 140 | .69 | .5 | 12.9 |
| 3 | 01067853 | 245 | 1.30 | 2.6 | 10.8 |
| 4 | 01067855 | 107 | .65 | .7 | 13.4 |
| 5 | 01067859 | 220 | .13 | 2.8 | 12.0 |
| 6 | 01067861 | 145 | 4.20 | .5 | 13.4 |
| **12/20/93** | | | | | |
| 1 | 01067851 | 118 | 1.27 | 1.5 | 13.6 |
| 2 | 01067852 | 154 | -- | .6 | 15.4 |
| 3 | 01067853 | 231 | 1.7 | 1.7 | 14.0 |
| 4 | 01067855 | 97 | -- | .6 | 14.3 |
| 5 | 01067859 | 213 | -- | 3.5 | 13.3 |
| 6 | 01067861 | 143 | -- | 1.5 | 14.1 |
| **1/07/94** | | | | | |
| 1 | 01067851 | 131 | 0.57 | 0.3 | 13.2 |
| 2 | 01067852 | 197 | -- | .2 | 14.7 |
| 3 | 01067853 | 314 | .98 | 1.1 | 14.3 |
| 4 | 01067855 | 149 | -- | 1.1 | 14.3 |
| 5 | 01067859 | -- | -- | -- | -- |
| 6 | 01067861 | 192 | -- | .2 | 14.7 |
| **1/25/94** | | | | | |
| 1 | 01067851 | 135 | 0.50 | 0.3 | -- |
| 2 | 01067852 | 256 | -- | .2 | -- |
| 3 | 01067853 | 343 | 1.0 | .8 | -- |
| 4 | 01067855 | 129 | -- | 1.0 | -- |
| 5 | 01067859 | 233 | -- | .9 | -- |
| 6 | 01067861 | 202 | -- | .2 | -- |
| **2/23/94** | | | | | |
| 1 | 01067851 | 108 | 2.5 | 0.2 | -- |
| 2 | 01067852 | 113 | -- | .2 | -- |
| 3 | 01067853 | 149 | 4.7 | .7 | -- |
| 4 | 01067855 | 100 | -- | .3 | -- |
| 5 | 01067859 | 196 | -- | .7 | -- |
| 6 | 01067861 | 158 | -- | .1 | -- |

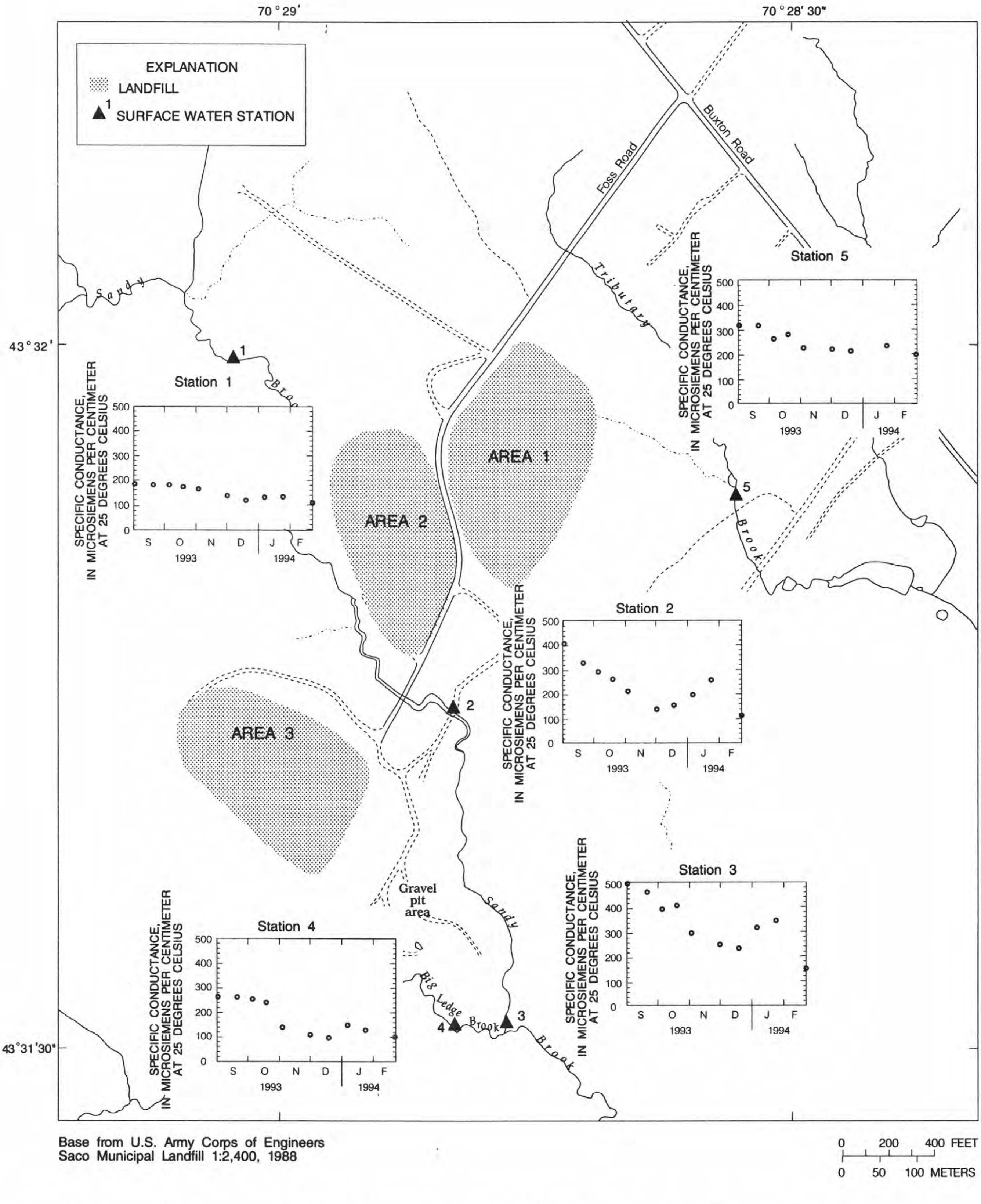



**Figure 23.** Temporal variations in specific conductance of surface water at the Saco Landfill, Saco, Maine, September 1993-February 1994. (Surface-water station names listed in table 4.)

when streamflows were lowest. Specific conductances during this time ranged from 184 µS/cm at the upstream Sandy Brook station to 496 µS/cm at the downstream Sandy Brook station. As rainfall in November and December increased streamflows, specific conductance in the stream decreased considerably at the downstream station on Sandy Brook but remained fairly constant at the upstream station (fig. 23). During September and October, the streamflows and field parameters for Big Ledge Brook were virtually constant (table 10). During this period, the brook channel was dry 100 yards upstream, and all flow measured was from ground-water discharge. Seepage was visible on the northeast bank of the stream, which indicates that the water is from the lower aquifer in the gravel pit area. Specific conductance decreased in Big Ledge Brook with increased streamflows in November and December, as it did at the Sandy Brook stations.

The continuous specific-conductance measurements at the stations on Sandy Brook record short-term changes during runoff events (fig. 24). During October, November, and December, each streamflow peak (fig. 24*B*) is accompanied by a sharp dip in the specific conductance in the downstream station, and a small dip at the upstream station (fig. 24*A*).

Organic chemicals were sampled at several surface-water stations in 1983 and in the spring of 1993 (table 9). Organic chemicals were detected at stations SW/SD-2 and SW/SD-6 (fig. 18), which are springs fed by leachate-enriched ground water. Chloroethane was detected in SW/SD-6 and in the adjacent well 83-5. Ethylbenzene and dichlorobenzene were detected in trace amounts at SW/SD-2. Samples collected in 1993 had fewer chemicals detected at fewer stations than samples collected in 1983.

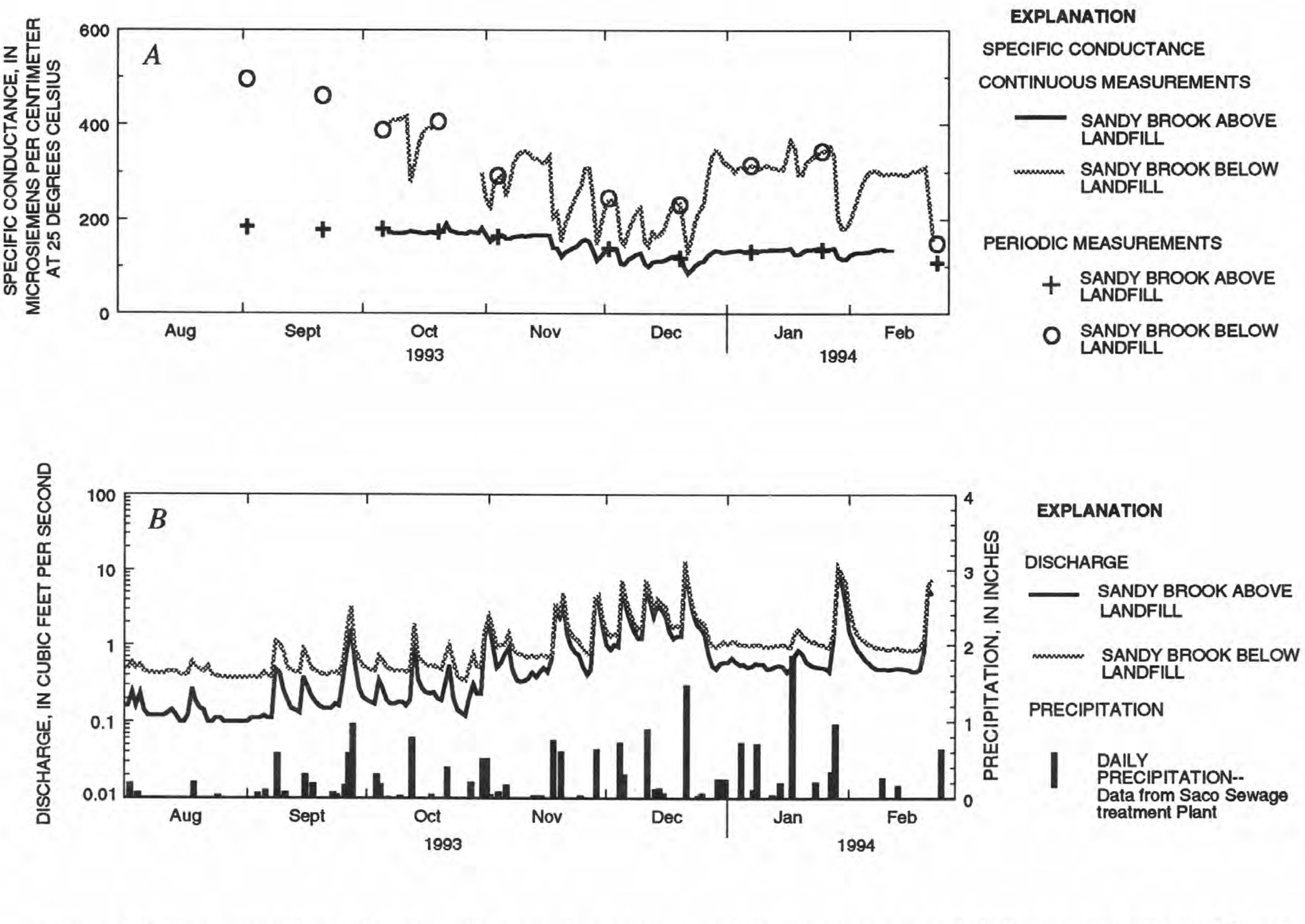



**Figure 24.** Hydrographs of (*A*) Specific conductance, and (*B*) discharge and daily precipitation at Sandy Brook above the Saco Landfill and at Sandy Brook below the Saco Landfill, Saco, Maine, August 1993-February 1994. (See figure 2 for locations of stations.)

## CONCEPTUAL MODEL OF THE HYDROLOGIC SYSTEM

Data collected and analyzed during this study are used to formulate a conceptual hydrologic model for the Saco Landfill area. Surface-water measurements can be used to quantify sources of streamflow. Ground-water levels help to identify ground-water flow directions. Water-chemistry data collected for ground water and surface water during 1975-93 are used to support interpretations of ground-water-flow patterns and discharge to streams. A water budget for the Sandy Brook Basin is developed using hydrologic and climate information.

### Water Budget for the Sandy Brook Basin Above Big Ledge Brook

Data used for water-balance computation include normal yearly precipitation at the National Weather Service station in Portland, mean annual streamflow estimated for Sandy Brook above and below the landfill (table 5), and average annual evapotranspiration (ET). Annual average ET in this water balance is the mean of four independent estimates (Knox and Nordensen, 1955; Morrisey, 1983; Lyford and Cohen, 1988; Tepper and others, 1990). Inflows and outflows of water are calculated for the 1.28-$mi^2$ basin at the upstream station (station 1) and the 1.42-$mi^2$ basin at the downstream station (station 3) (fig. 25).

A few simplifying assumptions about the system were made. At the surface-water divide on the north and east, the upper aquifer probably is less than 20 ft thick; the first assumption then, is that the ground-water divide coincides with the surface-water divide. The second assumption is that an insignificant amount of recharge to the upper aquifer enters the confining unit below. This water budget also does not address possible underflow of ground water out of the Sandy Brook Basin. Without numerical modeling of the system, this component cannot be determined.

Inflow to the upstream basin consists of precipitation only, and ground-water inflow at the surface-water divide is assumed to be negligible. A precipitation rate of 44 in/yr is equivalent to 980 Mgal/yr. Outflow consists of ET and streamflow. If an average ET rate of 21 in/yr is assumed, then 467 Mgal leaves the basin by way of ET each year. On the basis of the estimated mean annual streamflow of 2.1 $ft^3/s$ (table 5), surface-water outflow totals approximately 500 Mgal/yr. Total outflow is therefore 967 Mgal/yr; the difference between annual inflow and outflow is less than 2 percent for the upstream basin.

Inflow to the downstream basin includes all inputs from upstream sources plus any intervening inflow between the upstream and downstream stations. The drainage area between the two stations is 0.14 $mi^2$; precipitation for this area totals 107 Mgal/yr, less ET of 51 Mgal/yr; thus net input is 56 Mgal/yr. A mean annual streamflow of 2.7 $ft^3/s$ (table 5) yields a total surface-water outflow of approximately 640 Mgal/yr. Ground-water inflow is calculated as the difference between known inflows and outflows. This difference, approximately 80 Mgal/yr, can be attributed to ground-water inflow from beyond the basin boundaries, because all ground-water recharge within the basin has already been accounted for in the water budget.

The water balance has an associated error with each estimate, and the unknown component (ground-water inflow) has an associated error that is the sum of all other errors in the budget. An error of 2 percent was assigned to the precipitation estimate on the basis of the range of precipitation for southern coastal Maine (Knox and Nordenson, 1955). A 10-percent error assigned to the ET estimate represents the range of ET estimates from published sources. The error for annual streamflow is estimated at 20 percent, which represents a conservative estimate of the (unknown) actual error. The ground-water inflow estimate therefore has an associated error of approximately 30 percent.

### Water Flow at the Saco Landfill

The water budget shows the average yearly net flows of water in the Saco Landfill area, but it does not indicate any seasonal patterns of flow in surface water or ground water, nor does it help in the delineation of flow paths of ground water and any contaminants contained therein. The surface-water data for the continuous-record stations on Sandy Brook are used to separate rapid, storm-related runoff from sustained base flow. The ground-water levels, contaminant locations, and water-table maps are used to delineate ground-water-flow directions in the shallow and lower aquifers.

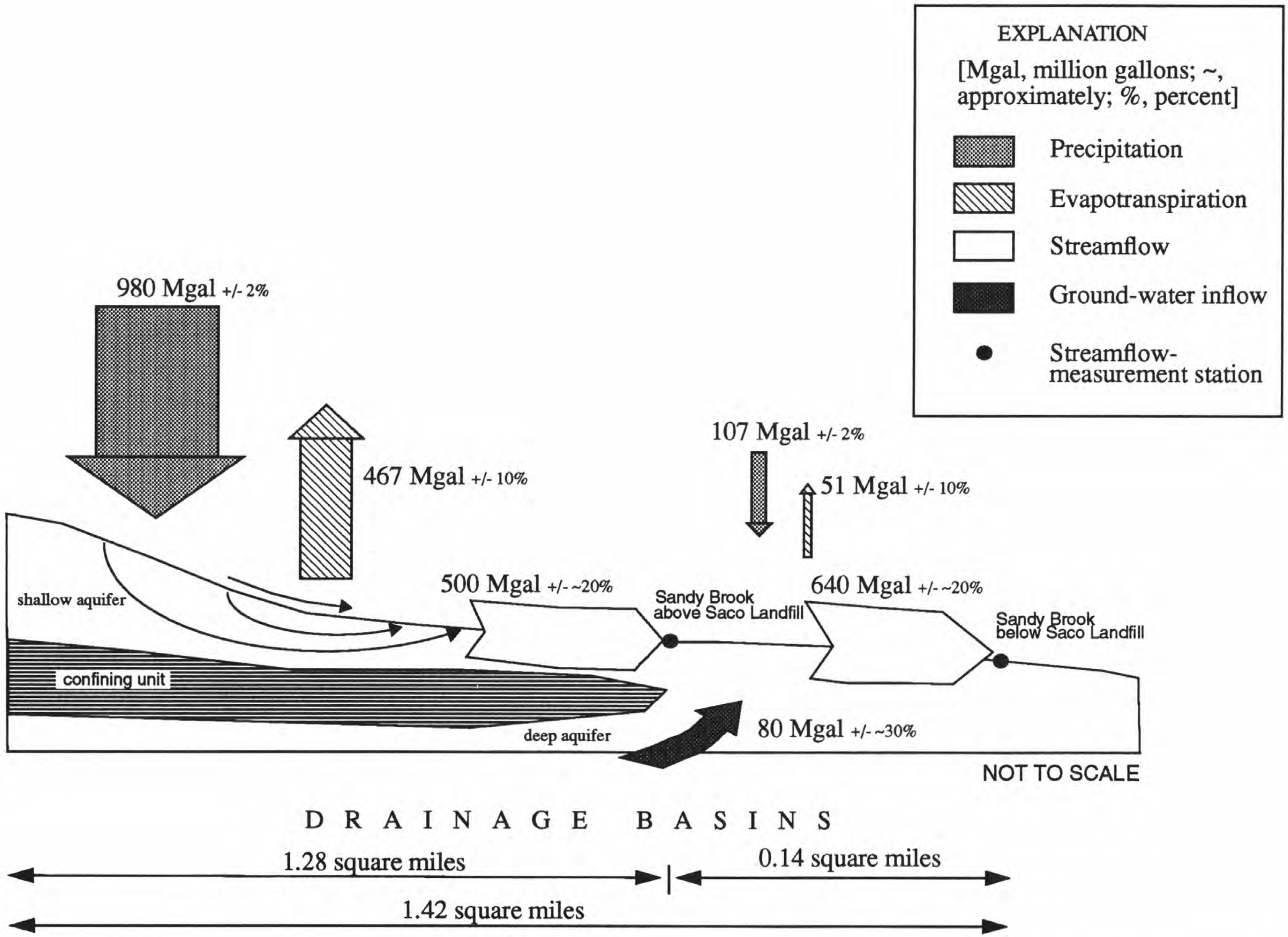



**Figure 25.** Schematic diagram of estimated average annual water budget for Sandy Brook Basin near the Saco Landfill, Saco, Maine. (Precipitation rate used is 44 inches per year, evapotranspiration (ET) rate is 21 inches per year. Error estimate for ET is based on the range of available estimates.)

## Ground Water

The unconfined aquifer at the Saco Landfill is recharged locally. During the spring of 1993, water levels were relatively high, and ground water flowed away from Areas 1 and 2 in all directions (fig. 12). This "snapshot" of the water-table position is based on measurements made in the spring, after the primary recharge period for the year, spring snowmelt. An area of ground-water mounding near Areas 1 and 2 causes radial flow from these landfill areas. The terrain-conductivity data shown in figure 21 confirm the ground-water-flow patterns near Areas 1 and 2. The absence of high terrain conductivity extending north of Areas 1 and 2 is caused by ground-water flow towards the landfill areas from the north (fig. 12), which diverts flow from this area back towards the east and west.

Ground-water-flow directions were not significantly different in October 1993 than during the spring, but the water-table mounds beneath Areas 1 and 2 had diminished. This reduction in mounding allowed ground water to flow farther towards the landfills from the north. Several areas (not mapped) where the saturated thickness of the upper aquifer was minimal in the spring were dry during the summer and autumn.

Near Area 3, the lower aquifer is unconfined and locally recharged. Flow directions interpreted from the water-level data (figs. 12, 13, and 15) indicate that ground water flows around the northwest end of Area 3 and also flows northeastward and southeastward from Area 3 towards Sandy Brook. These flow directions are also consistent with the terrain-conductivity data near Area 3 (fig. 22). In October, water levels were somewhat lower in the unconfined part of the lower aquifer southeast of Area 3, but the flow directions are virtually the same as for the spring. No water-table or other hydraulic head data are available for the lower aquifer farther west in the Big Ledge Brook Basin, where sand and gravels predominate (see figs. 5 and 6). As stated earlier, ground-water-fed base flows in Big Ledge Brook are much lower than for the other streams in the Saco Landfill area. The possibility that ground water from that part of the lower aquifer is discharging into Sandy Brook near the gravel pit is worthy of future study.

The small amount of available information indicates that ground water in the confined part of the lower aquifer may discharge to Sandy Brook near the gravel pit south of Area 3 (fig. 15). The gradients observed in this aquifer indicate that the recharge area is north of the landfill. Ground-water discharge from the lower aquifer or from the Big Ledge Brook Basin, or both, could account for the ground-water inflow from outside the Sandy Brook Basin identified in the water-budget calculations.

The fate of contaminants near Areas 1 and 2 is fairly clear, but the fate of contaminants near Area 3 is not. Because of the very low hydraulic conductivity of the glaciomarine clays, leachate from Areas 1 and 2 may not reach the lower aquifer. Flow directions shown in figures 12 and 13 indicate that ground water carrying leachate from these areas discharges to surface water near Areas 1 and 2—specifically, to the unnamed tributary to Deep Brook, Dubois Pond, and Sandy Brook. The pattern of terrain conductivity southeast of Area 3 (fig. 22) indicates that leachate may be moving east in the shallow part of the lower aquifer towards Sandy Brook, but not enough data are available to confirm whether the plume may be moving southward in deeper parts of the lower aquifer as well. Evidence from the surface-water-quality information indicates that at least some of the leachate plume discharges to Sandy Brook. Water-level and water-quality data would be needed to determine whether ground water flows southward under Sandy Brook. The terrain-conductivity (fig. 22) and water-chemistry data (from well B-302, table 7) on the northeastern side of Area 3 show another leachate plume moving towards Sandy Brook. Because the saturated thickness of the aquifer in this area is not great, Sandy Brook probably captures much of the plume in this area, but some of this plume may possibly flow downward into the confined part of the lower aquifer.

Water quality and ground-water-flow patterns in the bedrock aquifer are not known. Historical evidence that tannery sludge was deposited directly on the bedrock surface near Area 3 (NUS Corporation, 1987) and the presence of shallow bedrock below Area 3 indicate that some contamination may have entered the fractured bedrock system west of Sandy Brook.

## Surface Water

The three stream basins that are fed by the upper aquifer—Sandy Brook above the landfill (station 1), Sandy Brook at the landfill (station 2), and the unnamed tributary to Deep Brook (station 5)—all have similar base runoff rates per square mile of drainage area (table 5). Big Ledge Brook has a much lower base-runoff rate.

It drains areas of shallow bedrock and coarse-grained sand and gravel deposits (figs. 5 and 6). Apparently, its valley is not deeply enough incised to make Big Ledge Brook a strong discharge point for the lower aquifer. Sandy Brook downstream from the landfill (station 3) has a much higher sustained base-runoff rate than any other station. Ground water from the lower aquifer discharges to the brook in the gravel pit area. Some of this water is known to come from the west side of the brook, because leachate (presumably from Area 3) enters the stream, raising the specific conductance in the stream during base-flow periods (fig. 24). This cannot account for all the increase in streamflow between stations 1 and 3, however, as the total flow is greater than can be accounted for by recharge within the basin.

## SUMMARY AND CONCLUSIONS

This report provides a preliminary description of the geohydrologic system and water-quality conditions of the Saco Landfill in Saco, Maine, to help guide and design additional studies as part of the U.S. Environmental Protection Agency Superfund Program. The description includes the distribution of surficial and bedrock geologic units, depth to bedrock, streamflow, water quality in streams and ground water, sources of water in streams and ground water, and ground-water flow directions.

The Saco Landfill includes three former disposal areas, two of which (Areas 1 and 2) are capped and a third (Area 3) that is uncapped. Areas 1 and 2 lie to the east of Sandy Brook, the major stream in the area, and Area 3 lies to the west of Sandy Brook. Wastes have not been placed in the landfill areas since 1986. Discharge of leachate from the landfills to aquifers and streams near the landfill area has been documented since 1974.

The geohydrologic system consists of an upper unconfined aquifer and a lower semiconfined aquifer separated by a thick sequence of marine clays on the eastern side of Sandy Brook, an exposure of the lower aquifer on the southwestern side of the study area south of Area 3, and fractured crystalline bedrock north and west of Area 3. The upper aquifer consists of fine- to medium-grained sand that is generally less than 20 ft thick. The lower aquifer contains two sediment types: well-sorted sand and gravel and unsorted sediments (diamict). Thickness of the lower aquifer is varied, ranging from 25 to more than 100 ft in areas where it is confined by marine clays and from 0 to 100 ft where it is unconfined near Area 3. Quarrying operations have removed large areas of sand and gravel west of Sandy Brook.

Preliminary estimates of mean annual streamflow in Sandy Brook, from a partial year of continuous record, indicate that runoff per square mile is greater downstream from the landfill [1.90 $(ft^3/s)/mi^2$] than upstream [1.64 $(ft^3/s)/mi^2$]. Estimated mean annual flows in Sandy Brook average about 2.1 $ft^3/s$ upstream from the landfill and 2.7 $ft^3/s$ downstream from the landfill.

Ground-water quality in the upper aquifer east of Sandy Brook and in the lower aquifer west of Sandy Brook has been affected by leachate from the landfills. The specific conductance of ground water exceeds 2,000 µS/cm in some areas; background specific conductances are less than 200 µS/cm. Electromagnetic terrain-conductivity surveys supported by results of ground-water chemical analyses have been used to identify areas of likely ground-water contamination. Main areas of contamination are east and southeast of Area 1, west of Area 2, and southeast of Area 3. The extent of contamination in bedrock, if any, is unknown.

Contaminated ground water near Area 1 discharges primarily to an unnamed tributary of Deep Brook. Contaminated ground water near Areas 2 and 3 discharges to Sandy Brook and causes a noticeable change in surface-water quality. During periods of low flow, the specific conductance of streamwater increases from about 200 µS/cm upstream from the landfill to nearly 500 µS/cm downstream from the landfill.

Preliminary water-budget estimates computed from available streamflow and climatic data indicate that Sandy Brook gains about 80 Mgal/yr from sources outside the drainage-basin boundary. Possible sources include the lower aquifer north or west of the landfill and the fractured bedrock northwest of Sandy Brook.

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# APPENDIX 1:
# WELL LOGS FOR U.S. GEOLOGICAL SURVEY WELLS AT THE SACO LANDFILL, SACO, MAINE

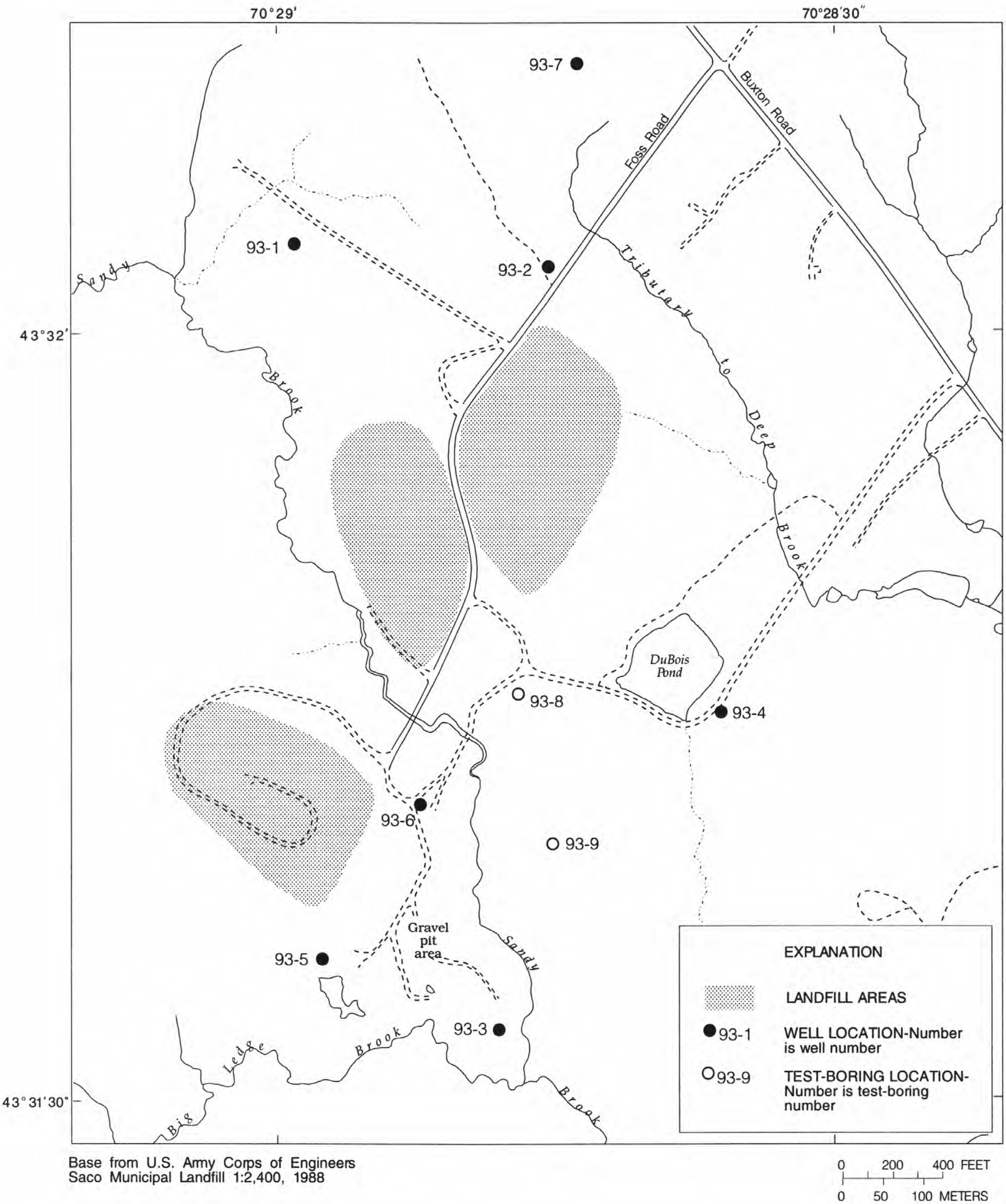



**Figure 1A.** Locations of U.S. Geological Survey wells and borings near the Saco Landfill, Saco, Maine.

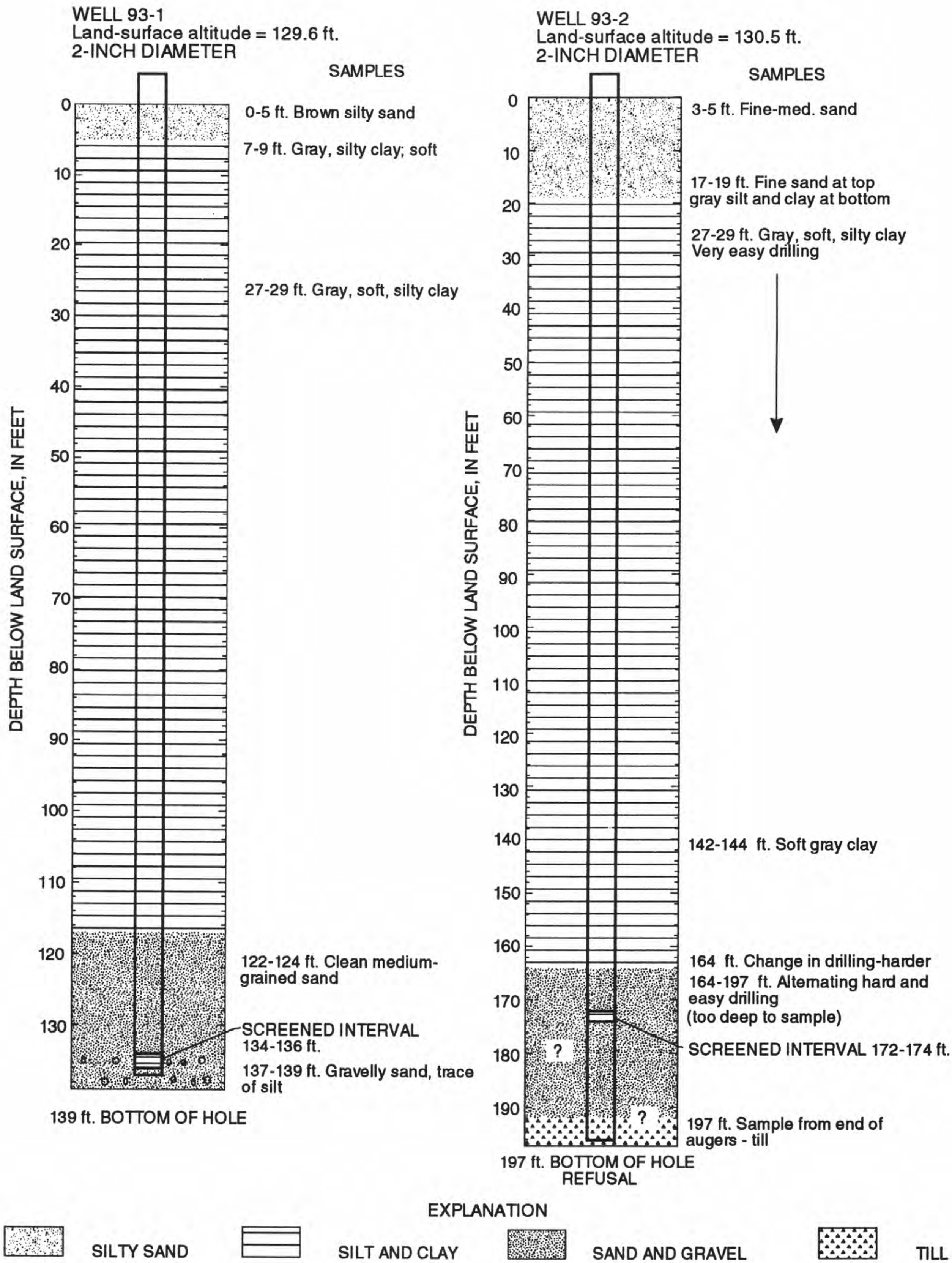



**Figure 1B.** Graphic geologic logs of wellls and borings drilled by the U.S. Geological Survey near the Saco Landfill, Saco, Maine 1993.

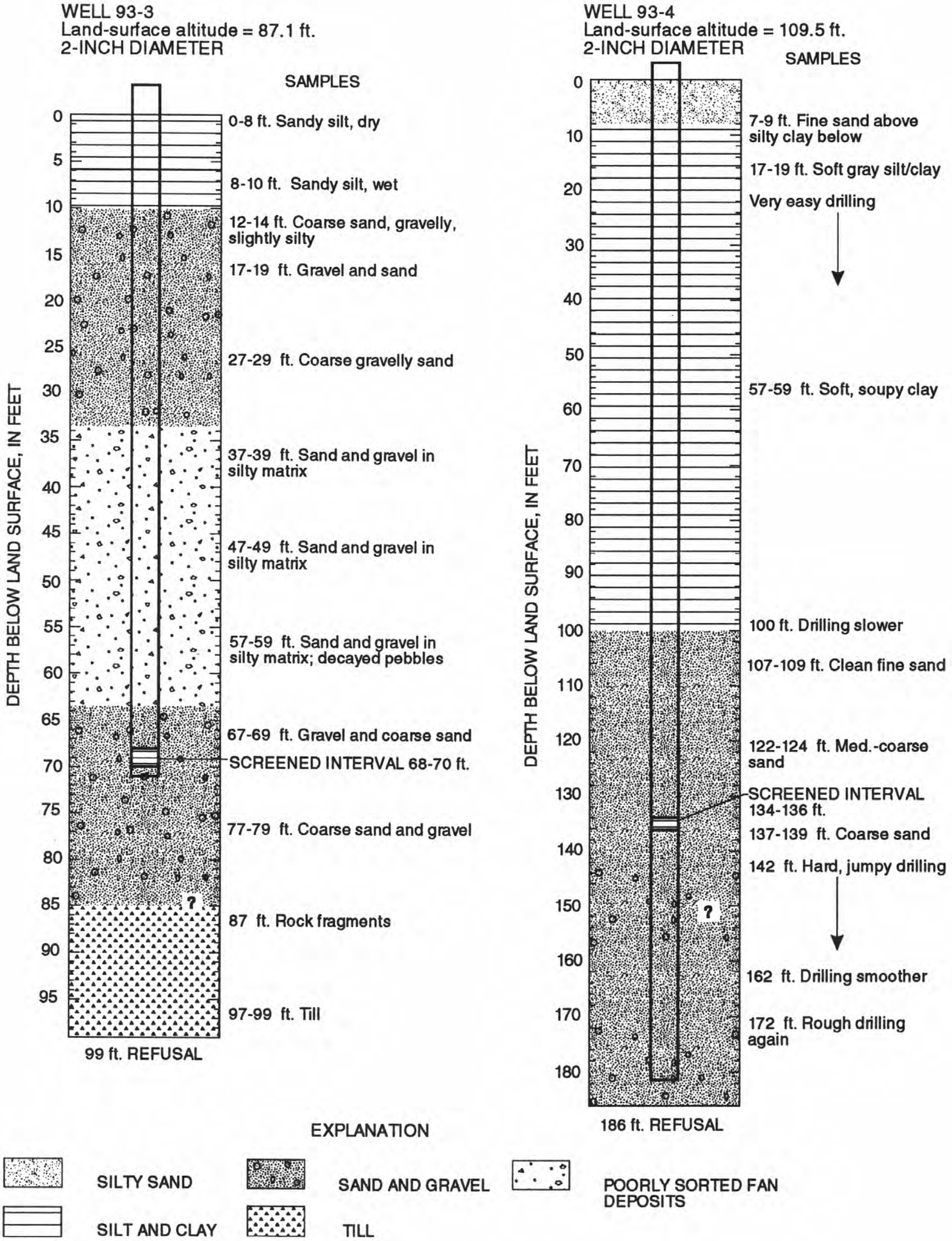



**Figure 1B.**—*Continued.*

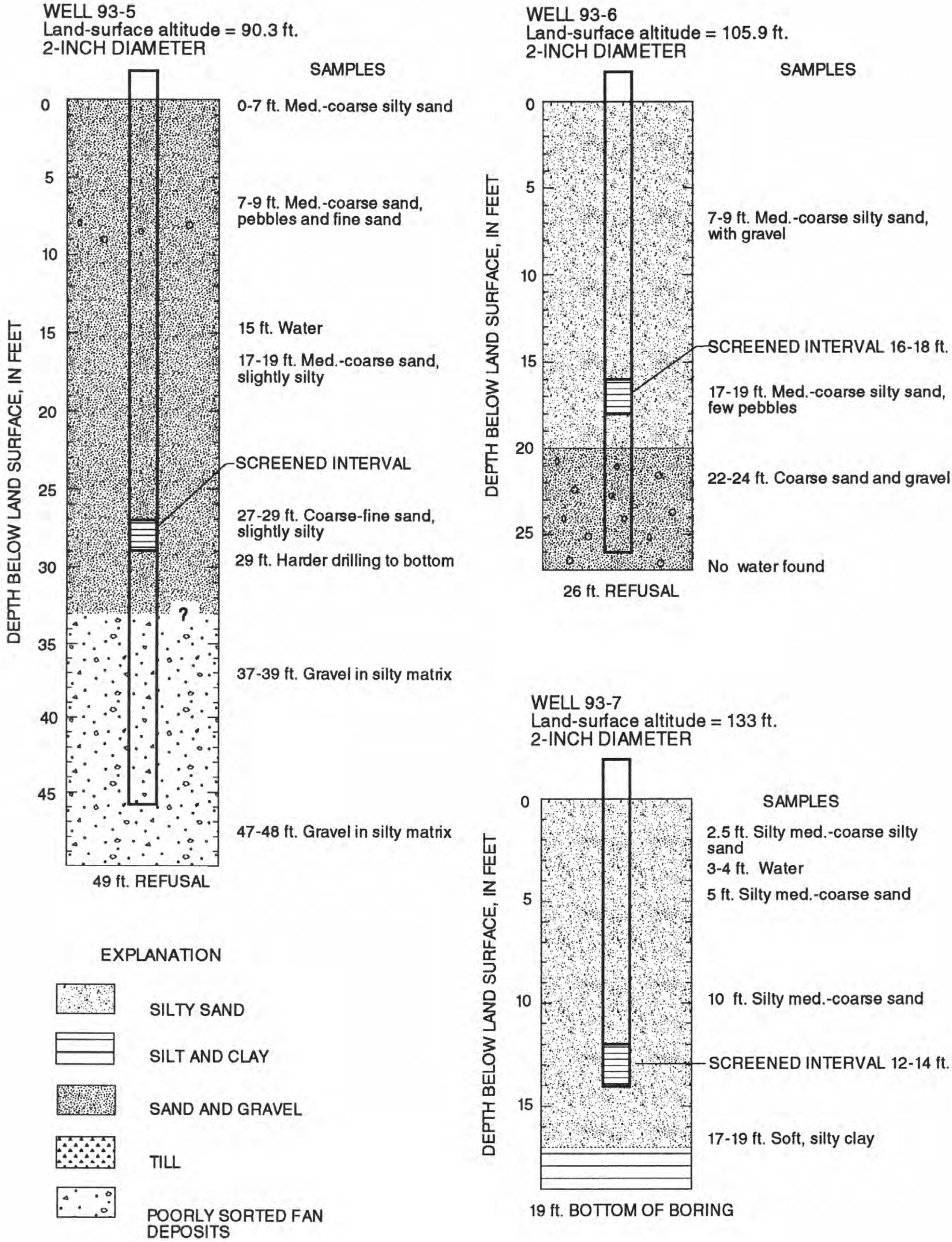



**Figure 1B.**—*Continued.*

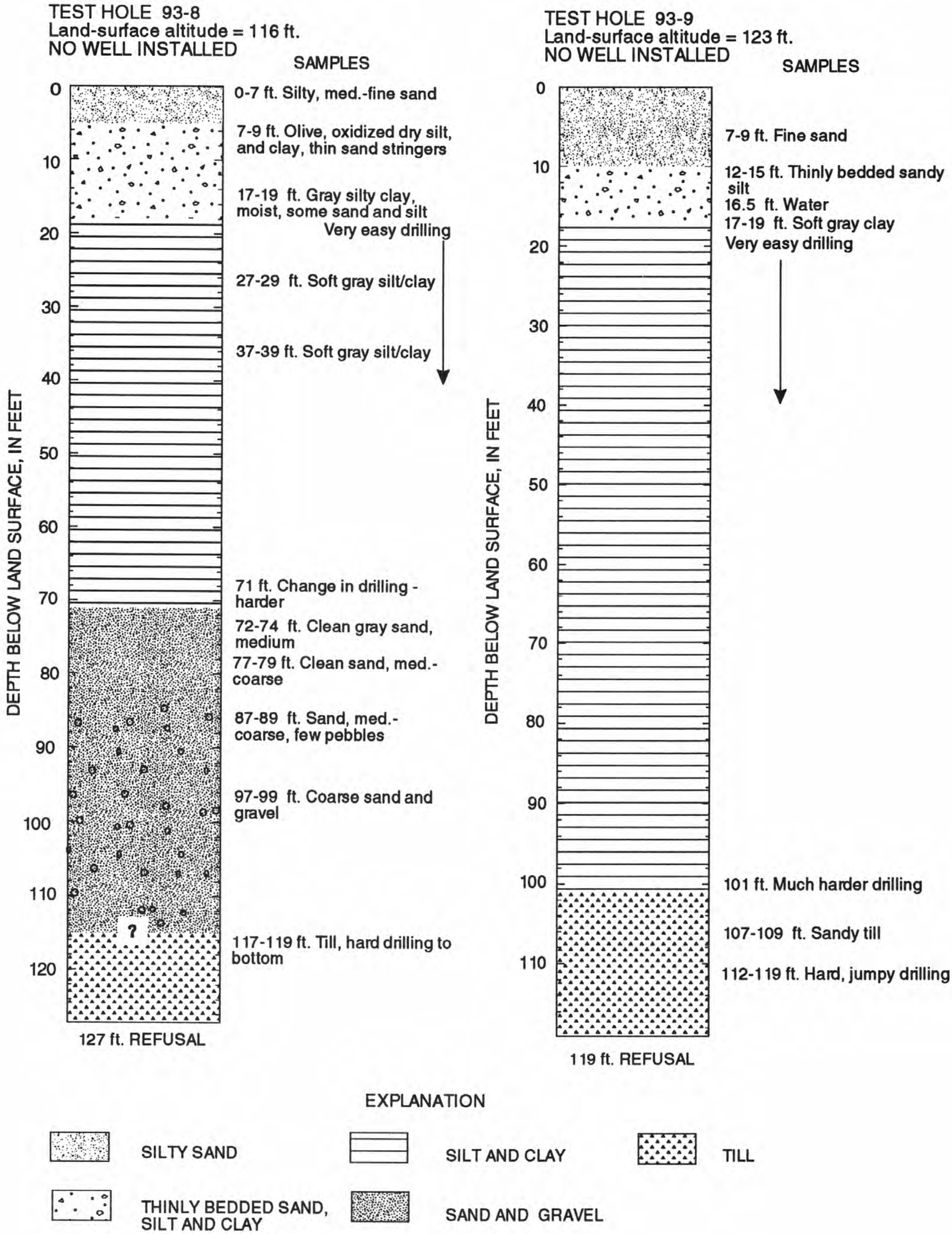



**Figure 1B.**—*Continued.*

# APPENDIX 2:
# GEOHYDROLOGIC SECTIONS INTERPRETED FROM SEISMIC REFRACTION SURVEYS

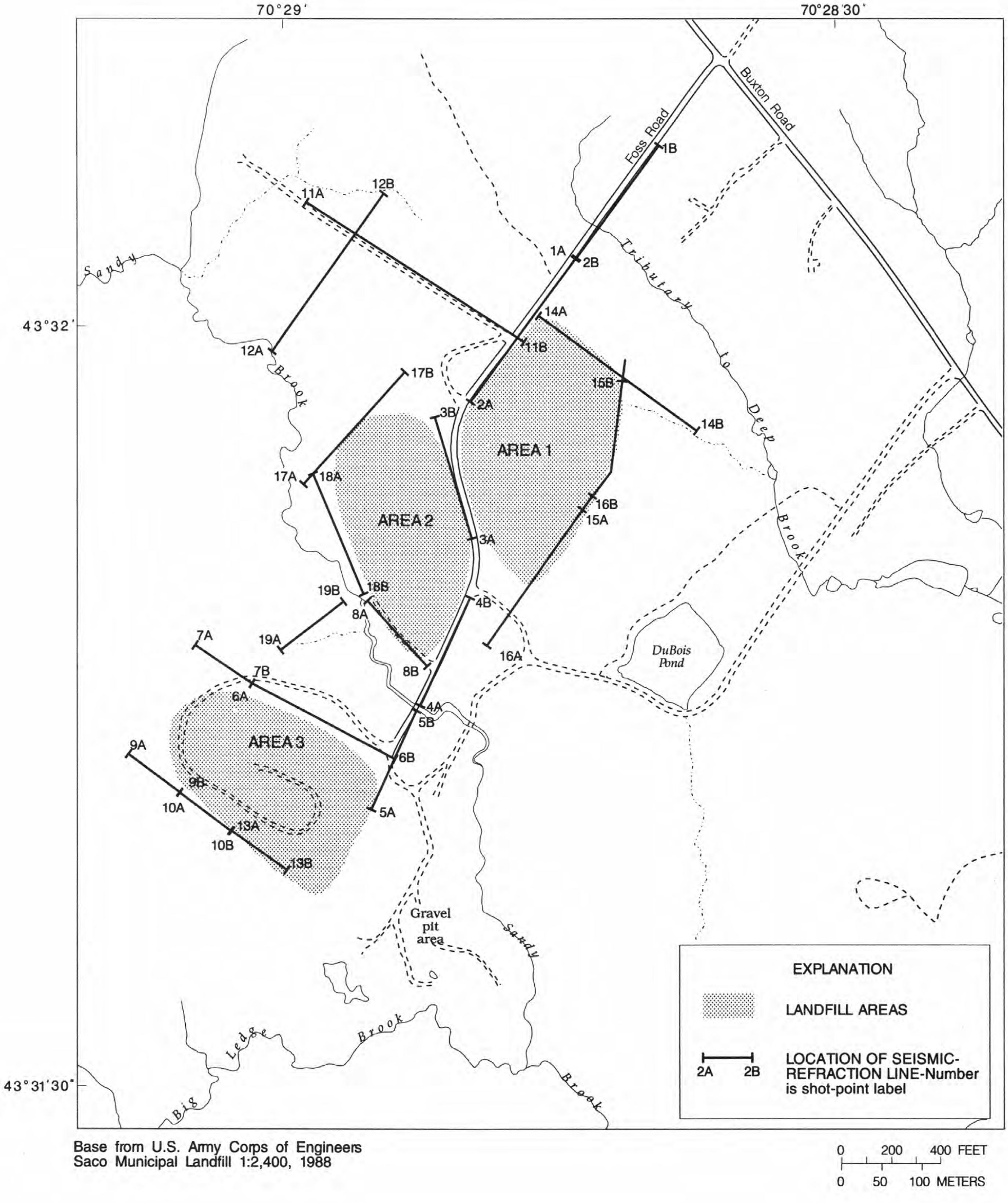



**Figure 2A.** Locations of seismic-refraction survey lines at the Saco Landfill, Saco, Maine.

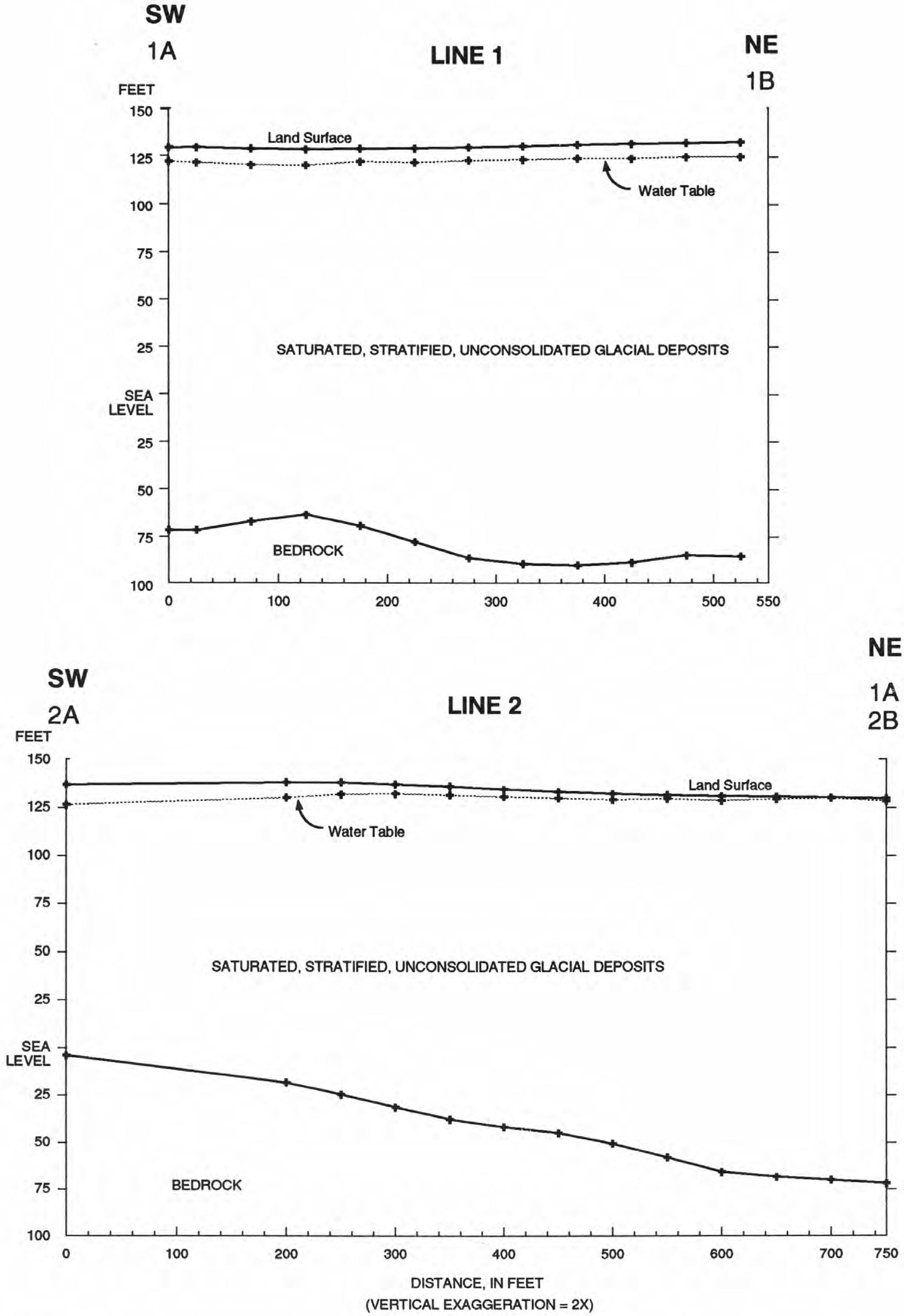



**Figure 2B.**—Profiles from seismic-refraction surveys at the Saco Landfill, Saco, Maine

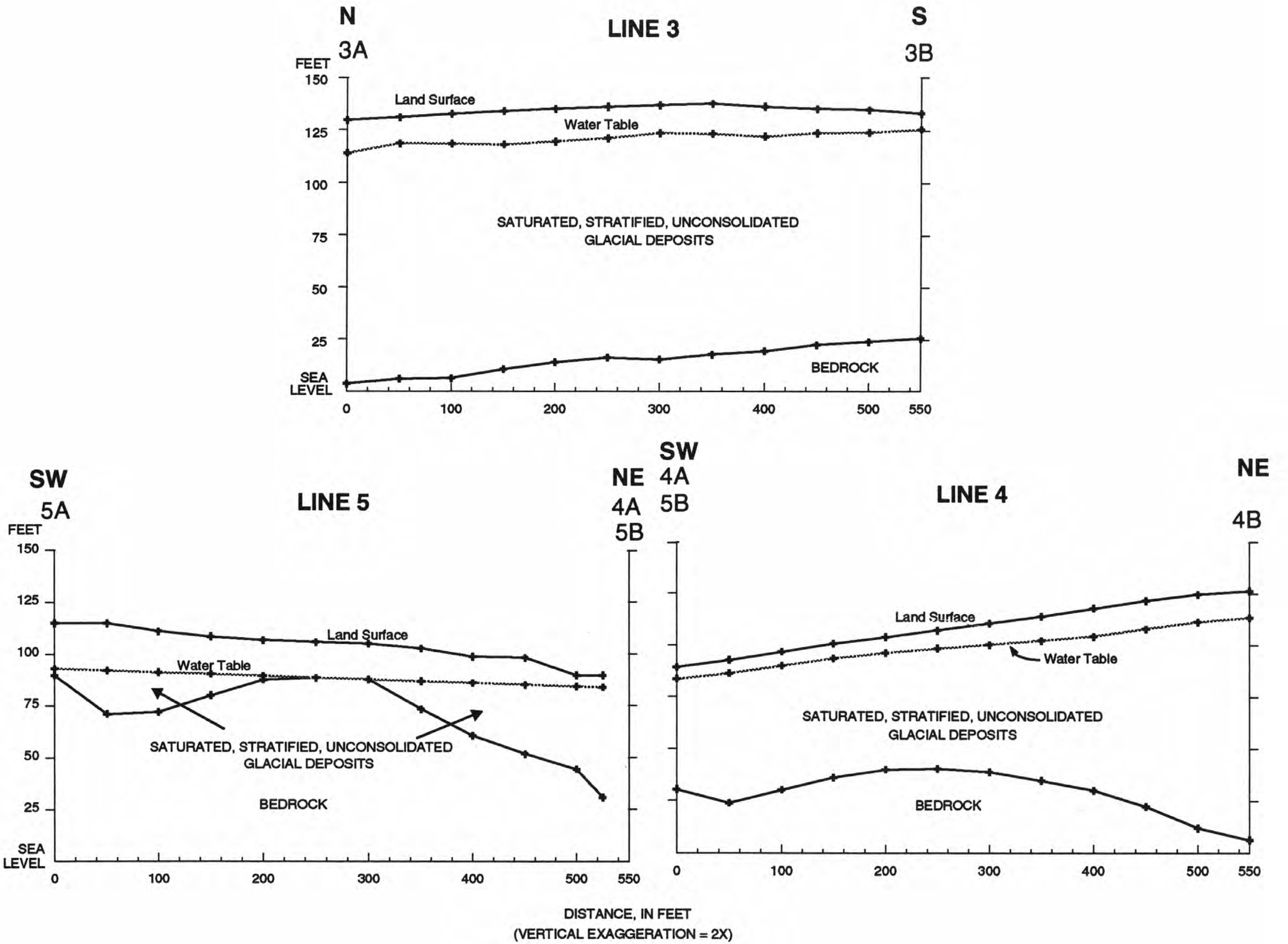
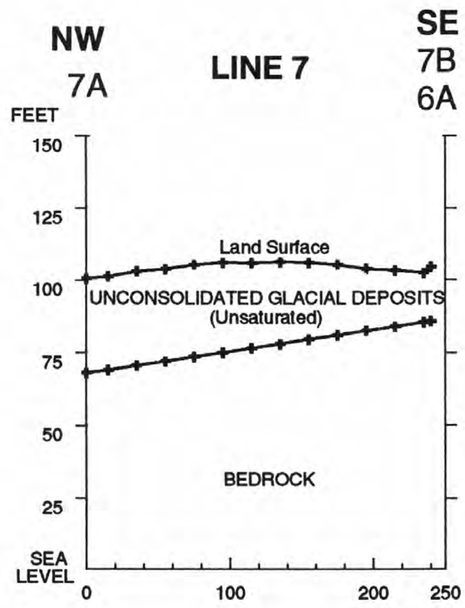



**Figure 2B.**—*Continued.*



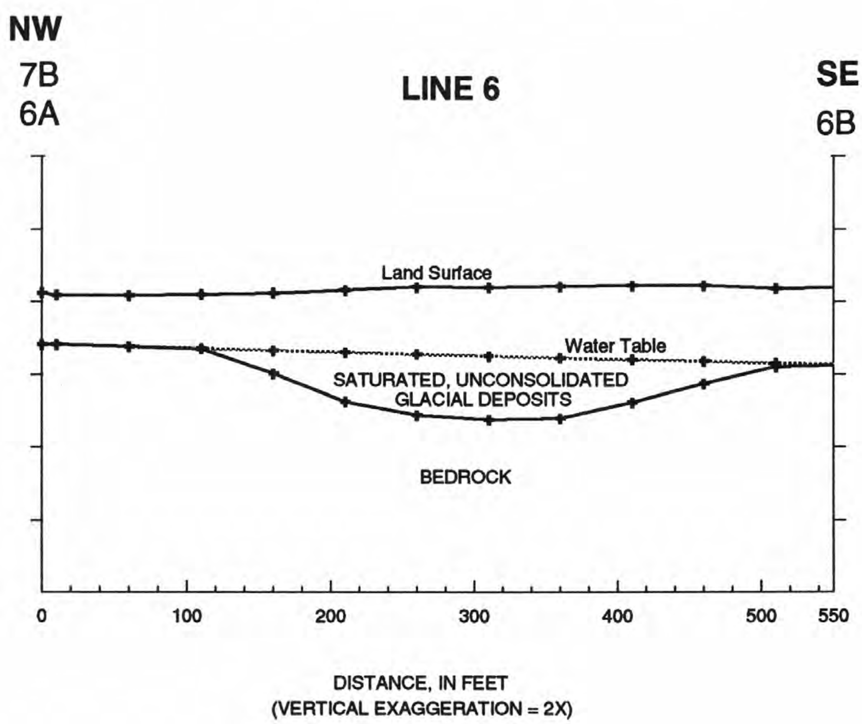




**Figure 2B.**—*Continued.*

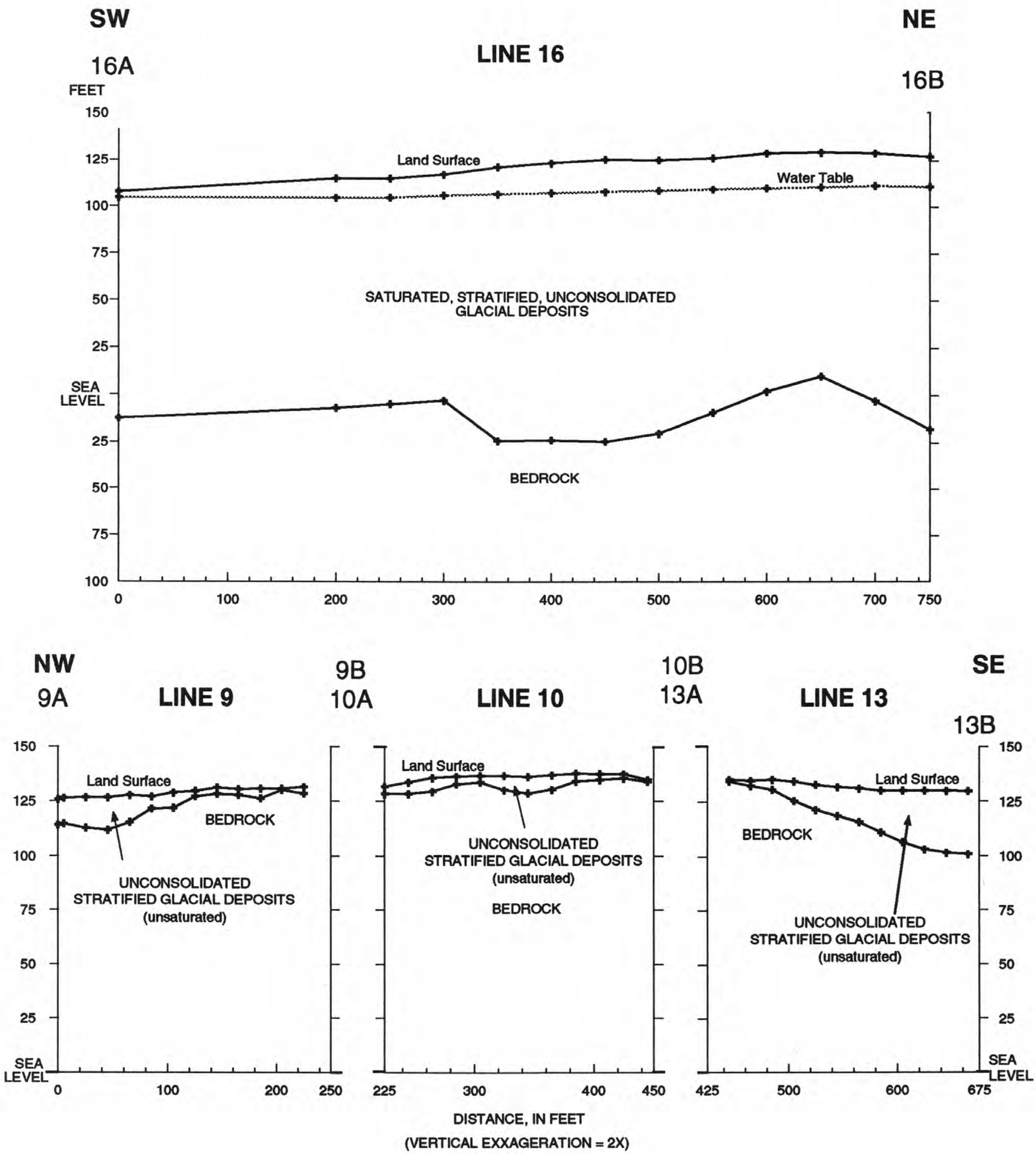
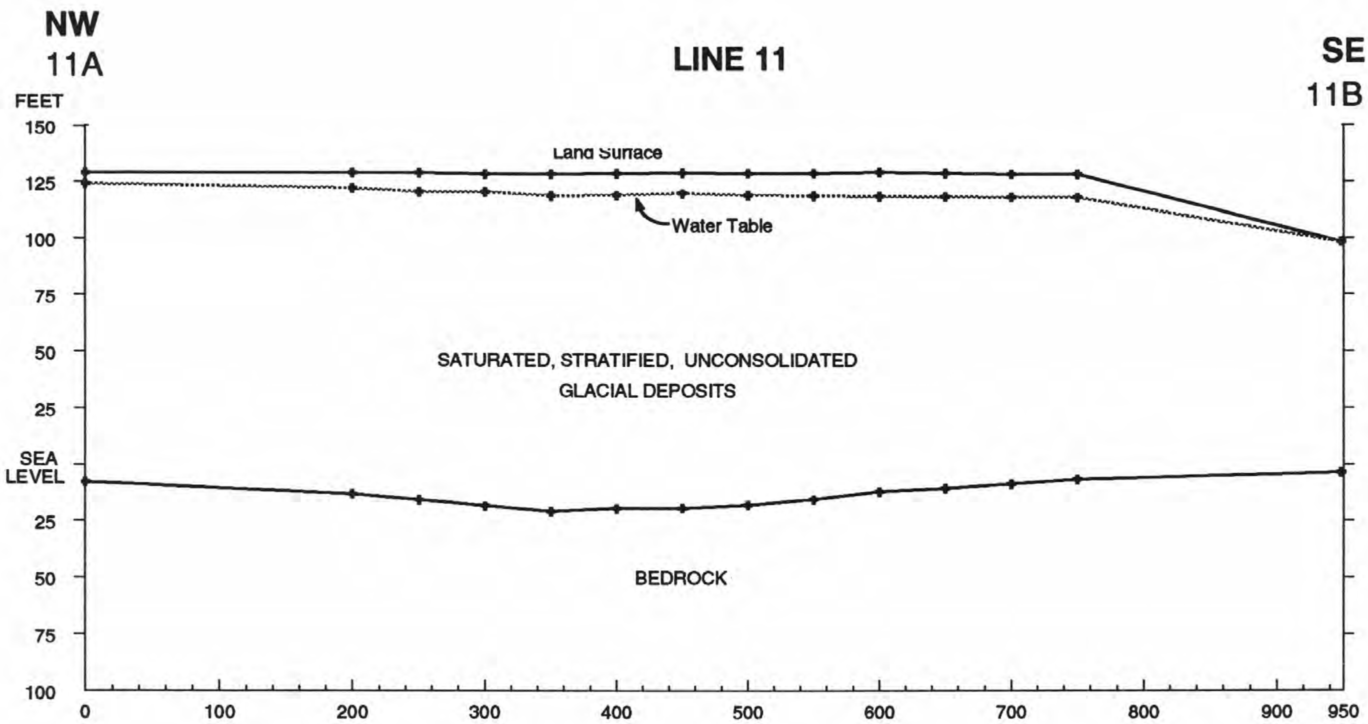



**Figure 2B.**—*Continued.*



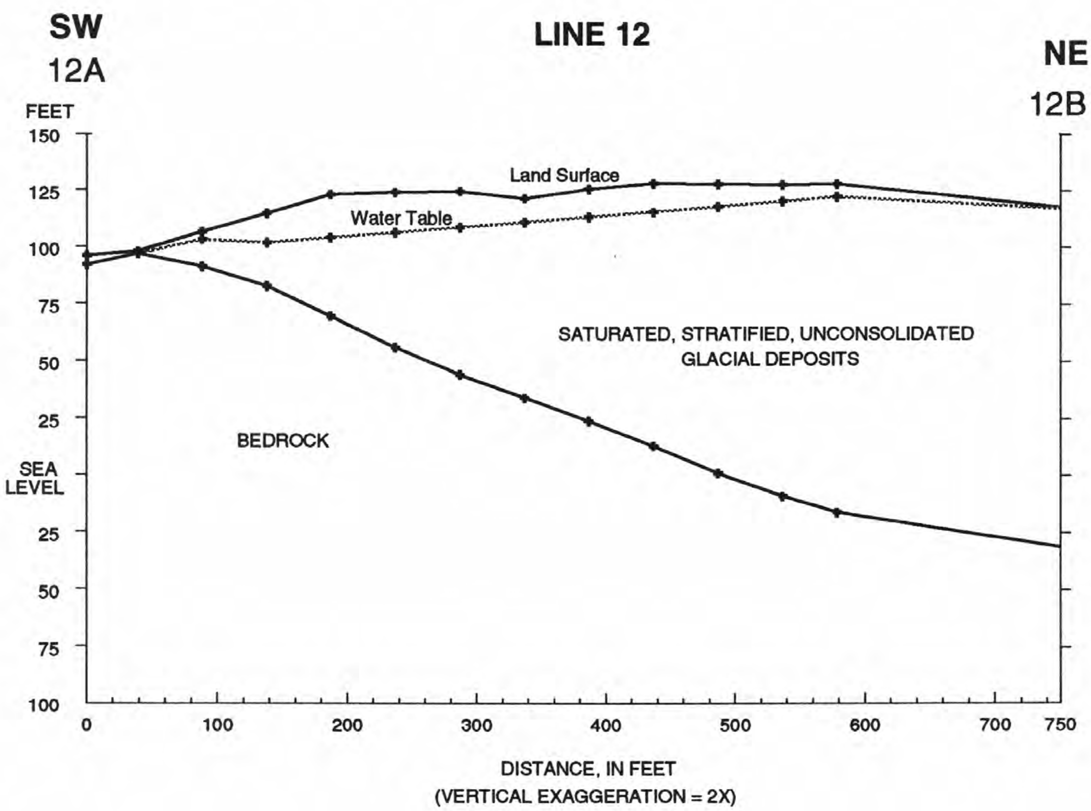
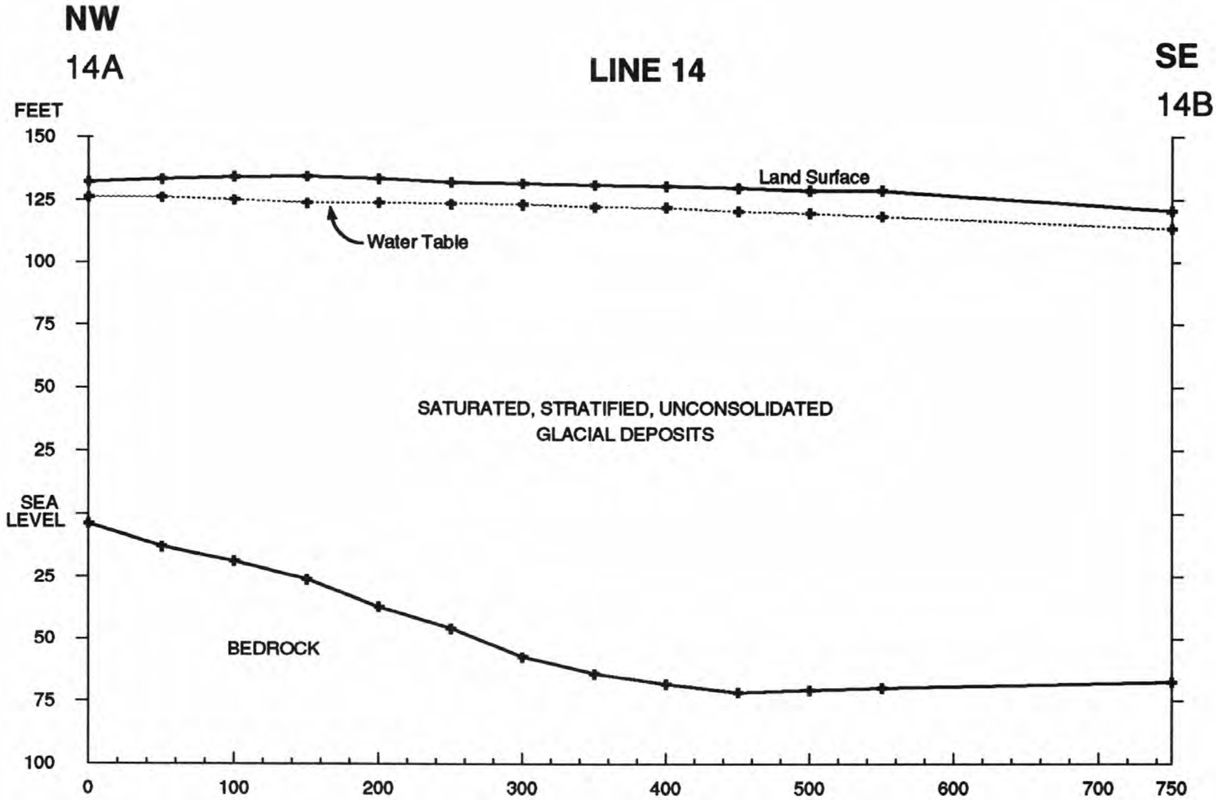




**Figure 2B.**—*Continued.*



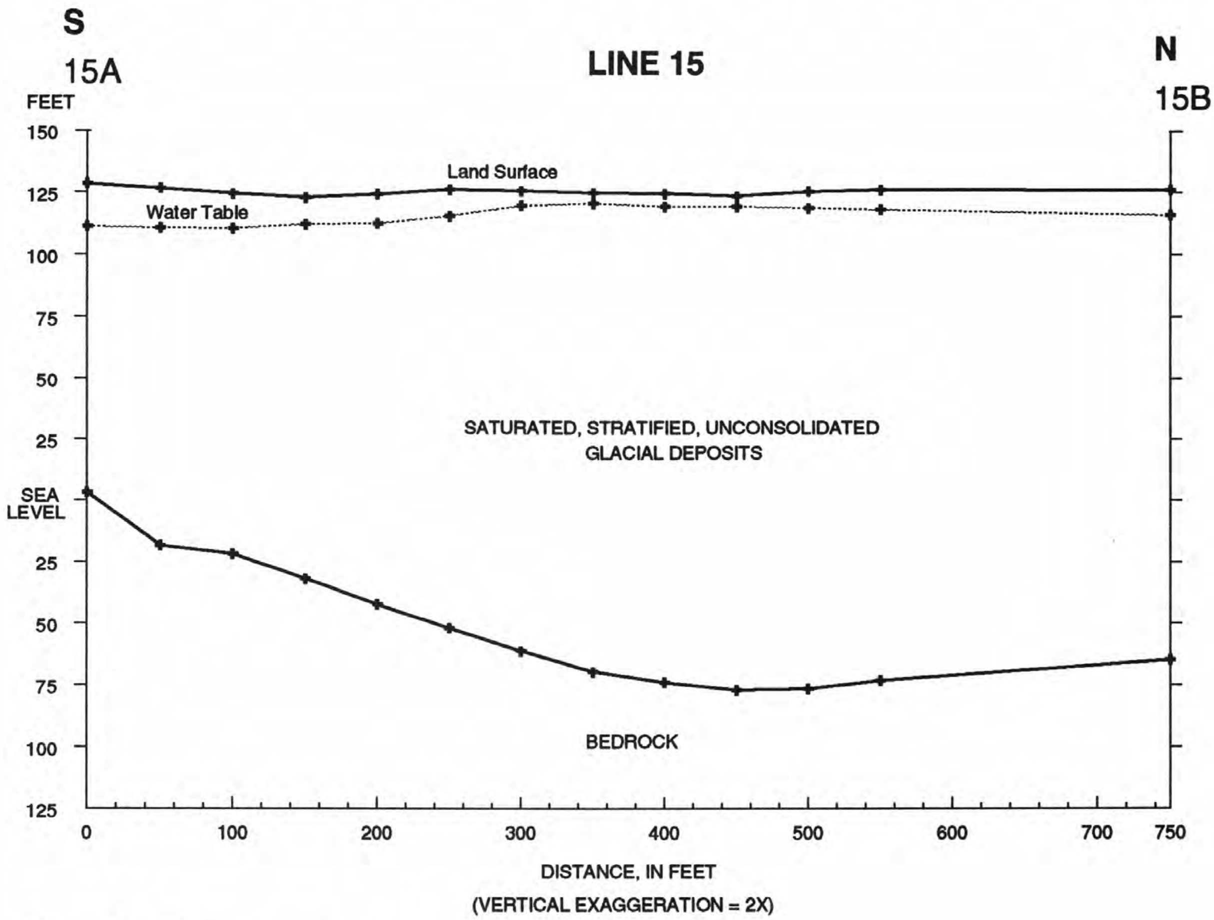
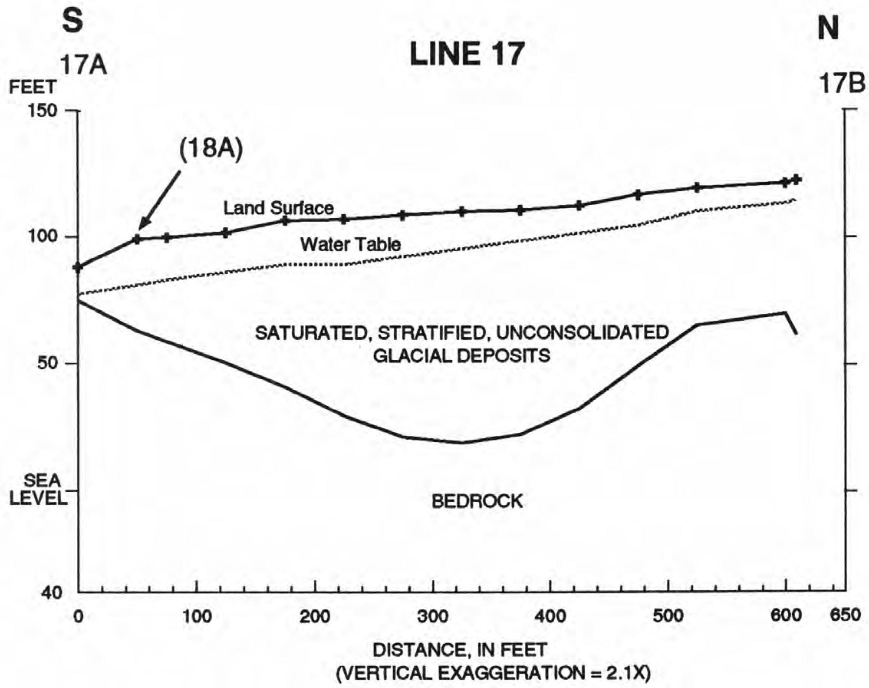




**Figure 2B.**—*Continued.*



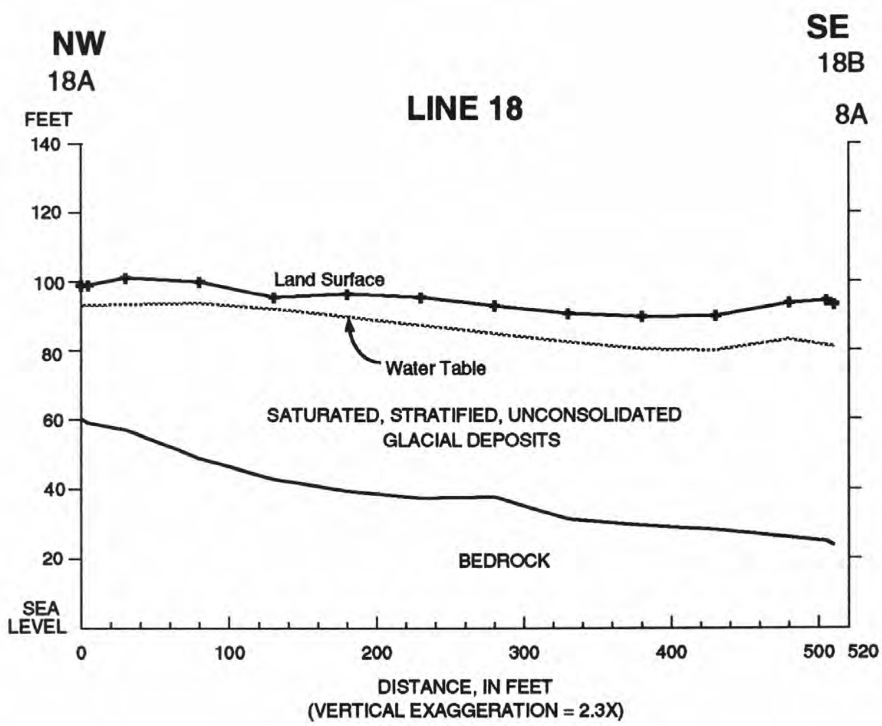




**Figure 2B.**—*Continued.*

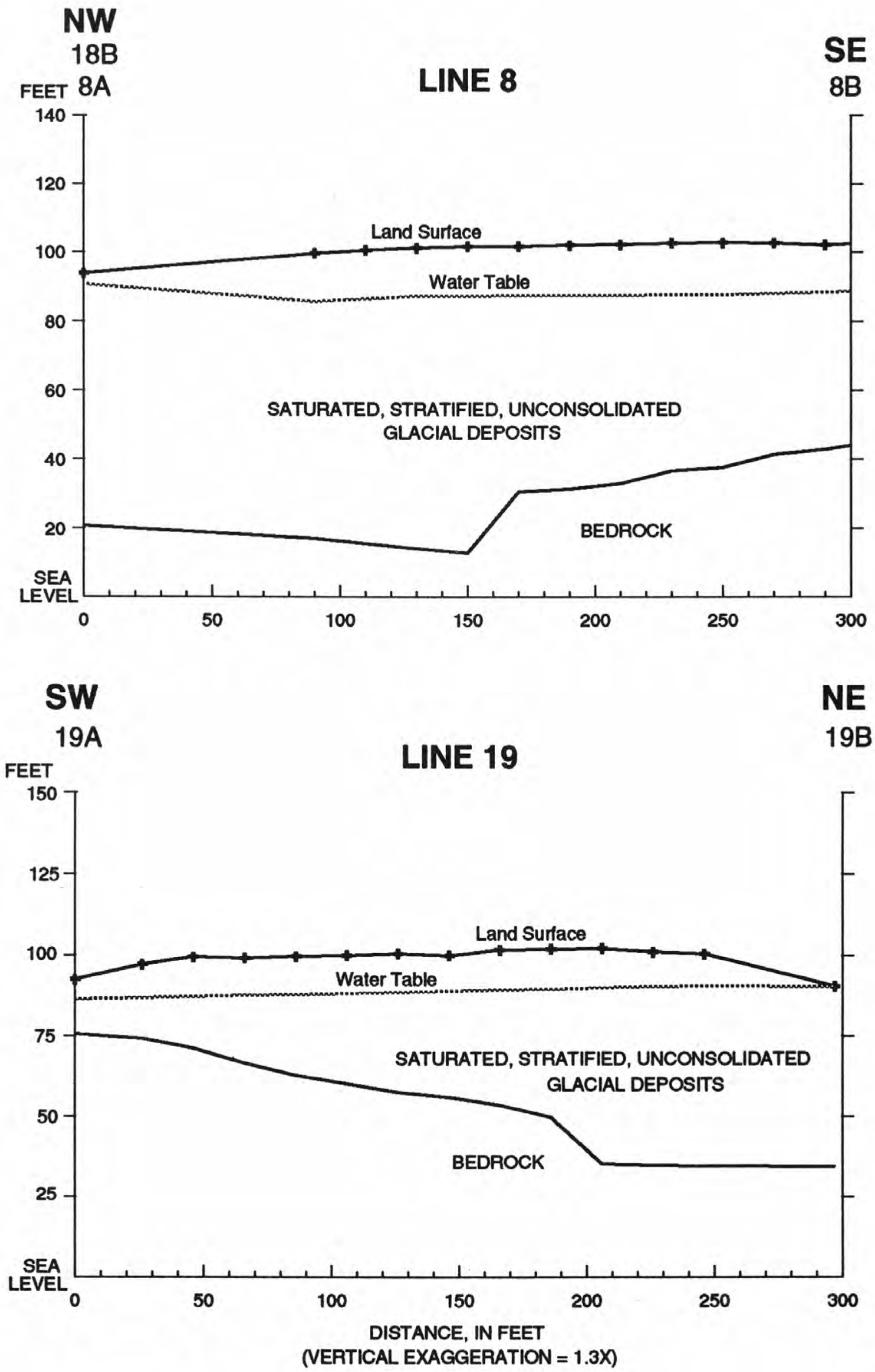



**Figure 2B.**—*Continued.*

# APPENDIX 3:
# SUPPLEMENTAL DATA FOR SURFACE-WATER STATIONS IN THE SACO LANDFILL STUDY AREA, SACO, MAINE

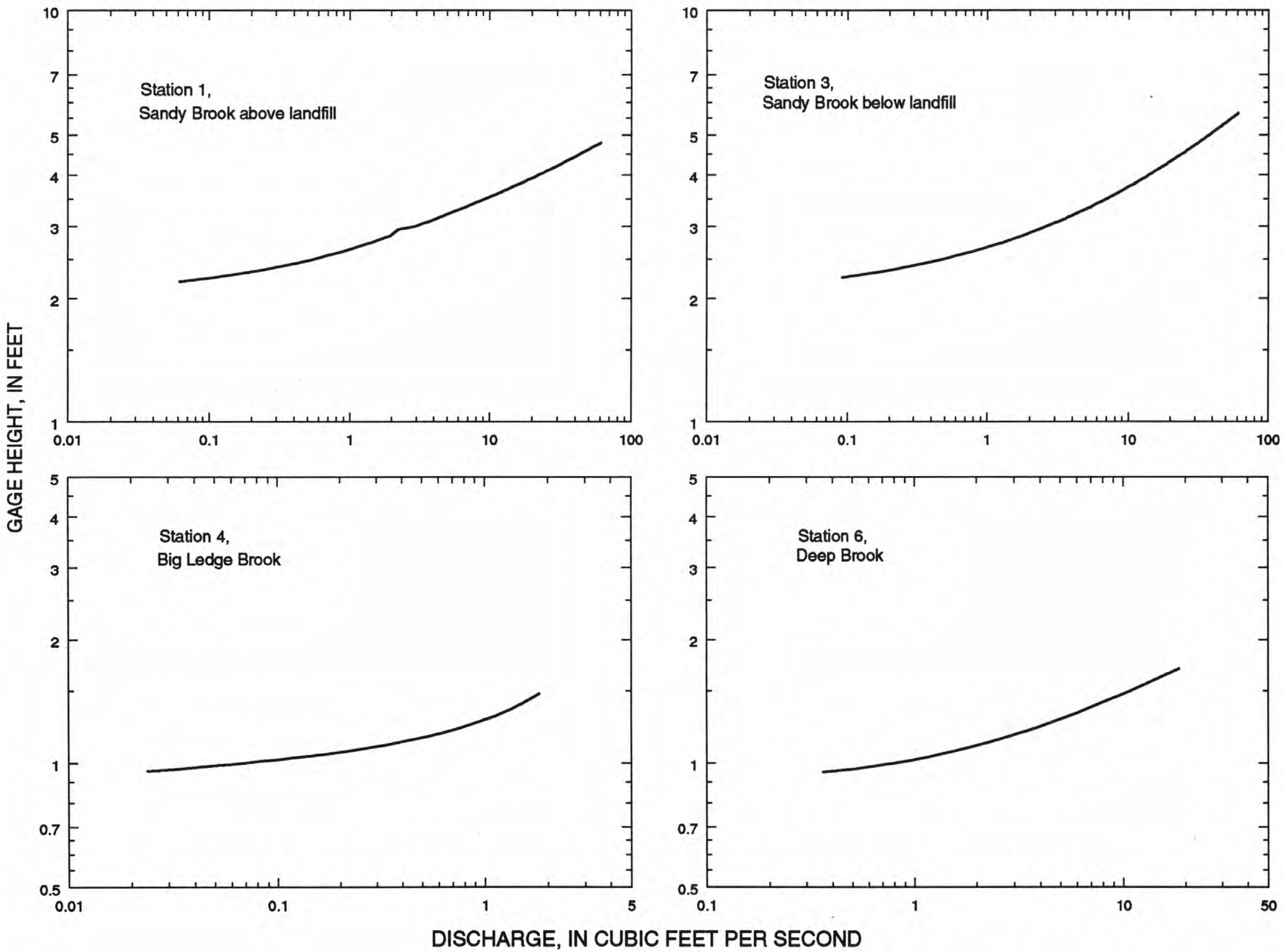



**Figure 3A.** Rating curves for selected surface-water stations near the Saco Landfill, Saco, Maine.

**Table 3A.** Daily mean discharge in cubic feet per second for Sandy Brook above landfill near Saco, Maine, July 1993 to February 1994

[U.S. Geological Survey station number 01067851; latitude 43°32′, longitude 070°29′04″; drainage area 1.28 square miles; datum is 89.80 feet above sea level. MAX, maximum; MIN, minimum; CFSM, cubic feet per second per square mile; IN., inches of runoff. $ft^3$, cubic feet; $ft^3/s$, cubic feet per second; $(ft^3/s)mi^2$; cubic feet per second per square mile]

| Day | July | August | September | October | November | December | January | February |
|---|---|---|---|---|---|---|---|---|
| 1 | --- | 0.16 | e0.10 | e0.19 | 1.9 | 1.0 | 0.59 | e1.5 |
| 2 | --- | .16 | e.11 | e.18 | 1.0 | .87 | .67 | e1.1 |
| 3 | --- | .24 | e.11 | e.17 | .50 | 1.0 | .60 | e.88 |
| 4 | --- | .16 | e.11 | e.34 | .58 | .95 | .55 | e.75 |
| 5 | --- | .23 | e.12 | e.27 | .73 | 6.8 | .56 | e.63 |
| 6 | --- | .14 | e.11 | e.19 | .91 | 3.1 | .51 | e.58 |
| 7 | --- | .12 | e.11 | .17 | .47 | 2.0 | .52 | e.52 |
| 8 | --- | .12 | e.48 | .17 | .35 | 1.5 | .57 | e.48 |
| 9 | --- | .12 | e.42 | .18 | .33 | 1.2 | .56 | e.48 |
| 10 | --- | .12 | e.26 | .18 | .34 | 1.2 | .56 | e.48 |
| 11 | --- | .12 | e.19 | .16 | .36 | 6.6 | .48 | .47 |
| 12 | --- | .13 | e.15 | .19 | .43 | 4.0 | .49 | .48 |
| 13 | --- | .14 | e.14 | 1.4 | .38 | 2.4 | .52 | .49 |
| 14 | --- | .12 | e.13 | .35 | .44 | 3.4 | .54 | .49 |
| 15 | --- | .10 | e.38 | .27 | .50 | 3.0 | .52 | .48 |
| 16 | --- | .10 | e.28 | .24 | .44 | 2.4 | .44 | .47 |
| 17 | 0.14 | .12 | e.22 | .23 | .66 | 1.5 | .47 | .45 |
| 18 | .13 | .27 | e.18 | .24 | 2.9 | 1.2 | e.72 | .45 |
| 19 | .12 | .18 | e.16 | .20 | 2.3 | 1.3 | e.85 | .47 |
| 20 | .18 | .15 | e.15 | .19 | 3.4 | 1.3 | e.75 | .84 |
| 21 | .20 | .14 | e.15 | .32 | 1.3 | 9.8 | e.60 | 5.5 |
| 22 | .20 | .10 | e.15 | .54 | .97 | 5.1 | e.55 | 4.7 |
| 23 | .15 | .10 | e.17 | .20 | .79 | 2.9 | e.52 | 2.4 |
| 24 | .13 | e.11 | e.16 | .14 | .74 | 1.9 | e.51 | 1.5 |
| 25 | .12 | e.11 | e.37 | .13 | .52 | 1.7 | e.50 | 1.1 |
| 26 | .12 | e.10 | e.84 | .12 | .41 | 1.4 | .49 | .91 |
| 27 | .28 | e.10 | e1.6 | .20 | .47 | .75 | e.45 | e.75 |
| 28 | .23 | e.10 | e.58 | .30 | 3.9 | .54 | e1.2 | e.69 |
| 29 | .22 | e.10 | e.27 | .23 | 3.6 | .48 | 9.5 | --- |
| 30 | .26 | e.10 | e.21 | .23 | 1.7 | .57 | 6.8 | --- |
| 31 | .20 | e.10 | --- | 1.3 | --- | .59 | e3.5 | --- |
| TOTAL ($ft^3$) | 2.68 | 4.16 | 8.41 | 9.22 | 33.32 | 72.45 | 36.09 | 30.04 |
| MEAN ($ft^3/s$) | .18 | .13 | .28 | .30 | 1.11 | 2.34 | 1.16 | 1.07 |
| MAX ($ft^3/s$) | .28 | .27 | 1.6 | 1.4 | 3.9 | 9.8 | 9.5 | 5.5 |
| MIN ($ft^3/s$) | .12 | .10 | .10 | .12 | .33 | .48 | .44 | .45 |
| CFSM $(ft^3/s)/mi^2$ | .14 | .10 | .22 | .23 | .87 | 1.83 | .91 | .84 |
| IN. | .08 | .12 | .24 | .27 | .97 | 2.11 | 1.05 | .87 |

PERIOD: TOTAL 189.02 $ft^3$ MEAN 0.86 $ft^3/s$ MAX 9.8 $ft^3/s$ MIN 0.10 $ft^3/s$ CFSM 0.67$(ft^3/s)/mi^2$ IN. 5.49

[e] Estimated.

**Table 3B.** Daily mean discharge in cubic feet per second for Sandy Brook below landfill near Saco, Maine, July 1993 to February 1994

[U. S. Geological Survey station number 01067853; latitude 43°31′32″, longitude 070°28′45″; drainage area 1.42 square miles; datum is 78.83 feet above sea level; MAX, maximum; MIN, minimum; CFSM, cubic feet per second per square mile; IN., inches of runoff; $ft^3$, cubic feet; $ft^3/s$, cubic feet per second; $(ft^3/s)mi^2$; cubic feet per second per square mile]

| Day | July | August | September | October | November | December | January | February |
|---|---|---|---|---|---|---|---|---|
| 1 | --- | 0.51 | e0.37 | e0.49 | 2.4 | 1.5 | 1.0 | e3.3 |
| 2 | --- | .49 | e.38 | e.47 | 1.7 | 1.3 | 1.1 | e1.8 |
| 3 | --- | .59 | e.37 | e.45 | .94 | 1.4 | 1.1 | e1.4 |
| 4 | --- | .49 | e.37 | e.72 | 1.0 | 1.3 | 1.0 | e1.2 |
| 5 | --- | .55 | e.43 | e.61 | 1.0 | 7.2 | 1.0 | e1.1 |
| 6 | --- | .46 | e.39 | e.51 | 1.4 | 3.9 | .99 | e1.0 |
| 7 | --- | .43 | e.38 | .47 | .91 | 2.6 | .98 | e.98 |
| 8 | --- | .43 | e1.1 | .46 | .78 | 2.0 | 1.0 | e.91 |
| 9 | --- | .42 | e1.0 | .46 | .75 | 1.6 | 1.0 | .92 |
| 10 | --- | .42 | e.82 | .46 | .72 | 1.6 | .96 | .89 |
| 11 | --- | .42 | e.50 | .44 | .69 | 7.3 | .95 | .87 |
| 12 | --- | .45 | e.46 | .47 | .72 | 5.2 | .96 | .88 |
| 13 | --- | .45 | e.44 | 1.9 | .69 | 2.9 | .98 | .91 |
| 14 | --- | .44 | e.43 | .74 | .72 | 4.1 | .99 | .89 |
| 15 | --- | .41 | e.88 | .60 | .73 | 3.6 | 1.0 | .86 |
| 16 | --- | .40 | e.67 | .55 | .69 | 3.2 | .95 | .85 |
| 17 | 0.47 | .42 | e.50 | .53 | .75 | 2.0 | .94 | .85 |
| 18 | .46 | .60 | e.45 | .54 | 3.6 | 1.7 | 1.4 | .85 |
| 19 | .46 | .52 | e.43 | .49 | 2.5 | 1.8 | 1.6 | .90 |
| 20 | .53 | .47 | e.41 | e.47 | 4.8 | 1.7 | 1.3 | 1.2 |
| 21 | .56 | .45 | e.40 | e.72 | 1.9 | 13 | 1.2 | 6.1 |
| 22 | .58 | .52 | e.43 | e.99 | 1.4 | 5.7 | e1.1 | 7.4 |
| 23 | .50 | .40 | e.44 | e.60 | 1.2 | 3.3 | 1.1 | 4.2 |
| 24 | .47 | e.39 | e.41 | e.38 | 1.1 | 2.3 | 1.0 | 2.2 |
| 25 | .46 | e.38 | e.62 | e.36 | .90 | 2.1 | 1.0 | 1.6 |
| 26 | .45 | e.38 | e1.6 | e.34 | .76 | 1.9 | .96 | 1.4 |
| 27 | .63 | e.37 | e3.2 | e.49 | .80 | 1.2 | .92 | 1.2 |
| 28 | .59 | e.37 | e.90 | e.74 | 4.1 | .98 | 1.4 | 1.1 |
| 29 | .57 | e.37 | e.65 | e.51 | 4.6 | .93 | e11 | --- |
| 30 | .63 | e.37 | e.53 | e.51 | 2.2 | 1.0 | 8.9 | --- |
| 31 | .55 | e.37 | --- | 1.5 | --- | 1.1 | 6.7 | --- |
| TOTAL ($ft^3$) | 7.91 | 13.74 | 19.96 | 18.97 | 46.45 | 91.41 | 56.48 | 47.46 |
| MEAN ($ft^3/s$) | .53 | .44 | .67 | .61 | 1.55 | 2.95 | 1.82 | 1.71 |
| MAX ($ft^3/s$) | .63 | .60 | 3.2 | 1.9 | 4.8 | 13 | 11 | 7.4 |
| MIN ($ft^3/s$) | .45 | .37 | .37 | .34 | .69 | .93 | .92 | .85 |
| CFSM $(ft^3/s)/mi^2$ | .37 | .31 | .47 | .43 | 1.09 | 2.08 | 1.28 | 1.20 |
| IN. | .21 | .36 | .52 | .50 | 1.22 | 2.39 | 1.48 | 1.25 |

PERIOD: TOTAL 290.98 $ft^3$ MEAN 1.32 $ft^3/s$ MAX 13 $ft^3/s$ MIN 0 .34 $ft^3/s$ CFSM 0.93 IN. 7.62

[e] Estimated.

**Table 3C.** Discharge measured at surface-water stations near the Saco Landfill, Saco, Maine, July 1993-January 1994

[Locations of stations shown in figures 2 and 18. Ice conditions after Jan. 1, 1994, prevented further measurements at most sites. --, indicates no data are available]

| Date | Discharge, in cubic feet per second | | | | | |
|---|---|---|---|---|---|---|
| | Sandy Brook above landfill (station 1 daily mean) | Sandy Brook at landfill (station 2) | Sandy Brook below landfill (station 3 daily mean) | Big Ledge Brook (station 4) | Unnamed tributary to Deep Brook (station 5) | Deep Brook near Saco (station 6) |
| 1993 | | | | | | |
| July 13 | -- | 0.12 | -- | 0.055 | -- | 0.86 |
| July 27 | 0.28 | .40 | 0.63 | .043 | -- | 1.4 |
| Aug. 10 | .12 | .13 | .42 | .049 | 0.014 | .71 |
| Aug. 24 | .11 | .15 | .39 | .034 | .004 | .56 |
| Sept. 8 | .48 | .32 | 1.1 | .040 | .009 | .58 |
| Sept. 21 | .15 | .31 | .40 | .033 | .010 | .56 |
| Oct. 6 | .19 | .24 | .51 | .038 | .036 | 1.0 |
| Oct. 20 | .19 | .19 | .47 | .039 | .014 | .88 |
| Nov. 4 | .58 | .61 | 1.0 | .49 | .095 | -- |
| Nov. 18 | 2.9 | 2.9 | 3.6 | 1.7 | .24 | 14. |
| Dec. 2 | .87 | .69 | 1.3 | .65 | .12 | 4.2 |
| Dec. 20 | 1.3 | 1.0 | 1.7 | .66 | .15 | 5.4 |
| 1994 | | | | | | |
| Jan. 7 | 0.52 | 0.72 | 0.98 | 0.14 | -- | -- |
| Jan. 25 | .50 | -- | 1.0 | .22 | -- | -- |

# APPENDIX 4:
# APPARENT TERRAIN-CONDUCTIVITY MEASUREMENTS, SACO LANDFILL, SACO, MAINE, JULY AND AUGUST 1993

## **Appendix 4.** Apparent terrain conductivity measurements, Saco Landfill, Saco, Maine

[Horizontal, horizontal dipole antenna orientation; Vertical, vertical dipole antenna orientation; --, no data]

| Station No. | Field No. | Apparent terrain conductivity, in millisiemens per meter | | | | | |
|---|---|---|---|---|---|---|---|
| | | 32.8-foot antenna spacing | | 65.6-foot antenna spacing | | 131.2-foot antenna spacing | |
| | | Horizontal | Vertical | Horizontal | Vertical | Horizontal | Vertical |
| [1]11.200 | 11.200 | 4.2 | 9.9 | 7.5 | 12.3 | 6.3 | -- |
| 11.210 | 11.210 | 5.1 | 7.8 | 8.1 | 12.3 | 6.3 | 14.4 |
| 11.220 | 11.220 | 4.6 | 8.2 | 8.4 | 11.7 | 10.8 | 11.4 |
| 11.230 | 11.230 | 6.4 | 8.2 | 9.0 | 12.6 | 9.0 | 11.7 |
| 11.240 | 11.240 | 6.2 | 10.2 | 8.8 | 13.5 | 9.6 | 10.8 |
| 11.250 | 11.250 | 7.0 | 10.8 | 10.8 | 12.0 | 10.2 | 19.5 |
| 11.260 | 11.260 | 9.7 | 13.2 | 12.0 | 15.0 | 11.7 | 12.3 |
| 11.270 | 11.270 | 18.6 | 8.2 | 15.3 | 9.6 | 12.0 | 7.5 |
| 11.280 | 11.280 | 10.2 | 12.6 | 12.6 | 16.2 | 11.7 | 11.4 |
| 11.290 | 11.290 | 9.2 | 10.8 | 11.1 | 13.8 | 9.2 | 10.2 |
| [2]12.200 | 12.200 | 5.4 | 8.7 | 7.4 | 12.3 | 8.5 | 1.2 |
| 12.210 | 12.210 | 5.0 | 8.2 | 7.6 | 12.6 | 9.3 | 15.0 |
| 12.220 | 12.220 | 5.4 | 9.2 | 8.4 | 13.2 | 10.8 | 13.2 |
| 12.230 | 12.230 | 6.3 | 10.2 | 9.0 | 13.2 | 9.6 | 12.3 |
| 12.240 | 12.240 | 8.8 | 12.0 | 11.1 | 12.8 | 12.9 | 15.6 |
| 12.250 | 12.250 | 9.1 | 13.2 | 11.4 | 15.0 | 17.4 | 11.4 |
| 12.260 | 12.260 | 9.2 | 15.3 | 12.0 | 15.3 | 13.8 | 9.6 |
| 12.270 | 12.270 | 9.9 | 11.7 | 10.8 | 11.7 | 13.8 | 9.0 |
| 12.280 | 12.280 | 6.6 | 9.6 | 8.4 | 12.9 | 13.2 | 15.6 |
| 12.290 | 12.290 | 5.4 | 8.2 | 7.8 | 12.9 | 9.0 | 11.7 |
| 12.350 | 12.350 | 12.0 | 13.2 | 16.2 | 19.5 | 16.2 | 24.6 |
| [3]13.200 | 13.200 | 6.9 | 9.3 | 9.0 | 12.0 | 6.0 | 2.9 |
| [3]13.210 | 13.210 | 7.2 | 11.1 | 8.4 | 14.4 | 9.6 | 15.0 |
| [3]13.220 | 13.220 | 8.7 | 13.2 | 10.8 | 15.0 | 9.0 | 12.0 |
| [3]13.230 | 13.230 | 10.8 | 14.4 | 12.0 | 15.0 | 10.2 | 13.2 |
| [3]13.240 | 13.240 | 11.4 | 14.7 | 13.5 | 15.6 | 12.0 | 13.2 |
| [3]13.245 | 13.245 | 12.6 | 15.3 | -- | -- | -- | -- |
| 13.250 | 13.250 | 12.9 | 15.9 | 12.0 | 15.6 | 12.3 | 13.8 |
| 13.260 | 26.130 | 15.0 | 18.0 | 16.2 | 15.6 | 15.6 | 12.6 |
| 13.270 | 27.130 | 13.2 | 21.0 | 13.8 | 18.3 | 13.5 | 8.4 |
| 13.280 | 28.130 | 15.6 | 17.4 | 15.0 | 14.7 | 12.9 | 9.3 |
| 13.290 | 29.130 | 9.6 | 7.8 | 10.5 | 12.0 | 8.7 | 10.5 |
| 13.350 | 13.350 | 12.0 | 11.7 | 10.8 | 13.2 | 9.0 | 12.3 |
| 14.110 | 14.110 | 9.6 | 10.5 | 11.7 | 13.5 | 6.3 | 6.6 |
| 14.120 | 14.120 | 6.8 | 11.1 | 9.0 | 12.3 | 9.0 | 10.5 |
| 14.130 | 14.130 | 6.3 | 10.2 | 8.7 | 11.7 | 9.3 | 11.7 |
| 14.140 | 14.140 | 5.9 | 16.8 | 8.1 | 15.0 | 9.0 | 8.7 |
| 14.150 | 14.150 | 5.6 | 9.9 | 7.8 | 11.7 | 6.0 | 7.2 |
| 14.160 | 14.160 | 6.2 | 9.3 | 8.4 | 9.9 | 9.0 | 7.8 |

**Appendix 4.** Apparent terrain conductivity measurements, Saco Landfill, Saco, Maine--*Continued*

| Station No. | Field No. | Apparent terrain conductivity, in millisiemens per meter | | | | | |
|---|---|---|---|---|---|---|---|
| | | 32.8-foot antenna spacing | | 65.6-foot antenna spacing | | 131.2-foot antenna spacing | |
| | | Horizontal | Vertical | Horizontal | Vertical | Horizontal | Vertical |
| 14.170 | 14.170 | 6.2 | 9.6 | 8.4 | 10.5 | 7.2 | 8.7 |
| 14.180 | 14.180 | 7.6 | 10.2 | 9.0 | 9.9 | 9.6 | 8.4 |
| 14.200 | 14.200 | 6.3 | 7.5 | 10.5 | 9.0 | 10.5 | 0.3 |
| 14.230 | 14.230 | 14.7 | 21.3 | 15.6 | 18.0 | 11.4 | 9.9 |
| 14.260 | 26.140 | 19.2 | 18.9 | 18.0 | 14.7 | 18.9 | 12.3 |
| 14.270 | 27.140 | 16.8 | 19.2 | 16.8 | 17.7 | 12.9 | 11.1 |
| 14.280 | 28.140 | 16.2 | 20.1 | 17.7 | 15.3 | 13.2 | 9.9 |
| 14.290 | 29.140 | 10.2 | 15.9 | 12.6 | 18.0 | 11.1 | 12.6 |
| 14.350 | 14.350 | 9.6 | 13.2 | 10.8 | 14.7 | 10.5 | 11.4 |
| [4]15.050 | 15.050 | 12.9 | 12.6 | 9.9 | 6.3 | 6.0 | 4.3 |
| 15.060 | 15.060 | 12.9 | 14.0 | 10.8 | 7.2 | 7.2 | 6.3 |
| 15.070 | 15.070 | 12.0 | 12.6 | 10.8 | 9.9 | 8.7 | 5.9 |
| [5]15.080 | 15.080 | 12.6 | 12.9 | 11.7 | 14.1 | 11.1 | 11.4 |
| 15.090 | 15.090 | 11.1 | 13.5 | 12.0 | 25.2 | 11.7 | 7.2 |
| 15.100 | 15.100 | 8.7 | 10.5 | 9.0 | 10.8 | 10.5 | 9.9 |
| 15.110 | 15.110 | 7.8 | 11.1 | 9.3 | 12.0 | 9.3 | 9.9 |
| 15.120 | 15.120 | 9.0 | 4.2 | 9.3 | 11.1 | 9.0 | 9.0 |
| 15.130 | 15.130 | 11.4 | 7.8 | 9.0 | 12.3 | 6.9 | 7.5 |
| 15.140 | 15.140 | 8.1 | 9.9 | 8.7 | 11.4 | 8.4 | 8.4 |
| 15.150 | 15.150 | 5.7 | 10.8 | 7.5 | 10.2 | 8.4 | 6.9 |
| 15.160 | 15.160 | 6.6 | 9.9 | 7.8 | 9.9 | 6.0 | 6.3 |
| 15.170 | 15.170 | 7.5 | 9.6 | 9.0 | 7.2 | 9.3 | 6.6 |
| 15.180 | 15.180 | 7.6 | 9.6 | 8.7 | 10.2 | 8.4 | 8.7 |
| 15.190 | 15.190 | 5.4 | 9.0 | 8.1 | 9.3 | 7.2 | 16.2 |
| [2]15.200 | 15.200 | 5.7 | 6.9 | 3.6 | 11.1 | 8.1 | 3.6 |
| 15.230 | 15.230 | 20.4 | 18.0 | 18.3 | 4.8 | 10.8 | 15.0 |
| 15.260 | 26.150 | 16.8 | 20.7 | 17.1 | 15.3 | 13.5 | 12.0 |
| 15.270 | 27.150 | 18.9 | 15.6 | 18.0 | 14.7 | 15.6 | 10.2 |
| 15.280 | 28.150 | 14.4 | 18.6 | 15.9 | 18.0 | 13.2 | 11.1 |
| 15.290 | 29.150 | 15.0 | 19.2 | 16.2 | 13.8 | 12.0 | 9.0 |
| 15.350 | 15.350 | 12.0 | 7.8 | 13.2 | 15.3 | 12.0 | 8.4 |
| 16.110 | 16.110 | 8.4 | 11.1 | 9.6 | 12.6 | 6.0 | 29.0 |
| 16.120 | 16.120 | 8.4 | 9.6 | 9.9 | 10.8 | 9.6 | 8.4 |
| 16.130 | 16.130 | 7.8 | 9.6 | 9.6 | 9.9 | 9.9 | 7.8 |
| 16.140 | 16.140 | 5.1 | 10.2 | 8.4 | 9.9 | 4.2 | 4.1 |
| 16.150 | 16.150 | 6.2 | 9.0 | 7.5 | 6.6 | 7.8 | 3.6 |
| 16.160 | 16.160 | 6.4 | 8.7 | 8.1 | 8.4 | 8.4 | 6.3 |
| 16.170 | 16.170 | 8.4 | 7.8 | 8.7 | 8.4 | 8.4 | 4.5 |
| 16.180 | 16.180 | 7.6 | 9.0 | 7.8 | 11.4 | 8.4 | 8.1 |
| [6]16.190 | 16.190 | 6.6 | 8.7 | 7.8 | 9.0 | -- | -- |

**Appendix 4.** Apparent terrain conductivity measurements, Saco Landfill, Saco, Maine--*Continued*

| Station No. | Field No. | Apparent terrain conductivity, in millisiemens per meter | | | | | |
|---|---|---|---|---|---|---|---|
| | | 32.8-foot antenna spacing | | 65.6-foot antenna spacing | | 131.2-foot antenna spacing | |
| | | Horizontal | Vertical | Horizontal | Vertical | Horizontal | Vertical |
| [2]16.200 | 16.200 | 7.6 | 4.5 | 9.3 | 11.4 | 11.1 | -- |
| 16.210 | 16.210 | 32.0 | 10.2 | 19.8 | -0.9 | 10.2 | 5.7 |
| 16.220 | 16.220 | 28.2 | 7.8 | 21.5 | 14.4 | 15.9 | 8.4 |
| 16.230 | 16.230 | 25.5 | -6.0 | 20.7 | 12.6 | 15.9 | 5.3 |
| 16.230 | 16.230 | 27.9 | 0.7 | 22.5 | 13.8 | 14.4 | 6.9 |
| 16.240 | 16.240 | 27.0 | 13.5 | 25.2 | 10.8 | 14.7 | 8.1 |
| 16.250 | 16.250 | 18.0 | 9.6 | 15.0 | 19.2 | 15.0 | 10.2 |
| 16.260 | 26.160 | 15.6 | 18.6 | 16.2 | 13.8 | 14.7 | 11.4 |
| 16.260 | 16.260 | 16.5 | 21.0 | 18.9 | 18.9 | 16.2 | 9.0 |
| 16.270 | 27.160 | 18.3 | 14.1 | 15.9 | 11.1 | 15.0 | 10.8 |
| 16.280 | 28.160 | 20.4 | 15.0 | 17.1 | 12.6 | 11.7 | 8.7 |
| 16.290 | 29.160 | 12.6 | 16.5 | 14.4 | 14.7 | 10.8 | 9.6 |
| 16.350 | 16.350 | 13.8 | 16.8 | 15.0 | 15.0 | 12.9 | 8.6 |
| 17.160 | 16.170 | 7.8 | 7.5 | 6.3 | 6.9 | 6.8 | 4.4 |
| 17.230 | 17.230 | 20.4 | 7.0 | 20.1 | 10.5 | 15.0 | 24.0 |
| 17.260 | 26.170 | 11.4 | 15.0 | 13.8 | 14.4 | 12.6 | 10.5 |
| 17.270 | 27.170 | 10.8 | 12.9 | 12.3 | 13.5 | 10.8 | 13.8 |
| 17.280 | 28.170 | 9.3 | 14.1 | 12.3 | 15.0 | 10.8 | 10.2 |
| 17.290 | 29.170 | 6.3 | 10.2 | 9.6 | 12.6 | 9.3 | 9.0 |
| 17.350 | 17.350 | 12.6 | 16.2 | 13.5 | 15.6 | 12.6 | 9.9 |
| 18.160 | 16.180 | 9.0 | 9.6 | 6.6 | 8.4 | 6.0 | 3.4 |
| 18.170 | 17.180 | 9.6 | 8.4 | 8.5 | 7.9 | 9.9 | 3.6 |
| 18.230 | 18.230 | 19.5 | 9.3 | 16.5 | 10.8 | 12.6 | 12.0 |
| 18.260 | 26.180 | 8.4 | 13.2 | 10.5 | 14.4 | 9.6 | 12.6 |
| 18.270 | 27.180 | 8.0 | 11.2 | 10.5 | 11.7 | 9.0 | 6.6 |
| 18.280 | 28.180 | 9.3 | 12.0 | 11.4 | 13.2 | 8.4 | 8.7 |
| 18.290 | 29.180 | 9.0 | 12.9 | 11.4 | 12.9 | 9.0 | 8.7 |
| 18.350 | 18.350 | 10.2 | 15.0 | 12.6 | 15.3 | 12.0 | 10.2 |
| 19.160 | 16.190 | 10.5 | 10.2 | 8.1 | 6.3 | 4.4 | 1.4 |
| 19.170 | 17.190 | 8.7 | 8.1 | 8.1 | 6.9 | 5.0 | 3.0 |
| 19.230 | 19.230 | 17.1 | 7.0 | 15.0 | 15.0 | 11.1 | 9.0 |
| 19.260 | 26.190 | 8.6 | 12.9 | 10.2 | 15.3 | 9.3 | 12.0 |
| 19.270 | 27.190 | 7.0 | 12.3 | 10.8 | 11.4 | 9.6 | 9.3 |
| 19.280 | 28.190 | 14.4 | 14.1 | 13.8 | 13.2 | 9.6 | 6.6 |
| 19.290 | 29.190 | 16.2 | 16.2 | 15.5 | 13.5 | 10.8 | 7.8 |
| 19.350 | 19.350 | 10.2 | 11.4 | 12.0 | 13.8 | 11.1 | 9.0 |
| 20.160 | 16.200 | 9.9 | 11.7 | 9.6 | 3.5 | 5.4 | 1.9 |
| 20.170 | 17.200 | 9.0 | 10.5 | 9.3 | 7.5 | 9.4 | 5.6 |
| 20.230 | 20.230 | 16.2 | 7.4 | 12.0 | 11.4 | 10.8 | 13.8 |
| 20.260 | 26.200 | 9.6 | 12.9 | 11.4 | 9.9 | 8.7 | 8.1 |

**Appendix 4.** Apparent terrain conductivity measurements, Saco Landfill, Saco, Maine--*Continued*

| Station No. | Field No. | Apparent terrain conductivity, in millisiemens per meter | | | | | |
|---|---|---|---|---|---|---|---|
| | | 32.8-foot antenna spacing | | 65.6-foot antenna spacing | | 131.2-foot antenna spacing | |
| | | Horizontal | Vertical | Horizontal | Vertical | Horizontal | Vertical |
| 20.270 | 27.200 | 11.1 | 12.3 | 10.8 | 15.0 | 9.9 | 6.6 |
| [7]20.280 | 28.200 | 13.2 | 15.3 | 15.0 | 13.5 | 10.2 | 7.8 |
| 20.290 | 29.200 | 18.3 | 13.8 | 16.2 | 12.3 | 10.8 | 5.7 |
| 20.350 | 20.350 | 8.4 | 13.2 | 11.4 | 15.0 | 10.2 | 12.0 |
| 21.160 | 16.210 | 12.3 | 9.6 | 7.8 | 6.2 | 5.7 | 1.8 |
| 21.170 | 17.210 | 19.8 | 13.5 | 16.2 | 12.0 | 8.8 | -.9 |
| 21.230 | 21.230 | 17.1 | 9.0 | 19.8 | 8.4 | 17.4 | 5.4 |
| 21.250 | 25.210 | 18.6 | 9.6 | 13.8 | 9.6 | 9.9 | 9.6 |
| 21.260 | 26.210 | 12.6 | 13.5 | 12.0 | 8.4 | 10.8 | 8.1 |
| 21.270 | 27.210 | 7.9 | 11.1 | 9.3 | 9.0 | 10.2 | 7.2 |
| 21.280 | 28.210 | 13.2 | 13.8 | 13.8 | 14.7 | 10.5 | 6.0 |
| 21.290 | 29.210 | 13.8 | 14.7 | 13.5 | 12.9 | 9.6 | 6.9 |
| 21.350 | 21.350 | 9.0 | 13.2 | 12.0 | 14.1 | 10.8 | 8.7 |
| 22.160 | 16.220 | 16.5 | 14.7 | 11.4 | 3.0 | 5.4 | -3.3 |
| 22.170 | 17.220 | 33.0 | 34.0 | 24.0 | 12.9 | 9.0 | -2.2 |
| 22.250 | 25.220 | 15.3 | 17.4 | 15.9 | 10.8 | 11.4 | 8.9 |
| 22.260 | 26.220 | 12.0 | 12.3 | 12.3 | 9.9 | 9.6 | 4.5 |
| 22.270 | 27.220 | 10.2 | 11.4 | 11.1 | 21.0 | 9.6 | 6.2 |
| 22.280 | 28.220 | 10.2 | 12.6 | 12.0 | 12.0 | 9.2 | 8.4 |
| 22.290 | 29.220 | 12.6 | 15.6 | 12.6 | 12.6 | 9.6 | 6.6 |
| 22.350 | 22.350 | 12.0 | 15.6 | 13.2 | 16.2 | 12.0 | 8.4 |
| 23.160 | 16.230 | 11.4 | 5.0 | 8.7 | -1.6 | 4.6 | -6.2 |
| 23.170 | 17.230 | 26.4 | 8.7 | 20.4 | 8.1 | 10.2 | -1.5 |
| 23.250 | 25.230 | 18.0 | -2.7 | 18.6 | 8.0 | 15.9 | 12.0 |
| 23.260 | 26.230 | 8.9 | 9.6 | 10.5 | 10.5 | 11.1 | 5.6 |
| 23.270 | 27.230 | 9.0 | 10.5 | 9.0 | 10.5 | 6.9 | 3.5 |
| 23.280 | 28.230 | 10.5 | 12.3 | 12.0 | 12.0 | 9.2 | 6.8 |
| 23.290 | 29.230 | 9.3 | 12.6 | 11.4 | 12.6 | 9.0 | 8.2 |
| 23.290 | 23.290 | 8.7 | 11.1 | -- | -- | 8.4 | 8.2 |
| 23.300 | 23.300 | 10.2 | 12.0 | 9.0 | 11.4 | 9.0 | 8.0 |
| 23.310 | 23.310 | 12.6 | 12.0 | 12.9 | 11.4 | 9.6 | 9.0 |
| 23.320 | 23.320 | 13.8 | 14.7 | 13.8 | 13.8 | 10.8 | 8.3 |
| 23.330 | 23.330 | 12.9 | 15.6 | 13.8 | 13.8 | 10.2 | 8.7 |
| 23.340 | 23.340 | 12.0 | 14.4 | 13.8 | 16.2 | 12.0 | 12.3 |
| 24.170 | 17.240 | 12.0 | 10.8 | 9.3 | 2.5 | 1.3 | -2.5 |
| 24.250 | 25.240 | 24.6 | 34.0 | 26.1 | 14.4 | 32.0 | 8.7 |
| 24.260 | 26.240 | 9.3 | 4.6 | 10.8 | 9.9 | 7.5 | 7.3 |
| 24.270 | 27.240 | 6.9 | 9.5 | 7.9 | 9.0 | 8.0 | 8.4 |
| 24.280 | 28.240 | 8.1 | 11.1 | 9.2 | 11.4 | 8.2 | 5.8 |
| 24.290 | 29.240 | 8.7 | 11.7 | 9.9 | 10.2 | 8.7 | 6.0 |

**Appendix 4.** Apparent terrain conductivity measurements, Saco Landfill, Saco, Maine--*Continued*

| Station No. | Field No. | Apparent terrain conductivity, in millisiemens per meter | | | | | |
|---|---|---|---|---|---|---|---|
| | | 32.8-foot antenna spacing | | 65.6-foot antenna spacing | | 131.2-foot antenna spacing | |
| | | Horizontal | Vertical | Horizontal | Vertical | Horizontal | Vertical |
| 25.170 | 17.250 | 8.7 | 6.3 | 7.5 | 1.9 | 7.4 | -1.0 |
| [2]25.250 | 25.250 | 32.0 | 23.1 | 43.0 | 20.1 | 6.3 | 12.0 |
| 25.260 | 26.250 | 9.3 | 9.6 | 10.5 | 5.9 | 7.2 | 9.2 |
| 25.270 | 27.250 | 7.4 | 8.8 | 7.1 | 6.1 | 7.0 | 4.8 |
| [8]25.280 | 28.250 | 7.3 | 8.2 | 8.5 | 8.7 | 6.8 | 4.2 |
| 25.290 | 29.250 | 6.6 | 9.9 | 8.7 | 9.6 | 7.2 | 5.0 |
| [2]26.250 | 25.260 | 19.8 | 27.0 | 18.0 | 20.7 | -1.3 | 5.4 |
| 26.260 | 26.260 | 11.4 | 10.2 | 10.8 | 8.4 | 6.6 | 1.3 |
| 26.270 | 27.260 | 9.0 | 9.9 | 6.6 | 4.9 | 5.9 | 2.6 |
| [8]26.280 | 28.260 | 9.6 | 7.4 | 8.1 | 5.9 | 3.8 | 1.0 |
| 26.290 | 29.260 | 7.8 | 11.4 | 8.0 | 8.6 | 6.8 | 4.0 |
| 27.250 | 25.270 | 17.7 | 15.6 | 13.2 | 7.4 | 7.1 | 3.4 |
| 27.260 | 26.270 | 8.7 | 8.5 | 8.5 | 6.4 | 6.0 | 3.2 |
| 27.270 | 27.270 | 7.8 | 7.0 | 5.6 | 3.2 | 4.0 | .5 |
| [8]27.280 | 28.270 | 7.8 | 7.0 | 5.7 | 6.2 | 1.8 | .0 |
| 27.290 | 29.270 | 5.8 | 7.6 | 7.2 | 7.8 | 5.6 | 1.4 |
| [9]28.250 | 25.280 | 12.3 | 10.2 | 9.0 | 1.0 | 6.0 | -0.8 |
| 29.160 | 29.160 | 3.1 | 2.2 | 1.6 | 1.1 | 1.7 | 0.2 |
| 29.170 | 29.170 | -1.7 | 2.3 | 1.1 | 7.0 | 2.5 | 7.5 |
| 29.180 | 29.180 | 5.1 | 4.3 | 4.8 | 1.1 | 2.9 | -1.6 |
| 29.190 | 29.190 | 5.1 | 7.5 | 6.6 | 4.3 | 3.9 | .8 |
| 29.200 | 29.200 | 7.2 | 6.3 | 6.2 | 3.8 | 5.5 | 1.8 |
| 29.210 | 29.210 | 7.2 | 6.3 | 3.6 | 3.0 | 4.6 | 5.4 |
| 29.220 | 29.220 | 5.7 | 2.0 | 4.8 | 3.6 | 3.6 | 3.9 |
| 29.230 | 29.230 | 4.5 | 5.2 | 4.5 | 1.4 | 2.7 | 2.5 |
| 29.240 | 29.240 | .5 | 3.0 | 2.1 | 4.0 | 3.6 | 3.1 |
| [10]29.250 | 29.249 | 1.9 | 2.1 | 1.9 | 1.2 | 2.5 | 1.6 |
| 29.260 | 29.260 | .0 | 2.3 | .0 | 1.4 | 3.3 | 2.4 |
| 30.160 | 30.160 | 1.0 | .8 | 1.8 | .3 | 7.6 | 9.0 |
| 30.170 | 30.170 | 6.5 | 4.3 | 4.4 | 1.7 | 5.8 | -4.2 |
| 30.180 | 30.180 | 1.6 | 2.1 | 5.0 | 3.2 | 7.8 | 5.2 |
| 30.190 | 30.190 | 6.4 | 5.7 | 6.5 | 3.7 | 8.4 | 11.1 |
| 30.200 | 30.200 | 6.7 | 5.8 | 5.2 | 2.5 | 8.7 | 5.2 |
| 30.210 | 30.210 | 3.3 | 5.2 | 3.2 | 1.8 | 13.8 | -2.0 |
| 30.220 | 30.220 | 7.5 | 3.6 | 6.5 | -1.7 | 10.8 | 7.8 |
| 30.230 | 30.230 | 6.0 | 7.4 | 4.9 | 5.4 | 9.9 | 3.8 |
| 30.240 | 30.240 | 6.3 | 9.3 | 5.2 | 3.7 | 9.0 | -1.0 |
| 30.250 | 30.250 | 2.0 | 3.0 | 2.8 | 2.9 | 5.6 | 2.6 |
| 30.260 | 30.260 | .3 | 1.2 | .5 | 1.6 | 2.8 | 2.5 |
| 30.280 | 28.300 | 2.6 | 3.6 | 2.5 | 2.8 | 4.0 | 1.7 |

**Appendix 4.** Apparent terrain conductivity measurements, Saco Landfill, Saco, Maine--*Continued*

| Station No. | Field No. | Apparent terrain conductivity, in millisiemens per meter | | | | | |
|---|---|---|---|---|---|---|---|
| | | 32.8-foot antenna spacing | | 65.6-foot antenna spacing | | 131.2-foot antenna spacing | |
| | | Horizontal | Vertical | Horizontal | Vertical | Horizontal | Vertical |
| [11]30.290 | 29.300 | -- | -- | 6.6 | 2.0 | 3.2 | -3.6 |
| 31.170 | 17.310 | 4.0 | 6.0 | 0.4 | -1.0 | -.5 | -0.4 |
| 31.180 | 18.360 | 14.7 | -6.0 | 5.6 | -5.0 | 2.2 | .8 |
| 31.190 | 31.190 | 10.8 | 5.8 | 7.2 | 5.0 | 7.5 | 1.1 |
| 31.200 | 31.200 | 7.8 | 6.1 | 7.4 | 7.1 | 7.8 | 4.2 |
| 31.210 | 31.210 | 12.9 | 9.6 | 9.0 | 5.2 | 6.9 | 1.6 |
| 31.220 | 31.220 | 9.6 | 5.5 | 7.8 | 3.1 | 7.2 | 7.8 |
| [12]31.230 | 31.230 | 10.5 | 6.8 | 9.5 | 3.0 | 7.5 | -3.0 |
| 31.240 | 31.240 | 2.6 | 5.8 | 2.5 | 9.6 | 3.8 | 5.4 |
| 31.250 | 31.250 | 2.7 | -2.3 | 4.5 | -1.7 | 2.4 | 11.4 |
| 31.260 | 31.260 | 1.6 | .4 | .9 | -5.5 | 4.2 | 4.2 |
| 31.280 | 28.310 | 5.3 | 5.4 | 4.6 | 2.3 | 6.2 | -.9 |
| 31.290 | 29.310 | 3.6 | 6.6 | 4.0 | 4.0 | 1.5 | 1.5 |
| 32.170 | 17.320 | 5.0 | 1.8 | 2.2 | .5 | .3 | -.6 |
| 32.180 | 18.350 | 7.2 | -.1 | 5.5 | -2.2 | 3.4 | 1.5 |
| 32.280 | 28.320 | 5.5 | 7.4 | 3.1 | 4.2 | 7.8 | 2.8 |
| 32.290 | 29.320 | 3.6 | 4.6 | 3.4 | 4.0 | 1.2 | 4.4 |
| 33.170 | 17.330 | .1 | -.4 | -.1 | -.2 | .0 | -1.3 |
| 33.180 | 18.340 | -6.0 | -2.5 | 5.2 | .8 | -.3 | 2.0 |
| 33.280 | 28.330 | 4.6 | 5.0 | 3.8 | 3.2 | 4.4 | 5.2 |
| 33.290 | 29.330 | 2.8 | 5.3 | 3.3 | 5.8 | 2.0 | 3.4 |
| 34.170 | 17.340 | -.5 | -1.7 | -1.8 | -.2 | -.7 | .2 |
| 34.180 | 18.330 | 3.9 | 1.9 | 3.0 | 2.7 | .7 | -3.7 |
| 34.280 | 28.340 | 11.7 | 10.5 | 9.4 | 3.4 | 3.8 | -3.0 |
| 34.290 | 29.340 | 7.6 | 4.6 | 6.4 | 1.1 | 3.0 | -3.0 |
| [6]34.300 | 30.340 | 2.8 | 3.7 | .8 | 2.5 | -- | -- |
| 35.170 | 17.350 | -2.3 | -1.6 | -1.3 | -.6 | -1.3 | 1.0 |
| 35.180 | 18.320 | 7.5 | -.9 | 4.7 | -12.3 | .8 | -.9 |
| 35.280 | 28.350 | 8.0 | 9.9 | 8.9 | 6.1 | 6.2 | .3 |
| 35.290 | 29.350 | 2.0 | 3.5 | 4.2 | 4.0 | 3.0 | -1.2 |
| 35.300 | 30.350 | 1.9 | 2.6 | 2.0 | 2.6 | .5 | .9 |
| 36.170 | 17.360 | -1.4 | .1 | -.3 | -.2 | -.4 | 1.0 |
| 36.180 | 18.310 | 7.0 | 2.5 | 4.0 | -2.6 | -.2 | -.8 |
| 36.280 | 28.360 | 3.8 | 6.6 | 3.6 | 4.2 | 1.5 | 1.4 |
| 36.290 | 29.360 | 3.0 | 2.8 | 1.9 | .6 | 1.8 | -2.5 |
| 36.300 | 30.360 | 1.6 | 2.8 | 1.4 | 2.7 | .6 | -.7 |
| 37.160 | 37.160 | .7 | 3.4 | .8 | 5.6 | -.4 | 1.0 |
| 37.170 | 37.170 | 4.0 | 4.0 | 1.4 | 2.3 | -1.0 | .4 |
| 37.180 | 37.180 | 3.2 | 2.8 | 1.0 | 1.6 | -.3 | -4.0 |
| 37.190 | 37.190 | 14.4 | .9 | 6.8 | -6.0 | 1.3 | 1.0 |

**Appendix 4.** Apparent terrain conductivity measurements, Saco Landfill, Saco, Maine--*Continued*

| Station No. | Field No. | Apparent terrain conductivity, in millisiemens per meter | | | | | |
|---|---|---|---|---|---|---|---|
| | | 32.8-foot antenna spacing | | 65.6-foot antenna spacing | | 131.2-foot antenna spacing | |
| | | Horizontal | Vertical | Horizontal | Vertical | Horizontal | Vertical |
| 37.200 | 37.200 | .8 | 3.3 | .7 | 6.6 | -1.1 | 5.2 |
| 37.210 | 37.210 | 0.3 | 3.8 | -0.5 | 4.0 | -1.2 | 2.8 |
| 37.220 | 37.220 | .2 | 2.6 | .0 | 4.9 | -2.0 | 5.1 |
| 37.230 | 37.230 | 18.0 | -9.6 | 5.4 | 8.2 | -2.0 | 6.0 |
| 37.240 | 37.240 | 16.8 | 9.0 | -5.6 | 9.0 | -1.2 | 1.4 |
| 37.250 | 37.250 | -6.0 | 6.2 | -15.0 | 15.0 | -.9 | 2.2 |
| 37.260 | 37.260 | 1.3 | 5.8 | -.9 | 7.6 | -1.2 | 2.0 |
| 37.280 | 28.370 | 1.9 | 3.9 | 1.9 | 2.1 | 7.4 | 1.2 |
| 37.290 | 29.370 | 1.5 | .0 | .5 | .5 | 2.0 | -8.0 |
| 37.300 | 30.370 | 1.1 | 1.5 | 1.3 | -2.1 | 1.2 | -12.0 |
| 38.160 | 38.160 | 2.4 | -1.1 | -1.1 | -.4 | -.7 | -1.9 |
| 38.170 | 38.170 | .5 | 2.0 | .3 | 2.3 | -1.2 | .7 |
| 38.180 | 38.180 | 2.2 | -5.2 | 1.5 | .7 | -1.5 | -2.1 |
| 38.190 | 38.190 | 1.6 | 1.7 | -1.8 | 4.3 | -.5 | -.6 |
| 38.200 | 38.200 | -.1 | 1.6 | -.9 | 1.6 | -.5 | -.8 |
| 38.210 | 38.210 | .4 | -.4 | -.5 | .3 | -.4 | -.7 |
| 38.220 | 38.220 | -.3 | .6 | -.3 | 1.1 | -1.1 | .6 |
| 38.230 | 38.230 | .5 | 1.1 | .4 | .8 | -1.0 | -.2 |
| 38.240 | 38.240 | 1.4 | .9 | 1.0 | .4 | -.3 | -.3 |
| 38.250 | 38.250 | .6 | .9 | -.6 | 1.7 | -.4 | -.7 |
| 38.260 | 38.260 | .8 | 2.0 | .6 | 1.7 | .1 | .3 |
| 38.280 | 28.380 | 1.3 | -.4 | 1.5 | -.3 | -2.5 | 1.1 |
| [2]38.290 | 29.380 | -3.4 | -2.8 | -.6 | -9.0 | -3.0 | -24.0 |
| [2]38.300 | 30.380 | -4.2 | 6.0 | -3.0 | -27.0 | -- | -- |
| [13]39.280 | 28.390 | .4 | .8 | -- | -- | -- | -- |
| [13]39.290 | 29.390 | -3.4 | -3.5 | -- | -- | -- | -- |

[1] Near powerline; also many rusted tin cans on surface—looks like old private house dump.
[2] Near high-voltage powerline.
[3] Located just northeast of landfill area 1 (13 feet from edge).
[4] Located 66 feet west of station 15.060.
[5] Located near metal gate.
[6] Inadequate space for 131-foot spacing—no measurement made.
[7] Measurement position offset 30 feet east to avoid small gravel pit.
[8] Varying meter reading—may be high-voltage powerline effect or influence of rising bedrock surface.
[9] 131-foot measurement made 20 feet northeast of station.
[10] Measurement made 33 feet west of station location.
[11] No measurement made at the 32.8-foot spacing.
[12] Scrap metal on land surface.
[13] No measurements made at the 65.6 and 131.1-foot spacing.

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