# Sewage Plume in a Sand and Gravel Aquifer, Cape Cod, Massachusetts



United States Geological Survey Water-Supply Paper 2218

Prepared in cooperation with the Massachusetts Department of Environmental Quality Engineering Division of Water Pollution Control

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*By* Dennis R. LeBlanc

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FIGURES



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**Metric Conversion Factors**

The following factors may be used to convert inch-pound units to the International System of Units (SI).

| Multiply inch-pound units | By | To obtain SI Units |
|---|---|---|
| inch (in) | 2.540 | centimeter (cm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| acre | 0.4047 | square hectometer ($hm^2$) |
| gallon (gal) | 3.785 | liter (L) |
| million gallons (Mgal) | 3,785 | cubic meter ($m^3$) |
| billion gallons (Bgal) | 3,785,000 | cubic meter ($m^3$) |
| inch per year (in/yr) | 25.4 | millimeter per year (mm/a) |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |
| foot per mile (ft/mi) | 0.1894 | meter per kilometer (m/km) |
| million gallons per day (Mgal/d) | 3,785 | cubic meters per day ($m^3/d$) |
| micromho ($\mu$mho) | 1.000 | microsiemen ($\mu$S) |

NGVD of 1929 (National Geodetic Vertical Datum of 1929): A geodetic vertical datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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**Abstract**

Secondarily treated domestic sewage has been disposed of on surface sand beds at the sewage treatment facility at Otis Air Force Base, Massachusetts, since 1936. Infiltration of the sewage through the sand beds into the underlying unconfined sand and gravel aquifer has resulted in a plume of sewage-contaminated ground water that is 2,500 to 3,500 feet wide, 75 feet thick, and more than 11,000 feet long. The plume extends south and southwest of the sand beds in the same direction as the regional flow of ground water, and is overlain by 20 to 50 feet of ground water derived from precipitation that recharges the aquifer. The bottom of the plume generally coincides with the contact between the permeable sand and gravel and underlying finer grained sediments.

The distributions in the aquifer of specific conductance, temperature, boron, chloride, sodium, phosphorus, nitrogen (total of all species), ammonia, nitrate, dissolved oxygen, and detergents are used to delineate the plume. In ground water outside the plume, the detergent concentration is less than 0.1 milligrams per liter as MBAS (methylene blue active substances), the ammonia-nitrogen concentration is less than 0.1 milligrams per liter, the boron concentration is less than 50 micrograms per liter, and specific conductance is less than 80 micromhos per centimeter. In the center of the plume, detergent concentrations as high as 2.6 milligrams per liter as MBAS, ammonia-nitrogen concentrations as high as 20 milligrams per liter, boron concentrations as high as 400 micrograms per liter, and specific conductance as high as 405 micromhos per centimter were measured.

Chloride, sodium, and boron are transported by the southward-flowing ground water without significant retardation, and seem to be diluted only by hydrodynamic dispersion. The movement of phosphorus is greatly restricted by sorption. Phosphorus concentrations do not exceed 0.05 milligrams per liter farther than 2,500 feet from the sand beds. Detergent concentrations in the plume are highest between 3,000 and 10,000 feet from the sand beds and reflect the introduction of nonbiodegradable detergents in 1946 and the conversion to biodegradable detergents in 1964.

The center of the plume as far as 5,000 feet from the sand beds contains nitrogen as ammonia, but no nitrate and no dissolved oxygen. Ammonia is gradually oxidized to nitrate between 5,000 and 8,000 feet from the sand beds, and at distances greater than 8,000 feet oxidation of ammonia is essentially complete. Ammonia also is oxidized to nitrate along the top and sides of the plume within 5,000 feet of the beds where the contaminated ground water mixes with uncontaminated ground water that contains up to 11 milligrams per liter dissolved oxygen.

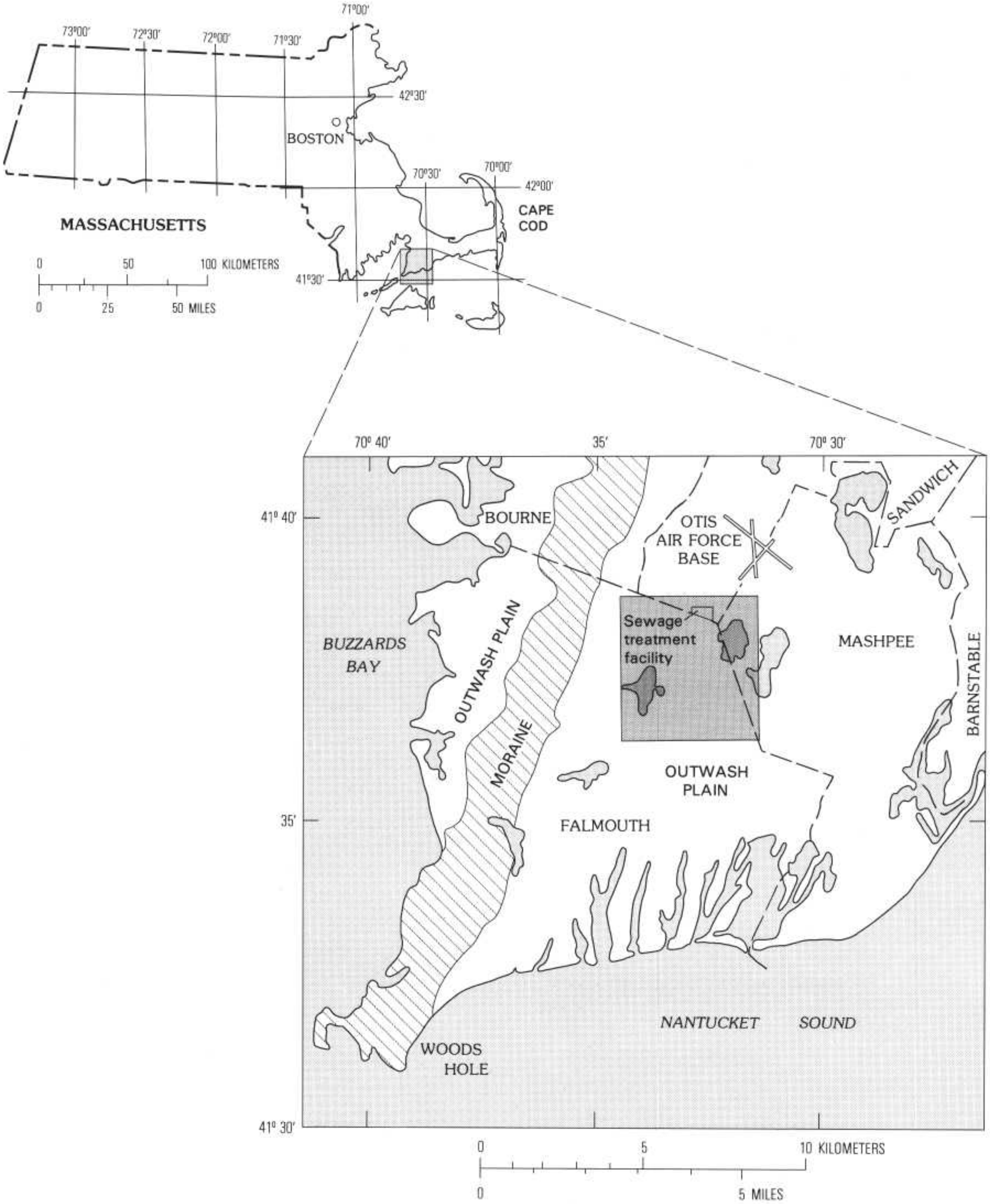
## INTRODUCTION

Effluent produced by sewage treatment facilities commonly is discharged to surface water or onto land surface. One method of land disposal of treated sewage—infiltration-percolation or rapid infiltration—has been used at Otis AFB (Air Force Base), Cape Cod, Mass. (fig. 1) since 1936. At the Otis AFB facility, the treatment-plant effluent is discharged onto 12 acres of rectangular sand beds. The effluent then rapidly infiltrates the ground and percolates to the water table. Infiltration-percolation is used to dispose of treated sewage to the ground at other locations in Massachusetts and has been proposed for use by several communities on Cape Cod.

Rapid infiltration of treated sewage has caused contamination of ground water at other sites where this method of land disposal is used (Preul, 1968; Schmidt, 1973; Bouwer, 1973; Aulenbach and Tofflemire, 1975; Hughes, 1975; Koerner and Haws, 1979; Cox, 1979). Because most rapid-infiltration facilities in Massachusetts are located on sand and gravel aquifers and many communities in the State obtain most or all of their water supplies from these aquifers, the public and water-supply officials are concerned that land disposal of sewage may adversely affect the chemical quality of ground water.

### Purpose

Because of local, State, and Federal concern about the effects of land disposal of sewage on ground-water quality, the U.S. Geological Survey, in cooperation with the Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, has studied the impact on ground-water quality of 45 years of sewage disposal at the Otis AFB sewage treatment facility. The purposes of the study were (1) to describe the extent and chemical composition of the zone of contaminated ground water at the Otis AFB facility and (2) to




**EXPLANATION**

STUDY AREA—Area shown in figures 2, 6, 8, 10, 12, 13, and 16

TOWN BOUNDARY

**Figure 1.** Study area.

provide, through a detailed study at one site, a basis for evaluating the potential for ground-water contamination at the other land-disposal sites in the State.

## Objectives and Approach

The objectives of the study were to (1) determine the lateral and vertical extent of the zone of sewage-contaminated ground water in the aquifer, and (2) determine the concentrations of dissolved substances in the contaminated zone. The approach used to meet these objectives is outlined in table 1. Information about ground-water quality and ground-water flow in the Otis AFB area (Meade and Vaccaro, 1971; Palmer, 1977) and on Cape Cod in general (Frimpter and Gay, 1979; Guswa and LeBlanc, 1981) were used to design the approach.

## Definition of Terms

In this report, ground water that contains dissolved substances introduced into the aquifer by sewage disposal at the Otis AFB treatment facility is referred to as contaminated ground water. The body of contaminated ground water in the aquifer is referred to as the plume. The wastewater treated at the Otis AFB facility is referred to as sewage because the wastewater is generated primarily by domestic sources.

**Table 1.** Five phases of study

| | |
|---|---|
| PHASE 1: | Assemble and interpret data collected during earlier studies. Determine the most likely path of plume from preliminary water-table map and water-quality information. |
| PHASE 2: | Locate private wells along likely path of plume, and collect and analyze water samples for specific conductance, nitrate, ammonia, and chloride to detect contaminated zone. Determine the chemical composition of the treated sewage. |
| PHASE 3: | Design a network of observation wells. Drill wells, measure water levels, and collect and analyze water samples to (1) improve water-table map and (2) determine the general location of plume. |
| PHASE 4: | Design a second-level network of observation sites. Drill test holes and collect water samples for chemical analysis in the field during drilling to guide selection of screen-setting depths and subsequent drilling sites. Install clusters of wells screened at different depths to sample the center and boundaries of plume. |
| PHASE 5: | Analyze lithologic, hydrologic, and chemical data to describe the location and chemical composition of the plume. |

## Acknowledgments

The author thanks the many persons who have kindly given time, information, and guidance during this study. Particular thanks are given to persons in the Geological Survey who assisted in the data collection and the preparation of this report and to the following individuals and agencies: Edward Cox, Robert Shedlock, and Julio Olimpio of the Geological Survey, who reviewed the report; Abram Peters, Otis Air Force Base; Richard Witt, Falmouth Department of Public Works; Lou Hambly, Massachusetts Division of Fisheries and Wildlife; Ralph Vaccaro, Woods Hole Oceanographic Institution; Francis G. Sullivan; Paul Harney; Ernest Doherty; the late Harold McMahon; and the Massachusetts Audubon Society.

# PHYSICAL AND CULTURAL SETTING

The Otis AFB sewage treatment facility is located on a broad sand and gravel outwash plain that slopes gently southward to Nantucket Sound (fig. 1). The treatment facility is 7 miles south and 2 miles east of hills and ridges of recessional moraines which bound the outwash plain and 4 miles north of the heads of several narrow saltwater bays which extend 2 miles inland from Nantucket Sound.

The study area includes 7 $mi^2$ of the sand and gravel plain at and south of the sand beds at the Otis AFB sewage treatment plant (fig. 2). The plain is pitted with many kettle holes, some of which contain ponds. The largest ponds are Coonamessett, Ashumet, and Johns Ponds (fig. 2). The Coonamessett River, which flows south from Coonamessett Pond, is the only stream in the study area. Several broad valleys cross the outwash plain from north to south. The valleys contain a few wetlands and ponds, but most of the valleys do not contain streams. The Ashumet Valley (fig. 2) is 500 to 900 feet wide and 30 feet deep but contains no surface-water bodies except at its lower end near Nantucket Sound.

The study area south of Otis AFB is predominantly rural. A wildlife management area which contains fields and woodlands of pitch pine and oak covers 1.9 $mi^2$. Two

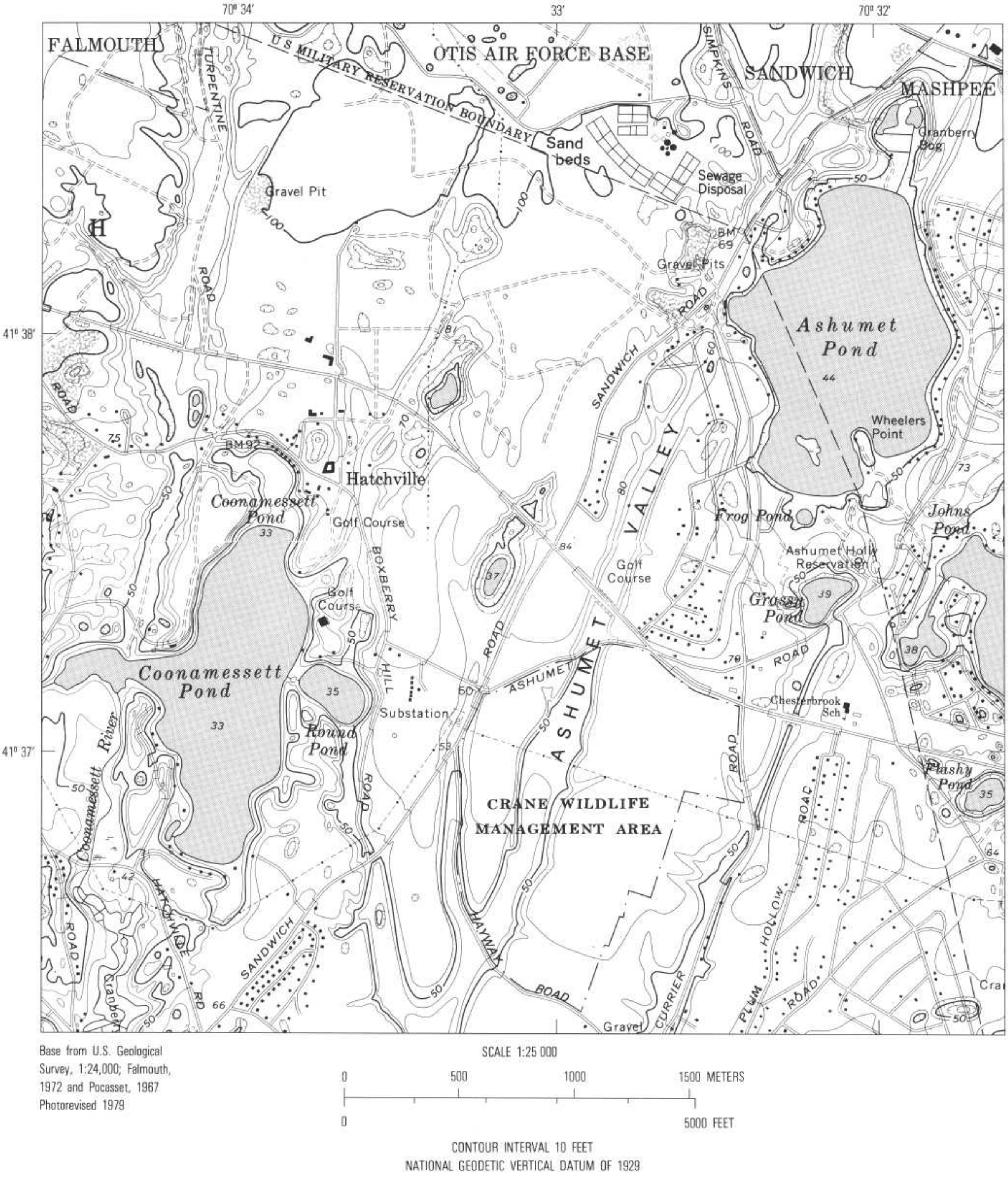



**Figure 2.** Physical and cultural features.

golf courses cover a total of 0.4 mi$^2$. Sandwich Road and Route 151 are the major roads that pass through the area. There has been little commercial and industrial development along these routes. Most private homes in the area have been built since 1960 and are located near Ashumet and Johns Ponds, Plum Hollow Road, and

Ashumet Valley north of Route 151. These homes obtain drinking water from shallow small-diameter wells and use septic tanks and cesspools for wastewater disposal. Cranberry bogs along the Coonamessett River and several horse stables are the main agricultural activities in the area, although the wildlife management area occupies land once used for ranching and vegetable farming.

Otis AFB has been a military reservation since at least 1936. During World War II the reservation housed as many as 70,000 troops, and between 1948 and 1973 the base was a major installation of the U.S. Air Force. Since 1973, the base has been used by the Massachusetts Air and Army National Guards and the U.S. Coast Guard.

## OTIS AIR FORCE BASE SEWAGE TREATMENT FACILITY

The Otis AFB sewage treatment facility (fig. 3) provides secondary treatment to sewage produced on the base. A small treatment plant with 4 acres of sand beds served the base between 1936 and 1941. The present treatment plant was constructed in 1941 at the site of the smaller plant. Primary treatment of the sewage consists of a comminutor with a bar screen, an aerated grease-removal unit, and Imhoff tanks. Secondary treatment consists of trickling filters and secondary settling tanks.

The treated sewage is discharged to 24 one-half-acre sand beds (fig. 3). The beds are rectangular and have flat sandy surfaces. Each sand bed was designed to be flooded with an average of 125,000 gallons of treated sewage per day. The treated sewage then infiltrates the ground and percolates to the water table. The surface of the beds is about 20 feet above the water table. Sediment cores collected at one bed from land surface to the water table showed 1 foot of sand, 2 feet of sandy loam and silt, and 18 feet of medium sand (Kerfoot and Ketchum, 1974, p. 20).

The treatment plant was designed to treat an average of 3 Mgal/d and a maximum of 6 Mgal/d of sewage. However, actual sewage flows since World War II have been lower than the design rates. The estimated daily volume of sewage treated at the Otis AFB facility from 1936 through 1980 is shown in figure 4. Records of the volume of sewage treated at the plant were available for only part of the 45-year period. Sewage flows for the remainder of the period were estimated from water-supply records and from the history of the base. Based on data from figure 4, eight billion gallons of sewage were treated at the Otis AFB facility from 1936 through 1980.

Sludge from the treatment plant is dried on sludge-drying beds and transported for disposal to the Otis AFB landfill 2.5 miles northwest of the plant. Sludge may have been stored or buried at the sewage treatment plant in the past.

The chemical quality of samples of the treated sewage collected between January 1974 and August 1980 is summarized in table 2. Few data are available on the chemical quality of the treated sewage prior to 1974. Kerfoot and others (1975, p. 52–53) reported that the concentrations of some chemicals in the treated sewage, such as ammonia and nitrate, vary seasonally due to changes in air temperature that affect the treatment process. The concentrations of other substances in the treated sewage, such as detergents, have changed over longer periods as the type and quantity of chemicals used on the base have changed.

## AQUIFER AT OTIS AIR FORCE BASE

### Hydrogeology

The aquifer recharged by treated sewage at the Otis AFB facility is composed of sand, gravel, silt, and clay deposited during the retreat of the Pleistocene ice sheets from southern New England 14,000 years ago (Oldale, 1976, p. 1). A hydrogeologic section of the aquifer through the study area is shown in figure 5. The lithologic descriptions and stratigraphy were determined from samples collected from the test borings shown on the section and from 11 additional borings that penetrated to depths of more than 100 feet below land surface and are shown on the location map in figure 5.

The top 90 to 140 feet of the aquifer is well sorted, brown, medium to very coarse sand with some gravel. North of Route 151, the sand and gravel outwash overlies fine to very fine sand and some silt. South of Route 151, the outwash overlies fine to very fine sand and silt and dense sandy till. The till contains lenses of silt and clay and sand and gravel. These unconsolidated sediments overlie crystalline bedrock. The bedrock surface generally slopes from west to east through the study area (Oldale, 1969, p. B123).

Hydraulic conductivity is a measure of the ability of the aquifer sediments to transmit water and is defined as the volume of water at the existing kinematic viscosity that will move in a unit time under a unit hydraulic gradient through a unit area of the aquifer measured at right angles to the direction of flow. The hydraulic conductivity of the sediments was estimated by comparison with measured values of the hydraulic conductivity of similar sediments at other locations on Cape Cod (Guswa and Londquist, 1976; Guswa and LeBlanc, 1981) and from general relationships between grain-size distribution of sediments and hydraulic conductivity (Freeze and Cherry, 1979, p. 29; Todd, 1980, p. 71–72). The estimated hydraulic conductivity of the sand and gravel outwash is 200 to 300 ft/d. The hydraulic conductivity of the fine to very fine sand and the sandy till is lower than the


**Figure 3.** View northwest of the Otis Air Force Base sewage treatment plant. Photograph courtesy of the U.S. Air National Guard.

hydraulic conductivity of the sand and gravel, but the magnitude of this difference cannot be estimated from available data.

The crystalline bedrock has a very low hydraulic conductivity compared to the hydraulic conductivity of the unconsolidated sediments. Because of its very low hydrau-