U.S. Department of the Interior
U.S. Geological Survey

Detection of Fresh Ground Water and a Contaminant Plume beneath Red Brook Harbor, Cape Cod, Massachusetts, 2000

By TIMOTHY D. MCCOBB and DENIS R. LEBLANC

Water-Resources Investigations Report 02-4166

In cooperation with the
AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE

Northborough, Massachusetts
2002

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

Chief, Massachusetts-Rhode Island District
U.S. Geological Survey
Water Resources
10 Bearfoot Road
Northborough, MA 01532

or visit our Web site at
http://ma.water.usgs.gov

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM, WATER-QUALITY INFORMATION, AND ABBREVIATIONS AND ACRONYMS

CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer

VERTICAL DATUM

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 the United States and Canada, formerly called the Sea Level Datum of 1929.

WATER-QUALITY INFORMATION

Chemical concentration is given in units of milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams and micrograms per liter are units expressing the mass of the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. Micrograms per liter is approximately equivalent to "parts per billion." Milligrams per liter is approximately equivalent to "parts per million."

ABBREVIATIONS

mg/L	milligram per liter	µS/cm	microsiemen per centimeter
ppt	parts per thousand	mS/m	millisiemen per meter
µg/L	microgram per liter		

ACRONYMS

AFCEE	Air Force Center for Environmental Excellence
CCL_4	carbon tetrachloride
DCE	dichloroethene
GPS	global positioning system
MCL	maximum contaminant level
MLS	multilevel sampler
MMR	Massachusetts Military Reservation
PCE	tetrachloroethene
TCE	trichloroethene
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOCs	volatile organic compounds

Detection of Fresh Ground Water and a Contaminant Plume beneath Red Brook Harbor, Cape Cod, Massachusetts, 2000

By Timothy D. McCobb *and* Denis R. LeBlanc

Abstract

Trichloroethene and tetrachloroethene were detected in ground water in a vertical interval from about 68 to 176 feet below sea level beneath the shoreline where the contaminant plume emanating from a capped landfill on the Massachusetts Military Reservation intersects Red Brook Harbor. The highest concentrations at the shoreline, about 15 micrograms per liter of trichloroethene and 1 microgram per liter of tetrachloroethene, were measured in samples from one well at about 176 feet below sea level. The concentrations of nutrients, such as nitrate and ammonium, and trace metals, such as iron and manganese, in these same samples are typical of uncontaminated ground water on Cape Cod. Fresh ground water (bulk electrical conductance less than 100 millisiemens per meter) is present beneath the harbor at 40 of 48 locations investigated within about 250 feet of the shoreline. Fresh ground water also was detected at one location approximately 450 feet from shore. The harbor bottom consists of soft sediments that range in thickness from 0 to greater than 20 feet and overlie sandy aquifer materials. Trichloroethene was detected at several locations in fresh ground water from the sandy aquifer materials beneath the harbor. The highest trichloroethene concentration, about 4.5 micrograms per liter, was measured about 450 feet from shore.

INTRODUCTION

A plume of contaminated ground water, known as the Landfill-1 (LF-1) plume, has migrated from the former landfill on the Massachusetts Military Reservation (MMR) to Red Brook Harbor, a small coastal embayment along the Cape Cod coast of Buzzards Bay (fig. 1). The source of the LF-1 plume is military and domestic refuse deposited between 1941 and 1989 in unlined disposal cells. As precipitation percolated through disposed wastes, contaminants were carried into the underlying ground water. The subsequent flow of contaminated ground water created the contaminant plume.

The primary volatile organic compounds (VOCs) contaminating the ground water are trichloroethene (TCE), tetrachloroethene (PCE), and carbon tetrachloride (CCl_4). Each of these constituents has a maximum contaminant level (MCL) drinking water standard, established by the U.S. Environmental Protection Agency (USEPA), of 5 micrograms per liter (µg/L) (USEPA, 2002). The LF-1 plume, as defined by VOC detections greater than the MCL, extends about 18,000 ft to the west from the south-central portion of the MMR, and has a maximum width of about 5,500 ft (fig. 1). The thickness of the plume averages 35 ft with a maximum thickness of 125 ft (Air Force Center for Environmental Excellence, 1999).

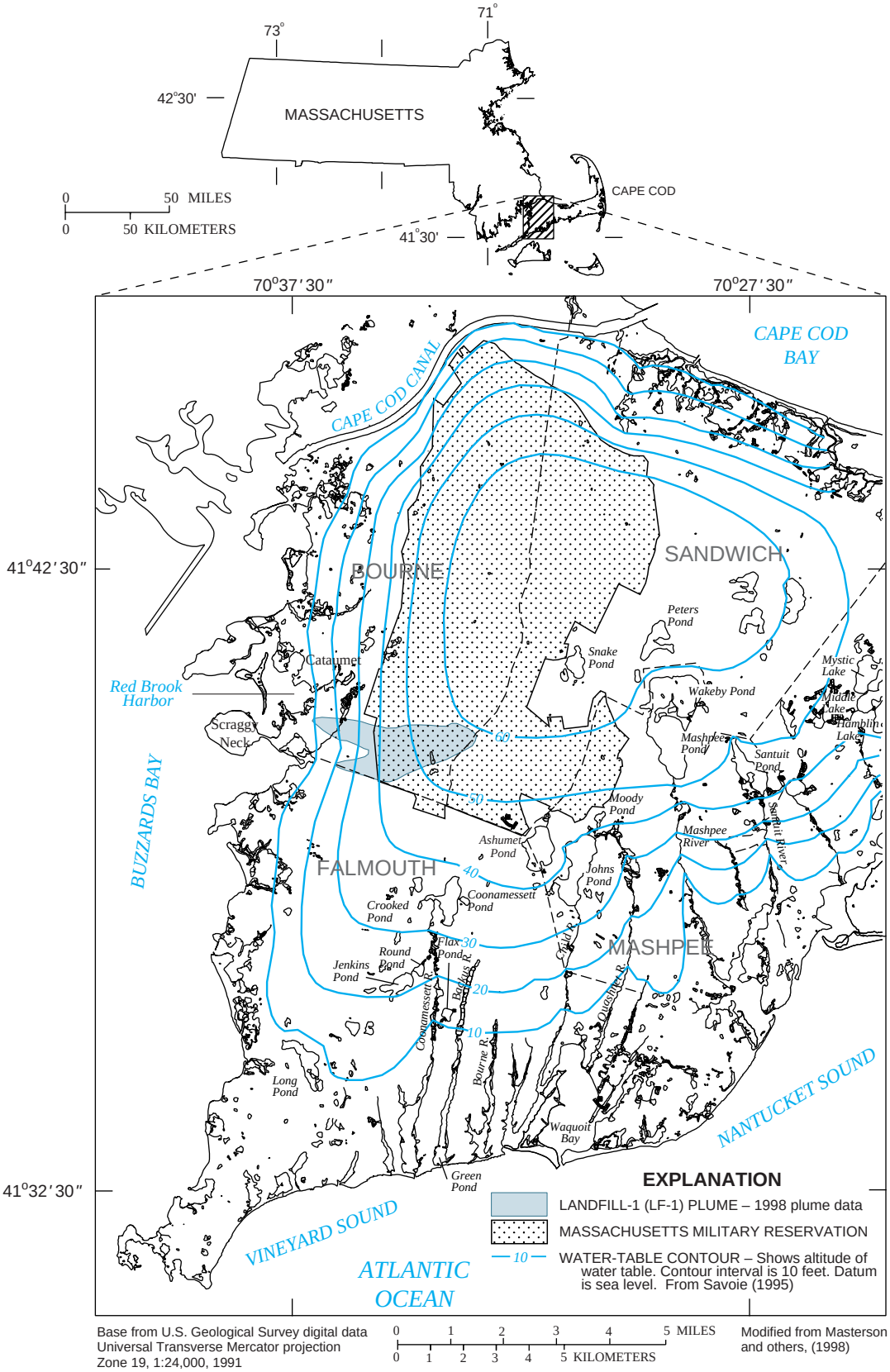


Figure 1. Location of the Massachusetts Military Reservation, the Landfill-1 plume, Buzzards Bay, and the altitude of the water table (1995), western Cape Cod, Massachusetts.

In December 1995, the landfill cells were capped to prevent precipitation from entering the wastes. In August 1999, a ground-water remediation system, in which contaminated ground water is withdrawn from five extraction wells along the western boundary of the MMR, upgradient of Route 28 and approximately 1.4 mi east of Red Brook Harbor (fig. 2), began operation. The system treats the water by means of granular activated carbon filtration, and returns the treated water to the aquifer through infiltration galleries near the extraction points in order to minimize changes to the regional ground-water-flow system. The downgradient portion of the plume, west of the extraction wells, was permitted by regulators to continue flowing toward the coast provided that the natural attenuation of contaminants is monitored and the extent of discharge to Red Brook Harbor is investigated.

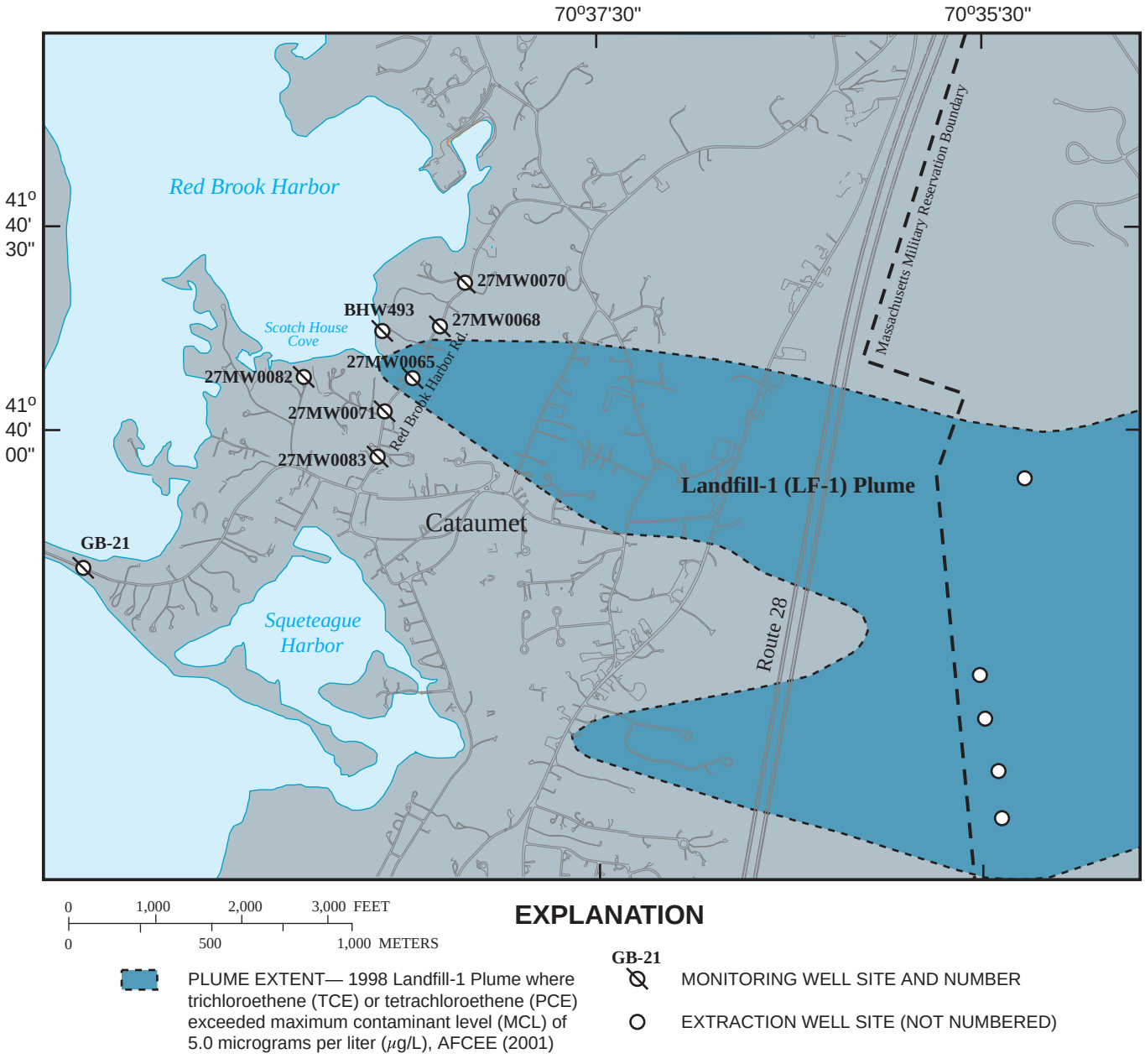


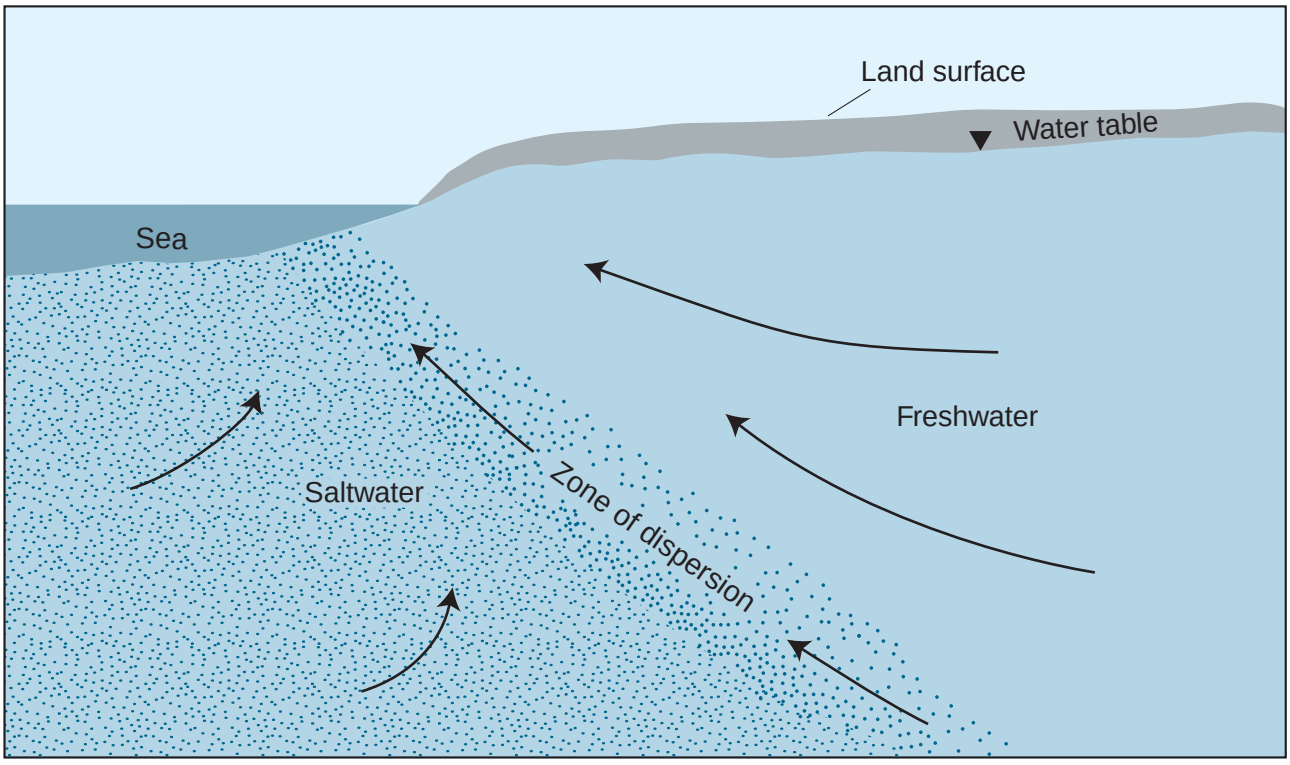
Figure 2. Location of the Landfill-1 plume and geophysical logging sites in the vicinity of Red Brook Harbor, Cape Cod, Massachusetts, August 2000.

To understand more about if and where the LF-1 plume discharges to Red Brook Harbor, the U.S. Geological Survey (USGS), in cooperation with the Air Force Center for Environmental Excellence (AFCEE), investigated in spring and summer 2000 where fresh ground water discharges to the harbor, and what the concentrations of VOCs are in the ground water underlying the harbor. This report presents the data collected and an interpretation of these data. The work at Red Brook Harbor provides baseline field data needed to assess the effects of the contaminant plume on human health and the environment, particularly on harbor ecology (i.e., shellfish and their habitats).

Red Brook Harbor, which contains more than 250 boat moorings, has a maximum depth of about 8 ft (measured at mean low water level) and a tidal fluctuation of up to about 5 ft (National Oceanic and Atmospheric Administration, 1993). Sediments within wading distance of the shoreline consist of sand and gravel.

The first objective of the investigation was to determine the characteristics of the LF-1 plume and the ground-water system at the eastern edge of Red Brook Harbor in the Scotch House Cove area, where the plume had a potential to discharge (fig. 2). In 1996, five monitoring wells were installed along Red Brook Harbor Road. Each well is screened over a single vertical interval and is sampled on a quarterly basis as part of the monitoring of the LF-1 plume. During installation of these wells, a screened auger was used to collect a profile of ground-water samples as the auger was advanced to depth. The data from the 1996 screening samples (fig. 2) provided the only vertical definition of the plume at its leading edge (Operational Technologies Corporation, 1996).

The second objective was to determine if fresh ground water is present beneath the bottom of the harbor and, if possible, how far the freshwater extends off shore. A conceptual model of the interface between saltwater and freshwater suggests that most of the freshwater discharges close to shore, with the amount of freshwater discharge decreasing in the seaward direction (fig. 3). Farther seaward, only saltwater is encountered beneath the harbor. Between the freshwater and saltwater is a mixing zone where brackish water is found between the freshwater and saltwater.



[Modified from Barlow, 2000]

Figure 3. Conceptual model of ground-water-flow patterns and the interface between freshwater and saltwater in an idealized coastal aquifer.

The third objective was to determine if TCE and PCE are present in the fresh ground water beneath the harbor and, if possible, how far offshore the contaminants are present. The screened-auger sampling results from 1996 showed the highest concentrations of TCE and PCE in the LF-1 plume were deep in the fresh ground water (as deep as 200 ft below sea level) as the plume approached the shoreline. CCl_4 was not detected in the screened auger samples collected in 1996. If the contaminants had traveled far enough to reach a discharge zone, the highest concentrations were expected to be in the most seaward freshwater discharge, or in the brackish ground-water zone.

ACKNOWLEDGMENTS

The authors would like to thank Rose Forbes and Spence Smith of AFCEE for their support and advice; Kathryn Hess, Michael Jasinski, Gail Moede, Matthew Quitadamo, Jennifer Savoie, and Justin Slosky of the USGS for their assistance with the collection and analysis of data; Rob Reynolds and Ryan Poirier of TG & B Marine Services for providing a unique barge system and for their assistance with the collection of data; George Seaver and John York for their advice and local knowledge of the Red Brook Harbor area; and the Dimmick family for allowing access and drilling along the shoreline of the harbor.

FIELD INVESTIGATION AND RESULTS

A combination of onshore well drilling, groundwater sampling, geophysical logging, and offshore surveying of bulk electrical conductance and pore water sampling from temporary drive points, were used to determine freshwater and contaminant locations near and beneath Red Brook Harbor.

Ground-Water Quality

The leading edge of the LF-1 plume was previously defined by the analysis of the samples from six wells installed in 1996 (Operational Technologies Corporation, 1996). Five of the wells were installed along Red Brook Harbor Road (27MW0070, 27MW0068, 27MW0065, 27MW0071, and 27MW0083) and one well was installed at a site located on the south shore of Red Brook Harbor (27MW0082) (fig. 2). The LF-1 plume delineated in figure 2 represents the MCL exceedence (greater than 5 μg/L for TCE and PCE) during periodic sampling performed from June 1997 to November 1998 (Air Force Center For Environmental Excellence, 2000). Quarterly monitoring from March 1999 through January 2001 has shown TCE and PCE concentrations along Red Brook Harbor Road as high as 9.3 and 0.8 μg/L, respectively. TCE and PCE concentrations upgradient of Red Brook Harbor Road and downgradient of the remediation extraction wells were as high as 22.0 and 2.7 μg/L, respectively, in January 2001 (Air Force Center For Environmental Excellence, 2001).

The wells along Red Brook Harbor Road are about 600 ft from the shoreline. No vertical delineation of the plume in the Red Brook Harbor area had been done since the wells were installed in 1996. A vertical profile of TCE and PCE from well 27MW0065 in 1996 is shown in figure 4*A*.

To provide understanding of the plume closer to its potential discharge point, an observation well 2 in. in diameter and a multilevel sampler (MLS) were installed by hollow-stem augering at a site located as close to the shoreline as possible in May 2000 (site BHW 493, fig. 2). The 2-in-diameter well was completed with a 2-ft-long screen set to cover an interval from about 174 to 176 ft below sea level (table 1). The MLS was completed with 15 sampling ports set from about 28 to 176 ft below sea level; only 11 ports between 68 and 176 ft below sea level yielded water (table 1). Each port consists of polyethylene tubing of 0.17-in. inside diameter; the tubing extends from land surface to a nylon-fabric screen at the sampling depth (LeBlanc and others, 1991). A measuring point (MP) was established at the top of the observation well and surveyed to a known vertical datum at the top of well 27MW0065 (Operational Technologies Corporation, 1996).

The well and each port of the MLS exhibit intermittent flowing conditions at the land surface. Flows fluctuate with the changing tides. These flowing conditions indicate an upward hydraulic gradient at the shoreline and tidal influence on hydraulic heads throughout the aquifer near the harbor.

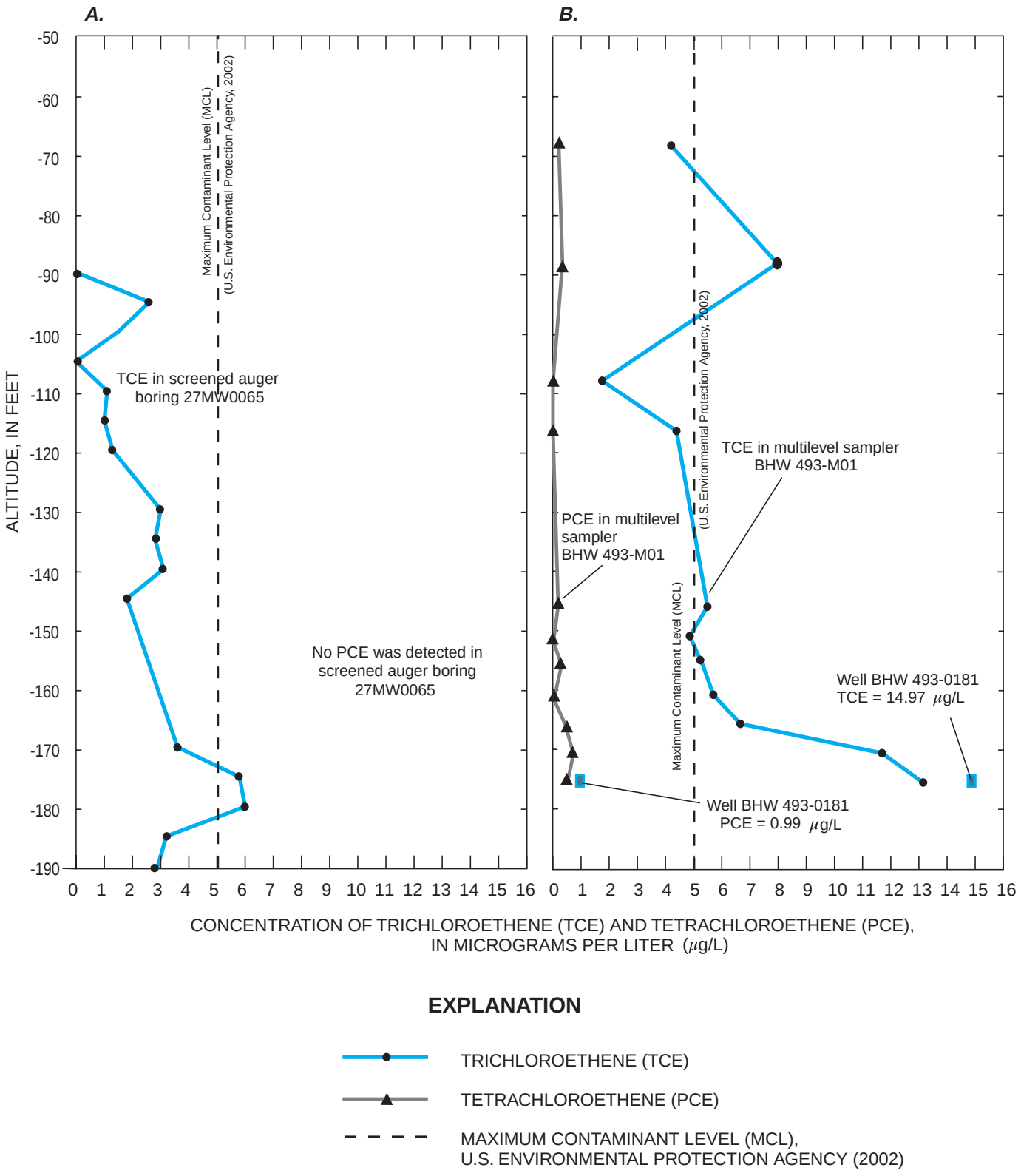


Figure 4. Vertical distribution of volatile organic compounds in (*A*) screened-auger boring 27MW0065, on Red Brook Harbor Road, February 1996 and (*B*) well BHW 493-0181 and multilevel sampler BHW 493-M01, on the shore of Red Brook Harbor, Cape Cod, Massachusetts, August 2000.

Table 1. Well-construction data and field water-quality analyses for well BHW 493-0181 and multilevel sampler BHW 493-M01, Cape Cod, Massachusetts, August 2000

[**Latitude and longitude**: In °, degrees; ′, minutes; and ″, seconds. **Altitude:** In feet above or (-) below sea level (NGVD of 1929). mg/L, milligram per liter; µS/cm, microsiemen per centimeter; --, no yield]

Well or multilevel-sampler-port identifier	Latitude ° ′ ″	Longitude ° ′ ″	Diameter of casing (inches)	Altitude of land surface (feet)	Altitude of middle of screen (feet)	Date sampled	Specific conduc-tance (µS/cm)	pH (standard units)	Temper-ature (degrees Celsius)	Oxygen, dissolved (mg/L)
MA-BHW 493-0181	41 40 16.49	70 37 04.77	2.00	4.85	-175.46	8-29-00	104	6.5	12.2	6.49
MA-BHW 493-M01-01PT	41 40 16.52	70 37 04.73	.17	5.10	-27.76	8-29-00	--	--	--	--
MA-BHW 493-M01-02GNT	41 40 16.52	70 37 04.73	.17	5.10	-47.74	8-29-00	--	--	--	--
MA-BHW 493-M01-03RT	41 40 16.52	70 37 04.73	.17	5.10	-67.72	8-29-00	142	6.2	12.6	2.77
MA-BHW 493-M01-04BUT	41 40 16.52	70 37 04.73	.17	5.10	-87.77	8-29-00	107	6.4	12.8	5.48
MA-BHW 493-M01-05BKT	41 40 16.52	70 37 04.73	.17	5.10	-107.81	8-29-00	132	6.1	13.5	6.04
MA-BHW 493-M01-06WT	41 40 16.52	70 37 04.73	.17	5.10	-116.33	8-29-00	148	6.7	--	4.40
MA-BHW 493-M01-07O	41 40 16.52	70 37 04.73	.17	5.10	-126.33	8-29-00	--	--	--	--
MA-BHW 493-M01-08GY	41 40 16.52	70 37 04.73	.17	5.10	-136.33	8-29-00	--	--	--	--
MA-BHW 493-M01-09Y	41 40 16.52	70 37 04.73	.17	5.10	-146.33	8-29-00	--	--	--	--
MA-BHW 493-M01-10P	41 40 16.52	70 37 04.73	.17	5.10	-151.33	8-29-00	112	6.6	--	5.20
MA-BHW 493-M01-11GN	41 40 16.52	70 37 04.73	.17	5.10	-156.33	8-29-00	104	6.4	14.3	6.14
MA-BHW 493-M01-12R	41 40 16.52	70 37 04.73	.17	5.10	-161.33	8-29-00	107	6.3	--	4.90
MA-BHW 493-M01-13BU	41 40 16.52	70 37 04.73	.17	5.10	-166.33	8-29-00	100	6.4	12.8	7.14
MA-BHW 493-M01-14BK	41 40 16.52	70 37 04.73	.17	5.10	-171.33	8-29-00	100	6.5	13.1	6.73
MA-BHW 493-M01-15W	41 40 16.52	70 37 04.73	.17	5.10	-176.33	8-29-00	101	6.5	14.4	5.34

Water samples were collected from the new well and MLS on August 29, 2000, for analysis of VOCs, nutrients, and trace metals. The 2-in. well was sampled with a submersible pump fitted with Teflon discharge tubing. The ports on the MLS were sampled with a peristaltic pump fitted with Norprene tubing. Sampling protocol and sample preservation methods are summarized in Savoie and LeBlanc (1998). EPA Method 8260B was used to analyze ground-water samples for the presence of 12 target VOCs at the Severn-Trent on-site laboratory at the MMR. The nutrient and trace-metal samples were analyzed at the USGS National Water Quality Laboratory in Lakewood, Colorado.

Results of the chemical analyses of the samples are given in figure 4*B* and tables 1–4. Eleven ports of the MLS yielded sufficient water for collection of a VOC sample; seven ports yielded sufficient water for collection of nutrient and trace-metal samples. TCE concentrations in the MLS ranged from 1.75 to 13.15 mg/L, whereas PCE concentrations ranged from "not detected" (below the detection limit of 0.195 µg/L) to 0.53 mg/L. The maximum concentrations in the MLS were observed at the same vertical location as the 2-in. well screen. TCE and PCE concentrations in the 2-in. well were 14.97 and 0.99 mg/L, respectively. Carbon tetrachloride was not detected in samples collected from the new well or MLS.

The physiochemical parameters (table 1) and concentrations of nutrients (table 2) and metals (table 3) are typical of uncontaminated ground water on Cape Cod (LeBlanc, 1984). The ground water in the sampled interval had a specific conductance of less than 150 microsiemens per centimeter (µS/cm), pH ranging from 6.1 to 6.7, dissolved-oxygen concentrations ranging from 3 to 6 milligrams per liter (mg/L), and nitrate concentrations less than 0.3 mg/L as nitrogen. No chemical indicators of the landfill plume, other than the VOCs, were evident from the analyses that were performed.

Geophysical Survey of Monitoring Wells

Natural-gamma and electromagnetic-induction geophysical logs were run in eight wells near Red Brook Harbor (fig. 2 and table 5). The natural-gamma logs record the vertical variation in the decay of naturally occurring radioactive elements, in counts per second; higher counts generally indicate finer-grained sediments. The electromagnetic-induction logs record the vertical variation in bulk electrical conductance of the formation outside the borehole in millisiemens per meter (mS/m); sediments saturated with freshwater typically have a conductance that is less than 100 mS/m. The logs were recorded digitally by use of a Mount Sopris recorder and logging tools. The application of borehole geophysics to characterize lithology and properties of the pore water is documented in the U.S. Geological Survey's Techniques of Water-Resources Investigations series (Keys and MacCary, 1971).

Table 2. Nutrient analyses of water samples collected from well BHW 493-0181 and multilevel sampler BHW 493-M01, Cape Cod, Massachusetts, August 2000

[Source of data: U.S. Geological Survey National Water Quality Laboratory. **Altitude:** In feet above or (-) below sea level (NGVD of 1929). mg/L, milligram per liter; <, actual value is less than value shown]

Well or multilevel-sampler-port identifier	Date sampled	Time	Altitude, middle of screen (feet)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrite + nitrate dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)
MA-BHW 493-0181	8-29-00	1200	-175.46	<0.010	0.253	<0.020	0.370
MA-BHW 493-M01-03RT	8-29-00	1620	-67.72	<.010	.122	<.020	.210
MA-BHW 493-M01-04BUT	8-29-00	1610	-87.77	<.010	.206	<.020	.270
MA-BHW 493-M01-05BKT	8-29-00	1530	-107.81	<.010	.289	<.020	<.010
MA-BHW 493-M01-11GN	8-29-00	1400	-156.33	<.010	.217	<.020	<.010
MA-BHW 493-M01-12R	8-29-00	1330	-161.33	<.010	.219	<.020	.031
MA-BHW 493-M01-14BK	8-29-00	1315	-171.33	<.010	.250	<.020	.035
MA-BHW 493-M01-15W	8-29-00	1300	-176.33	<.010	.245	<.020	.037

Table 3. Major cation and trace-metal analyses of water samples collected from well BHW 493-0181 and multilevel sampler BHW 493-M01, Cape Cod, Massachusetts, August 2000

[Source of data: U.S. Geological Survey National Water Quality Laboratory. **Altitude:** In feet above or (-) below sea level (NGVD of 1929). mg/L, milligram per liter; µg/L, microgram per liter; <, actual value is less than value shown]

Well or multilevel-sampler-port identifier	Date sampled	Time	Altitude, middle of screen (feet)	Calcium, dissolved (mg/L as Ca)	Barium, dissolved (µg/L as Be)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Chro-mium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)
MA-BHW 493-0181	8-29-00	1200	-175.46	5.4	3.9	<1.6	<8.0	<14	<13	<10	<10	<100	<4
MA-BHW 493-M01-03RT	8-29-00	1620	-67.72	6.2	7.4	<1.6	<8.0	<14	<13	<10	<10	<100	<4
MA-BHW 493-M01-04BUT	8-29-00	1610	-87.77	5.1	4.3	<1.6	<8.0	<14	<13	<10	<10	<100	<4
MA-BHW 493-M01-05BKT	8-29-00	1530	-107.81	3.7	6.5	<1.6	<8.0	<14	<13	<10	<10	<100	<4
MA-BHW 493-M01-11GN	8-29-00	1400	-156.33	4.3	4.5	<1.6	<8.0	<14	<13	<10	<10	<100	<4
MA-BHW 493-M01-12R	8-29-00	1330	-161.33	4.6	3.9	<1.6	<8.0	<14	<13	<10	<10	<100	<4
MA-BHW 493-M01-14BK	8-29-00	1315	-171.33	5.1	3.8	<1.6	<8.0	<14	<13	<10	<10	<100	<4
MA-BHW 493-M01-15W	8-29-00	1300	-176.33	5.2	4.1	<1.6	<8.0	<14	<13	<10	<10	<100	<4

Well or multilevel-sampler-port identifier	Date sampled	Time	Altitude, middle of screen (feet)	Magne-sium, dissolved (mg/L as Mg)	Manga-nese, dissolved (µg/L as Mn)	Molyb-denum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Sodium, dissolved (mg/L as Na)	Silica, dissolved (mg/L as SiO_2)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)
MA-BHW 493-0181	8-29-00	1200	-175.46	2.5	<2.2	<34	<40	10	15	<7.0	38	<10	<20
MA-BHW 493-M01-03RT	8-29-00	1620	-67.72	2.8	38.0	<34	<40	14	16	<7.0	48	<10	<20
MA-BHW 493-M01-04BUT	8-29-00	1610	-87.77	2.3	25.0	<34	<40	12	15	<7.0	38	<10	<20
MA-BHW 493-M01-05BKT	8-29-00	1530	-107.81	2.7	386.0	<34	<40	15	13	<7.0	36	<10	<20
MA-BHW 493-M01-11GN	8-29-00	1400	-156.33	2.0	255.0	<34	<40	11	14	<7.0	35	<10	<20
MA-BHW 493-M01-12R	8-29-00	1330	-161.33	2.1	2.4	<34	<40	11	14	<7.0	35	<10	<20
MA-BHW 493-M01-14BK	8-29-00	1315	-171.33	2.3	2.9	<34	<40	10	15	<7.0	37	<10	<20
MA-BHW 493-M01-15W	8-29-00	1300	-176.33	2.4	3.0	<34	<40	9.7	15	<7.0	37	<10	<20

Table 4. Volatile organic compound analyses of water samples collected from well BHW 493-0181 and multilevel sampler BHW 493-M01, Cape Cod, Massachusetts, August 2000

[Source of data: Severn Trent Laboratories. Shaded values indicate concentration greater than maximum contaminant level (MCL), set by U.S. Environmental Protection Agency. **Altitude:** In feet above or (-) below sea level (NGVD of 1929). mg/L, milligram per liter; µg/L, microgram per liter; <, actual value is less than value shown]

Well or multilevel-sampler-port identifier	Date	Altitude, middle of screen (feet)	1,1-Di-chloroethene (µg/L)	*trans*-1,2-Di-chloroethene (µg/L)	*cis*-1,2-Di-chloroethene (µg/L)	Tri-chloroethene (µg/L)	Carbon tetrachloride (µg/L)
MA-BHW 493-0181	8-29-00	-175.46	<0.233	<0.166	<0.157	<0.205	<0.128
MA-BHW 493-M01-03RT	8-29-00	-67.72	<.233	<.166	<.157	<.205	<.128
MA-BHW 493-M01-04BUT	8-29-00	-87.77	<.233	<.166	<.157	<.205	<.128
MA-BHW 493-M01-05BKT	8-29-00	-107.81	<.233	<.166	<.157	<.205	<.128
MA-BHW 493-M01-06WT	8-29-00	-116.33	<.233	<.166	<.157	<.205	<.128
MA-BHW 493-M01-09Y	8-29-00	-146.33	<.233	<.166	<.157	<.205	<.128
MA-BHW 493-M01-10P	8-29-00	-151.33	<.233	<.166	<.157	<.205	<.128
MA-BHW 493-M01-11GN	8-29-00	-156.33	<.233	<.166	<.157	<.205	<.128
MA-BHW 493-M01-12R	8-29-00	-161.33	<.233	<.166	<.157	<.205	<.128
MA-BHW 493-M01-13BU	8-29-00	-166.33	<.233	<.166	<.157	<.205	<.128
MA-BHW 493-M01-14BK	8-29-00	-171.33	<.233	<.166	<.157	<.205	<.128
MA-BHW 493-M01-15W	8-29-00	-176.33	<.233	<.166	<.157	<.205	<.128

Well or multilevel-sampler-port identifier	Date	Altitude, middle of screen (feet)	Benzene (µg/L)	Trichloro-ethene (µg/L)	Toluene (µg/L)	Tetrachloro-ethene (µg/L)	Ethyl-benzene (µg/L)	*m&p*-Xylene (µg/L)	*o*-Xylene (µg/L)
MA-BHW 493-0181	8-29-00	-175.46	<0.354	14.97	<0.210	[1]0.99	<0.196	<0.530	<0.245
MA-BHW 493-M01-03RT	8-29-00	-67.72	<.354	4.20	<.210	[1].21	<.196	<.530	<.245
MA-BHW 493-M01-04BUT	8-29-00	-87.77	<.354	7.97	<.210	[1].34	<.196	<.530	<.245
MA-BHW 493-M01-05BKT	8-29-00	-107.81	<.354	1.75	<.210	<.195	<.196	<.530	<.245
MA-BHW 493-M01-06WT	8-29-00	-116.33	<.354	4.39	<.210	<.195	<.196	<.530	<.245
MA-BHW 493-M01-09Y	8-29-00	-146.33	<.354	5.49	<.210	[1].21	<.196	<.530	<.245
MA-BHW 493-M01-10P	8-29-00	-151.33	<.354	4.86	<.210	<.195	<.196	<.530	<.245
MA-BHW 493-M01-11GN	8-29-00	-156.33	<.354	5.33	<.210	[1].31	<.196	<.530	<.245
MA-BHW 493-M01-12R	8-29-00	-161.33	<.354	5.70	<.210	<.195	<.196	<.530	<.245
MA-BHW 493-M01-13BU	8-29-00	-166.33	<.354	6.66	<.210	[1].45	<.196	<.530	<.245
MA-BHW 493-M01-14BK	8-29-00	-171.33	<.354	11.69	<.210	[1].72	<.196	<.530	<.245
MA-BHW 493-M01-15W	8-29-00	-176.33	<.354	13.15	<.210	[1].53	<.196	<.530	<.245

[1]Estimated value.

Table 5. Well-construction data for natural-gamma and electromagnetic-induction geophysical logging, Cape Cod, Massachusetts, August 2000

[Locations shown in figure 2. **Latitude and longitude**: In °, degrees; ′, minutes; and ″, seconds. **Altitude:** In feet above or (-) below sea level (NGVD of 1929). EM, electromagnetic induction]

Well No.	Latitude ° ′ ″	Longitude ° ′ ″	Land-surface altitude (feet)	Depth to water (feet)	Water-level altitude (feet)	Date logged	Logging performed	Total depth logged (feet)
BHW 493-0181	41 40 16	70 37 05	4.85	tidal	tidal	5-08-00	Natural Gamma/EM	180.3
27MW0065	41 40 11	70 37 02	15.47	6.68	8.79	3-24-96	Natural Gamma/EM	195.7
27MW0068	41 40 17	70 36 57	[1]22.5	10.85	11.7	8-08-00	Natural Gamma/EM	194.7
27MW0070	41 40 19	70 36 56	[1]26	13.57	12	8-08-00	Natural Gamma/EM	151.8
27MW0071	41 40 04	70 37 07	[1]40	35.69	4	8-08-00	Natural Gamma/EM	166.0
27MW0082	41 40 10	70 37 20	[1]13	tidal	tidal	8-08-00	Natural Gamma/EM	181.3
27MW0083	41 40 00	70 37 08	37.20	31.28	5.92	8-08-00	Natural Gamma/EM	185.4
GB-21	41 39 46	70 37 53	[1]4	tidal	tidal	8-08-00	Natural Gamma/EM	125.4

[1]Estimated value.

The natural-gamma logs (fig. 5) indicate some variations in sediment grain size with depth. For example, a zone interpreted to consist of finer-grained sediments is evident between 75 and 110 ft below sea level in well BHW 493-0181 at the shoreline of Red Brook Harbor. The sediments deeper than 60 ft below sea level at well GB-21, on the causeway to Scraggy Neck (fig. 2), also appear to be finer grained than the shallower sediments. The natural-gamma logs generally indicate, however, that coarse-grained sediments are present deep within the aquifer (greater than 150 ft below sea level) at most locations near the harbor.

The electromagnetic-induction logs indicate that fresh ground water is present at least to the full depths of the wells, except for wells 27MW0082 and GB-21. At well 27MW0082, near the southern shore of the harbor (fig. 2), there is a sharp transition between fresh and saline ground water between 100 and 110 ft below sea level (fig. 5). At well GB-21, at the eastern end of the causeway to Scraggy Neck (fig. 2), saline water was detected throughout the vertical section. Fresh ground water is present to at least an altitude of 176 ft below sea level at well BHW 493-0181, which is only 75 ft from the shoreline.

Survey of Bulk Electrical Conductance of Harbor-Bottom Sediments

Profiles of the bulk electrical conductance of the sediments beneath the harbor bottom were obtained at 62 locations (fig. 6). The data were collected using the Geoprobe Direct Image Soil Conductivity System, which consists of a drive point fitted with an electrical conductance sensor. The point was driven into the sandy sediments in successive intervals. At each interval, a direct reading of the bulk electrical conductance of the water-saturated sediments was displayed on a computer connected to the system at the surface. The point was advanced until fresh ground water was encountered or until the point could not be driven any farther into the sediments. A record also was kept of the thickness of the soft sediments at each site, which was determined by recording the vertical distance between the harbor bottom and the depth at which the point could no longer be pushed downward without the use of a driving hammer. Tables 6 and 7 (at back of the report) include the data obtained during the profiling. A map that summarizes the results is shown in figure 7, and graphs of selected profiles are shown in figure 8.

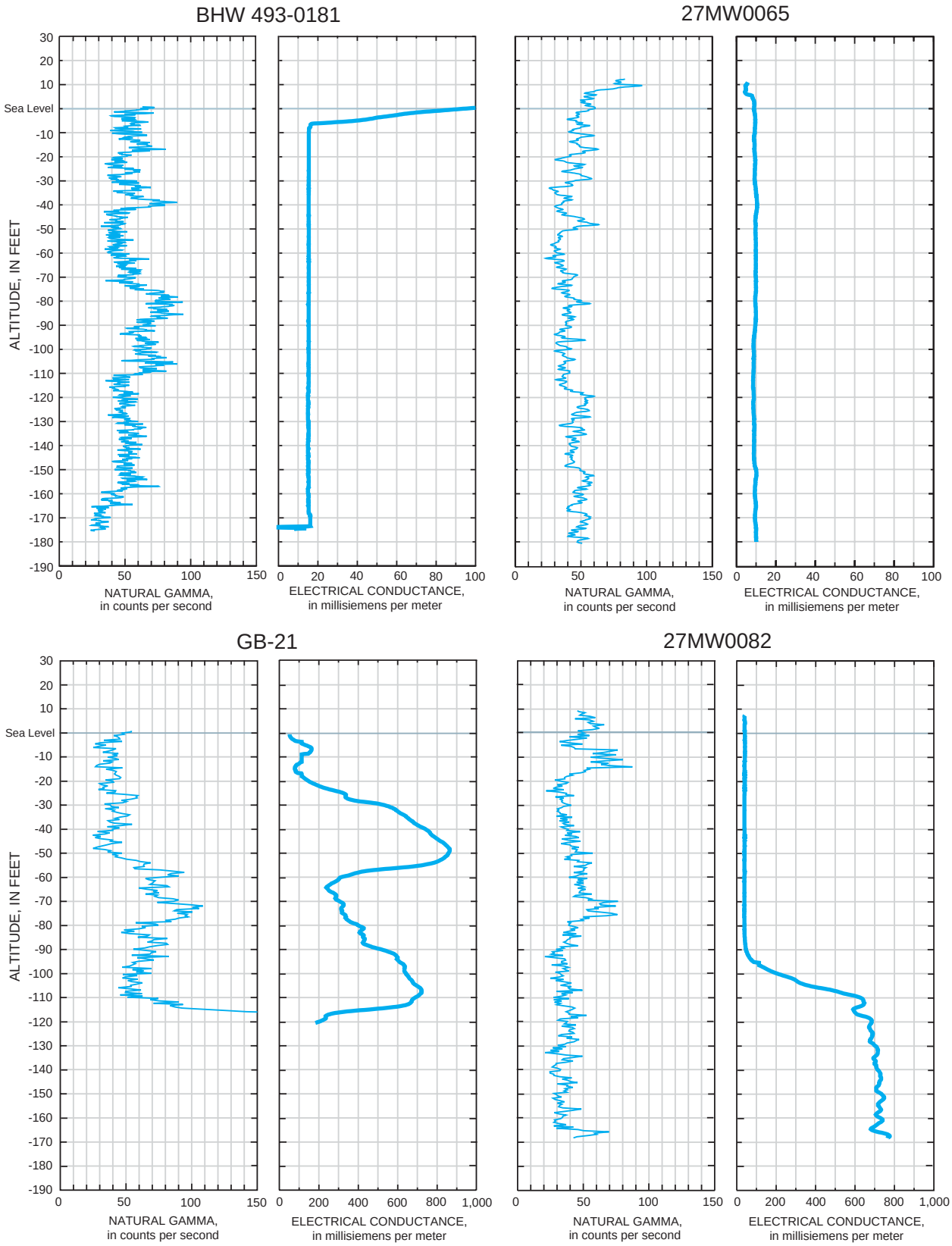


Figure 5. Natural gamma and electromagnetic-induction logs from wells near Red Brook Harbor, Cape Cod, Massachusetts, August 2000.

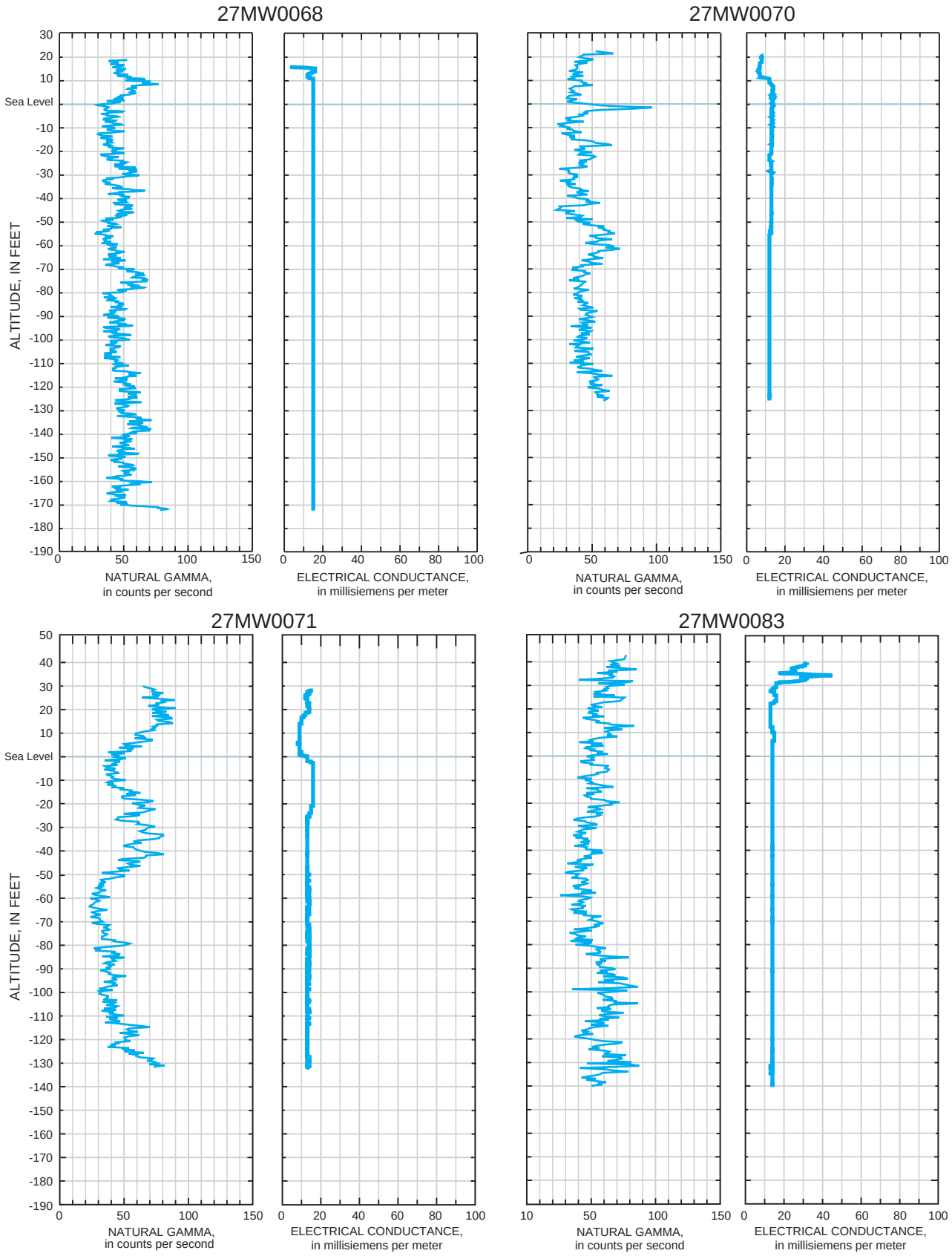


Figure 5. Natural gamma and electromagnetic-induction logs from wells near Red Brook Harbor, Cape Cod, Massachusetts, August 2000—*Continued*.

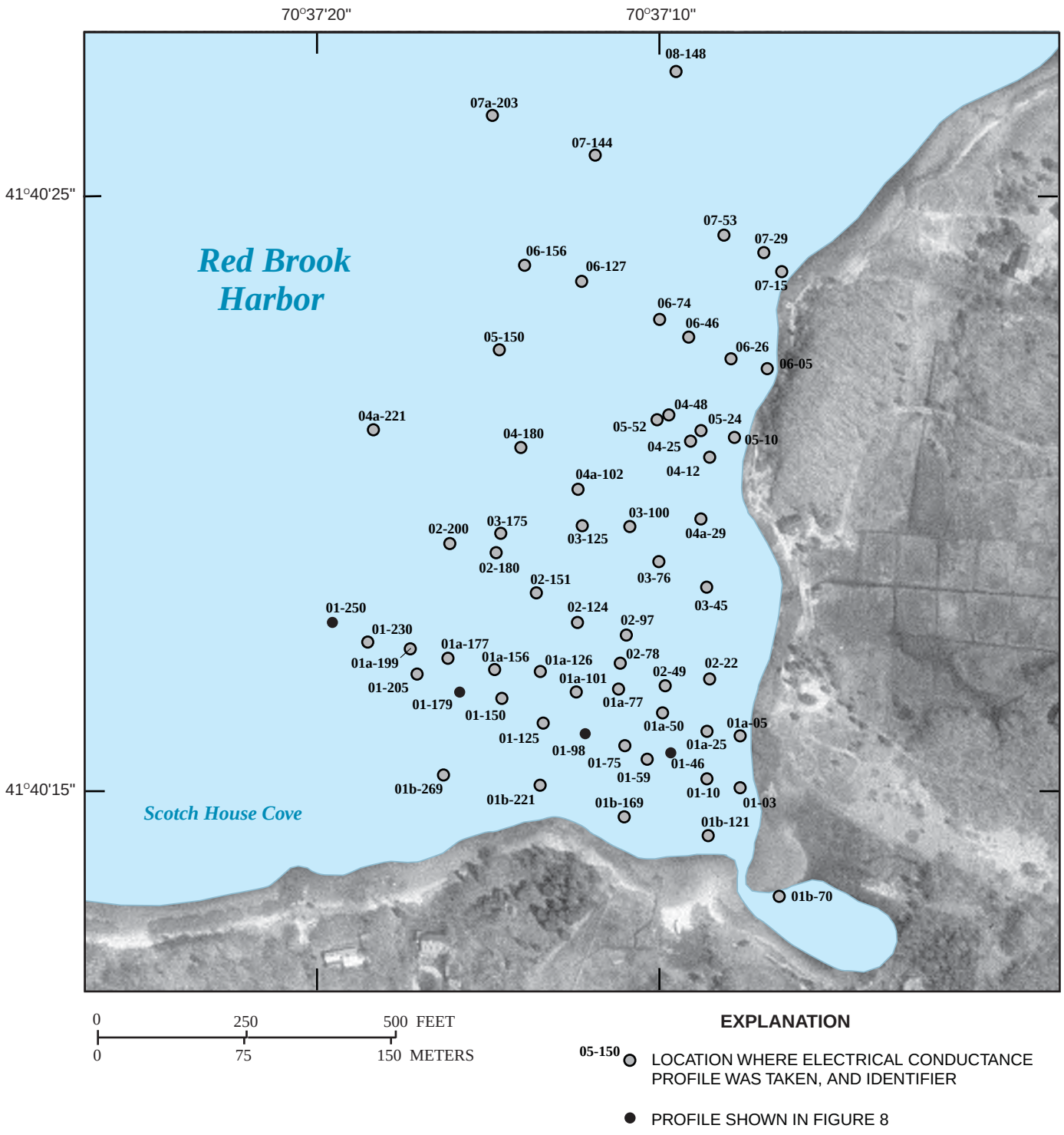


Figure 6. Locations of sites where electrical conductance profiles were taken in sediments beneath Red Brook Harbor, Cape Cod, Massachusetts, August 2000.

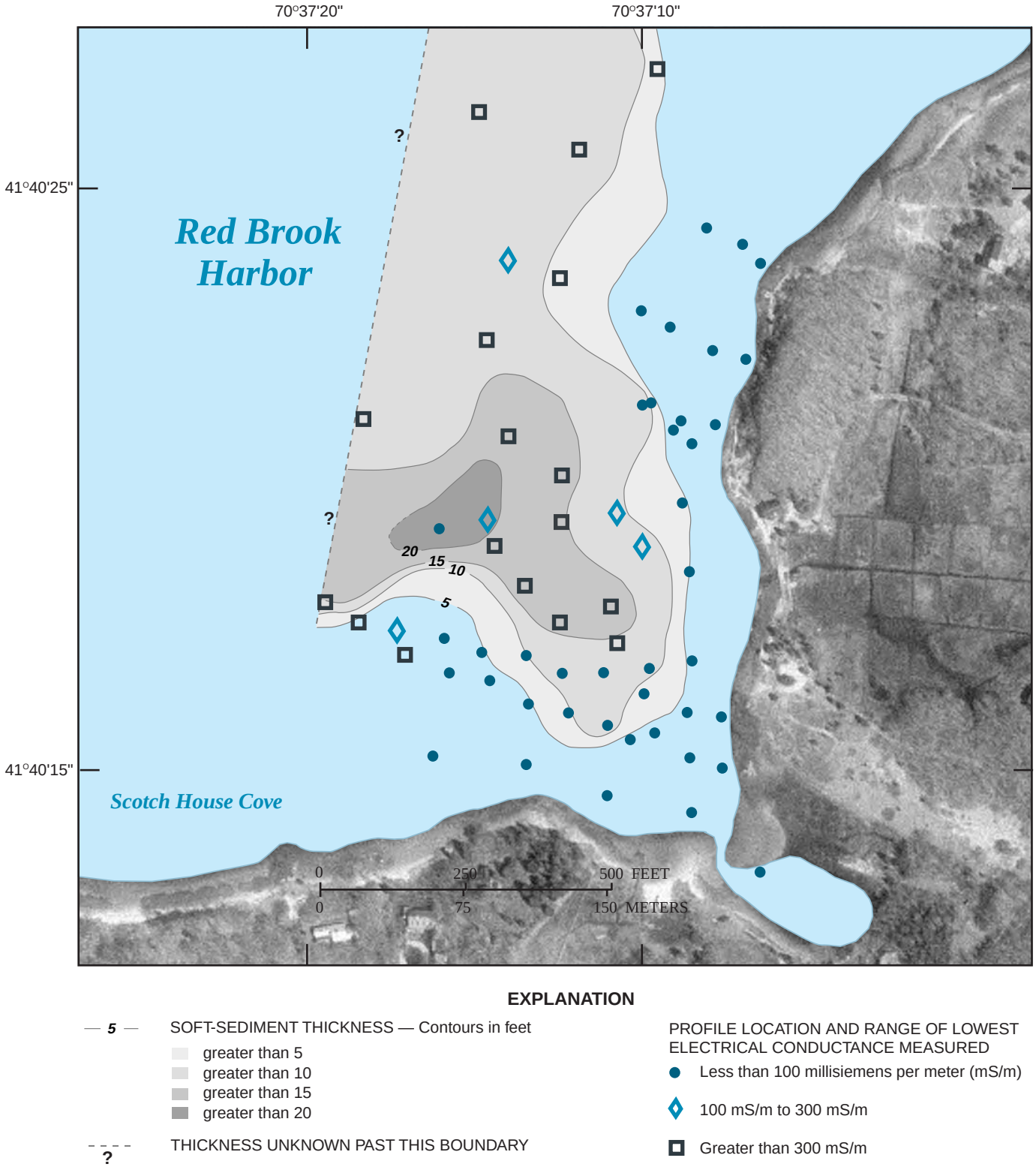


Figure 7. Lowest bulk electrical conductance measured at profile sites, and contoured thickness of soft sediments, Red Brook Harbor, Cape Cod, Massachusetts, August 2000.

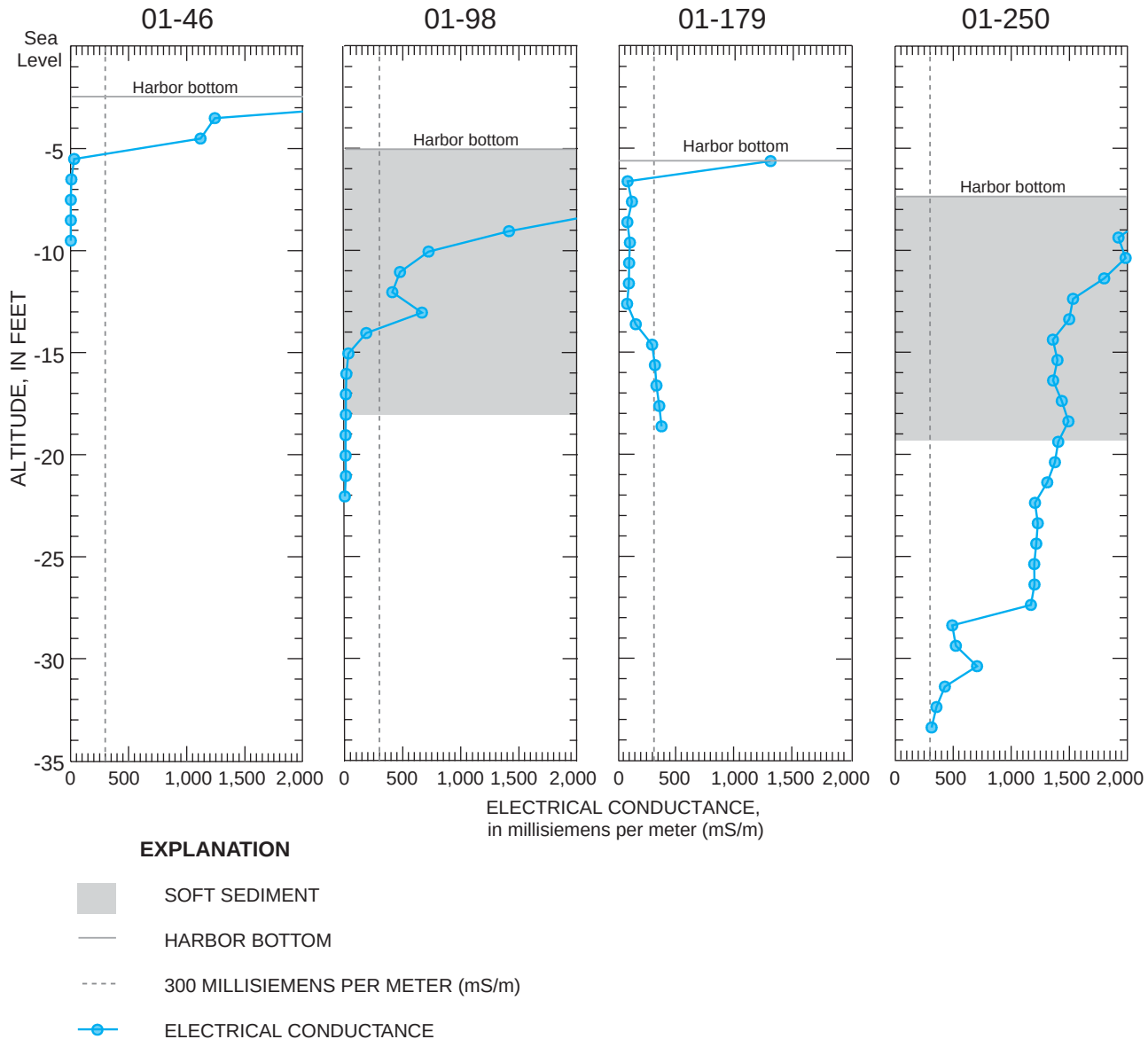


Figure 8. Vertical electrical conductance profiles from beneath Red Brook Harbor, Cape Cod, Massachusetts. Electrical conductance below 300 mS/m is considered fresh or brackish water. (Locations of temporary profiles are shown in fig. 6.)

All on-harbor work was done from a 15-ft-by-15-ft barge that provided a mobile and stable work platform that could accommodate the use of heavy power equipment in conditions of changing tides and weather. To anchor the barge, two 25-ft steel pipes were lowered into the harbor-bottom sediment. When the barge was moved to the next sampling station, the pipes were raised and an attached motorboat pushed the barge.

Measurement stations were located with the use of a global positioning system (GPS). Vertical control was provided by a recording tide gage that was installed temporarily for this effort. An MP was established at the recording tide gage by differential surveying to shoreline well BHW 493-0181. The time of each measurement and depth of water at each station were correlated with the tide-gage record to convert recorded depths below the water surface at each station to altitudes above mean sea level.

Profiles were obtained on the southeastern side of Red Brook Harbor in an area locally known as Scotch House Cove. The measurement stations generally are along transects extending northwestward from the shoreline; deviations from these transects were made in the field to avoid moored boats in the area.

The electrical conductance at each measurement point represents the bulk electrical conductance, in millisiemens per meter, of the water-saturated sediments. The electrical conductance is affected by the pore-fluid conductivity, lithology, and the porosity (water content) of the sediments (Archie, 1942). Several experiments were conducted to determine the response of the electrical conductance sensor in sand containing water with various salinities. On the basis of these experiments, criteria were developed to interpret the field measurements. Electrical conductivities greater than 300 mS/m were interpreted as saltwater-saturated sediments (salinity greater than 15 parts per thousand (ppt)); conductivities of 100–300 mS/m were interpreted as brackish-water-saturated sediments (salinity ranging from about 1.4 to 15 ppt); and conductivities less than 100 mS/m were interpreted as freshwater-saturated sediments (salinity less than 1.4 ppt) (Robinove and others, 1958). These criteria were based on a porosity of about 0.40 (sand). Higher-porosity sediment, such as silts and clays, would be expected to have higher electrical conductivity (Archie, 1942).

Examples of electrical conductance profiles are shown on fig. 8 (profiles 01-46 to 01-250; locations shown on fig. 6) to illustrate the general features that were observed at most of the measurement sites. The electrical conductance usually was greater than 300 mS/m in the first several feet below the harbor bottom. Where the soft sediments are thick, a gradual decrease in conductance often was observed with increasing depth through the sediments. The lowest conductance generally was found below the soft sediments, where they were present, or at least several feet into the bottom where the soft sediments were thin or absent.

The results of the electrical conductance profiling are summarized in figure 7. The symbols represent the lowest electrical conductance value that was observed at each site. The depth, or altitude, of the lowest value varied from site to site and depended on the distance from shore and the thickness of the soft sediment. Conductance values indicative of freshwater-saturated sediments were obtained at most sites within about 250 ft from shore. At locations farther from shore, with one exception (site 02-200), conductance values indicative of freshwater were not obtained within the depth range of the profiling device.

The thickness of the soft sediments, as determined by ease of penetration of the drive point, varied from less than 1 ft to more than 20 ft. An area of thick soft sediments was observed in the center of the sampled area (fig. 7). Conductance values indicative of freshwater-saturated sediments were measured in this area at site 02-200 (fig. 6) in sandy sediments beneath 24 ft of soft sediments. At some locations, lower conductance values were measured within the soft sediments.

The data summarized in figure 7 indicate that fresh ground water is present at least as far as 450 ft from shore on the southeastern side of Red Brook Harbor. The freshwater is near the harbor bottom in the areas closest to shore. This observation is consistent with the hypothesis that most of the fresh ground water discharges near shore, with the shallowest ground water discharging to the harbor closest to shore. The data also suggest that the veneer of soft sediments beneath the harbor may cause the deeper ground water to discharge farther from shore.

Point Measurements of VOC Concentrations in Pore Water from Harbor-Bottom Sediments

The electrical-conductance results were used to select 19 locations at which water samples were collected for VOC analysis from the sandy sediments beneath Red Brook Harbor (fig. 9). TCE concentrations measured in these samples are shown in figure 10. Most of the sampling sites are located within 250 ft from shore because of the presence of fresh ground water in this zone.

From aboard the mobile barge, a Geoprobe Systems temporary well point was used to obtain the samples. The well point consisted of a steel drive pipe, an expendable point, and an internal stainless steel well screen. The assembly was driven to the desired depth by hand or with the aid of an electric-percussion hammer, then the driving pipe was pulled back to expose the screen. The expendable point was left permanently in the sediments. The assembly was driven to a depth at which freshwater-saturated sediments had been indicated by the electrical conductance profiles. After the screen was exposed, a 3/16-in-diameter Teflon tube was slipped down the inside of the drive pipe into the screened interval, and a peristaltic pump was used to pump up ground water. Samples were collected after a sufficient volume of water was pumped to purge the well point and to ensure that no contamination from previous sampling was present. Results are summarized in table 8 (at back of the report).

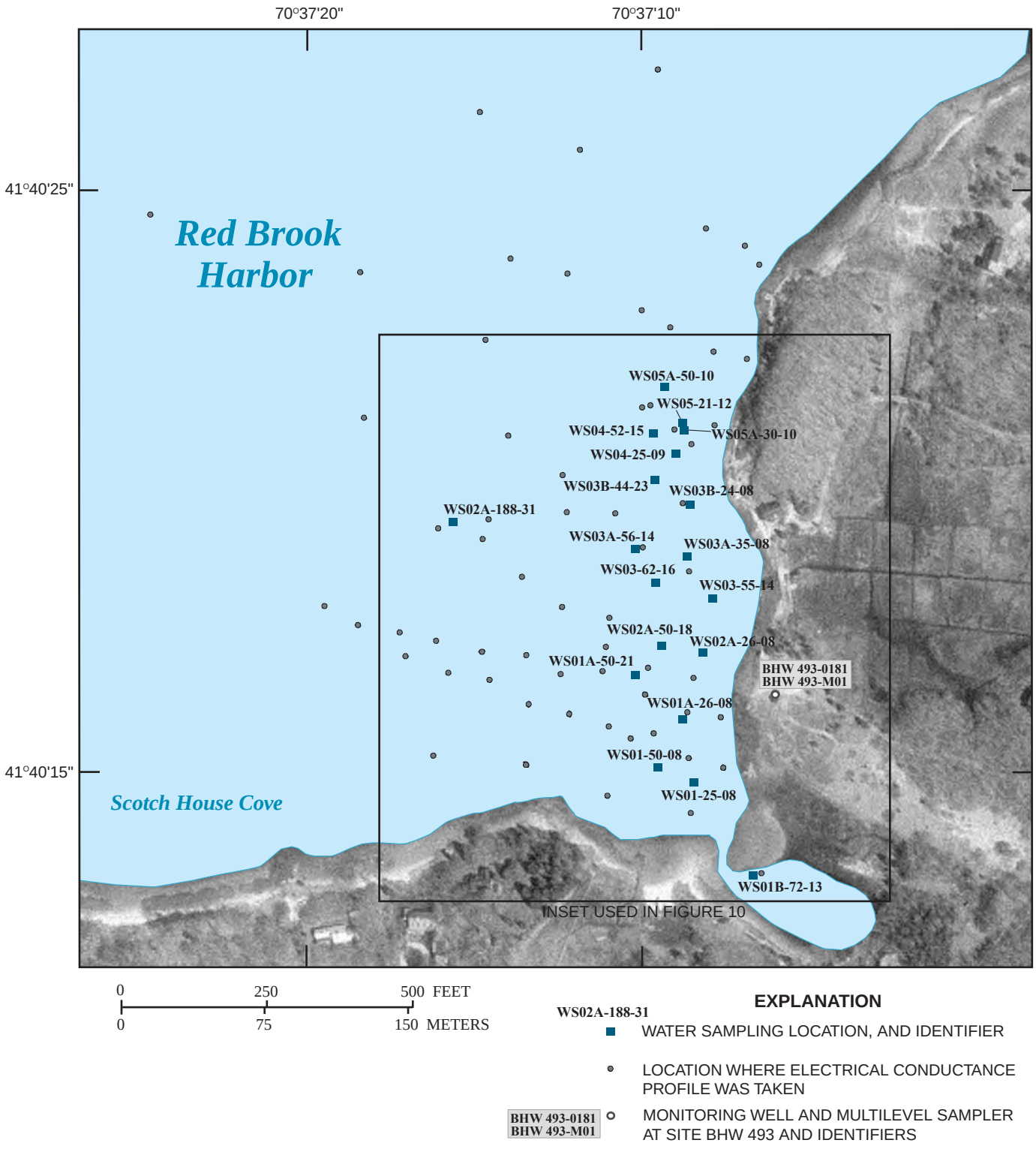


Figure 9. Locations and site identifiers for pore-water samples collected from temporary well points beneath Red Brook Harbor, Cape Cod, Massachusetts, August 2000.

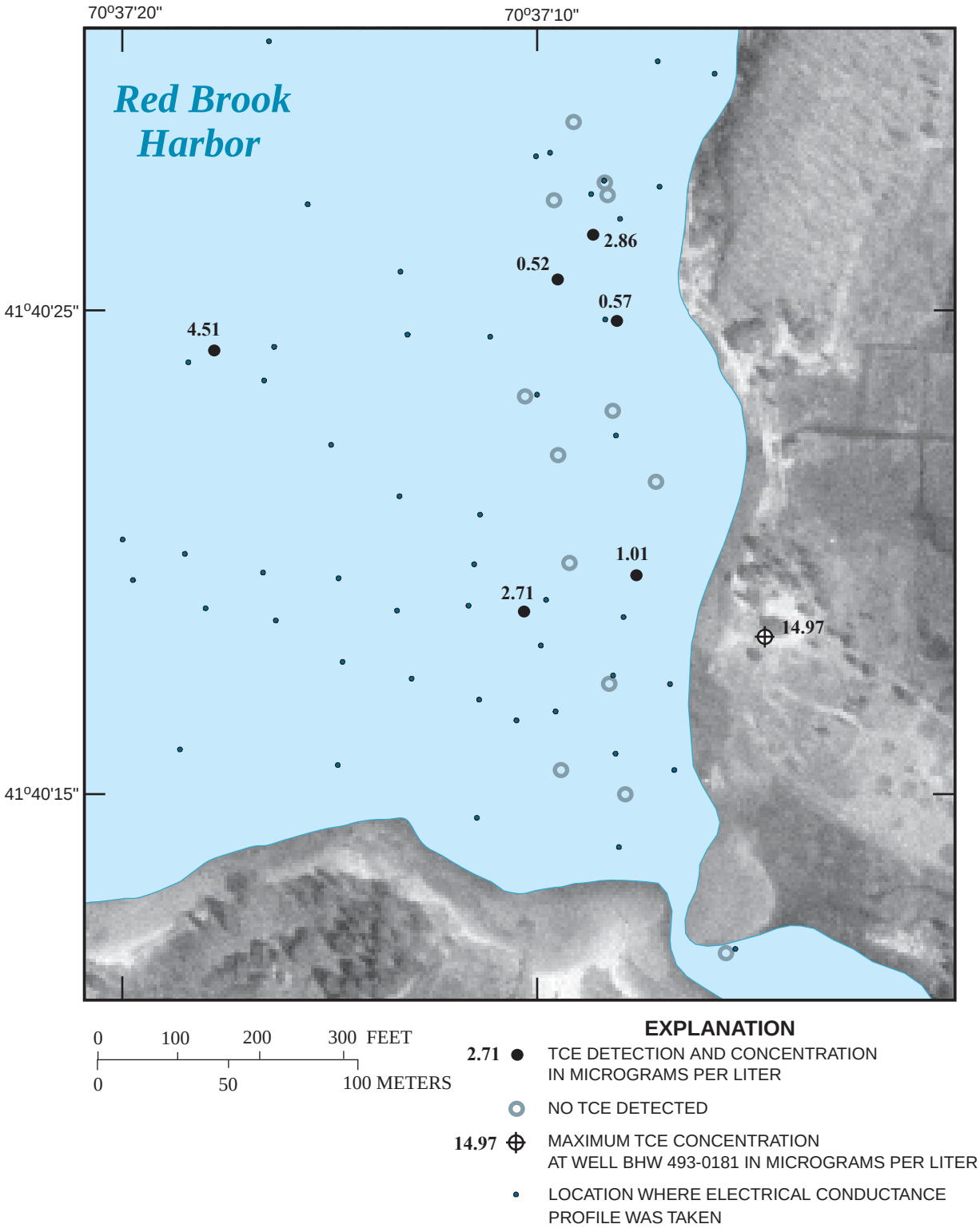


Figure 10. Concentrations of trichloroethene measured in pore-water samples collected from temporary well points beneath Red Brook Harbor, Cape Cod, August 2000.

Altitude control was obtained by the same method used for the electrical-conductance profiles. The depth to which the point was driven varied from site to site; the depth depended on the electrical-conductance data and the ability to drive the point into the sediments. Therefore, the data do not come from a common elevation horizon or depth below the harbor bottom. In all cases, however, the samples were obtained from the coarse-grained sediments beneath the soft sediments. Water could not be obtained directly from the soft sediments, which had the consistency of soft, wet clay and were almost black.

TCE was detected at six of the 19 sites. PCE was not detected in any of the samples. The maximum concentration of TCE at the five sites within 250 ft from shore was 2.86 mg/L. A water sample that had 4.51 µg/L TCE was obtained near electrical-conductance profile 02-200, which is the site where freshwater was detected beneath the area of thickest soft sediment (figs. 6 and 7), at an altitude of about 38 ft below sea level, or about 32 ft below the harbor bottom. Specific conductance of the water samples ranged from 156 µS/cm to 14,340 µS/cm (table 8). The specific conductance of the harbor seawater, measured from a grab sample at the surface, was greater than 40,000 µS/cm. This indicates that the water samples from beneath the harbor ranged from fresh to brackish conditions. Dissolved-oxygen concentrations in all but one of the water samples collected from the 19 sites (table 8) were less than 0.5 mg/L.

DETECTION OF FRESH GROUND WATER BENEATH RED BROOK HARBOR

The electrical-conductance profiles and water samples from beneath Red Brook Harbor indicate that fresh ground water extends at least 450 ft from the shoreline beneath the southeastern side of the harbor. Freshwater was consistently detected in the shallow sediments within 250 ft from shore. These data, along with field observations of seeps and springs near the shoreline, suggest that significant ground-water discharge occurs close to shore. The discharge location of the fresh ground water that was observed 450 ft from shore beneath 24 ft of soft sediment cannot be determined from the data obtained in this study.

The soft sediments mapped during electrical-conductance profiling may act as a low-permeability cap that impedes the upward flow of fresh ground water and causes it to discharge farther from shore than if the sediments were thin or absent. Conductance results from deep in the soft sediments at some locations indi-cate fresh or brackish water, suggesting the diffusion or slow mixing of fresh ground water from the aquifer into the soft-sediment layer.

At many sites, particularly those farther from shore where freshwater was encountered at depth (e.g., site 01-179, fig. 6 and fig. 8), there is also evidence of tidal pumping and mixing. Tidal pumping occurs when seawater flows into the sediments and mixes with discharging fresh ground water at high tide. As the tide recedes, the mixture discharges into the surface waters. Close to shore at Red Brook Harbor, the hydraulic head in the freshwater aquifer is greater than that in the shallow seawater above; therefore, the mixing process is inhibited, and freshwater can be detected within a foot of the harbor bottom. Farther from shore, however, particularly where soft sediments are present, the hydraulic head in the sediments is lower, and the head in the seawater above can be greater than the head in the sediments at high tide, causing seawater to flow into the sediments. This tidally-dependent flow varies greatly with tidal variations, the depth of the saltwater, distance from shore, and the nature of the bottom sediments. Therefore, the vertical location of freshwater varies considerably from site to site. This is consistent with the field observations of Robinson and others (1998), which showed that ground-water discharge rates to a coastal system are generally inversely correlated with tidal activity, exhibit significant spatial variation, and decrease rapidly offshore.

DETECTION OF THE CONTAMINANT PLUME UPGRADIENT FROM AND BENEATH RED BROOK HARBOR

The VOC data obtained from the new wells near the shore of Red Brook Harbor (BHW 493) and the well points driven into the harbor bottom indicate that the northern lobe of the LF-1 plume has reached the harbor. TCE has been present consistently at concentrations of 6 to 9.3 µg/L in well 27MW0065 since it was installed in 1996 (Air Force Center for Environmental Excellence, written commun., 2001). The profile of TCE and PCE concentrations at the BHW 493 wells is similar to the profile obtained during the drilling of 27MW0065. Both sets of data indicate that TCE can be

detected in a 100-ft-thick zone near the coast, with the highest concentration, about 15 μg/L, near the bottom of the aquifer more than 170 ft below sea level.

The presence of TCE and PCE at the shoreline in a zone that is more than 100 ft thick indicates that the contaminants could discharge over a wide range of distances from shore. The shallowest ground water discharges closest to shore, and uncontaminated ground water above the zone of solvents may be the source of water to the seeps and springs along the shoreline that are sampled regularly by AFCEE. Contaminants related to the LF-1 plume have not been detected to date in these features (Air Force Center for Environmental Excellence, 2001). Some of the water discharging within 250 ft of shore may originate from the upper part of the solvents zone, as is suggested by data from the five sites where TCE was detected at low concentrations (less than 3 μg/L) in pore water from the sediments a few feet below the harbor bottom. The deeper parts of the solvents zone may discharge farther offshore. The detection of the highest concentration of TCE observed beneath the harbor (4.5 μg/L at about 38 ft below sea level) at the sampling site farthest from shore is consistent with this hypothesis; however, the sampling points were too widely spaced to allow the determination of a spatial distribution of TCE concentrations in the bottom sediments.

The data do not indicate whether TCE and PCE are present in the water as it discharges to the harbor. Because the soft sediments were present at most sampling sites, it was not possible to obtain samples for analysis in the first few centimeters of the bottom sediments. Even if TCE and PCE are present in the ground water just before it discharges to the harbor, it is unlikely that the compounds could be detected in the ocean water. The electrical conductance profiles suggest that some mixing of seawater and ground water occurs in the top several feet of bottom sediments because of tidal pumping and density differences between the surface water and ground water, which would dilute concentrations before discharge. The recently completed study of two nearby VOC-containing plumes where they discharge to a quiescent freshwater pond indicate orders of magnitude of dilution in the pond water within a few centimeters of the bottom (Savoie and others, 2000). Given the strong tidal currents and low concentrations of TCE in the LF-1 plume at Red Brook Harbor, TCE concentrations in the ocean would be rapidly diluted to below-detection levels.

Biodegradation of VOCs as they pass through the organically enriched bottom sediments may also explain why detections of contaminants in the harbor-bottom sediments (maximum 4.51 μg/L) are not seen at levels equivalent to the detections in the wells along the shore (maximum 14.97 μg/L). No TCE degradation products, such as dichloroethene (DCE), were detected in any pore-water samples, suggesting that a transformation of PCE and TCE in this organic-rich sediment to ethene or carbon dioxide may occur.

SUMMARY

The U.S. Geological Survey, in cooperation with the Air Force Center for Environmental Excellence, performed a field investigation to determine if and where the Landfill-1 (LF-1) plume from the Massachusetts Military Reservation is discharging to Red Brook Harbor. Trichloroethene and tetrachloroethene were detected in two new wells installed at the shoreline where the LF-1 plume intersects Red Brook Harbor. The solvents were detected in a vertical interval from about 68 to 176 ft below sea level. The highest concentrations, about 15 mg/L TCE and 1 mg/L PCE, were measured at about 176 ft below sea level. The concentrations of nutrients, such as nitrate and ammonium, and trace metals, such as iron and manganese, in the plume at the shoreline are typical of uncontaminated ground water on Cape Cod.

A comprehensive survey of electrical conductance of harbor-bottom sediments indicated that fresh ground water is present beneath the southeastern side of Red Brook Harbor at 40 of 48 sampling locations within about 250 ft of the shoreline. Fresh ground water also was detected at one location 450 ft from shore. The survey showed that the harbor bottom is comprised of soft sediments that vary greatly in thickness (from less than 1 ft to greater than 20 ft) and overlie sandy aquifer materials. The soft sediments may act as a low-permeability cap on the harbor bottom and cause some freshwater to discharge farther seaward under the harbor than would otherwise be the case.

Temporary-drive-point sampling from sandy sediments underlying the harbor bottom showed that TCE was present at several locations in the fresh ground water beneath the harbor. The highest concentration, about 4.5 mg/L, was measured at a location about 450 ft from shore, in the vicinity of the most seaward freshwater. Significant tidal pumping within the harbor-bottom sediments may dilute TCE concentrations before discharge to the harbor.

REFERENCES CITED

Air Force Center for Environmental Excellence, 1999, Landfill-1 (LF-1) source and plume update: AFCEE Fact Sheet no. 99-06, 5 p.

Air Force Center for Environmental Excellence, 2000, Landfill-1 ecological baseline characterization report, 1999: Jacobs Engineering Group, Inc., v. 1, variously paged.

Air Force Center for Environmental Excellence, 2001, Landfill-1 quarterly system performance and ecological impact monitoring report, December 2000—February 2001: Jacobs Engineering Group, Inc., variously paged.

Archie, G.E., 1942, The electrical resistivity log as an aid in determining some reservoir characteristics: Transactions of the Society of Petroleum Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, v. 146, p. 54–62.

Barlow, P.M., 2000, Atlantic Coastal Zone: U.S. Geological Survey Fact Sheet 085-00, 4 p.

Keys, W.S., and MacCary, L.M., 1971, Application of borehole geophysics to water-resources investigations: U.S. Geological Survey Techniques for Water-Resources Investigation, book 2, chap. E1, 126 p.

LeBlanc, D.R., 1984, Sewage plume in a sand and gravel aquifer, Cape Cod, Massachusetts: U.S. Geological Survey Water-Supply Paper 2218, 28 p.

LeBlanc, D.R., Garabedian, S.P., Hess, K.H., Gelhar, L.W., Quadri, R.D, Stollenwerk, K.G., and Wood, W.W., 1991, Large-scale natural-gradient tracer test in sand and gravel, Cape Cod, Massachusetts—1. Experimental design and observed tracer movement: Water Resources Research, v. 27, no. 5, p. 895–910.

Masterson, J.P., Walter, D.A., and LeBlanc, D.R., 1998, Delineation of contributing areas to selected public-supply wells, western Cape Cod, Massachusetts: U.S. Geological Survey Water-Resources Investigation Report 98-4237, 42 p.

National Oceanic and Atmospheric Administration, 1993, South coast of Cape Cod and Buzzards Bay, Massachusetts, nautical chart 13229 (25th ed.): National Oceanic and Atmospheric Administration, variously paged.

Operational Technologies Corporation, 1996, Plume containment design data gap fieldwork technical memorandum: Operational Technologies Corporation, v. 1, variously paged.

Robinove, C.J., Langford, R.H., and Brookhart, J.W., 1958, Saline-water resources of North Dakota: U.S. Geological Survey Water-Supply Paper 1428, 72 p.

Robinson, M., Gallagher, D., and Reay, W., 1998, Field observations of tidal and seasonal variations in ground water discharge to tidal estuarine surface water: Ground Water Monitoring and Remediation, v. 18, no. 1, p. 83–92.

Savoie, Jennifer, 1995, Altitude and configuration of the water table, western Cape Cod aquifer, Massachusetts, March 1993: U.S. Geological Survey Open-File Report 94-462, 1 pl.

Savoie, Jennifer, and LeBlanc, D.R., eds. 1998, Water-quality data and methods of analysis for samples collected near a plume of sewage-contaminated ground water, Ashumet Valley, Cape Cod, Massachusetts, 1993–94: U.S. Geological Survey Water-Resources Investigations Report 97-4269, 208 p.

Savoie, J.G., LeBlanc, D.R., Blackwood, D.S., McCobb, T.D., Rendigs, R.R., and Clifford, Scott, 2000, Delineation of discharge areas of two contaminant plumes by use of diffusion samples, Johns Pond, Cape Cod, Massachusetts, 1998: U.S. Geological Survey Water-Resources Investigations Report 00-4017, 30 p.

U.S. Environmental Protection Agency, 2002, Current drinking water standards, accessed on April 7, 2002, at URL http://www.epa.gov/mcl.html.

TABLES 6–8

Table 6. Location, depth, and water-level data for electrical-conductance profiles beneath Red Brook Harbor, Cape Cod, August 2000

[Locations shown in figure 6. **Latitude and longitude**: In °, degrees; ′, minutes; and ″, seconds. **Altitude:** In feet above or (-) below sea level (NGVD of 1929). **Harbor water-level altitude:** Harbor water-level altitude was determined by a temporary recording tide gage near the shoreline. Measured water depth at station was determined by use of a handheld fathometer at the sample time indicated]

Site identifier	Latitude ° ′ ″	Longitude ° ′ ″	Date sampled	Time	Harbor water-level altitude	Measured water depth at station (feet)	Harbor-bottom altitude
01-03	41 40 14.94	70 37 07.98	8-15-00	0900	3.65	4.3	-0.7
01-10	41 40 15.11	70 37 08.77	8-15-00	0920	3.64	6.0	-2.4
01-46	41 40 15.54	70 37 09.57	8-15-00	0930	3.59	6.1	-2.5
01-59	41 40 15.46	70 37 10.10	8-15-00	0942	3.49	7.1	-3.6
01-75	41 40 15.67	70 37 10.60	8-15-00	0950	3.41	7.8	-4.4
01-98	41 40 15.89	70 37 11.51	8-15-00	1012	3.14	8.2	-5.1
01-125	41 40 16.07	70 37 12.44	8-15-00	1020	3.03	7.3	-4.3
01-150	41 40 16.50	70 37 13.34	8-15-00	1040	2.71	8.9	-6.2
01-179	41 40 16.63	70 37 14.28	8-15-00	1115	2.17	7.8	-5.6
01-205	41 40 16.92	70 37 15.26	8-15-00	1429	.06	6.8	-6.7
01-230	41 40 17.47	70 37 16.35	8-15-00	1454	.14	6.8	-6.7
01-250	41 40 17.80	70 37 17.12	8-22-00	1535	2.92	10.3	-7.4
01a-05	41 40 15.81	70 37 08.02	8-17-00	1132	3.32	4.3	-1.0
01a-25	41 40 15.90	70 37 08.79	8-17-00	1139	3.20	5.3	-2.1
01a-50	41 40 16.21	70 37 09.76	8-17-00	1145	3.10	6.4	-3.3
01a-77	41 40 16.63	70 37 10.73	8-17-00	1330	1.11	7.0	-5.9
01a-101	41 40 16.58	70 37 11.70	8-17-00	1415	.43	6.2	-5.8
01a-126	41 40 16.92	70 37 12.48	8-17-00	1440	.13	5.8	-5.7
01a-156	41 40 16.98	70 37 13.50	8-17-00	1536	.11	7.2	-7.1
01a-177	41 40 17.18	70 37 14.56	8-17-00	1551	.14	7.4	-7.3
01a-199	41 40 17.33	70 37 15.39	8-17-00	1602	.21	7.2	-7.0
01b-70	41 40 13.12	70 37 07.18	8-23-00	1340	3.12	4.0	-.9
01b-121	41 40 14.17	70 37 08.74	8-23-00	1445	3.74	5.6	-1.9
01b-169	41 40 14.47	70 37 10.65	8-23-00	1500	3.77	6.1	-2.3
01b-221	41 40 15.03	70 37 12.52	8-23-00	1505	3.77	8.1	-4.3
01b-269	41 40 15.20	70 37 14.65	8-23-00	1520	3.73	8.6	-4.9
02-22	41 40 16.49	70 37 08.64	8-15-00	1521	.27	2.4	-2.1
02-49	41 40 16.68	70 37 09.69	8-15-00	1544	.29	4.1	-3.8
02-78	41 40 17.05	70 37 10.65	8-15-00	1616	.49	5.2	-4.7
02-97	41 40 17.55	70 37 10.56	8-16-00	0849	3.88	8.0	-4.1
02-124	41 40 17.74	70 37 11.65	8-16-00	0921	4.11	11.5	-7.4
02-151	41 40 18.27	70 37 12.57	8-16-00	1255	1.45	8.6	-7.2
02-180	41 40 18.93	70 37 13.46	8-16-00	1315	1.13	7.8	-6.7
02-200	41 40 19.12	70 37 14.48	8-22-00	1610	2.28	9.9	-7.6
03-45	41 40 18.33	70 37 08.72	8-16-00	1401	.66	2.5	-1.8
03-76	41 40 18.75	70 37 09.78	8-16-00	1421	.44	4.4	-4.0
03-100	41 40 19.35	70 37 10.40	8-16-00	1450	.23	6.0	-5.8
03-125	41 40 19.38	70 37 11.52	8-16-00	1540	.30	8.4	-8.1
03-175	41 40 19.27	70 37 13.32	8-22-00	1100	1.01	9.0	-8.0
04-12	41 40 20.53	70 37 08.63	8-16-00	1603	.38	4.0	-3.6

Table 6. Location, depth, and water-level data for electrical-conductance profiles beneath Red Brook Harbor, Cape Cod, August 2000—*Continued*

Site identifier	Latitude ° ′ ″	Longitude ° ′ ″	Date sampled	Time	Harbor water-level altitude	Measured water depth at station (feet)	Harbor-bottom altitude
04-25	41 40 20.78	70 37 09.02	8-16-00	1613	0.43	5.6	-5.2
04-48	41 40 21.21	70 37 09.57	8-16-00	1625	.51	7.2	-6.7
04-180	41 40 20.71	70 37 12.85	8-22-00	1138	1.72	9.9	-8.2
04a-29	41 40 20.02	70 37 11.61	8-23-00	0840	.37	4.7	-4.3
04a-102	41 40 21.04	70 37 16.16	8-23-00	0915	.48	7.6	-7.1
04a-221	41 40 19.51	70 37 08.85	8-23-00	1000	.61	9.2	-8.6
05-10	41 40 20.85	70 37 08.09	8-17-00	0813	2.37	4.9	-2.5
05-24	41 40 20.92	70 37 08.84	8-17-00	0938	3.61	7.6	-4.0
05-52	41 40 21.17	70 37 09.76	8-17-00	1036	3.75	10.7	-7.0
05-150	41 40 22.36	70 37 13.35	8-22-00	1315	3.36	11.5	-8.1
06-05	41 40 21.99	70 37 07.34	8-17-00	0955	3.67	4.3	-.6
06-26	41 40 22.12	70 37 08.10	8-17-00	1010	3.73	6.3	-2.6
06-46	41 40 22.55	70 37 09.09	8-17-00	1029	3.75	8.6	-4.9
06-74	41 40 22.85	70 37 09.75	8-17-00	1036	3.75	11.1	-7.4
06-127	41 40 23.49	70 37 11.45	8-23-00	1250	2.18	11.1	-8.9
06-156	41 40 23.76	70 37 12.75	8-22-00	1350	3.73	11.9	-8.2
07-15	41 40 23.61	70 37 07.03	8-17-00	1056	3.64	6.3	-2.7
07-29	41 40 23.94	70 37 07.35	8-17-00	1104	3.61	6.8	-3.2
07-53	41 40 24.25	70 37 08.25	8-17-00	1110	3.55	8.4	-4.9
07-144	41 40 25.63	70 37 11.13	8-22-00	1430	3.67	11.9	-8.2
07a-203	41 40 26.30	70 37 13.42	8-23-00	1107	.91	11.1	-10.2
8-148	41 40 27.00	70 37 09.32	8-22-00	1500	3.77	13.2	-9.4

Table 7. Values of measured bulk electrical conductance for profiles beneath Red Brook Harbor, Cape Cod, Massachusetts, August 2000

[Locations shown in figure 6. Site location, depth, and water-level data is in table 6. Shaded area indicates location of soft sediments. **Altitude:** In feet above or (-) below sea level (NGVD of 1929). EC, electrical conductance; mS/m, millisiemen per meter; --, not sampled]

Depth below harbor bottom (feet)	Site identifier													
	01-03		01-10		01-46		01-59		01-75		01-98		01-125	
	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)
0	-0.7	3,607	-2.4	300	-2.5	3,607	-3.6	1,448	-4.4	3,607	-5.1	3,607	-4.3	482
1	-1.7	2.06	-3.4	2.16	-3.5	1,241	-4.6	901	-5.4	2,051	-6.1	3,607	-5.3	295
2	-2.7	2.07	-4.4	1.1	-4.5	1,118	-5.6	13.11	-6.4	828	-7.1	3,607	-6.3	141
3	-3.7	1.54	--	--	-5.5	29.8	-6.6	6.96	-7.4	630.9	-8.1	2,352	-7.3	20.2
4	-4.7	2.3	--	--	-6.5	5.95	-7.6	3.31	-8.4	270.9	-9.1	1,416	-8.3	14.5
5	-5.7	1.87	--	--	-7.5	2.47	-8.6	3.91	-9.4	145.3	-10.1	723	-9.3	9.23
6	-6.7	2.17	--	--	-8.5	2.8	-9.6	9.12	-10.4	85.9	-11.1	476	-10.3	2.45
7	--	--	--	--	-9.5	1.61	-10.6	8.5	-11.4	49	-12.1	410	-11.3	2.04
8	--	--	--	--	--	--	-11.6	1.95	-12.4	26.9	-13.1	665	-12.3	1.97
9	--	--	--	--	--	--	--	--	-13.4	18.8	-14.1	186	--	--
10	--	--	--	--	--	--	--	--	-14.4	3.27	-15.1	34	--	--
11	--	--	--	--	--	--	--	--	-15.4	2.5	-16.1	16.1	--	--
12	--	--	--	--	--	--	--	--	--	--	-17.1	11.94	--	--
13	--	--	--	--	--	--	--	--	--	--	-18.1	10.6	--	--
14	--	--	--	--	--	--	--	--	--	--	-19.1	9.8	--	--
15	--	--	--	--	--	--	--	--	--	--	-20.1	9.6	--	--
16	--	--	--	--	--	--	--	--	--	--	-21.1	10.2	--	--
17	--	--	--	--	--	--	--	--	--	--	-22.1	2.6	--	--
18	--	--	--	--	--	--	--	--	--	--	--	--	--	--
19	--	--	--	--	--	--	--	--	--	--	--	--	--	--
20	--	--	--	--	--	--	--	--	--	--	--	--	--	--
21	--	--	--	--	--	--	--	--	--	--	--	--	--	--
22	--	--	--	--	--	--	--	--	--	--	--	--	--	--
23	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24	--	--	--	--	--	--	--	--	--	--	--	--	--	--
25	--	--	--	--	--	--	--	--	--	--	--	--	--	--
26	--	--	--	--	--	--	--	--	--	--	--	--	--	--
27	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 7. Values of measured bulk electrical conductance for profiles beneath Red Brook Harbor, Cape Cod, Massachusetts, August 2000—*Continued*

Depth below harbor bottom (feet)	Site identifier													
	01-150		01-179		01-205		01-230		01-250		01a-05		01a-25	
	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)
0	-6.2	137	-5.6	1,305	-6.7	3,607	-6.7	2,867	-7.4	2,839	-1.0	1,022	-2.1	1,127
1	-7.2	46	-6.6	74.5	-7.7	608	-7.7	2,094	-8.4	2,177	-2.0	2.81	-3.1	15.39
2	-8.2	31	-7.6	111	-8.7	373	-8.7	1,956	-9.4	1,922	-3.0	1.05	-4.1	2.56
3	-9.2	10.8	-8.6	72.4	-9.7	428	-9.7	2,109	-10.4	1,984	-4.0	0.7	-5.1	2.89
4	-10.2	1.92	-9.6	95	-10.7	478	-10.7	1,697	-11.4	1,800	-5.0	0.84	--	--
5	-11.2	2.31	-10.6	87	-11.7	395	-11.7	1,801	-12.4	1,532	--	--	--	--
6	--	--	-11.6	86	-12.7	380	-12.7	1,809	-13.4	1,498	--	--	--	--
7	--	--	-12.6	71	-13.7	659	-13.7	1,801	-14.4	1,358	--	--	--	--
8	--	--	-13.6	144	--	--	--	--	-15.4	1,397	--	--	--	--
9	--	--	-14.6	286	--	--	--	--	-16.4	1,360	--	--	--	--
10	--	--	-15.6	309	--	--	--	--	-17.4	1,436	--	--	--	--
11	--	--	-16.6	323	--	--	--	--	-18.4	1,493	--	--	--	--
12	--	--	-17.6	348	--	--	--	--	-19.4	1,405	--	--	--	--
13	--	--	-18.6	367	--	--	--	--	-20.4	1,375	--	--	--	--
14	--	--	--	--	--	--	--	--	-21.4	1,310	--	--	--	--
15	--	--	--	--	--	--	--	--	-22.4	1,205	--	--	--	--
16	--	--	--	--	--	--	--	--	-23.4	1,228	--	--	--	--
17	--	--	--	--	--	--	--	--	-24.4	1,215	--	--	--	--
18	--	--	--	--	--	--	--	--	-25.4	1,198	--	--	--	--
19	--	--	--	--	--	--	--	--	-26.4	1,200	--	--	--	--
20	--	--	--	--	--	--	--	--	-27.4	1,169	--	--	--	--
21	--	--	--	--	--	--	--	--	-28.4	492	--	--	--	--
22	--	--	--	--	--	--	--	--	-29.4	523	--	--	--	--
23	--	--	--	--	--	--	--	--	-30.4	706	--	--	--	--
24	--	--	--	--	--	--	--	--	-31.4	429	--	--	--	--
25	--	--	--	--	--	--	--	--	-32.4	356	--	--	--	--
26	--	--	--	--	--	--	--	--	-33.4	314	--	--	--	--
27	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 7. Values of measured bulk electrical conductance for profiles beneath Red Brook Harbor, Cape Cod, Massachusetts, August 2000—*Continued*

Depth below harbor bottom (feet)	Site identifier													
	01a-50		01a-77		01a-101		01a-126		01a-156		01a-177		01a-199	
	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)
0	-3.3	1,065	-5.9	2,502	-5.8	1,205	-5.7	978	-7.1	851	-7.3	1,200	-7.0	1,140
1	-4.3	783	-6.9	2,307	-6.8	940	-6.7	771.4	-8.1	711	-8.3	771	-8.0	887
2	-5.3	468	-7.9	1,546	-7.8	636	-7.7	576.9	-9.1	540	-9.3	149	-9.0	766
3	-6.3	452	-8.9	1,191	-8.8	425	-8.7	407	-10.1	72.6	-10.3	91	-10.0	598
4	-7.3	56.3	-9.9	1,477	-9.8	319	-9.7	310.7	-11.1	15.5	--	--	-11.0	209
5	-8.3	8.83	-10.9	1,339	-10.8	282	-10.7	275.2	-12.1	14.7	--	--	-12.0	223
6	-9.3	5.88	-11.9	1,282	-11.8	242	-11.7	205.3	-13.1	6.07	--	--	-13.0	190
7	-10.3	10.96	-12.9	1,265	-12.8	159	-12.7	146.6	-14.1	6.37	--	--	-14.0	162
8	-11.3	6.46	-13.9	1,054	-13.8	110.7	-13.7	14.07	-15.1	9.24	--	--	-15.0	132
9	-12.3	7.33	-14.9	1,036	-14.8	103.5	-14.7	7.38	-16.1	11	--	--	-16.0	182
10	-13.3	4.73	-15.9	1,056	-15.8	44.5	-15.7	7.87	-17.1	3.98	--	--	--	--
11	-14.3	2.79	-16.9	949	-16.8	30	-16.7	5.78	--	--	--	--	--	--
12	-15.3	1.23	-17.9	786	-17.8	24.1	-17.7	5.51	--	--	--	--	--	--
13	--	--	-18.9	960	-18.8	20.4	--	--	--	--	--	--	--	--
14	--	--	-19.9	930	-19.8	19.1	--	--	--	--	--	--	--	--
15	--	--	-20.9	807	-20.8	17.6	--	--	--	--	--	--	--	--
16	--	--	-21.9	728	-21.8	17.4	--	--	--	--	--	--	--	--
17	--	--	-22.9	281	-22.8	14.3	--	--	--	--	--	--	--	--
18	--	--	-23.9	218	-23.8	11.9	--	--	--	--	--	--	--	--
19	--	--	-24.9	162	-24.8	10.7	--	--	--	--	--	--	--	--
20	--	--	-25.9	134	-25.8	4.68	--	--	--	--	--	--	--	--
21	--	--	-26.9	99	--	--	--	--	--	--	--	--	--	--
22	--	--	-27.9	75.3	--	--	--	--	--	--	--	--	--	--
23	--	--	-28.9	58.3	--	--	--	--	--	--	--	--	--	--
24	--	--	-29.9	42.9	--	--	--	--	--	--	--	--	--	--
25	--	--	--	--	--	--	--	--	--	--	--	--	--	--
26	--	--	--	--	--	--	--	--	--	--	--	--	--	--
27	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 7. Values of measured bulk electrical conductance for profiles beneath Red Brook Harbor, Cape Cod, Massachusetts, August 2000—*Continued*

Depth below harbor bottom (feet)	Site identifier													
	01b-70		01b-121		01b-169		01b-221		01b-269		02-22		02-49	
	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)
0	-0.9	1,641	-1.9	1,304	-2.3	1,106	-4.3	412	-4.9	1,178	-2.1	3,607	-3.8	3,607
1	-1.9	1,176	-2.9	213	-3.3	557	-5.3	7.9	-5.9	542	-3.1	2,568	-4.8	2,187
2	-2.9	1,079	-3.9	17.9	-4.3	4.18	-6.3	3.4	-6.9	626	-4.1	369	-5.8	1,538
3	-3.9	1,002	-4.9	18.5	-5.3	4.33	--	--	-7.9	801	-5.1	390	-6.8	952
4	-4.9	1,123	-5.9	5.8	-6.3	3.29	--	--	-8.9	880	-6.1	204	-7.8	650
5	-5.9	640	-6.9	2.67	--	--	--	--	-9.9	636	-7.1	1.68	-8.8	613
6	-6.9	636	-7.9	2.78	--	--	--	--	-10.9	579	-8.1	1.81	-9.8	365
7	-7.9	222	--	--	--	--	--	--	-11.9	574	-9.1	1.39	-10.8	235
8	-8.9	32	--	--	--	--	--	--	-12.9	816	--	--	-11.8	119
9	-9.9	17.9	--	--	--	--	--	--	-13.9	245	--	--	-12.8	77.7
10	-10.9	15.3	--	--	--	--	--	--	-14.9	302	--	--	-13.8	44.4
11	-11.9	14.8	--	--	--	--	--	--	-15.9	301	--	--	-14.8	32.3
12	-12.9	13.9	--	--	--	--	--	--	-16.9	5.37	--	--	-15.8	25.4
13	-13.9	14.8	--	--	--	--	--	--	-17.9	3.96	--	--	-16.8	12.4
14	-14.9	13.5	--	--	--	--	--	--	--	--	--	--	-17.8	10.4
15	-15.9	14.5	--	--	--	--	--	--	--	--	--	--	-18.8	10.5
16	--	--	--	--	--	--	--	--	--	--	--	--	-19.8	7.4
17	--	--	--	--	--	--	--	--	--	--	--	--	-20.8	1.76
18	--	--	--	--	--	--	--	--	--	--	--	--	-21.8	1.81
19	--	--	--	--	--	--	--	--	--	--	--	--	--	--
20	--	--	--	--	--	--	--	--	--	--	--	--	--	--
21	--	--	--	--	--	--	--	--	--	--	--	--	--	--
22	--	--	--	--	--	--	--	--	--	--	--	--	--	--
23	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24	--	--	--	--	--	--	--	--	--	--	--	--	--	--
25	--	--	--	--	--	--	--	--	--	--	--	--	--	--
26	--	--	--	--	--	--	--	--	--	--	--	--	--	--
27	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 7. Values of measured bulk electrical conductance for profiles beneath Red Brook Harbor, Cape Cod, Massachusetts, August 2000—*Continued*

Depth below harbor bottom (feet)	Site identifier													
	02-78		02-97		02-124		02-151		02-180		02-200		03-45	
	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)
0	-4.7	3,607	-4.1	3,607	-7.4	2,560	-7.2	3,607	-6.7	2,481	-7.6	2,590	-1.8	1,093
1	-5.7	2,502	-5.1	2,812	-8.4	2,380	-8.2	2,895	-7.7	2,508	-8.6	1,918	-2.8	808
2	-6.7	2,220	-6.1	2,684	-9.4	2,629	-9.2	2,440	-8.7	2,420	-9.6	2,185	-3.8	944
3	-7.7	1,943	-7.1	2,325	-10.4	1,970	-10.2	1,857	-9.7	2,361	-10.6	2,039	-4.8	943
4	-8.7	2,037	-8.1	2,065	-11.4	1,999	-11.2	1,588	-10.7	1,974	-11.6	1,737	-5.8	920
5	-9.7	2,204	-9.1	1,416	-12.4	1,825	-12.2	1,930	-11.7	1,820	-12.6	1,943	-6.8	953
6	-10.7	1,412	-10.1	1,516	-13.4	1,847	-13.2	1,632	-12.7	1,888	-13.6	1,521	-7.8	754
7	-11.7	1,459	-11.1	1,259	-14.4	1,552	-14.2	1,790	-13.7	1,682	-14.6	1,343	-8.8	255
8	-12.7	1,175	-12.1	1,417	-15.4	1,542	-15.2	1,469	-14.7	1,528	-15.6	1,460	-9.8	42
9	-13.7	1,162	-13.1	1,376	-16.4	1,452	-16.2	1,623	-15.7	1,566	-16.6	1,239	-10.8	17.06
10	-14.7	1,078	-14.1	1,230	-17.4	1,744	-17.2	1,391	-16.7	2,050	-17.6	1,230	-11.8	15.6
11	-15.7	1,031	-15.1	1,255	-18.4	1,116	-18.2	1,473	-17.7	1,611	-18.6	1,071	-12.8	2.11
12	-16.7	1,019	-16.1	1,250	-19.4	1,678	-19.2	1,442	-18.7	1,919	-19.6	1,029	-13.8	1.53
13	-17.7	984	-17.1	1,044	-20.4	1,570	-20.2	1,510	-19.7	1,581	-20.6	872	--	--
14	--	--	-18.1	1,077	--	--	-21.2	1,364	-20.7	1,486	-21.6	815	--	--
15	--	--	-19.1	1,014	--	--	-22.2	1,285	-21.7	1,406	-22.6	740	--	--
16	--	--	-20.1	1,019	--	--	-23.2	1,412	-22.7	1,217	-23.6	672	--	--
17	--	--	--	--	--	--	-24.2	1,238	-23.7	1,161	-24.6	572	--	--
18	--	--	--	--	--	--	-25.2	1,105	-24.7	951	-25.6	500	--	--
19	--	--	--	--	--	--	--	--	-25.7	930	-26.6	448	--	--
20	--	--	--	--	--	--	--	--	--	--	-27.6	400	--	--
21	--	--	--	--	--	--	--	--	--	--	-28.6	361	--	--
22	--	--	--	--	--	--	--	--	--	--	-29.6	310	--	--
23	--	--	--	--	--	--	--	--	--	--	-30.6	286	--	--
24	--	--	--	--	--	--	--	--	--	--	-31.6	250	--	--
25	--	--	--	--	--	--	--	--	--	--	-32.6	222	--	--
26	--	--	--	--	--	--	--	--	--	--	-33.6	203	--	--
27	--	--	--	--	--	--	--	--	--	--	-34.6	172	--	--
28	--	--	--	--	--	--	--	--	--	--	-35.6	72.5	--	--
29	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 7. Values of measured bulk electrical conductance for profiles beneath Red Brook Harbor, Cape Cod, Massachusetts, August 2000—*Continued*

Depth below harbor bottom (feet)	Site identifier													
	03-76		03-100		03-125		03-175		04-12		04-25		04-48	
	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)
0	-4.0	2,344	-5.8	2,270	-8.1	2,532	-8.0	2,660	-3.6	1,131	-5.2	1,267	-6.7	1,210
1	-5.0	1,967	-6.8	1,995	-9.1	2,398	-9.0	2,021	-4.6	302	-6.2	32.5	-7.7	720
2	-6.0	1,351	-7.8	1,956	-10.1	2,075	-10.0	2,112	-5.6	13.4	-7.2	22.1	-8.7	424
3	-7.0	1,526	-8.8	1,930	-11.1	2,055	-11.0	2,096	-6.6	6.4	-8.2	17.8	-9.7	412
4	-8.0	1,603	-9.8	1,586	-12.1	1,943	-12.0	1,863	-7.6	2.83	-9.2	16.2	-10.7	298
5	-9.0	1,132	-10.8	1,952	-13.1	1,697	-13.0	1,657	--	--	-10.2	43.7	-11.7	85.2
6	-10.0	1,149	-11.8	1,296	-14.1	1,673	-14.0	1,507	--	--	-11.2	30.8	-12.7	15.6
7	-11.0	1,152	-12.8	1,303	-15.1	1,513	-15.0	1,539	--	--	--	--	-13.7	1.64
8	-12.0	887	-13.8	1,167	-16.1	1,459	-16.0	1,417	--	--	--	--	-14.7	1.77
9	-13.0	860	-14.8	1,241	-17.1	1,397	-17.0	1,436	--	--	--	--	--	--
10	-14.0	744	-15.8	1,001	-18.1	1,263	-18.0	1,153	--	--	--	--	--	--
11	-15.0	671	-16.8	985	-19.1	1,225	-19.0	1,259	--	--	--	--	--	--
12	-16.0	539	-17.8	915	-20.1	1,019	-20.0	1,194	--	--	--	--	--	--
13	-17.0	446	-18.8	712	-21.1	1,146	-21.0	1,159	--	--	--	--	--	--
14	-18.0	361	-19.8	656	-22.1	1,141	-22.0	1,124	--	--	--	--	--	--
15	-19.0	278	-20.8	545	-23.1	1,076	-23.0	985	--	--	--	--	--	--
16	-20.0	200	-21.8	390	-24.1	1,003	-24.0	852	--	--	--	--	--	--
17	-21.0	159	-22.8	342	-25.1	409	-25.0	791	--	--	--	--	--	--
18	--	--	-23.8	274	-26.1	366	-26.0	714	--	--	--	--	--	--
19	--	--	-24.8	226	-27.1	352	-27.0	617	--	--	--	--	--	--
20	--	--	--	--	--	--	-28.0	561	--	--	--	--	--	--
21	--	--	--	--	--	--	-29.0	505	--	--	--	--	--	--
22	--	--	--	--	--	--	-30.0	440	--	--	--	--	--	--
23	--	--	--	--	--	--	-31.0	412	--	--	--	--	--	--
24	--	--	--	--	--	--	-32.0	364	--	--	--	--	--	--
25	--	--	--	--	--	--	-33.0	335	--	--	--	--	--	--
26	--	--	--	--	--	--	-34.0	296	--	--	--	--	--	--
27	--	--	--	--	--	--	-35.0	265	--	--	--	--	--	--
28	--	--	--	--	--	--	-36.0	247	--	--	--	--	--	--
29	--	--	--	--	--	--	-37.0	203	--	--	--	--	--	--

Table 7. Values of measured bulk electrical conductance for profiles beneath Red Brook Harbor, Cape Cod, Massachusetts, August 2000—*Continued*

Depth below harbor bottom (feet)	Site identifier													
	04-180		04a-29		04a-102		04a-221		05-10		05-24		05-52	
	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)
0	-8.2	2,381	-4.3	1,181	-7.1	2,023	-8.6	2,381	-2.5	839	-4.0	1,257	-7.0	749
1	-9.2	2,237	-5.3	1,005	-8.1	2,220	-9.6	2,440	-3.5	277	-5.0	14.4	-8.0	750
2	-10.2	2,420	-6.3	569	-9.1	1,650	-10.6	2,344	-4.5	318	-6.0	9.96	-9.0	546
3	-11.2	2,289	-7.3	45.5	-10.1	2,187	-11.6	1,913	-5.5	232	-7.0	9.65	-10.0	420
4	-12.2	2,058	-8.3	12.2	-11.1	2,023	-12.6	1,822	-6.5	3.75	-8.0	9.3	-11.0	511
5	-13.2	1,968	-9.3	9.63	-12.1	2,109	-13.6	1,735	-7.5	1.85	--	--	-12.0	472
6	-14.2	1,688	-10.3	6.3	-13.1	1,807	-14.6	1,599	--	--	--	--	-13.0	362
7	-15.2	1,761	-11.3	4.97	-14.1	1,408	-15.6	1,718	--	--	--	--	-14.0	262
8	-16.2	1,532	-12.3	3.95	-15.1	1,630	-16.6	1,538	--	--	--	--	-15.0	128
9	-17.2	1,536	-13.3	3.91	-16.1	1,602	-17.6	1,415	--	--	--	--	-16.0	18.8
10	-18.2	1,699	-14.3	3.92	-17.1	1,465	-18.6	1,312	--	--	--	--	-17.0	7.35
11	-19.2	1,486	--	--	-18.1	1,258	-19.6	1,429	--	--	--	--	-18.0	6.84
12	-20.2	1,169	--	--	-19.1	1,297	-20.6	1,391	--	--	--	--	-19.0	5.39
13	-21.2	1,477	--	--	-20.1	1,230	-21.6	1,471	--	--	--	--	-20.0	5.3
14	-22.2	1,286	--	--	-21.1	940	-22.6	1,575	--	--	--	--	-21.0	6.37
15	-23.2	1,262	--	--	-22.1	1,240	-23.6	1,500	--	--	--	--	--	--
16	-24.2	1,165	--	--	-23.1	1,191	-24.6	1,600	--	--	--	--	--	--
17	-25.2	1,103	--	--	-24.1	1,141	-25.6	1,443	--	--	--	--	--	--
18	-26.2	1,101	--	--	-25.1	1,039	-26.6	1,371	--	--	--	--	--	--
19	-27.2	943	--	--	-26.1	924	-27.6	1,351	--	--	--	--	--	--
20	-28.2	931	--	--	-27.1	912	-28.6	1,278	--	--	--	--	--	--
21	-29.2	893	--	--	-28.1	823	-29.6	1,213	--	--	--	--	--	--
22	-30.2	843	--	--	-29.1	758	--	--	--	--	--	--	--	--
23	-31.2	824	--	--	-30.1	735	--	--	--	--	--	--	--	--
24	-32.2	820	--	--	-31.1	713	--	--	--	--	--	--	--	--
25	-33.2	776	--	--	-32.1	674	--	--	--	--	--	--	--	--
26	-34.2	780	--	--	-33.1	649	--	--	--	--	--	--	--	--
27	-35.2	740	--	--	-34.1	646	--	--	--	--	--	--	--	--
28	-36.2	731	--	--	-35.1	611	--	--	--	--	--	--	--	--
29	-37.2	738	--	--	-36.1	586	--	--	--	--	--	--	--	--

Table 7. Values of measured bulk electrical conductance for profiles beneath Red Brook Harbor, Cape Cod, Massachusetts, August 2000—*Continued*

Depth below harbor bottom (feet)	Site identifier													
	05-150		06-05		06-26		06-46		06-74		06-127		06-156	
	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)
0	-8.1	3,108	-0.6	1,347	-2.6	736	-4.9	1,149	-7.4	218	-8.9	2,547	-8.2	2,709
1	-9.1	2,408	-1.6	494	-3.6	413	-5.9	2.01	-8.4	104.4	-9.9	2,457	-9.2	2,526
2	-10.1	2,102	-2.6	513	-4.6	416	-6.9	1.19	-9.4	107	-10.9	2,207	-10.2	2,790
3	-11.1	2,204	-3.6	520	-5.6	428	--	--	-10.4	109	-11.9	2,154	-11.2	2,290
4	-12.1	1,925	-4.6	481	-6.6	438	--	--	-11.4	92.6	-12.9	1,953	-12.2	2,131
5	-13.1	1,920	-5.6	381	-7.6	461	--	--	-12.4	90.1	-13.9	1,980	-13.2	2,000
6	-14.1	1,841	-6.6	192	-8.6	404	--	--	-13.4	90.6	-14.9	2,053	-14.2	1,826
7	-15.1	1,721	-7.6	64.7	-9.6	161	--	--	-14.4	99.8	-15.9	1,981	-15.2	1,850
8	-16.1	1,845	-8.6	19.2	-10.6	7.35	--	--	--	--	-16.9	342	-16.2	2,049
9	-17.1	1,735	-9.6	11.73	-11.6	3.98	--	--	--	--	-17.9	529	-17.2	1,622
10	-18.1	1,483	--	--	--	--	--	--	--	--	-18.9	515	-18.2	1,750
11	-19.1	1,516	--	--	--	--	--	--	--	--	-19.9	545	-19.2	1,672
12	-20.1	1,531	--	--	--	--	--	--	--	--	-20.9	631	-20.2	725
13	-21.1	1,663	--	--	--	--	--	--	--	--	-21.9	551	-21.2	515
14	-22.1	1,648	--	--	--	--	--	--	--	--	-22.9	533	-22.2	500
15	-23.1	1,569	--	--	--	--	--	--	--	--	-23.9	544	-23.2	571
16	-24.1	1,558	--	--	--	--	--	--	--	--	-24.9	490	-24.2	308
17	-25.1	1,530	--	--	--	--	--	--	--	--	-25.9	577	-25.2	394
18	-26.1	1,358	--	--	--	--	--	--	--	--	-26.9	452	-26.2	568
19	-27.1	1,407	--	--	--	--	--	--	--	--	-27.9	446	-27.2	504
20	-28.1	1,372	--	--	--	--	--	--	--	--	-28.9	470	-28.2	623
21	-29.1	1,378	--	--	--	--	--	--	--	--	-29.9	422	-29.2	355
22	-30.1	1,344	--	--	--	--	--	--	--	--	-30.9	453	-30.2	276
23	-31.1	1,290	--	--	--	--	--	--	--	--	-31.9	360	-31.2	283
24	-32.1	1,284	--	--	--	--	--	--	--	--	-32.9	449	-32.2	445
25	-33.1	1,260	--	--	--	--	--	--	--	--	--	--	-33.2	333
26	-34.1	1,259	--	--	--	--	--	--	--	--	--	--	-34.2	326
27	-35.1	1,223	--	--	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	--	--												

Table 7. Values of measured bulk electrical conductance for profiles beneath Red Brook Harbor, Cape Cod, Massachusetts, August 2000—*Continued*

Depth below harbor bottom (feet)	Site identifier											
	07-15		07-29		07-53		07-144		07a-203		08-148	
	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)	Altitude (feet)	EC (mS/m)
0	-2.7	1,215	-3.2	991	-4.9	1,137	-8.2	2,706	-10.2	2,546	-9.4	2,420
1	-3.7	51.2	-4.2	88.9	-5.9	66.2	-9.2	2,506	-11.2	2,606	-10.4	2,366
2	-4.7	1.26	-5.2	213	-6.9	122.3	-10.2	2,244	-12.2	2,274	-11.4	1,930
3	-5.7	1.19	-6.2	241	-7.9	129.3	-11.2	2,222	-13.2	2,182	-12.4	1,730
4	--	--	-7.2	1.41	-8.9	197.3	-12.2	2,002	-14.2	2,097	-13.4	670
5	--	--	-8.2	1.32	--	--	-13.2	2,100	-15.2	2,277	-14.4	866
6	--	--	--	--	--	--	-14.2	2,265	-16.2	1,864	-15.4	876
7	--	--	--	--	--	--	-15.2	1,905	-17.2	1,797	-16.4	845
8	--	--	--	--	--	--	-16.2	1,577	-18.2	1,769	-17.4	854
9	--	--	--	--	--	--	-17.2	1,768	-19.2	1,803	-18.4	853
10	--	--	--	--	--	--	-18.2	2,101	-20.2	1,984	-19.4	725
11	--	--	--	--	--	--	-19.2	1,952	-21.2	2,133	-20.4	844
12	--	--	--	--	--	--	-20.2	1,912	-22.2	2,068	-21.4	870
13	--	--	--	--	--	--	-21.2	1,947	-23.2	2,161	-22.4	910
14	--	--	--	--	--	--	-22.2	1,907	-24.2	1,870	-23.4	773
15	--	--	--	--	--	--	-23.2	1,933	-25.2	2,032	-24.4	842
16	--	--	--	--	--	--	-24.2	2,017	-26.2	2,018	-25.4	841
17	--	--	--	--	--	--	-25.2	986	-27.2	2,017	--	--
18	--	--	--	--	--	--	-26.2	574	-28.2	2,076	--	--
19	--	--	--	--	--	--	-27.2	721	-29.2	2,044	--	--
20	--	--	--	--	--	--	-28.2	942	-30.2	2,013	--	--
21	--	--	--	--	--	--	-29.2	850	-31.2	2,015	--	--
22	--	--	--	--	--	--	-30.2	919	-32.2	1,878	--	--
23	--	--	--	--	--	--	-31.2	757	-33.2	2,029	--	--
24	--	--	--	--	--	--	-32.2	842	--	--	--	--
25	--	--	--	--	--	--	-33.2	1,310	--	--	--	--
26	--	--	--	--	--	--	-34.2	1,917	--	--	--	--
27	--	--	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	--	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--	--	--	--	--

Table 8. Sampling data, field water-quality analyses, and volatile organic compound detections for temporary well points in Red Brook Harbor, Cape Cod, August 2000)

[Source of VOC data: Severn Trent Laboratories. Locations shown in figure 9. **Latitude and longitude**: In °, degrees; ′, minutes; and ″, seconds. **Altitude:** In feet above or (-) below sea level (NGVD of 1929). **Harbor water-level altitude:** Harbor water-level altitude was determined by a temporary recording tide gage near the shoreline. Measured water depth at station was determined by use of a handheld fathometer at the sample time indicated. **Trichloroethene detection limit:** 0.205 mg/L. **VOC compounds not detected (detection limit in µg/L):** 1,1-Dichloroethene (0.233); *trans*-1,2-Dichloroethene (0.166); *cis*-1,2-Dichloroethene (0.157); 1,1,1-Trichloroethane (0.228); Carbon Tetrachloride (0.128); Benzene (0.354); Toluene (0.210); Tetrachloroethene (0.195); Ethylbenzene (0.196); *m* & *p*-Xylene (0.530); *o*-Xylene (0.245). VOC, volatile organic compound; mg/L, milligram per liter; µg/L, microgram per liter; µS/cm, microsiemen per centimeter; <, actual value is less than value shown; --, silty, not measurable]

Site identifier	Latitude ° ′ ″	Longitude ° ′ ″	Date sampled	Sample time	Measured water depth at station (feet)	Harbor water-level altitude (feet)	Altitude, harbor bottom (feet)	Depth, top of screen (feet)	Depth, bottom of screen (feet)	Altitude, top of screen (feet)	Altitude, bottom of screen (feet)	Specific conduc-tance (µS/cm)	Oxygen, dissolved (mg/L)	Trichloro-ethene (mg/L)
WS02A-26-08	41 40 16.93	70 37 08.49	8-24-00	1015	2.3	0.36	-1.9	8	9	-9.9	-10.9	235	0.115	1.01
WS02A-50-18	41 40 17.07	70 37 09.45	8-24-00	1104	4.9	.55	-4.4	18	19	-22.4	-23.4	830	.140	<.205
WS01-25-08	41 40 14.72	70 37 08.75	8-24-00	1351	4.1	2.29	-1.8	8	9	-9.8	-10.8	184	.235	<.205
WS01-50-08	41 40 14.98	70 37 09.60	8-24-00	1400	5.8	2.51	-3.3	8	9	-11.3	-12.3	231	.040	<.205
WS01B-72-13	41 40 13.10	70 37 07.41	8-24-00	1530	6.0	3.91	-2.1	13	14	-15.1	-16.1	156	.020	<.205
WS03A-35-08	41 40 18.61	70 37 08.85	8-25-00	0850	4.1	.33	-3.8	8	9	-11.8	-12.8	191	.135	<.205
WS03A-56-14	41 40 18.77	70 37 10.03	8-25-00	1005	5.2	.16	-5.0	14	15	-19.0	-20.0	14,340	3.900	<.205
WS04-25-09	41 40 20.39	70 37 09.10	8-25-00	1150	5.6	.18	-5.4	9	10	-14.4	-15.4	1,350	.015	2.86
WS01A-26-08	41 40 15.84	70 37 08.95	8-25-00	1220	2.6	.28	-2.3	8	9	-10.3	-11.3	186	.000	<.205
WS05A-30-10	41 40 20.80	70 37 08.89	8-30-00	0950	10.3	4.59	-5.7	10	11	-15.7	-16.7	2,130	.020	<.205
WS05A-50-10	41 40 21.55	70 37 09.34	8-30-00	1213	9.4	1.76	-7.6	10	11	-17.6	-18.6	9,750	.030	<.205
WS03B-24-08	41 40 19.53	70 37 08.78	8-30-00	1338	3.5	.08	-3.4	8	9	-11.4	-12.4	216	.355	[1].57
WS03B-44-23	41 40 19.95	70 37 09.59	8-30-00	1518	5.0	.12	-4.9	23	24	-27.9	-28.9	616	.485	[1].52
WS02A-188-31	41 40 19.27	70 37 14.24	8-30-00	1627	6.3	.14	-6.2	31	32	-37.2	-38.2	6,240	--	4.51
WS04-52-15	41 40 20.75	70 37 09.58	8-31-00	906	10.9	3.84	-7.1	15	16	-22.1	-23.1	1,280	.110	<.205
WS03-55-14	41 40 17.89	70 37 08.27	8-31-00	1120	5.7	4.05	-1.6	14	15	-15.6	-16.6	239	.085	<.205
WS01A-50-21	41 40 16.58	70 37 10.07	8-31-00	1225	4.5	2.49	-2.0	21	22	-23.0	-24.0	515	--	2.71
WS03-62-16	41 40 18.17	70 37 09.58	8-31-00	1507	5.0	.14	-4.9	16	17	-20.9	-21.9	582	.300	<.205
WS05-31-12	41 40 20.90	70 37 08.91	8-31-00	1604	4.0	.09	-3.9	12	13	-15.9	-16.9	1,870	--	<.205

[1]Estimated value.