Assessment of Ground and Surface Water Impacts: Provincetown Landfill and Septic Disposal Site Provincetown, Massachusetts

Daniel W. Urish, Mary J. O'Reilly, Raymond M. Wright, and Reinhard K. Frohlich

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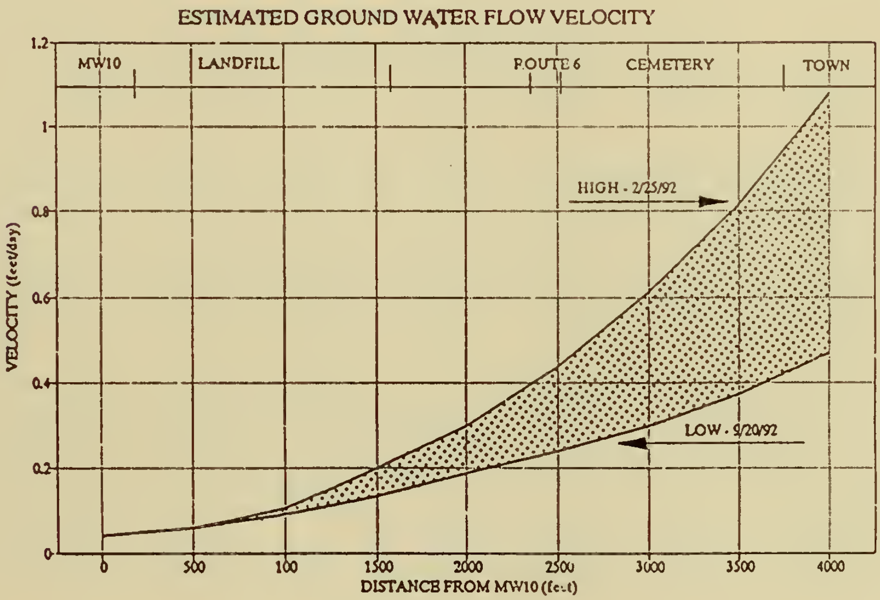

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ASSESSMENT OF
GROUND AND SURFACE WATER IMPACTS:
PROVINCETOWN LANDFILL AND SEPTIC DISPOSAL SITE
PROVINCETOWN, MASSACHUSETTS

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EXECUTIVE SUMMARY

The Provincetown Landfill is a 25-acre site within the Cape Cod National Seashore. The landfill has been in operation since 1954, prior to the transfer of lands from the Commonwealth to the National Park Service. The operation has been managed by the Provincetown Department of Public Works since initiation. From March 5, 1964 to present this operation has continued under a Special Use Permit (SUP) issued to the Town of Provincetown by the National Park Service. The landfill was considered incompatible with the values and purposes for which the seashore was established because of the adverse affect on the National Seashore's resources and on the enjoyment of resources and facilities by visitors. It was officially closed on October 13, 1992 and now functions as a recycling and composting area only.

Additionally, a septage disposal facility is located at the northeast corner of the landfill. It consists of six unlined leaching beds arranged as three pairs and two larger septage lagoons. The septage lagoons contain a bottom clay layer and a sacrificial sandy layer which allows leakage to infiltrate to the groundwater.

Water quality monitoring and groundwater analysis was initiated in November, 1985 after installation of six monitor wells around the landfill perimeter by the town. Later three more wells were installed for a total of nine wells sampled by the town. Surveys were repeated quarterly. It was concluded that wells lying to the south of the landfill and septage lagoons were all heavily impacted with landfill leachate.

A study on recent changes in the trophic status of Duck and Bennett Ponds due to possible landfill enrichment was performed by Winkler in 1990. This report concludes that contamination has occurred in Duck and Bennett Ponds due to their proximity to the landfill. Increased phosphorus, total dissolved solids, alkalinity, specific conductance, pH, chlorides, and coliform counts have been measured in the pond water chemistry since 1986. Greatly increased sedimentation rates, stimulated by increased nutrients were observed in both ponds throughout the past 30 years. The Provincetown area is comprised of coarse unconsolidated sands of marine origin which produce an unconfirmed aquifer of high hydraulic conductivity. Records show Cape Cod has an average annual rainfall of 40.3 inches with approximately 17.0 inches infiltrating through the sandy sediments to become groundwater recharge. This is sufficient to establish a sizable freshwater lens in a landmass as large as the Provinceland area. Based on current study results it is probable that the bottom of the fresh water layer in the central part of the fresh water lens lies at a depth of 100-135 feet below the water table, most likely at about 120 feet, plus or minus 20 feet depending on seasonal fluctuation. The presence of this fresh water layer, or lens, creates a unique hydrogeologic environment that is quite different from the mainland.

The principal goal of this study was assessment of ground and surface water impacts from the Provincetown Landfill and Septic Disposal Site in an area extending from the landfill to Provincetown Harbor. To attain this goal, the following objectives were addressed:

1) The delineation of the flow system from the landfill to discharge locations. This defines the physical groundwater system including flow paths, velocity of flow, surface water-groundwater interactions, fresh-salt water relationships and seasonal variations in the groundwater system.

2) Characterization of the water quality around the landfill and throughout the flow path to points of discharge. Comprehensive sampling and analysis focuses on identifying the extent of groundwater contamination and any potential environmental threats to this distinctive ecosystem.

3) Investigation of the composition and dynamics of the freshwater outflow through the beachface. This analysis explores groundwater response to tidal fluctuations which portrays the complex flow system occurring at the coastal boundary.

The general location of the contaminant plume was first determined indirectly by geophysical methods. Initial reconnaissance was performed using electromagnetics to ascertain the horizontal extent of the plume. Electrical resistivity soundings were then conducted to define the vertical extent of the plume and to delineate the thickness of the fresh water lens. Based on these geophysical results, locations for monitor well installations were selected. Except for one upgradient control well, the sites were selected for position in the leachate flow path. Each site consisted of three nested wells at vertically distinct positions.

A detailed assessment of the groundwater quality around and downgradient of the landfill was determined by quarterly sampling surveys. The stations sampled included nine previously existing monitor wells surrounding the landfill, the fifteen multilevel monitor wells, and six surface water stations. A broad spectrum of constituents were analyzed including nutrients, inorganics, metals, volatile organics and field parameters.

An electrical resistivity profile was performed along the Route 6 median to confirm depth soundings indicating high water mineralization, and to obtain a best approximation for the suspected plume location. The results show strong evidence of a leachate plume extending from the location where the landfill trial intersects Route 6 for about 400 feet to the southeast. This coincides with the expected flow path based on initial water table mapping. As a result an additional well (MW15D) was placed in the median strip of Route 6 later in the study.

Water table maps were developed in order to ascertain groundwater flow direction and the gradients needed to determine velocity of groundwater flow. A series of six water table maps were constructed using over forty ground and surface water measuring points. Water table maps show that groundwater flows from the landfill in a south-southeast direction toward Provincetown Harbor. This is fairly well established in the region from the landfill to the cemetery, but uncertain between the cemetery and the beach due to a sparseness of measuring points. While the flow directions shift throughout the seasons, it is believed that the flow path moves from the landfill across Route 6, then continues southeasterly under the cemetery. It is believed that the landfill leachate flow path then passes under residential Provincetown to discharge into the harbor. The time of travel from the landfill to the harbor, a distance of 2900 feet, is probably about 10-30 years, depending primarily on the veracity of the estimated hydraulic conductivity.

Based on the measured water table elevations the water table divide of the fresh water lens lies somewhere to the northwest of the landfill, but the position is uncertain. All measurements taken during this study show regional flow to the southeast. Examination of the various water table maps show considerable variation in the direction of flow. Additionally, it is very likely that localized water table mounding does occur, adding to the complexities of the flowpath determination. Unfortunately there are no water level measuring stations in the landfill itself.

It seems likely that high evapotranspiration in the open water of ponds and wetlands to the west and southeast causes discharge to occur at these locations in the late summer. This is supported by pond monitor well water level measurements. At Duck Pond in September the groundwater levels are higher than the pond water levels indicating vertical flow into the pond. Both pond and groundwater levels increase in winter. But in the spring, as overland runoff concentrates in the pond, the pond surface is higher than the groundwater creating an influent pond condition.

The strongest evidence of landfill pollution is found in monitor wells to the south and southeast of the landfill. These wells contain very high levels of electrical conductivity, alkalinity, bicarbonate, ammonia, nitrate, orthophosphate, calcium, COD, sulfate, chloride, metals and VOC's. With distance from the landfill the concentration of contaminants decreases due to adsorption, dispersion, and dilution. Monitor Well 15, located about 800 feet downgradient, appears to be directly in the path of the landfill plume. Water quality samples from this well show elevated levels of electrical conductivity, ammonia, chloride, cadmium, COD, lead, and sodium as well as the presence of VOC's.

As groundwater moves along its pathway from the landfill to discharge in the harbor area, it receives not only fresh groundwater recharge which tends to mitigate the effects of landfill and septage leachate, but also contaminants from several other sources: the Route 6 highway with automotive contaminants and road salting; the cemetery; town on-site sewage disposal, and the by-products of long buried fish processing and other marine activities now lost in the beachfront sands. All of these are merged into the mixture of groundwater discharge through the beachface at low tide.

All of the wells along Route 6 in a line generally transverse to the probable leachate plume flowpath show concentration levels of water quality parameters greatly exceeding native water. Because of the distance downgradient from the landfill, it is believed the deeper wells are most indicative of possible landfill influence. In particular, the presence of high levels of VOC's in the Route 6 wells suggest the influence of landfill leachate in the deeper parts of the fresh water lens. The effect of highway salting is evident in the shallow well samples along Route 6.

The importation of water for the public water supply of Provincetown is an important hydrologic component since most of it passes to the groundwater through on-site sewage disposal systems. The shallow well at the upper beach along the harbor shows evidence of septic effluent. This is apparent from high nutrients levels which usually indicate sewage impact. High levels of electrical conductivity and chlorides are also found, but are ambiguous since this can also come from salt water overwash. The contribution of nitrogen in the upper level beach well sample in the ammonia form is low, but in the nitrate form it is the highest of any samples. Sulfate was also quite high, but this could be ambiguous due to the decomposing seaweed and other organic material frequently mixed with the sand in the upper beach.

The beach face is a highly dynamic environment. As evidenced both by direct salinity measurements, and by the greatly increased slope of the water table near the beach, the fresh groundwater lens decreases in thickness at the beach line as compared with much grater thickness at inland monitor wells. This, along with tidal dynamics, causes further mixing of the water in the lens at the beach zone. As the tide rises and moves shoreward there is a localized reversal of the groundwater gradient from seaward to shoreward due to the much faster rise of the tide water than the groundwater in the beach. This effect progresses shoreward for as much as 250 feet from high tide, effectively damming groundwater outflow during an incoming tide. This process also introduces a large quantity of salt water into the beach, overlying the fresher groundwater. As the tide goes out, both the dammed fresh water and the tidal induced salt water pour out, carrying with it all of the chemical constituents collected for years from a myriad of sources.

Conclusions as a result of the study are:

1. A classic fresh water lens based on the Ghyben-Herzberg Principle exists in the Provincelands region with an estimated fresh water thickness of about 100 to 135 feet in the central part of the landmass.

2. Leachate emanating from the landfill has impacted local groundwater quality to the south and southeast of the landfill and to a lesser extent impacted surface water quality to the west and southeast of the landfill. Fresh water ponds in the immediate vicinity of the landfill also show contamination from landfill surface runoff and groundwater discharge.

3. The leachate plume flows to the southeast in a descending flow path within the fresh water lens at a very slow pace, with an estimated travel time from the south edge of the landfill to the harbor beach of 10-30 years.

4. Evidence of landfill leachate input to the groundwater system is found in down gradient wells approximately 800 feet southeast of the nearest edge of the landfill, but is not identifiable in the more remote monitor wells.

5. Contaminant input from other sources, namely Route 6 highway salting, the cemetery, and town on-site sewage disposal, is evident in water quality samples taken from monitor wells located immediately down gradient of each of these sources.

6. The strong tidal dynamics at the harbor beach causes extensive mixing of all contaminants so that in the shallow groundwater outflow evidence of landfill leachate could not be distinguished. Based on the flow path derived from water table elevation measurements, it appears that leachate plume discharge would occur through the beach area on both sides of the MacMillian Wharf parking area.

Recommendations for further work are:

1. Establish a more comprehensive water table measurement network in order to produce a water table map for a broader region.

2. Install additional nested monitor wells in the area of the presumed flowpath, in Provincetown and along the upper beach on both sides of MacMillian's Wharf.

3. Accomplish additional water table measurements on a quarterly basis for one more year with supplemental measurement locations.

4. Accomplish one additional year of water quality sampling and measurements utilizing newly proposed monitor wells.

5. Accomplish a more comprehensive survey of discharge water quality at low tide at Provincetown Harbor beach on both sides of MacMillian's Wharf.

6. Construct a calibrated and validated computer groundwater flow model to simulate both wet and dry season conditions.

PREFACE

This report is organized in the following sections:

A) An EXECUTIVE SUMMARY which provides an overview of the investigation process, the finding and conclusions.

B) An INTRODUCTION which describes the objectives of the study and background information relative to the study area.

C) A METHODOLOGY AND RESULTS section which describes the procedure used for obtaining information and persents the basic data and findings.

D) A DISCUSSION section which describes in an integrated manner the interactions and meaning of the data and information collected.

E) A CONCLUSIONS section which endeavors to state the main findings of the report in a concise, explicit manner.

F) A RECOMMENDATIONS section which provides recommendations for further study and action with a rationale as to why such action would be useful.

This study is one of the several studies which have been and will be made regarding the Provincetown Landfill which contributes to a greater understanding of the issue of land use and environmental impact. It presents an investigation of Provincetown Landfill impacts on the groundwater and surface water environment. The extend of this study, as with all others, is limited by money and time. While the main focus of this study is the effect of the landfill and related septage disposal areas, associated investigations identify potential contamination from other sources. It is hoped that subsequent investigators will use the data presented to gain further insight, and as baseline information for future studies.

The authors are indebted to the many persons and agencies who contributed both knowledge and time in assisting in the information gathering process. Special appreciation is noted to Marina Brock and Dale Saad of the Barnstable Public Health Department for the analysis of water quality samples and information related to water quality on Cape Cod, to Kevin Mulhaney and Emily Beebe of the Provincetown Public Health Department for their assistance in information gathering and obtaining public cooperation, to Tom Cambareri of the Cape Cod Commission for continuing advice in hydrogeologic matters, to John Portnoy of the National Park Service for his assistance both in the field and in acting as facilitator in coordinating many facets of the project, to Kyle Jones of the National Park Service CACO for providing supplemental precipitation data, to Nigel Shaw of the National Park Service for making arrangements for use of graphic information system data files, to Doug Heath of the Boston Environmental Protection Agency Office who provided initial water table maps, to Roger Morin of the Denver Office of the U.S. Geological Survey who made special arrangements for supplemental borehole geophysical field work which gave valuable additional insight in interpreting subsurface data, to the many representatives of the towns and agencies who provided continuing suggestions during the course of the study, to the unknown private citizens who we encountered in the field who expressed sincere interest and offered helpful historic information, and finally to the six anomynous reviewers of the final report who by their professional insight and detailed comments contributed much to the quality of the final product.

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TABLE OF CONTENTS

PAGE

PAGE

PAGE

LIST OF FIGURES

FIGURE PAGE

LIST OF TABLES

CHAPTER 1. INTRODUCTION

1.1 Problem Statement

Preliminary field measurements by the National Park Service suggest contaminated groundwater flows from the Provincetown Landfill and Septage Lagoons to the southeast and discharges into Provincetown Harbor (Heath, 1990). Road salting, cemetery leachate, and individual septic disposal systems are additional sources of contamination to the groundwater emerging along the shore, an area frequented by fishermen and swimmers. The National Park Service has serious concerns about the effects of this contamination on groundwater quality around and down gradient of the landfill. Particular concern exists for the possible impact on public health and the natural resources of the harbor, adjacent Cape Cod Bay waters and local pond water quality. A research project for this study was funded by the Coastal Research Center, National Park Service.

1.2 Study Objectives

The principal goal of this study was an assessment of ground and surface water impacts from the Provincetown Landfill and Septic Disposal Site. To attain this goal, the following objectives were addressed:

1.) The delineation of the flow system from the landfill to discharge locations. This will define the physical groundwater system including flow paths, velocity of flow, surface water-groundwater interactions, fresh-salt water relationships and seasonal variations in the groundwater system.

2.) Characterization of the water quality around the landfill and throughout the flow path to points of discharge. Comprehensive sampling and analysis will focus on identifying the extent of groundwater contamination and any potential environmental threats to this distinctive ecosystem.

3.) Investigation of the composition and dynamics of the freshwater outflow through the beachface. This analysis will explore groundwater response to intense tidal fluctuations in order to portray the complex flow system occurring at the coastal boundary.

1.3 Location and Description of the Study Area

1.3.1 Geography and Demography

The Provincelands, which include both Provincetown and National Seashore area, is bounded to the north and west by the Atlantic Ocean and on the east by Cape Cod Bay (Figure 1). The town, a densely developed region, is nestled in the enclosed arm of "the hook". The focus of human activity, historically as well as at present, has been along this well protected harbor.

Provincetown is located at the northernmost portion, "the hook" of Cape Cod, Massachusetts and along with most of Cape Cod is a haven for tourists during the summer months. It has a year round population of 3,497 people which increases to 16,000 full time residents in the summer. During the peak tourist season the daily population can vary from 30-50,000 people, more than ten times the annual population (personal communication, October, 1992; Kevin Mullaney, Provincetown Health Agent).

1.3.2 Water Supply

The original sources of water for Provincetown residents were rainwater cisterns or dug wells. In 1892 Provincetown's first municipal groundwater well system was installed. By 1900 homeowners had reverted back to the cisterns because they thought the groundwater had a foul taste. In 1910 an alternate well water supply was developed in North Truro. This is the municipal water supply used today supplying over 300 million gallons of water a year to Provincetown's residents and visitors.

1.3.3 Geologic History

The Provincelands of Cape Cod were formed by redeposition of material supplied by the erosion of the Highlands of Truro, the northernmost extent of original glacial sediments. This northwesterly coastal drift and deposition of reworked glacial sands occurred sometime after the close of the Wisconsin Glaciation about 12,000 years ago (Strahler, 1972).

The Provincelands peninsula is a complex recurved spit created by a series of prograding sandspits (Fisher, 1972). According to Ziegler (1965), each sequential spit built up a short distance to the west and then hooked to the south. This process produced the width of the landmass and moved the entire peninsula to the west with the addition of each new

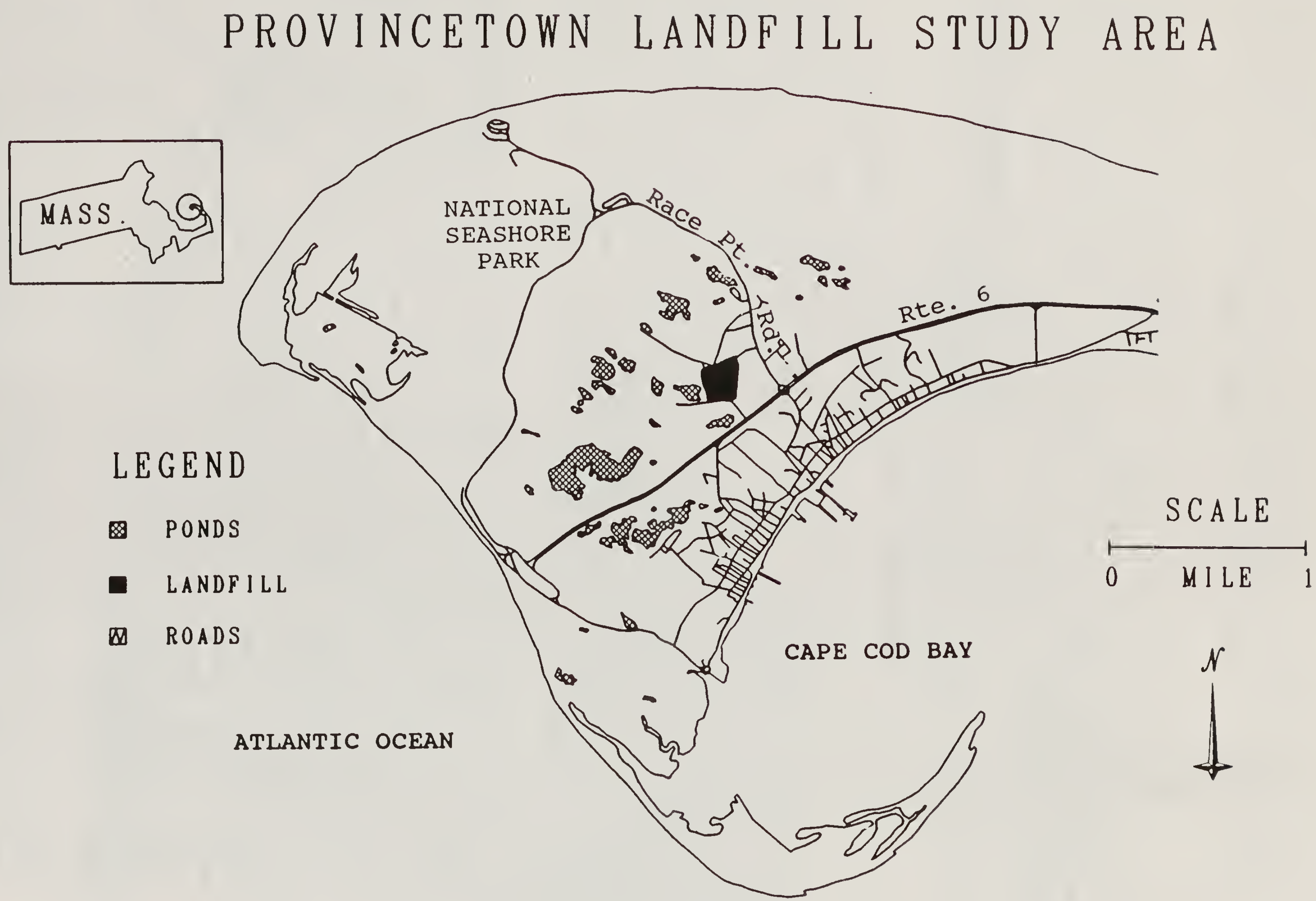


Fig. 1.1a. General location map of the study area.

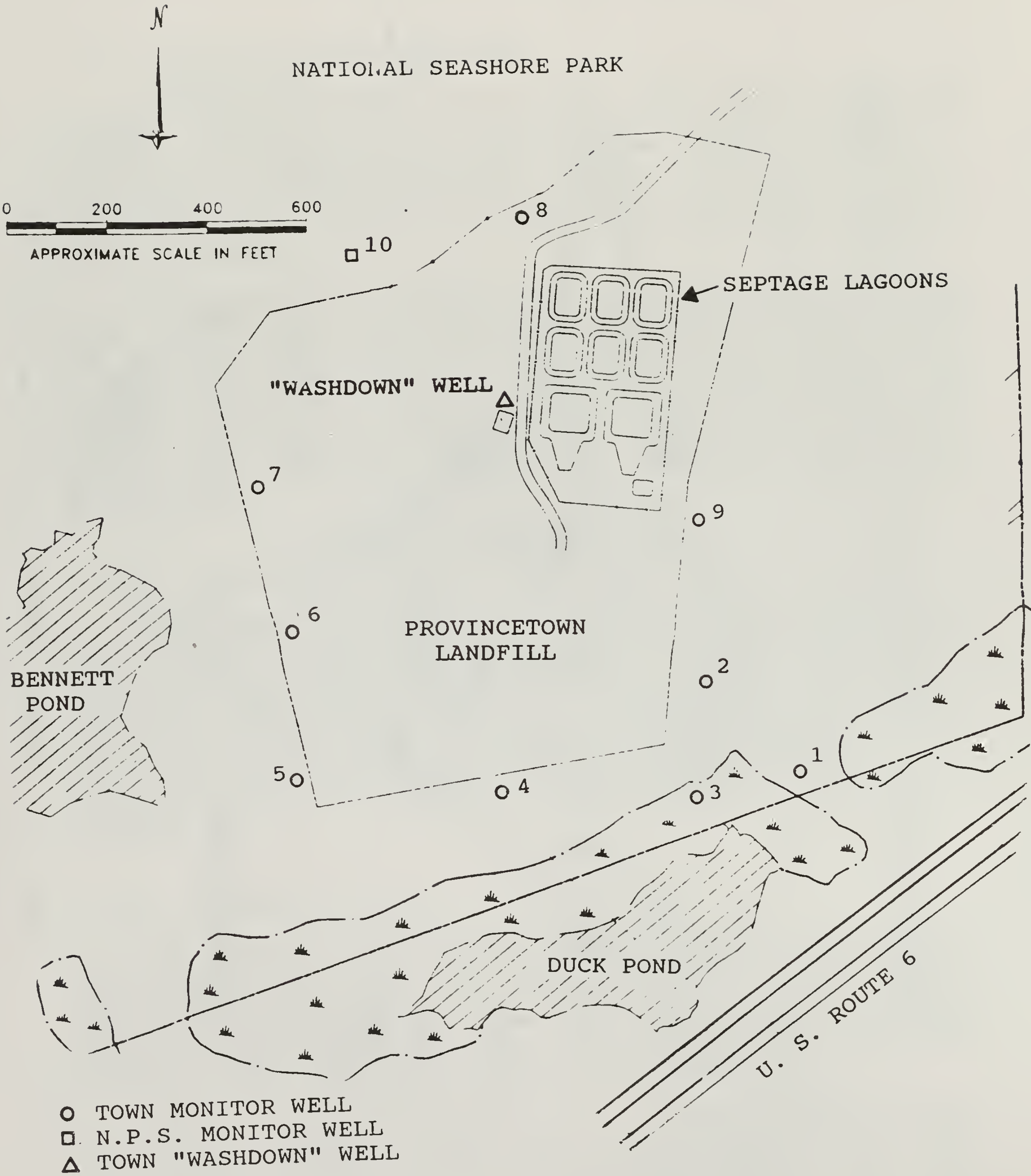


Fig. 1.1b. Location map of Provincetown Landfill area. (based on Normandeau Engineers report to Provincetown, MA 8/2/89)

spit. The oldest of the sandspits forming the hook was deposited to the south through what is now the town of Provincetown, but as sand drifting continued, sandspits formed progressively further north.

According to Strahler (1966), the Provincelands are one of the most interesting and spectacular deposits made by shore drifting of sand. They are composed of a vast expanse of migrating parabolic sand dunes, the highest over 100 feet above mean sea level. The Provincelands also contain several shallow fresh water ponds that have formed in the depressions between successive dune crests. The National Park Service has strived to preserve the original character of this shoreline as well as its unique coastal, glacial and dune landscape by incorporating it into the National Park system.

1.3.4 Hydrogeologic System

Oceanic landmasses under natural conditions frequently develop a freshwater lens if an adequate balance of groundwater recharge, hydraulic conductivity and land width exists (Urish, 1982). The Provincetown area is comprised of coarse unconsolidated sands of marine origin which produce an unconfined aquifer of high hydraulic conductivity. Records show Cape Cod has an average annual rainfall of 40.3 inches with approximately 17.0 inches infiltrating through the sandy sediments to become groundwater recharge (Strahler, 1972). This is sufficient to establish a sizable freshwater lens in a landmass as large as the Provinceland area.

The Ghyben-Herzberg principle of proportionality relates water table elevation with depth to the fresh-salt water interface (Ghyben,1889; Herzberg, 1901). This principle states that in general for every foot the fresh water of an unconfined aquifer rises above mean sea level, the fresh water extends approximately 40 feet below mean sea level (Cooper, 1964). An approximation of this fresh water lens configuration can be calculated for a cross section through Provincetown by multiplying the average water table height above effective mean sea level (Urish, 1982) at each location by 40. This theory assumes a sharp interfacial boundary exists between the salt and fresh water in a coastal aquifer. In true field conditions, however, a brackish transition zone separates the two layers. The location of the theoretical sharp interfacial boundary is equivalent to the midpoint of this transition zone (Todd, 1980).

The Ghyben-Herzberg Principle is generally more accurate in the central portion of a landmass provided there is no interfering lower boundary. Near the coastal boundary the interface moves upward, decreasing the thickness of the lens to a thin edge at the shore margin (Urish, 1987). Here tidal dynamics produces a mixing mechanism which increases the thickness of the transition zone (Todd, 1980) and creates a constantly fluctuating water table. This effect is very significant in the Provincelands, where there is a high hydraulic conductivity and a tidal range of up to twelve feet.

The depth to bedrock beneath the Provincelands is estimated at 400-500 feet (Strahler, 1972). This depth is well below the probable depth of the fresh-salt water interface, consequently the much lower hydraulic conductivity of bedrock would not affect flow patterns in the fresh water lens.

1.3.5 Climate

Cape Cod has a maritime humid climate characterized by a moderate range of temperatures and well developed summer and winter seasons. The extremes are moderated by the surrounding ocean waters. In July the high temperatures average 77.5 °F and the lows average 61.6 °F. February is the coldest month with average temperatures ranging from 24 °F to 38 °F.

During the two years of the study period, 1990 and 1991, precipitation at the Cape Cod National Seashore Weather Station at Truro, Massachusetts was 39.8 and 40.5 inches, respectively. This is very close to the long term average of 40.3 inches cited by Strahler (1972) for Provincetown. Hence, it is expected that the hydrogeologic conditions were near normal during the study period. During the study period average monthly precipitation ranged from 1.1 inches in July, 1991 to 6.1 inches in November, 1991. There is wide monthly variance in rainfall, but no real seasonal pattern. Figure 1.2 is a plot of precipitation for the period from January, 1990 to April, 1992. In addition to the Truro data a temporary rain gage was established at Race Point by the CACO Resource Management Office to ascertain if there was significant local geographic rainfall variance. Comparisons between this data and the Truro data indicates little difference.

1.4 Contaminant History

1.4.1 Landfill

The Provincetown Landfill is to the west of Race Point Road on a 25-acre site within the Cape Cod National Seashore. The landfill has been in operation since 1954, prior to the transfer of lands from the Commonwealth to the National Park Service. The operation has been managed by the Provincetown Department of Public Works since initiation. From March 5, 1964 to present this operation has continued under a Special

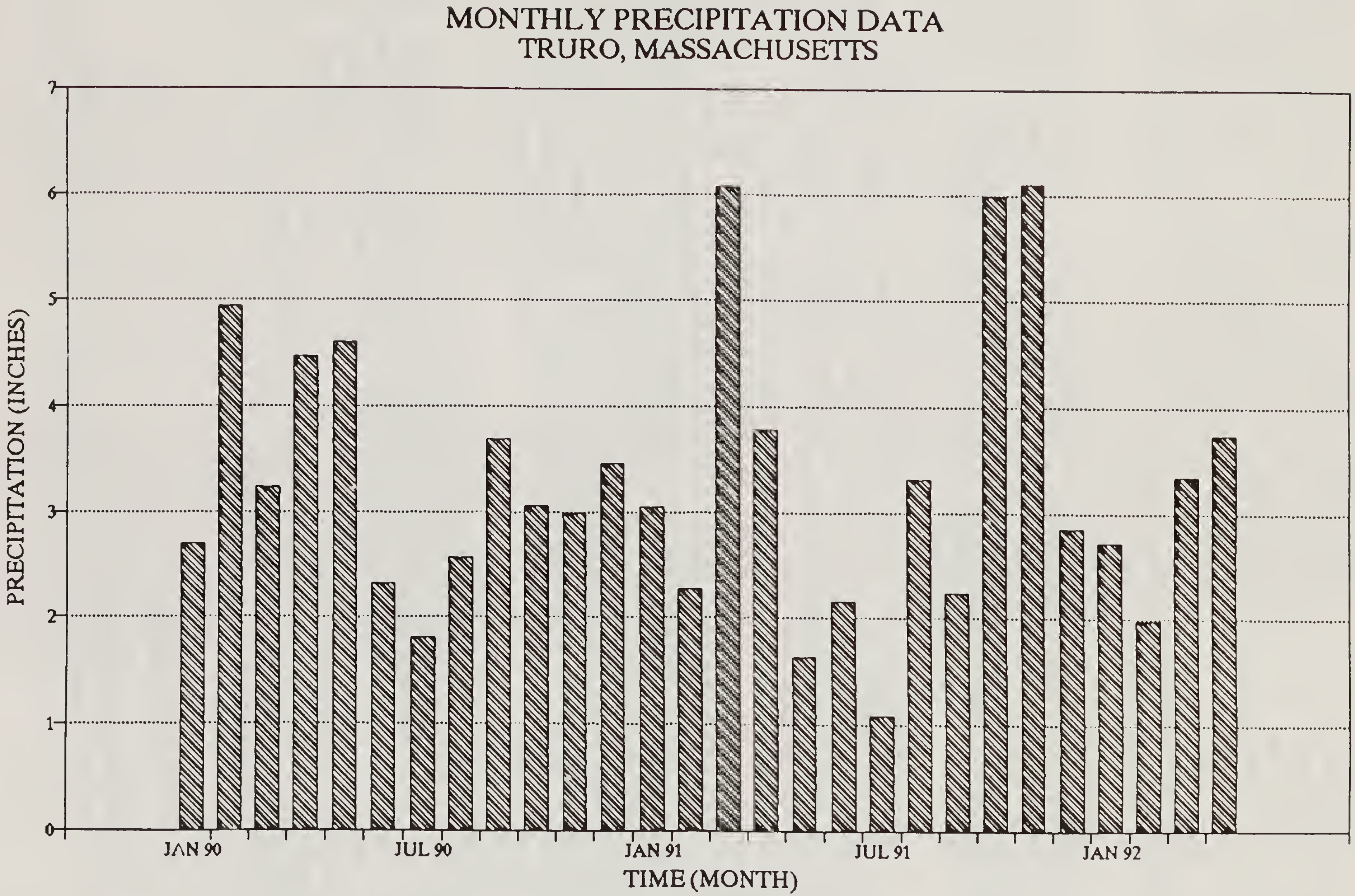


Fig. 1.2. Monthly precipitation data - Truro, Mass.

Use Permit (SUP) issued to the Town of Provincetown by the National Park Service.

During its operation the landfill has accepted residential waste, commercial waste, and construction debris. The commercial waste was mostly from restaurants since there are no major industries in the vicinity. In 1963 the Town of Provincetown was charged by the Massachusetts Department of Public Health with violations for operating an open dump with daily burning and direct surface disposal of sewage and fishing offal. In 1983 the Provincetown health Department gave approval to dispose of a small amount of asbestos from the Provincetown School Department.

Sanitary landfill site preparation in 1954 consisted of excavation and deposition of sufficient fill to reach a height of four feet above the water table. A septage pit was constructed on the northeast corner of the landfill. In 1983 the septage disposal operation was upgraded to a lagoon system.

The landfill is located in an open unvegetated area. Mapping of landfill topography was produced by Normandeau Engineering Inc. of Concord, New Hampshire in August of 1989. This showed the maximum elevation of the landfill at 46 feet above mean sea level. The perimeter of the landfill has an average slope of 0.18 with steeper grading occurring at the southeastern and northwestern borders. Erosion from surface water runoff along the sides of the landfill deposits sediment at the extreme edges of the landfill and into a forested wetland area bordering the site. Wind-blown litter is also dispersed around the site but the greatest accumulation occurs north of the landfill. Current fill rates of 1,000-2,000 cubic yards/month were calculated by SEA Consultants Inc. of Cambridge, Massachusetts for a 2-year period from August, 1989 to August 1991.

A Special Use Permit dated October 26, 1975 required the closure of the landfill on October 25, 1990. The landfill was considered incompatible with the values and purposes for which the seashore was established because of the adverse affect on the National Seashore's resources and on the enjoyment of resources and facilities by visitors. The landfill is currently in phase 1 of a 3-phase closure procedure. It was officially closed on October 13, 1992 and now functions as a recycling and composting area only.

1.4.2 Septage Lagoons

The septage disposal facility is located at the northeast corner of the landfill. It consists of six unlined leaching beds arranged as three pairs and two larger septage lagoons. The septage lagoons contain a bottom clay layer and a sacrificial sandy layer. Raw septage from residential and commercial sources is collected by septic haulers and discharged into the lagoons through a receiving box. The liquid fraction flows through a distribution chamber into the leaching beds leaving the solids to collect in the lagoons. One lagoon is drained every other year for cleaning. The sludge is dewatered, mixed at a 2:1 ratio with landfill waste and disposed of in the landfill.

On July 22, 1991 the Town of Provincetown commenced its shared used of the Tri-Town Septage Treatment Facility in Orleans. After this time the facility at the landfill was only to be used if the weekly limit of 52,000 gallons was surpassed. During the summer months, the volume of septage can increase tenfold to quantities of 20,000 - 30,000 gallons/day. In the summer of 1991 one of the lagoons was still utilized whenever this quantity was surpassed. By 1992 Tri-Town accepted all of Provincetown's septage. The septage lagoons have not been used since August of 1991.

1.4.3 Road Salting

Road salting in winter months is a common practice in the northeast region. All of the deposited salt eventually runs off the road surfaces and infiltrates into the ground, then to the water table. According to records of the Massachusetts Department of Public Works, 4.23 tons of salt per lane mile were deposited along Route 6 in 1989-90, 2.67 tons per lane mile in 1990-91, and 6.04 tons per lane mile in 1991-92. Thus, in the 2,400 feet long stretch of Route 6 between Race Point Road and Shank Painter Road an average of 7.84 tons per year were deposited.

Additionally, salting is accomplished on town roads, and there is a town salt storage location about 800 feet north of the intersection of Route 6 and Race Point Road. Quantities of salt used in the town operation are unknown.

1.4.4 Cemetery

The Provincetown Cemetery is located within the town boundary just south of the Midcape Highway (Route 6) in an area that encompasses over 22 acres. The oldest stone in the cemetery dates back to 1723. The burial practices used range from pine boxes to slate vaults and cement liners placed at a depth of 5-6' below the land surface. In this area the water table elevation is 20-25' below the ground surface although moisture from precipitation or tree root expansion could promote seepage into the water table. Indentations in the land surface where the burial housing has collapsed indicate that the seals are probably not leakproof (personal communication, 15 October, 1992, Ronald Martin, Provincetown Cemetery Director).

Decomposing bodies produce fluids that can seep into the groundwater (Bouwer, 1978). The embalming fluid currently used to preserve the body is formaldehyde. Past practices during the period 1880-1910 included the use of arsenic, a poisonous chemical element, which still may be leaching into the ground water as burial vaults disintegrate. The Provincetown cemetery does not have records on the history of past embalming practices.

A study by Schraps (1972) determined the typical chemical indicators found in shallow groundwater beneath graves were increased levels of chloride, sulfate, bicarbonate, and chemical oxygen demand.

1.4.5 Sewage Disposal

The residents and businesses of Provincetown depend upon on-site sewage disposal systems for disposing of their domestic liquid waste. There are no public sewer systems. The typical disposal system consists of a septic tank for the receiving water and a leaching field for dispersal into the ground.

Based on water use it is estimated that approximately 15,100,000 gallons of sewage effluent per month enters the ground water during the winter months (December, January, and February) and 46,700,000 gallons enters during the peak tourist season in the summer months (July and August). It is noteworthy that the water component of the sewage is imported from Truro and constitutes substantial addition to the local water budget. Based on an estimated area of 12,000,000,000 square feet for Provincetown and a pumpage total of 312,949,700 gallons in 1991, this represents the remarkable equivalent of about 42 inches per year. Even if 25% of the water imported to Provincetown were consumptive use, the remainder would add about 32 inches of water to the water table.

1.5 Previous Studies in the Area

Concern over the adverse effects the operation of the landfill may have on the environment has prompted several environmental studies to define existing conditions. These are summarized as follows:

1.5.1 Landfill Monitor Well Sampling

Landfill monitor well sampling was initiated by Barnstable County Health Department (Douglas, 1986). The nine monitor wells surrounding the landfill and both Duck and Bennett Ponds were sampled. Results show that the two wells immediately to the south of the landfill were heavily impacted by high levels of conductivity, alkalinity, chloride, sodium, iron, ammonium, calcium, magnesium, and manganese. Nitrogen was in the reduced form as ammonium with the likely source identified as the septage lagoons.

1.5.2 Groundwater Analysis

Water quality monitoring and ground water analysis by Camp, Dresser, and McKee Inc. of Boston, Massachusetts was initiated in November, 1985 after installation of six monitor wells around the landfill perimeter. Later three more wells were installed by the town for a total of nine wells sampled by the town. Surveys were repeated quarterly. These reports were submitted to the Provincetown Water Department and the National Park Service. The data were also included in bimonthly inspection reports from Normandeau Engineers Inc. to the Provincetown Director of Public Works. It was concluded that wells lying to the south of the landfill and septage lagoons were all heavily impacted with landfill leachate.

Water quality monitoring surveys are currently performed by SEA Consultants Inc. for the Town of Provincetown.

1.5.3 Landfill Contaminant Assessment

An assessment of landfill contamination was conducted by Lepore, et al. (1990). This study included an evaluation of groundwater and surface water quality as well as a determination of groundwater flow in the vicinity of the landfill. Results indicate that groundwater at monitor wells to the south, east and west of the landfill are contaminated with leachate from solid waste and from the septage lagoons located on the landfill. This leachate contains high concentrations of plant nutrients (e.g., nitrogenous compounds) and toxins (e.g., halogenated organic compounds) which can degrade aquatic ecosystems in the area of groundwater discharge.

1.5.4 Surface Water Studies

A study on recent changes in the trophic status of Duck and Bennett Ponds due to possible landfill enrichment was performed by Winkler (1990). This report concludes that contamination has occurred in Duck and Bennett Ponds due to their proximity to the landfill. Increased phosphorus, total dissolved solids, alkalinity, specific conductance, pH, chlorides, and coliform counts have been measured in the pond water chemistry since 1986. Greatly increased sedimentation rates, stimulated by increased nutrients were observed in both ponds throughout the past 30 years (Winkler, 1990).

1.5.5 Water Table Elevation Mapping

Water table elevation maps were generated by Doug Heath (1990) of the Environmental Protection Agency in 1990. Thirty-one surface and groundwater elevation stations were installed by the National Park Service in the vicinity of the landfill. Based on measurements at these stations, a water table contour map was prepared. This shows that groundwater flow from the landfill moves in a southeasterly direction. It was concluded that a strong ground water-surface water interrelationship exists in this complex flow system. Recommendations were given for future study.

1.5.6 Initial Site Assessment

An Initial Site Assessment (ISA) of the Sanitary Landfill in Provincetown, Massachusetts was performed by SEA Consultants Inc. in the summer of 1991 for the Provincetown Board of Selectmen. This ISA concluded that the most contaminated wells were located along the southern edge of the landfill. Monitoring of the two surface water bodies adjacent to the landfill, Duck and Bennett Pond, indicated elevated levels of total coliform bacteria.

CHAPTER 2. METHODOLOGY AND RESULTS

2.1 General Conceptual Approach

Preliminary water table mapping by Heath (1990) indicates groundwater primarily flows from the landfill toward the southeast discharging into Provincetown Harbor. Other pollutant sources are superimposed on the landfill leachate as it moves along this flow path. Monitor wells needed to be carefully placed to distinguish between these sources.

The general location of the contaminant plume was first determined indirectly by geophysical methods. Initial reconnaissance was performed using electromagnetics to ascertain the horizontal extent of the plume. Electrical resistivity soundings were then conducted to define the vertical extent of the plume and to delineate the thickness of the fresh water lens. Based on these geophysical results, locations for monitor well installations were selected. Except for one upgradient control well, the sites were selected for position in the leachate flow path. Each site consisted of three nested wells at vertically distinct positions.

A detailed assessment of the ground water quality around and downgradient of the landfill was determined by quarterly sampling surveys. The stations sampled included nine previously existing monitor wells surrounding the landfill, the fifteen multilevel monitor wells, and six surface water stations. A broad spectrum of constituents were analyzed including nutrients, inorganics, metals, volatile organics and field parameters.

Essential flow system characteristics were required in order to track the pathway and flow rate of the plume. The number of stations employed for preliminary water table mapping were expanded to develop more definitive water table contours from the landfill to the harbor. These measurements were also used to determine the depth of the fresh water lens using the Ghyben-Herzberg principle of proportionality (Ghyben, 1889; Herzberg, 1901).

The groundwater flow system at the beachface was more complex because of the effect of tidal dynamics. This impact was investigated in detail by direct measurements of groundwater fluctuations throughout the tidal cycle. These investigations produced information about the groundwater response to tidal phenomena including measurements of the time lag and tidal attenuation with distance from the shoreline and the optimum time for outflow. The quality of the groundwater outflowing into Provincetown Harbor was then investigated through shallow groundwater sampling along a transect parallel to the shoreline.

2.2 Geophysical Surveys

2.2.1 Electromagnetics

Terrain conductivity surveys were performed in order to ascertain the horizontal extent of the plume. This procedure is used for a preliminary qualitative survey to determine subsurface anomalous conditions. A Geonics Limited EM34-XL Terrain Conductivity Meter was used to map the terrain conductivity using inductive electromagnetic techniques. Seven surveys were conducted during May 1991 using both horizontal and vertical dipoles for additional exploration depths. Three different intercoil spacings were employed to obtain information at different depths. The survey locations are shown in Figure 2.1. Two surveys were located upgradient of the landfill (5 and 6) using both a 20- and 40-meter intercoil spacing. Three surveys downgradient (2,3,and 4) were executed using only the 10-meter spacing because of the thick growth of vegetation in this area. For survey 7 the 10-, 20-, and 40-meter coils were used. One survey along the Route 6 median was attempted but electrical interference encountered along Route 6 prevented any quality results at this location. The exploration depths obtained with EM34-3 at various intercoil spacings is shown in Table 2.1.

The survey results in Appendix A illustrate the lateral changes in terrain conductivity. The upgradient surveys show very consistent readings at both intercoil spacings using

Table 2.1. Exploration Depths for EM34-3 at Various Intercoil Spacings (McNeil, 1980)

Intercoil Spacing (meters)	Exploration Depth (meters) Horizontal Dipole	Exploration Depth (meters) Vertical Dipole
10	7.5	15.0
20	15.0	30.0
40	30.0	60.0

either dipole arrangements. This indicates little or no lateral change in terrain conductivity. The downgradient survey (Number 7) for the HD 20-meter intercoil spacing gave terrain conductivity readings of 10 - 15 millimhos per meter whereas the HD 20-meter readings upgradient (Numbers 5 and 6) were less than 5 millimhos per meter. The higher readings demonstrate the effect of a mineralized leachate plume.

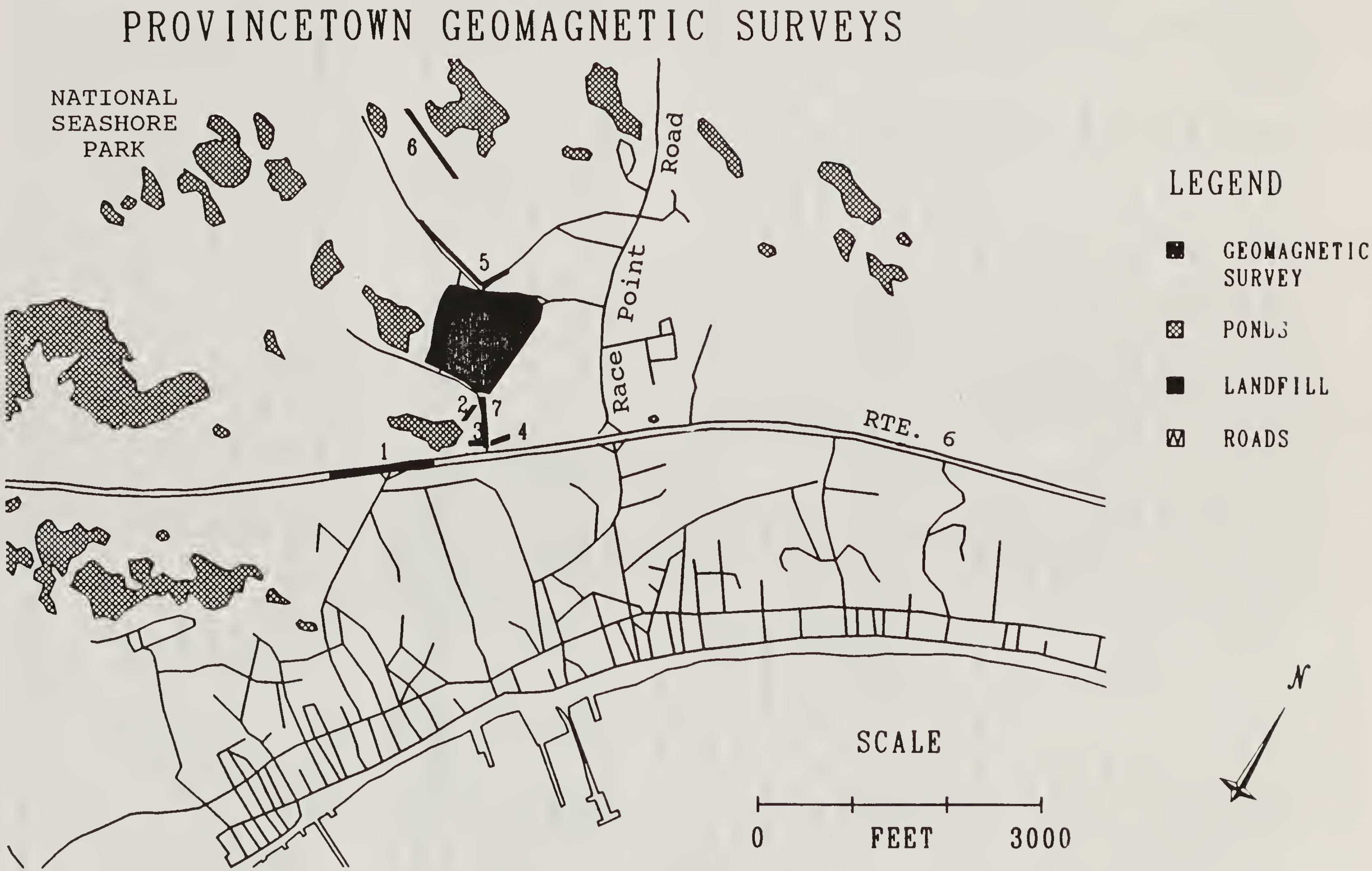


Fig. 2.1. Electromagnetic survey locations.

2.2.2 Geoelectrics

Surface geoelectrical surveys were conducted to determine the approximate location of the leachate plume and the depth of freshwater. The majority of this work was performed by Dr. Reinhard K. Frohlich, a Geophysics Professor at the University of Rhode Island. Two different field procedures were used : resistivity sounding and resistivity profiling. In a resistivity sounding the electrode spacing interval is successively increased to measure the change in resistivity with depth. The Schlumberger electrode arrangement is the recommended arrangement for sounding because it is less sensitive to undetected horizontal variations in resistivity and allows a faster field operation since only the current electrodes are moved (Mooney, 1980). In resistivity profiling the electrode spacing is fixed and the electrode array is moved along a transect to determine the resistivity variation in a horizontal direction within a depth range controlled by the electrode spacing. The Wenner electrode arrangement is the preferred arrangement for profiling because there is a wider spacing of the potential electrodes which results in larger potential differences that require less severe demands on precision (Mooney, 1980). The two configurations are represented in Figure 2.2. Symbols A and B refer to the current electrodes through which current is inserted into the ground. Symbols M and N refer to the electrode pair across which the voltage is measured.

A total of 10 electrical resistivity soundings were performed during October 1990 through November 1991. The locations for these soundings are shown in Figure 2.3. The soundings were conducted with a Soil Test Model R-60 and a Hewlett Packard Digital Voltmeter. The Schlumberger Array was used in the field work. The interpretations were performed by curve matching techniques both manually and with computer modeling. In most soundings the depth of penetration extended into the underlying seawater.

Electrical resistivity soundings in a coastal area can be effectively used to distinguish the boundary between the fresh water lens and underlying saltwater (Urish and Frohlich, 1990). Figure 2.4 is a typical sounding showing four layers: a thin organic-rich surface layer, a clean unsaturated layer, a fresh water saturated layer and a lower saturated salt layer. In this case the transition from salt water to the top of the transition zone is indicated by the marked break in slope of the downward limb. Interpretation identified the bottom of the fresh water layer at 115 feet. This is actually the top of the transition zone in which the electrical resistivity rapidly decreases to the very low values of seawater. The average for all soundings suggests the thickness of the fresh water layer is about 108 feet.

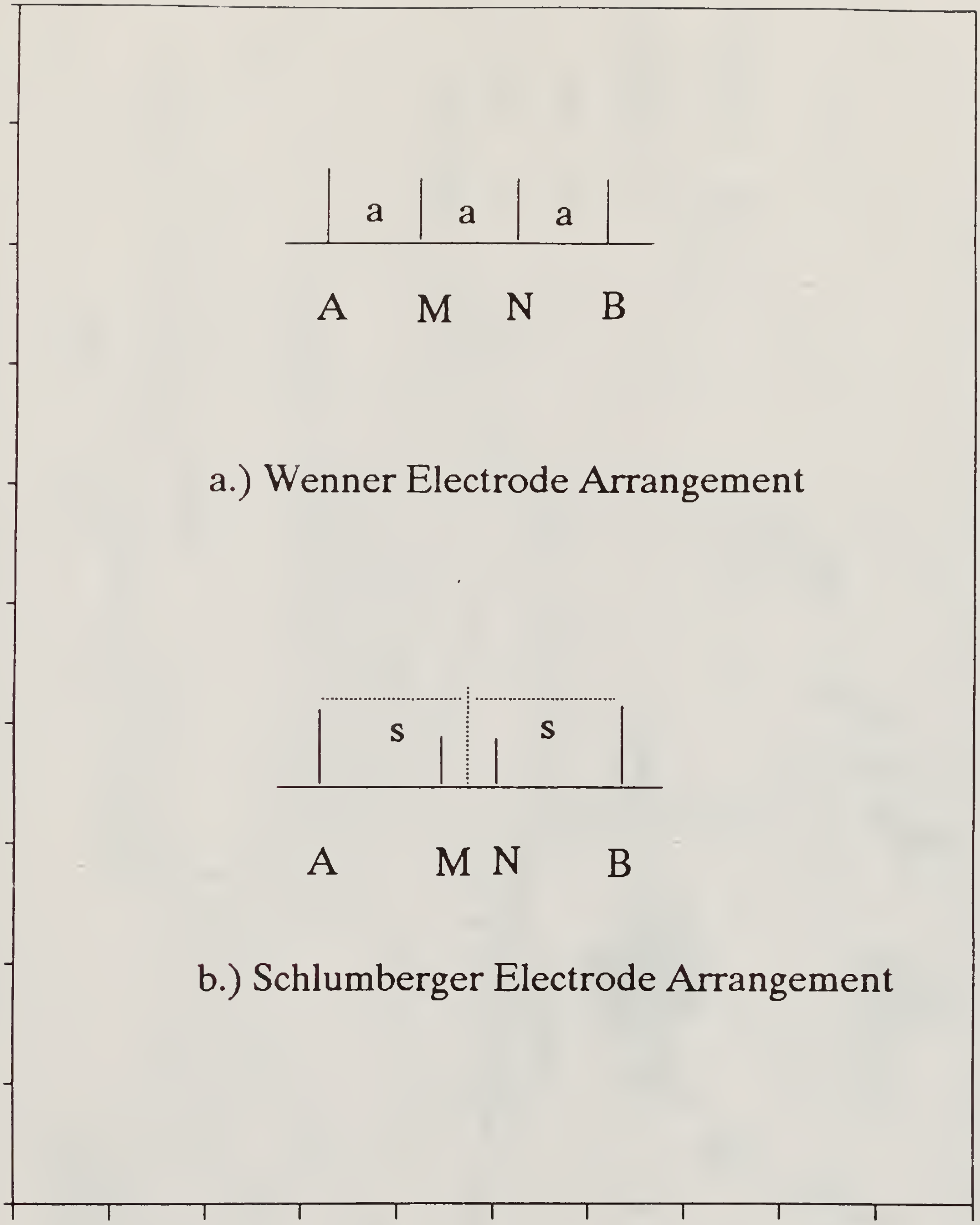


Figure 2.2 Electrode Array Configurations

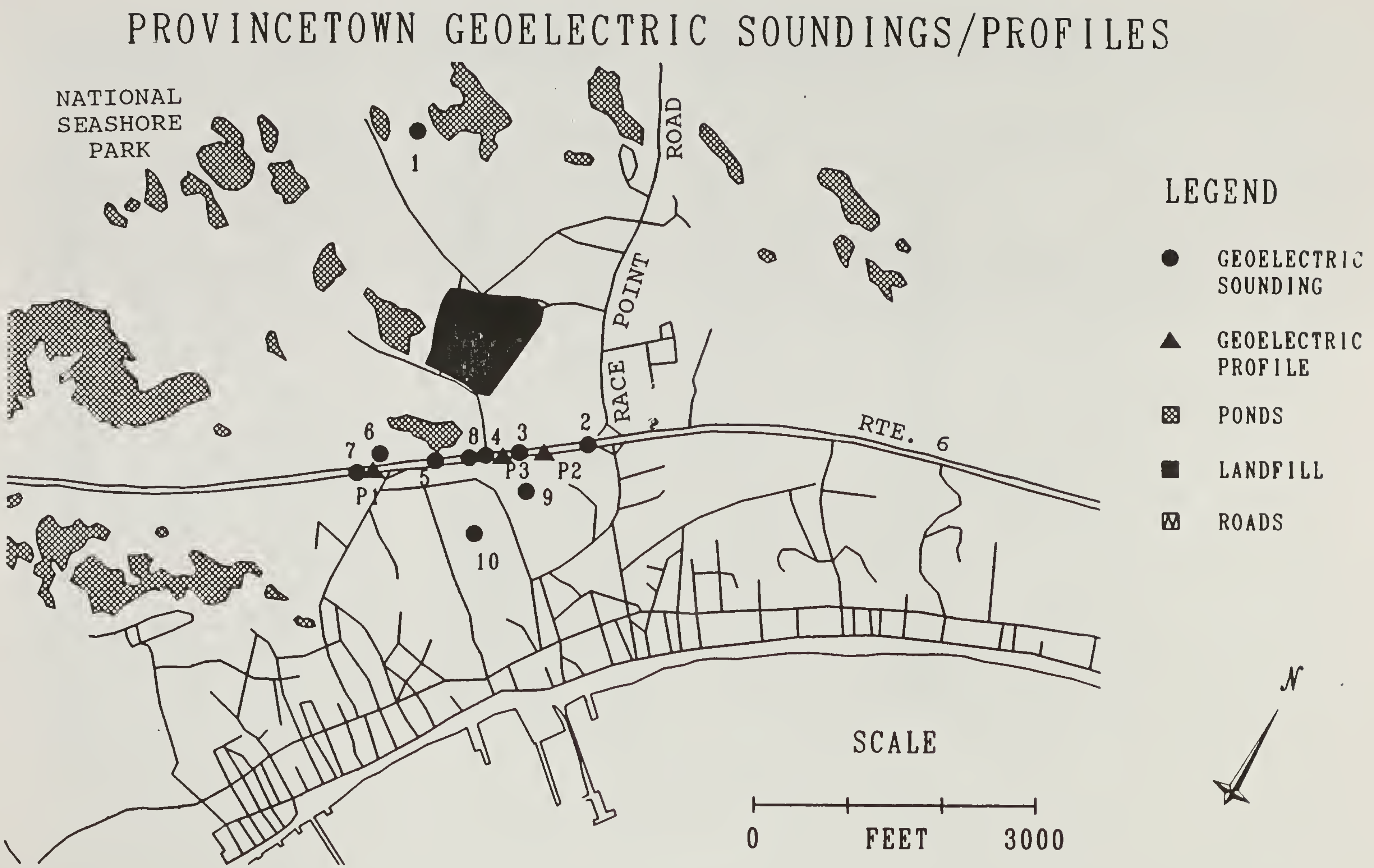


Fig. 2.3. Geoelectrical sounding and profile locations.

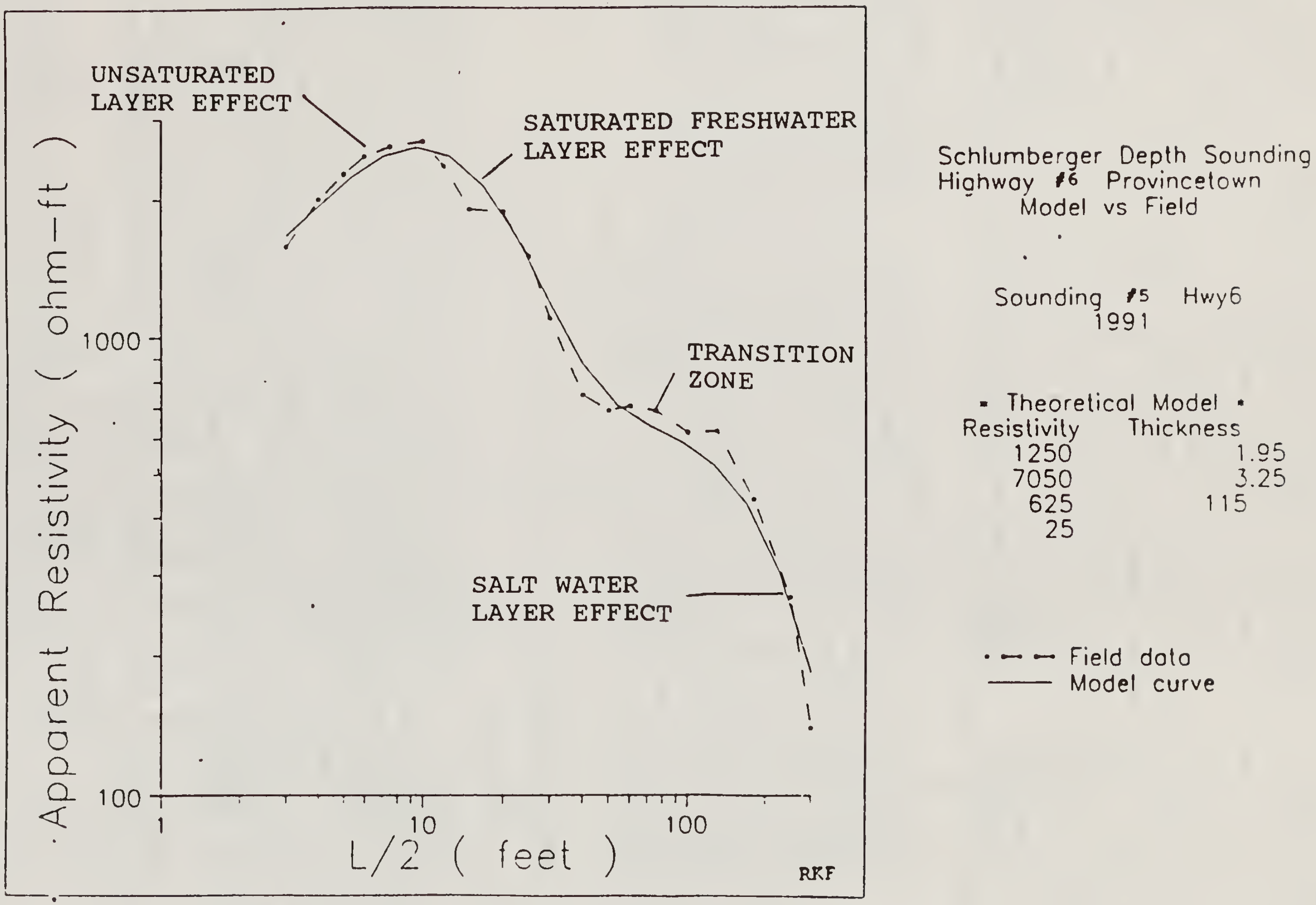


Fig. 2.4. Electrical resistivity sounding.

One sounding was located northwest of the landfill in a clean upgradient area and was used as a standard for comparison with potentially polluted areas. Seven soundings were conducted along the Route 6 median because, based on previous water table data, it was determined that the plume probably travels underneath this roadway. Route 6 is also an attainable area for geoelectrical surveys. Locating a reliable survey area is critical because changes in topography, the existence of buried pipes, and other debris can greatly influence the measurement, rendering interpretation very difficult. Two other soundings were located in the cemetery between Route 6 and the developed region of Provincetown. The cemetery area was a difficult area for geoelectrics because of many subsurface interferences and variations in topography. This produced lateral as well as horizontal resistivity differences, therefore, the results here were inconclusive.

An electrical resistivity profile was performed along the Route 6 median to confirm depth soundings indicating high water mineralization, and to obtain a best approximation for this suspected plume location. Figure 2.5 is a plot of the apparent resistivity readings obtained from this profile. The results show strong evidence of a leachate plume extending from the location where the landfill trail intersects Route 6 for about 400 feet to the southeast. This coincides with the expected flow path based on initial water table mapping. As a result of this resistivity profile an additional well (MW15D) was placed in the median strip of Route 6.

2.3 Monitor Wells

2.3.1 Location

Preliminary field measurements indicate that groundwater flow moves from the landfill in a southeasterly direction toward Provincetown Harbor on Cape Cod Bay. This flow path moves under the Midcape Highway (Route 6), the cemetery, and individual septic systems in the town. Monitoring wells were located in order to differentiate additional pollution inputs from these sources, through water quality sampling. However, due to physical constraints, the selection options for locations south of the highway were limited.

There were 9 existing monitor wells around the perimeter of the landfill prior to this project. They are numbered as 1-9 in Figure 2.6.

In the fall of 1990 five locations were chosen for monitor well placement. They are numbered 10 - 14 in Figure 2.6. One site was placed northwest of the landfill as an upgradient control well (MW10), two sites along Route 6 (MW11

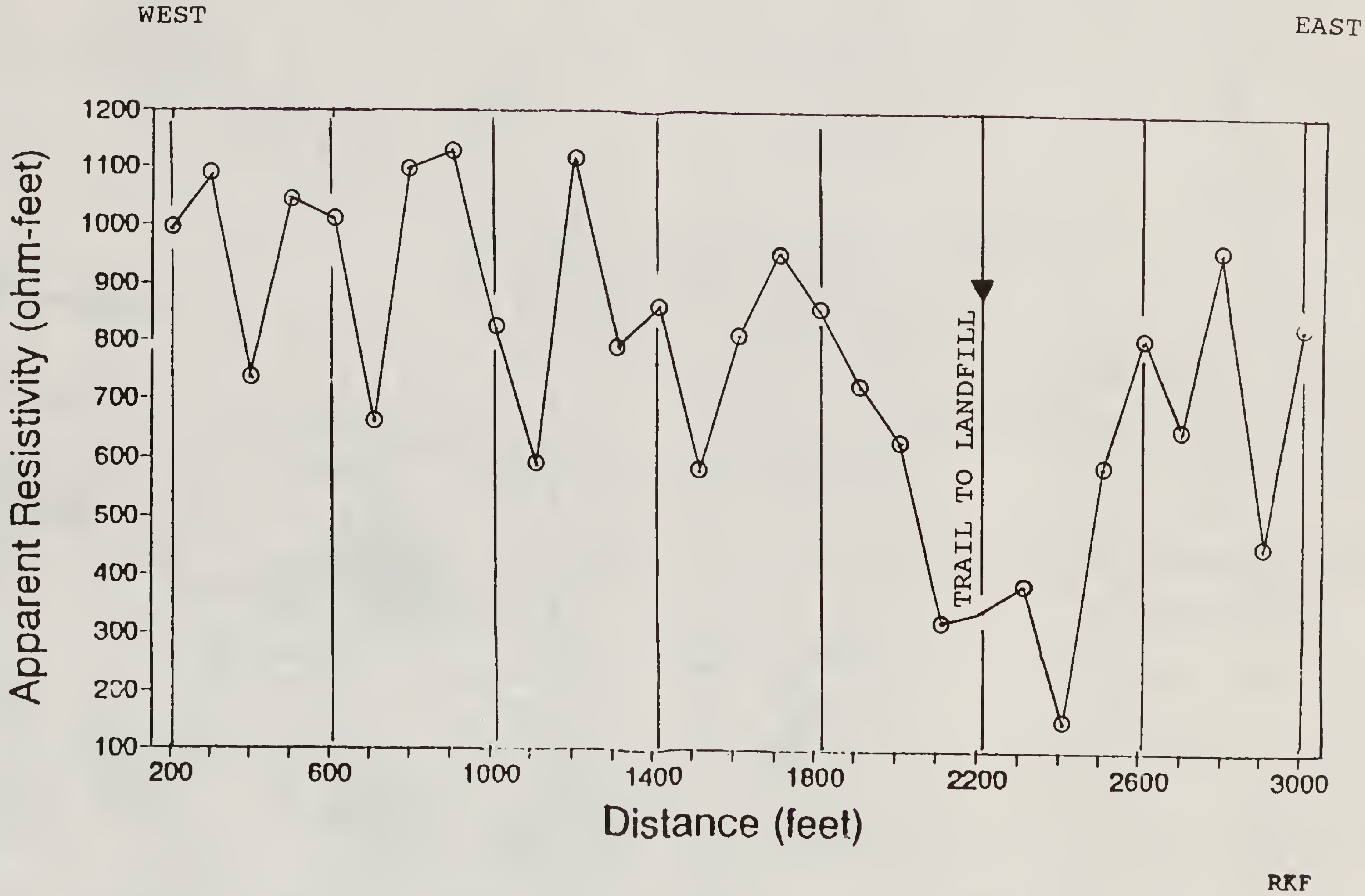


Fig. 2.5. Electrical resistivity profile along Highway No. 6, Provincetown, MA

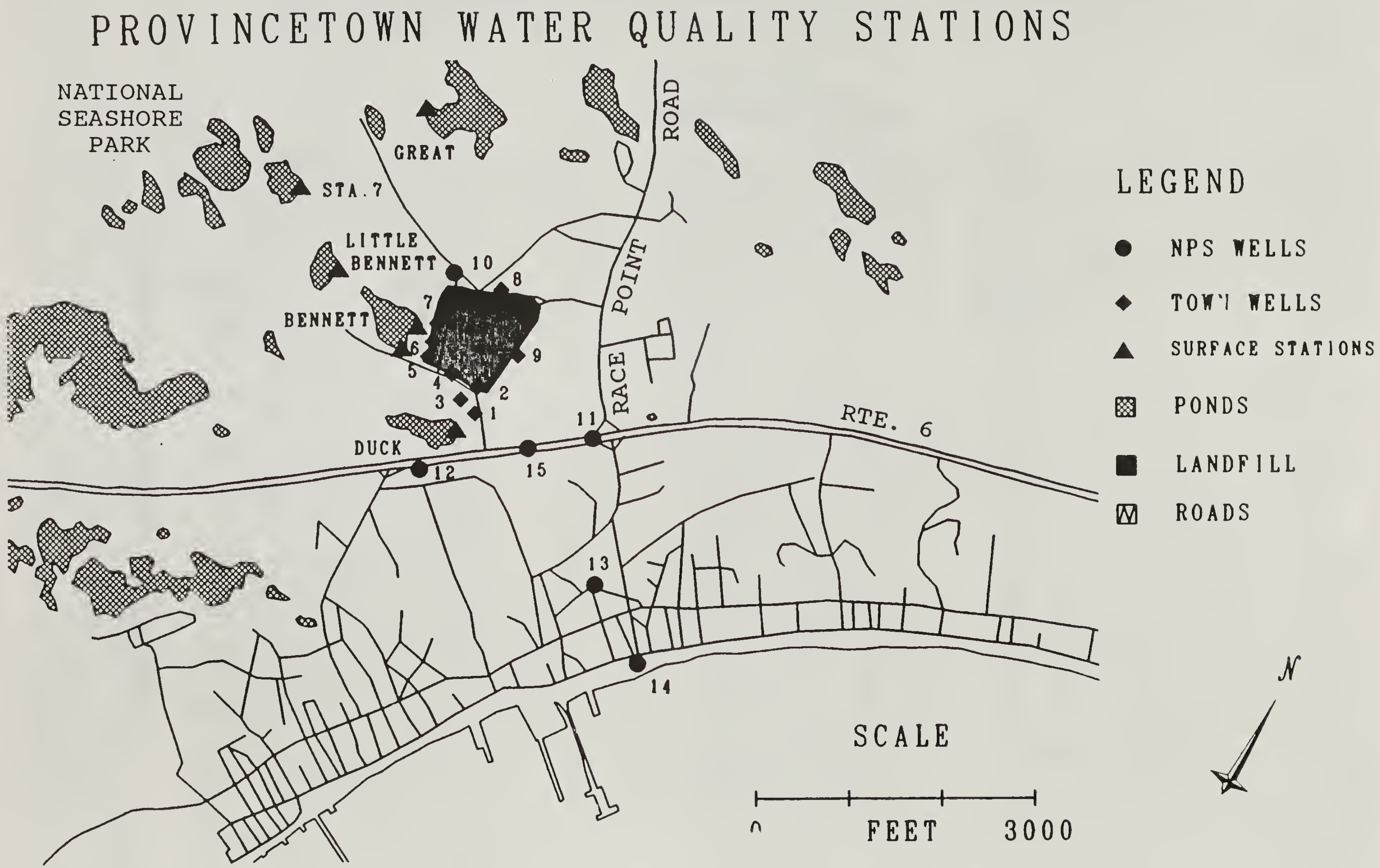


Fig. 2.6. Map of Provincetown landfill sampling locations.

and MW12), one downgradient of the cemetery (MW13), and one at the town beach (MW14). Each site consisted of three nested wells: a deep well (D) drilled to the approximate top of the fresh-salt water transition zone, a shallow well (S) placed about 10 feet below the water table, and an intermediate well (I) whose depth was based on the electrical conductivity and temperature measurements collected during the drilling of the deep well at that particular site.

Based on geophysical surveys along Route 6 indicating an unusually low resistivity value, an additional deep well was installed in January 1992, MW15. This site contains a singular deep well and was only included in the last sampling survey.

2.3.2 Installation

Six of the original nine landfill wells were installed by Guild Drilling Co., Inc. of East Providence, RI. in May of 1983 and the drilling logs are included in Appendix B. There are no installation records for the other three wells MW1, MW3, and MW7. Their depth and diameter were measured in the field and are included in Table 2.2. These wells were in good condition initially, but after the first survey the well casing of MW7 was severely bent. This prevented sampling for the next two surveys. Sampling was accomplished on the last survey.

The sixteen new monitor wells were installed from November 1990 - January 1991 by Desmond Drilling Co. of Orleans, Massachusetts in accordance with standard EPA monitor well specifications. The hole was drilled with a 3.75-inch inner diameter hollow stem auger that was decontaminated between sites so that no foreign chemicals were introduced during the drilling process. Split spoon samples and electrical conductivity measurements began at the water table and were taken at 5-foot intervals during the drilling process of the deep well at each site. The screen size and location were then determined by the engineer on site. Detailed monitor well characteristics are listed in Table 2.2.

The well pipe and screen were constructed of 2-inch diameter PVC material, set in place with bentonite grout to 3 feet below ground surface, and covered by a steel protective casing with a locking cap. The wells were then developed by overpumping with Truro town water or water from the town of Orleans, a nearby uncontaminated source.

The Cape Cod Test Boring Records for the 16 Cape Cod National Seashore wells are included in Appendix B.

Table 2.2. Monitor Well Characteristics

STATION	PIPE TOP ELEVATION feet	WELL DIAMETER inches	WELL DEPTH feet	SCREEN SIZE inches	SCREEN LENGTH feet	SCREEN DEPTH feet
TOWN WELLS						
MW1	13.92	2	19		5	14-19
MW2	19.93	2	22		5	17-22
MW3		2	9		5	4-9
MW4	17.46	2	20		5	15-20
MW5	9.43	2	15		5	10-15
MW6	10.92	2	15		5	10-15
MW7	15.75	2	15		5	10-15
MW8	23.27	2	30		5	25-30
MW9	18.86	2	21		5	16-21
NPS WELLS						
MW10S	24.62	2	30	0.01	5	25-30
MW10I	24.96	2	55	0.01	5	50-55
MW10D	24.84	2	104	0.01	5	99-104
MW11S	12.66	2	17	0.01	5	12-17
MW11I	12.58	2	67	0.01	5	62-67
MW11D	12.68	2	100	0.01	5	95-100
MW12S	12.92	2	22	0.01	15	7-22
MW12I	13.09	2	64	0.01	5	59-64
MW12D	13.03	2	112	0.01	5	107-112
MW13S	20.68	2	25	0.01	10	15-25
MW13I	20.66	2	78	0.01	10	68-78
MW13D	20.14	2	120	0.01	10	110-120
MW14S	9.5	2	17	0.01	10	7-17
MW14I	9.6	2	35	0.01	10	25-35
MW14D	9.57	2	85	0.01	5	73-78
MW15D	12.14	2	110	0.01	20	90-110

Note : Datum is NGVD 1929
S - Shallow Well
I - Intermediate Well
D - Deep Well

2.3.3 Soil Tests

A soil analysis was performed on a representative soil sample collected from grab samples during the installation of monitor well MW15. Falling head permeameter lab tests were performed on this sample to determine values of hydraulic conductivity needed for groundwater flow calculations. The test was performed five times varying the initial head and the time for water drop for each run. The estimated field hydraulic conductivity calculated for the composite sample ranged from 170 - 215 feet/day. This included a temperature adjustment to account for the variation in absolute viscosity of water between the laboratory temperature and the average field temperature of 11.5 °C. The average hydraulic conductivity was 193 feet/day at a porosity of 0.355.

A sieve analysis was also performed on this sample to construct a grain size distribution curve. The curve is included as Figure C-1 in Appendix C. Hydraulic conductivity can be estimated from this curve by both empirical and theoretical analysis. Mazzaferro, et al. (1979) provides a graph of glacial sediment in New England which relates grain size to hydraulic conductivity. For this sample a median grain size of 0.58 mm was obtained. This indicates a possible range of conductivity from 50 - 500 feet/day with a most likely median value of 200 feet/day. Hazen's equation (Freeze and Cherry, 1979) was also applied using the 10% size. This yields a hydraulic conductivity value of 430 feet/day. The 200 feet/day seems a more probable value for hydraulic conductivity in the Provincelands area.

A complete tabulation of the results from the soil tests appears in Appendix C.

2.3.4 Water Levels

In January 1990 the National Park Service (NPS) installed and surveyed 31 water level measuring sites in the vicinity of the Provincetown landfill. These stations include shallow 2" diameter piezometers, steel rebar staff gages, and previously installed monitor wells at the landfill. They are located in both ground and surface waters and were installed to characterize local ground water flow directions in the area.

On September 12, 1990 the NPS stations were examined and four new staff locations were added. The new staff gages consisted of 2" diameter steel pipes and were used to replace the more fragile steel rebar. On September 20, 1990 a total of three steel shallow wells were hand installed in Duck and Bennett Ponds. They have a 3" plastic screen and were placed approximately 2' below the pond bottom. They were added to provide information on whether the ponds were groundwater discharge or recharge areas.

After January 19 1 the 15 new monitor wells were added to the water table stations, yet supplemental shallow wells were still needed south of Route 6 for the development of a more complete water table map. Fire wells and private wells were examined but were unsuitable because of silting and availability problems. Further inspection of low elevation areas later produced three new stations in seasonally flooded wetland areas. Piezometers were installed at these three stations. The sampling locations are listed in Table 2.3 and a complete map of water table stations is shown in Figure 2.7.

Reference elevations were set on well pipe tops for direct measurement. The elevations were established by standard surveying techniques to a NGVD 1929 datum bench mark using BM 27 on Race Point Road and a Topcon AT-F2 Auto Level. The water levels were measured by wetted tape measurement using a 100 foot Lietz-Eslon fiberglass tape. The depth to the water level from the top of the pipe or well to the water surface was recorded in the field and then subtracted from the pipe top elevation to determine water table elevation. Water table elevation maps were then prepared from this information.

Water table maps were developed in order to ascertain groundwater flow direction and the gradients needed to determine velocity of groundwater flow. A series of six water table maps were constructed using over forty ground and surface water measuring points. A tabulation of water table elevation measurements taken at these stations throughout the project is shown in Appendix D. The water table maps produced from these data are also included in Appendix D.

Water levels fluctuate no more than 1.4 feet between winter and summer, indicative of a "floating" Ghyben-Herzberg lens. In contrast to terrestrial locations, the groundwater recharge in the Provincelands expands the fresh water layer thickness in the lower part of the lens rather than raising the water table. Figure 2.8 shows the typical fluctuation of the water levels at monitor well MW13 during the period of April 1991 to September 1992. Relative water levels in sets of monitor wells with screens set at different levels indicate vertical components of groundwater flow.

2.4 Water Quality

2.4.1 Sampling

An initial set of water quality samples was collected from Duck Pond and Bennett Pond in September 1990. These

Table 2.3. Summary Table of Sampling Locations

STATION	WATER QUALITY	WATER TABLE	STATION	WATER QUALITY	WATER TABLE
TOWN WELLS			STAFF GAGES		
MW1	x	x	S1		x
MW2	x	x	S2		x
MW3	x	x	S3		x
MW4	x	x	S5		x
MW5	x	x	S6-GREAT –	x	x
MW6	x	x	S7-STA.7	x	x
MW7	x	x	S7A		x
MW8	x	x	S8A		x
MW9	x	x	S9		x
			S11-LIL' BEN.	x	x
NPS WELLS			S12		x
MW10S	x	x	S12B-BEN. W –	x	x
MW10I	x	x	S12C-BEN. E –	x	x
MW10D	x	x	S16B-DUCK –	x	x
MW11S	x	x	S16C –		x
MW11I	x	x			
MW11D	x	x	PIEZOMETERS		
MW12S	x	x	P6		x
MW12I	x	x	P10		x
MW12D	x	x	P13		x
MW13S	x	x	P14		x
MW13I	x	x	P15		x
MW13D	x	x	P16		x
MW14S	x	x	P17		x
MW14I	x	x	P18		x
MW14D	x	x	P19		x
MW15D	x	x	P20		x
			P21		x
			Oak		x
			Court		x
			Shank		x

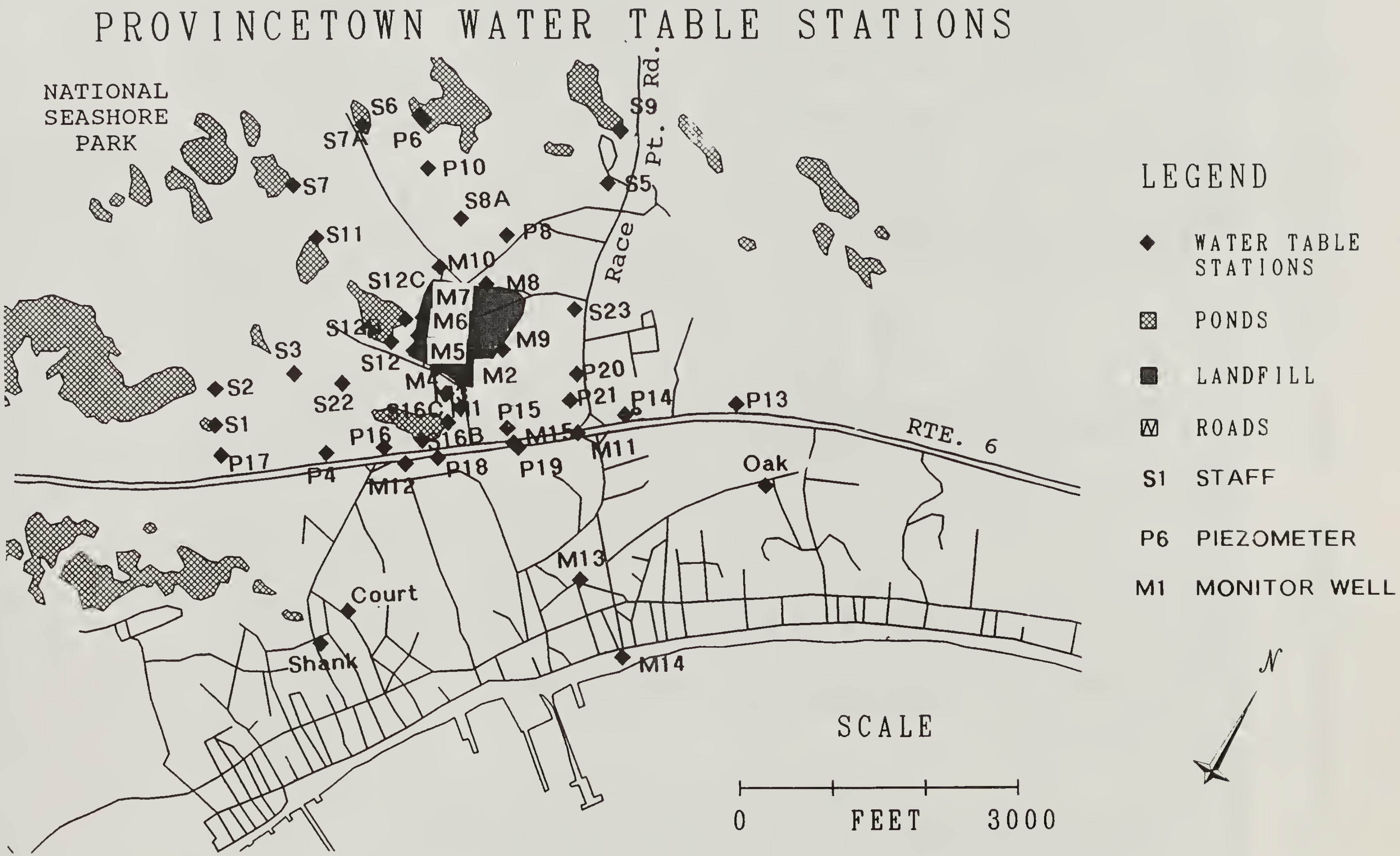


Fig. 2.7. Map of Provincetown water table stations.

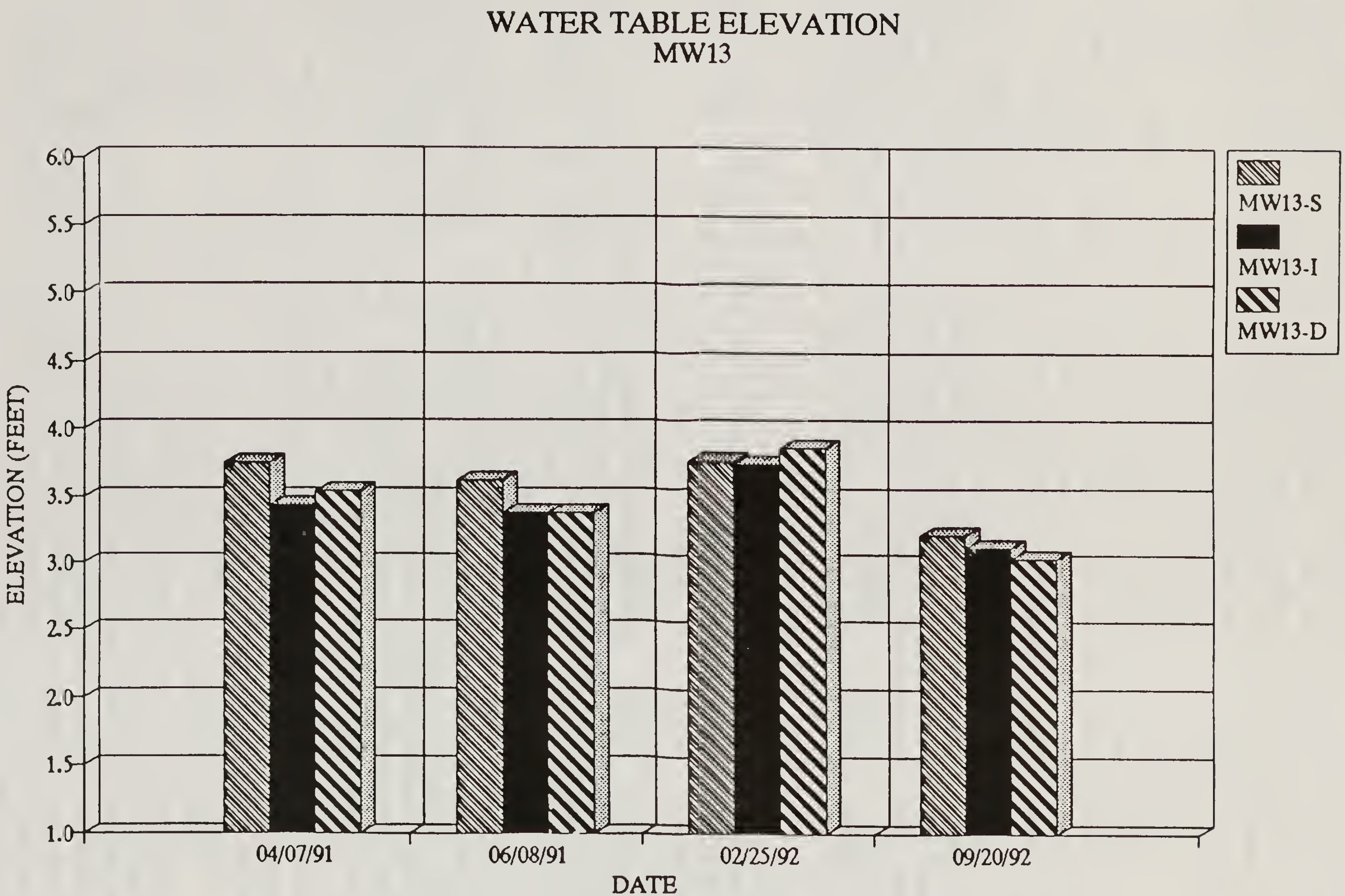


Fig. 2.8. Water level fluctuations at MW13.

consisted of both surface water and shallow groundwater samples. The stations were field tested for temperature and specific conductance and water samples were obtained for metals analysis at the University of Rhode Island - Civil Engineering (URI-CVE) Laboratory. On the basis of this initial survey, 6 surface water stations were added to the sampling program.

The water quality sampling program included the 15 multilevel monitor wells installed by the NPS, the 9 existing shallow monitor wells surrounding the landfill, and 6 surface water stations. The monitor well characteristics are listed in Table 2.2. The sampling locations are shown in Figure 2.6.

Four surveys were conducted at quarterly intervals over one year. The monitor wells were sampled using 0.5-inch inner diameter dedicated inertial pumps manufactured by Wattera Pumps Ltd. These high density polyethylene pumps allow quality samples to be obtained efficiently and economically, eliminating the need for a power source or decontamination between stations. The operating principle is based on the inertia of the column of water within the tubing. A foot valve at the end of the tubing allows water to enter the tube and prevents water from draining back out of the tube. The water is pumped by repeatedly raising and lowering the tube a short distance.

Water level measurements were taken at each well to determine the volume of water presently in the well. Three well volumes were then purged by manually pumping the Waterra tubing and measuring the quantity dispensed in a 5-gallon bucket. Field analysis for temperature, specific conductivity, pH, and dissolved oxygen was then measured using a discrete sample. Two more gallons were extracted and the field analysis was repeated. This process continued until the field measurements stabilized and the well was ready for sampling. Each sample bottle was then filled directly from the pump except for the bottle used for metals analysis. This sample was dispensed into a Nalgene filter apparatus for immediate filtering in the field, and the filtrate placed in the sample container. All samples were then transferred into an iced cooler.

The surface water stations consisted of six designated locations in five separate ponds within a 2,000' radius of the landfill. Field analysis for specific conductance, temperature, pH, and dissolved oxygen were accomplished at the site and then each bottle was individually filled. For the first two surveys the metal samples were not filtered, instead a total analysis was determined. In the last two surveys both a total and dissolved analysis was taken and consequently one sample was filtered in the field.

The first round of sampling was conducted in February 1991 shortly after well installation was completed. Two subsequent samplings occurred at quarterly intervals and the last sampling was conducted in February 1992, after installation of the additional monitor well (MW15D) in the Route 6 median. In addition the town landfill washdown well, installed during the project period, was sampled to obtain some indication of water quality directly below the water table. Well characteristics of this well are unknown.

2.4.2 Analysis

Field analysis for temperature and specific conductance was determined using a portable YSI conductivity meter (model 33 S-C-T meter). This meter was laboratory calibrated with NaCl standards. Dissolved oxygen was determined with a portable YSI dissolved oxygen meter calibrated periodically with the Winkler titration method (Winkler, 1888). PH was measured with an Orion Research Field pH meter (ionanalyzer/model 399A) which was calibrated daily with standards.

Laboratory analysis was conducted at three separate labs. The Barnstable County Health and Environmental Department (BCHED), a state operated lab under contract with the National Park Service, performed the analysis for ammonium, nitrate, chemical oxygen demand (COD), volatile organic compounds (VOC), and numerous metals: calcium, iron, magnesium, manganese, sodium, and zinc. Prepared bottles were received from the lab and the filled bottles delivered daily during the sampling survey.

Alkalinity and bicarbonate were measured after each sampling day, as recommended by Standard Methods, section 2310 B.1f (APHA, AWWA, WPCF 1989). This was accomplished in the NPS field lab in Truro by titration with 0.16N standard sulfuric acid solution and an automatic titrator according to method 2320 B.4b in Standard Methods (APHA, AWWA, WPCF 1989).

The remaining analyses were performed in the University of Rhode Island - Civil Engineering laboratory. These analyses included orthophosphate, total phosphorus, chloride, sulfate, and numerous metals: chromium, copper, cadmium, nickel, and lead.

The metals were analyzed by electrothermal atomic absorption with a Perkin-Elmer 5100PC Atomic Absorption Spectrophotometer (model 399A) equipped with a HGA 600 Graphite Furnace and a AS-60 Autosampler. Method 3113 B in Standard Methods (APHA, AWWA, WPCF 1989) was the procedure used. This method is very sensitive, determining concentrations as low as 0.1 ug/l. All the supplies used for collection and analysis were acid washed with 2N nitric acid. Samples taken for the dissolved fraction analyses were filtered in Nalgene filter units using 47 mm diameter, 0.45 um pore Nucleopore polycarbonate filters. Both the dissolved and total forms were preserved with Ultrex grade nitric acid prior to analysis.

Sulfate was determined using the turbidimetric method, method 4500 E.2 of Standard Methods (APHA, AWWA, WPCF 1989). The photometer used was a Milton Roy Spectronic Spectrophotometer (model 1001 plus).

Chloride was measured with a selective ion electrode and an ionanalyzer meter from Orion Research (model 407A). The analytical technique used was that prescribed by the manufacturer.

Orthophosphate was colorimetrically measured with a Technicon Autoanalyzer II. The samples were filtered using a Gelman Type A/E, glass fiber, 0.45 mm thick filter to avoid clogging the small diameter tubes in the autoanalyzer. Samples were then preserved with chloroform and stored at 4 degree celsius prior to analysis. The Automated Ascorbic Acid Method, method 4500-P E. of Standard Methods (APHA, AWWA, WPCF 1989) was the colorimetric method most suited to the concentration range expected. Two replicate analyses for each sample were performed and averaged to obtain a sample concentration.

Phosphorus may occur in combination with organic matter, therefore a digestion method must be employed in order to oxidize this organic matter and release phosphorus as orthophosphate. The Nitric Acid-Sulfuric Acid Method, method 4500-P B.4 of Standard Methods (APHA, AWWA, WPCF 1989) was the digestion method employed. After digestion the liberated orthophosphate was determined colorimetrically by the same method as the organic orthophosphate, the Ascorbic Acid Method, method 4500-P E. of Standard Methods (APHA, AWWA, WPCF 1989).

As a part of the water quality sampling and testing quality assurance plan, trip blanks and equipment blanks were collected during the sampling surveys.

All the collection and storage methods and the chemical analyses were performed using standard procedures in strict compliance with Standard Methods for Examination of Water and Wastewater (APHA, AWWA, WPCF 1989). A complete list of the constituents analyzed and the analytical method used is shown in Table 2.4. The water quality results from the four surveys are tabulated for each individual sampling location. These tables are included in Appendix E.

Table 2.3. Parameters Analysed for Water Quality

PARAMETER	LABORATORY	METHOD
Alkalinity (mg/l)	BCHED	titration
Bicarbonate (mg/l)	NPS	titration
Ammonia (mg/l)	BCHED	ion-chromatograph
Nitrate (mg/l)	BCHED	ion-chromatograph
Orthophosphate (mg/l)	URI	colorimetric
Phosphorus (mg/l)	URI	colorimetric
Chloride (mg/l)	URI	ion-electrode
Sulfate (mg/l)	URI	turbidimetric
COD (mg/l)	BCHED	colorimetric
Calcium (mg/l)	BCHED	AA-Flame
Iron (mg/l)	BCHED	AA-Flame
Magnesium (mg/l)	BCHED	AA-Flame
Manganese (mg/l)	BCHED	AA-Flame
Sodium (mg/l)	BCHED	AA-Flame
Zinc (mg/l)	BCHED	AA-Flame
Chromium (ug/l)	URI	AA-Furnace
Copper (ug/l)	URI	AA-Furnace
Cadmium (ug/l)	URI	AA-Furnace
Nickel (ug/l)	URI	AA-Furnace
Lead (ug/l)	URI	AA-Furnace
pH (Field)	URI	Orion Meter
Temperature (Field)	URI	YSI Meter
Conductivity (Field)	URI	YSI Meter
Conductivity @ 25 C	URI	YSI Meter
DO (Field)	URI	YSI Meter
VOC (ug/l)	BCHED	EPA 5021/5031

BCHED - Barnstable County Health/Environmental Lab
NPS - National Park Service Field Lab
URI - University of Rhode Island Civil Engineering Lab

Monitor well set 10, which consists of a set of three wells at different depths, was established as an unaffected, upgradient control well. The water quality characteristics of this well set generally appear to be those of natural conditions. These characteristics are low levels of electrical conductivity, chlorides, alkalinity, bicarbonate, ammonia, nitrates, orthophosphate, calcium, chemical oxygen demand, metals, and no volatile organic compounds. Exceptions to these characteristics appear at the intermediate and deep wells. The deep well contains elevated levels of alkalinity, calcium, and iron, and very low concentrations of dissolved oxygen. The intermediate well contains elevated concentrations of lead and chemical oxygen demand. Because this well set is in a region with a very minimal groundwater gradient, it is possible that some seasonal input from the landfill leachate may influence the water quality. This could occur because of localized water table mounding under the landfill, which would be sufficient to create an outward directed hydraulic gradient at the perimeter of the landfill.

The wells downgradient that were most affected by the landfill are wells 2, 4, and 9 (Figure 2.6). Samples from these wells show high levels of electrical conductivity, alkalinity, bicarbonate, ammonia, nitrate, orthophosphate, calcium, chemical oxygen demand, sulfate, chloride, metals, and volatile organic compounds; and low dissolved oxygen values.

The nested monitor wells on Route 6, monitor well set 11 and 15, have high levels of chloride, cadmium, chemical oxygen demand, lead, and sodium. Volatile organic compounds were also detected at these stations and monitor well 15 had very high levels of ammonia. Figure 2.9 shows the ranges of chloride concentrations for the monitor wells along the flow path from the landfill to the harbor. It is interesting to note that the chloride level was highest at the intermediate well in well set 11 suggesting a source other than underlying sea water. The deep well was also high in chlorides but the shallow well had low concentrations. Chlorides were also much lower at well 15 which is at a comparable depth to the deep well in well set 11. However, it should be noted that there is a strong possibility that the high chlorides in MW11 originate from salt storage at the town maintenance area about 800'upgradient from MW11.

Alkalinity, bicarbonate, and dissolved oxygen decreased with depth at each of the nested well sets. Ammonia, calcium, iron, manganese, and pH increased with depth. The water quality of the well set at the beach, well set 14, was not as consistent and is markedly affected by seasonal and tidal changes. The deep well was brackish and therefore had exceptionally high levels of electrical conductivity, chloride

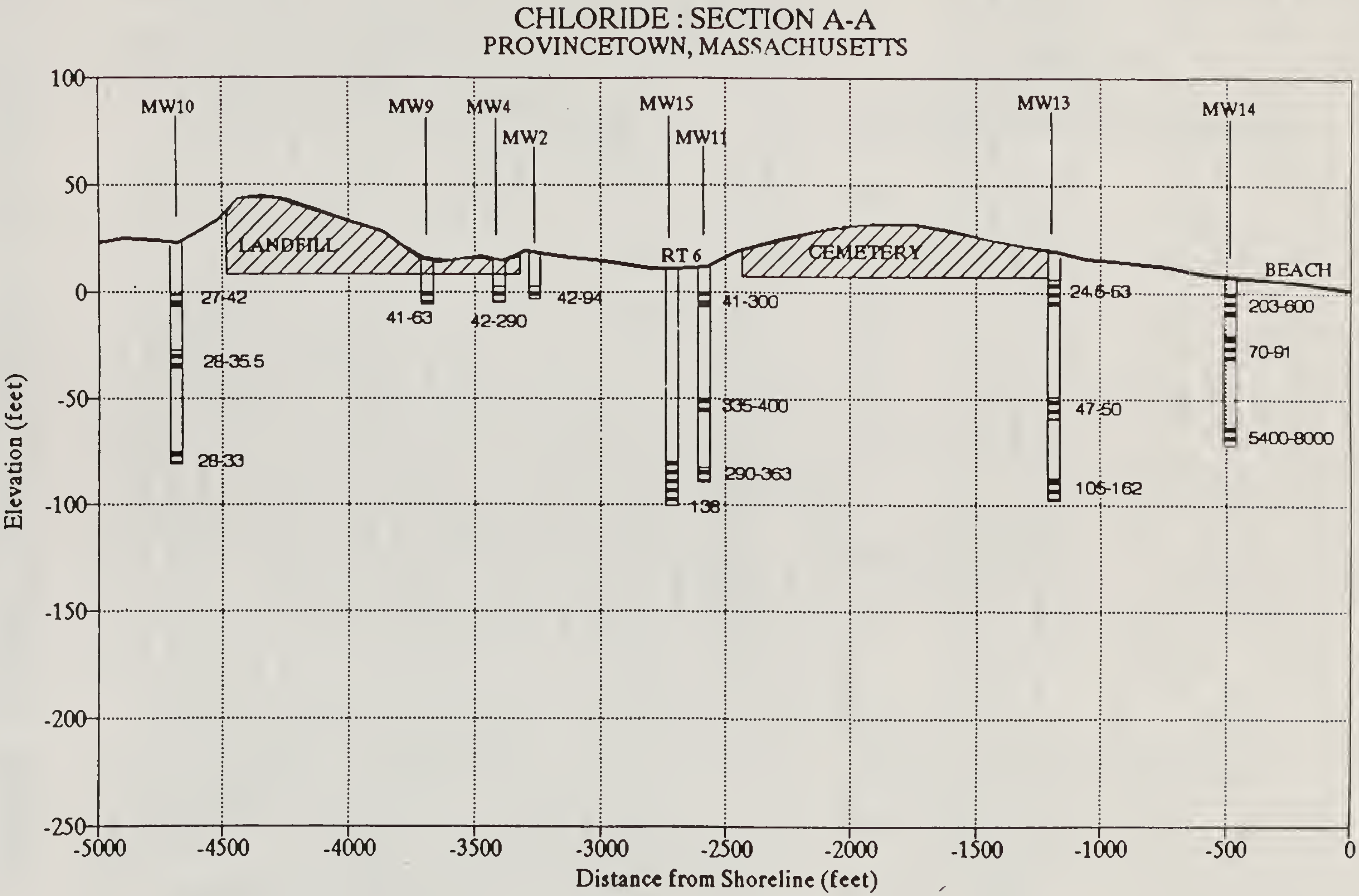


Fig. 2.9. Chloride concentrations in monitor wells from landfill to beach.

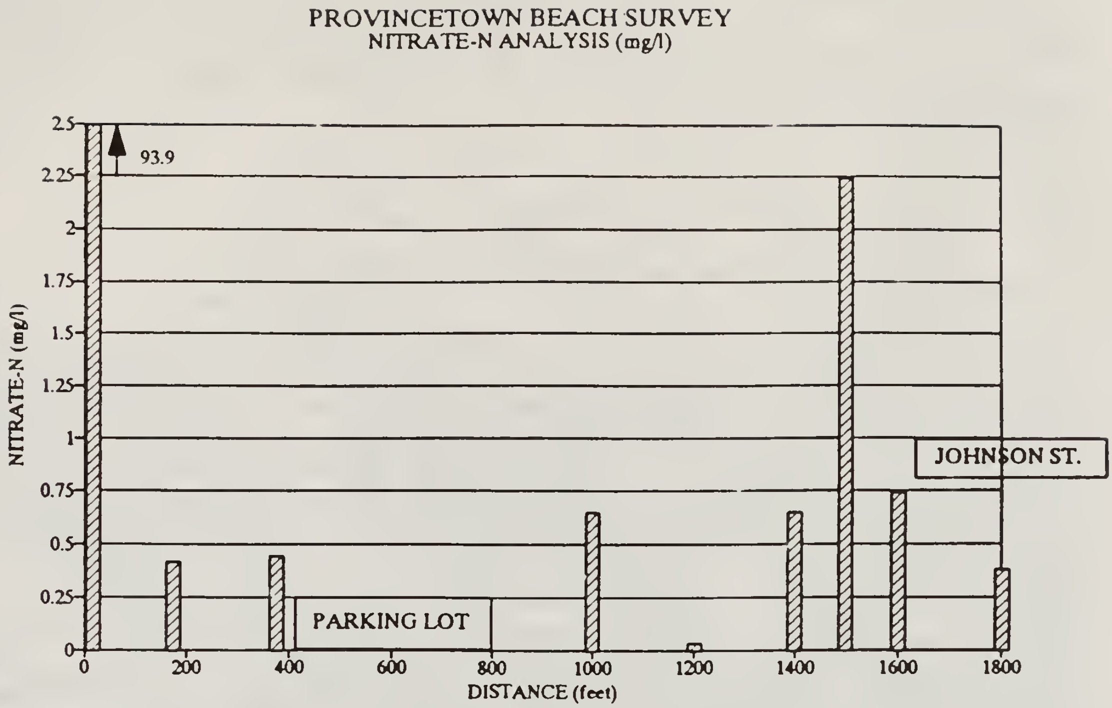
calcium, magnesium, sodium, and sulfate. These constituents were also elevated in the shallow well, but the intermediate well showed no signs of typical sea water constituents. Even electrical conductivity was relatively low. This well set contained some constituents that characterized contamination. Nitrate, ammonia, orthophosphate, and total phosphate were elevated at the shallow well. These constituents were also present in the deep well. Iron was considerably high in the deep well, with levels approaching that of the contaminated wells at the landfill.

The surface water quality of shallow ponds surrounding the landfill was analyzed. The concentration of metals, ammonia, and chemical oxygen demand increased with proximity to the landfill. No volatile organics were detected at these stations and alkalinity was very low as is expected in surface waters.

2.4.3 Beach Sampling

The quality of the water entering Cape Cod Bay and the extent to which landfill leachate may contribute to harbor pollution was investigated. An independent survey of the water quality along the beachface was carried out in May of 1992. A 2" diameter hand driven stainless steel probe was hammered 2.5' below the surface. Samples for nutrient and total metal analysis were collected by using a manual vacuum pump equipped with tygon tubing which was lowered inside the probe. Samples were obtained at low tide beginning at the Johnson street station and continuing southwest at intervals of approximately 100' for a total distance of 1400'. Surface water samples of low tide seepage were also periodically sampled along this transect. All samples showed a mixture of salt water and fresh water in widely varying proportions. Figure 2.10 shows the results of the nutrient analysis. Two locations show elevated levels of both nitrate and orthophosphate. Many restaurants along Commercial Street, which is the closest road that runs parallel to the shoreline, have septic problems during the summer months. The exceptionally high nitrate level southwest of the parking lot is possibly the result of a failed septic system just upgradient of the site. The second high nutrient site, 300 - 400 feet southwest of Johnson Street, exhibits a deep red iron oxide staining just below the ground surface. The staining continues from approximately the 1200 - 1500 feet stations, but is most prominent at the 1400 - 1500 feet stations.

A complete sampling of Provincetown Harbor water at both low and high tide was included in the fourth sampling survey in February 1992 and a full analysis was performed on these samples. The analysis is included with the water quality



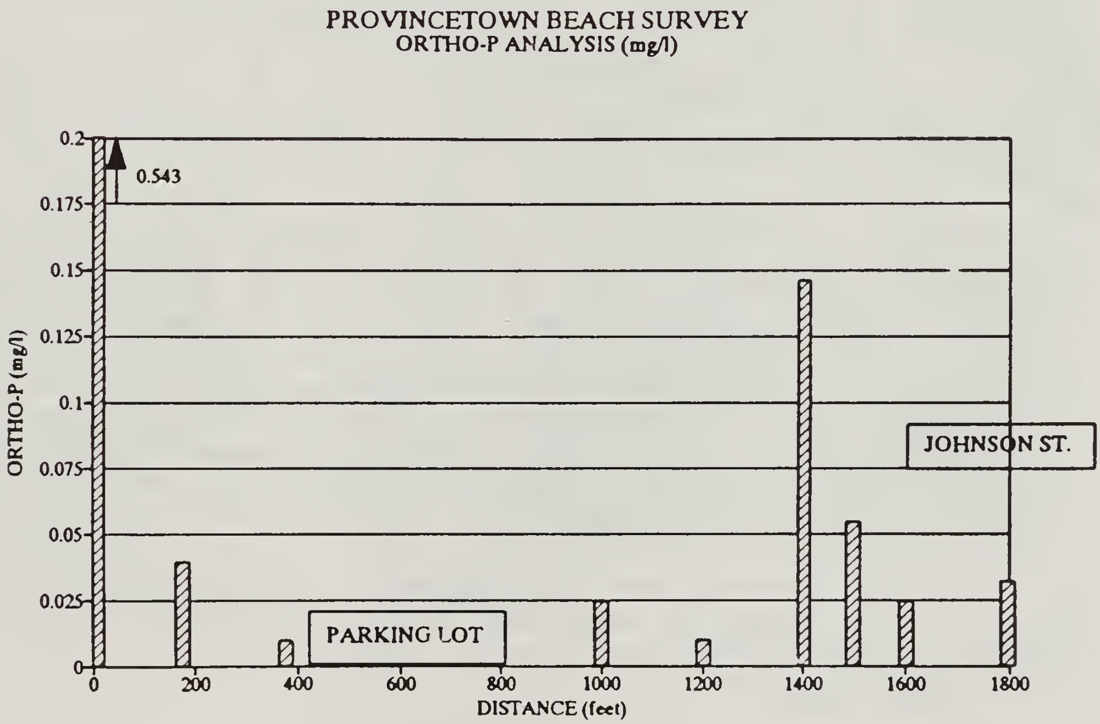


Fig. 2.10. Beachface survey - nutrient analysis.

spreadsheets in Appendix E. The results show extremely high levels of chloride, sulfate, calcium, magnesium, sodium, and chemical oxygen demand. This is expected in high salinity salt water samples.

2.5 Groundwater Flow System

2.5.1 Water Table Mapping

The location of the water table stations and the measuring method used to obtain water elevation measurements were described extensively in Section 2.3.5. These field data were used to produce water table maps. Water table maps (Appendix D) show that ground water flows from the landfill in a south-southeast direction toward Provincetown Harbor. This is fairly well established in the region from the landfill to the cemetery, but uncertain between the cemetery and the beach due to a sparseness of measuring points. While the flow directions shift throughout the seasons, it is believed that the flow path moves from the landfill across Route 6 through monitor well 15, then continues southeasterly through the cemetery. It is believed that the landfill leachate flow path then passes through residential Provincetown to discharge into the harbor to the southeast of MacMillans' Wharf. This may also be indicated by the chemical composition of the groundwater found in the beach zone, but because of the multiple possible pollutant inputs in Provincetown itself it is uncertain that the source is the landfill.

Figure 2.11 presents a water table map for September 1992, very close to the lowest level of the season. It indicates the regional flow path is to the southeast of the landfill. Flowlines delineate the path of the plume from its origin at the landfill. These flowlines indicate the plume exits into Cape Cod Bay near MacMillans' Wharf. Ground water would be unlikely to flow through the relatively impermeable bulkhead on the seaward side of the parking lot but would instead flow through the higher hydraulic conductivity sands on either side of this feature.

Darcy's Law was used in conjunction with the water table maps to determine the seasonal flow path gradients, average velocity ranges, and the time of travel from the landfill to the Provincetown Harbor.

2.5.2 Fresh Water Lens Thickness

In order to determine the vertical characteristics of the flow system, estimates of the fresh water lens thickness were made by four independent methods:

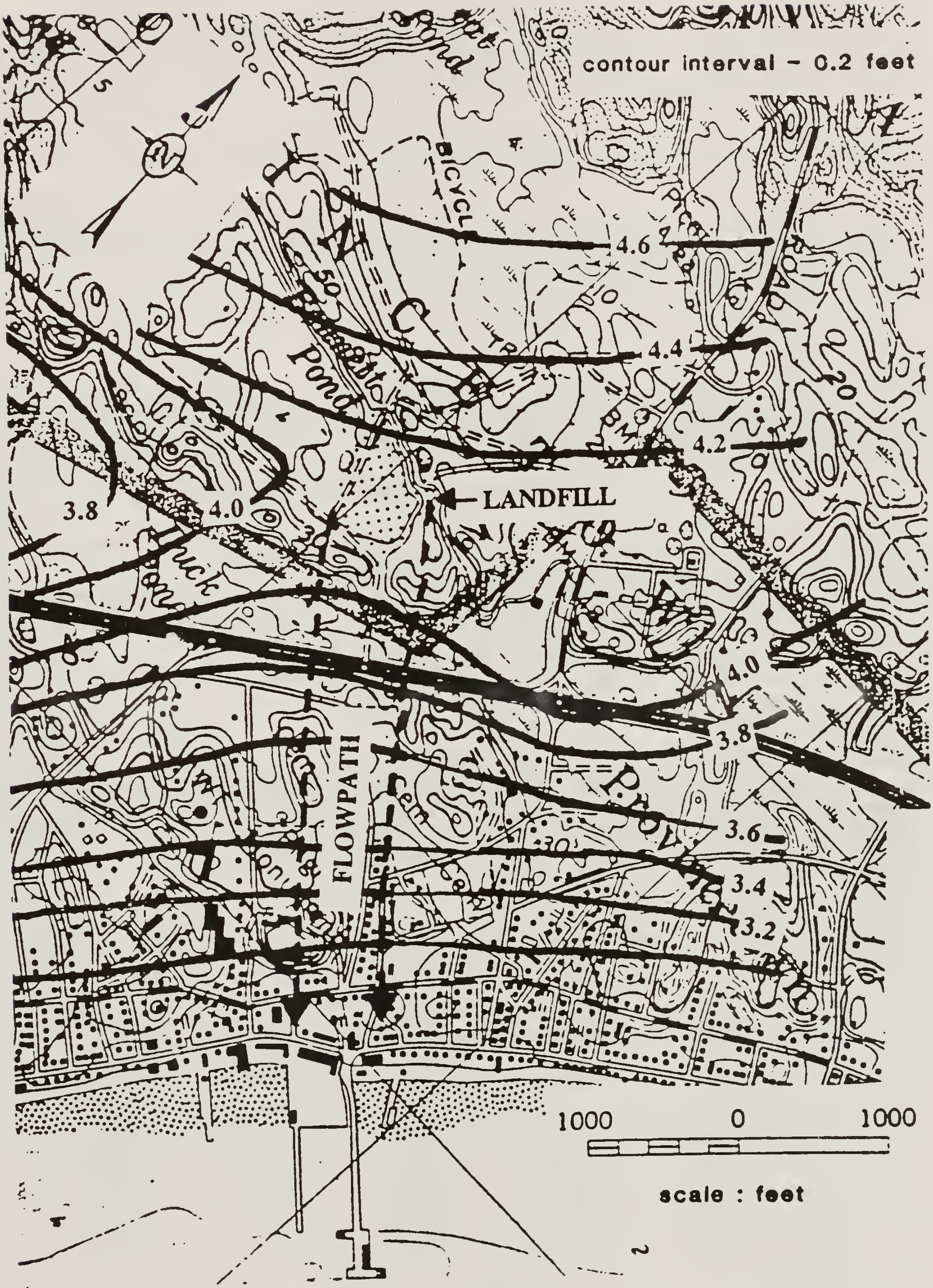


Fig. 2.11. Provincetown water table map - 9/20/92.

1.) theoretical analytical model using parameters of landmass width, ground water recharge (Fetter, 1980), and aquifer hydraulic conductivity (Todd, 1980);

2.) semi-empirical calculations based on water table elevations and the Ghyben-Herzberg Principle (Henry, 1964);

3.) electrical resistivity sounding interpretations based on resistivity contrast between fresh water and underlying salt water (Urish and Frohlich, 1990); and

4.) Direct water quality sampling for salinity and conductivity.

A simple analytical model for theoretical fresh water lens thickness is presented by Fetter (1980) as follows:

$$h^2 = \{w \times (R^2-r^2)\} / \{2K \times (1+G)\} \qquad (1)$$

where: h is the height of water table above mean sea level
w is the ground water recharge
R is the effective radius of a circular landmass
r is the distance from center of landmass toward shore
K is the hydraulic conductivity
G is $\rho_f / (\rho_s - \rho_f)$ which is a fresh water (ρ_f) and salt water (ρ_s) density ratio

Applying this equation to the Provincelands region using parameters of w = 17 inches/year (Strahler, 1972), R = 7000 feet, K = 200 feet/day, $\rho_f = 1.000$, and $\rho_s = 1.025$ gives the following fresh water lens thickness:

Table 2.5. Fresh Water Layer Results from the Analytical Model

Distance from Center feet	Monitor Well Location	Height above EMSL feet	Theoretical Lens Thickness feet	Fresh Water Layer Thickness feet
0	Great Pond	3.41	139.6	119.6
2800	MW10	3.26	133.8	113.8
3800	MW11	2.86	117.3	97.3
5100	MW13	2.33	95.6	75.6

Notes:
1 Theoretical lens thickness measured to midpoint of the transition zone
2 Theoretical lens thickness less 1/2 the transition zone (20 feet)

The elevation of the water table above effective mean sea level (EMSL) can be used in conjunction with the Ghyben-Herzberg principle to directly calculate the lens thickness to the midpoint of the transition zone. Assuming static equilibrium, the equation given by Cooper (1964) is:

$$z = h \times \{ \varrho_f / (\varrho_s - \varrho_f) \} \qquad (2)$$

where: z is the depth of the lens below EMSL
ϱ_f and ϱ_s are fresh and sea water densities respectively
and h is the height of fresh water above EMSL.

The height, h, depends on an establishment of EMSL (Urish and Ozbilgin, 1989) using beach slope and coastal ground water information. For Provincetown Harbor this results in an adjustment of -1.3 feet from water table elevations. The resultant lens thicknesses are as follows:

Table 2.6. Fresh Water Layer Results from the Semi-empirical Method

Distance from Center feet	Monitor Well Location	Sampling Dates 04/07/91 feet	06/08/91 feet	02/25/92 feet	09/20/92 feet	Average Lens Thickness feet	Fresh Water Layer Thickness feet
2000	MW10	165.6	153.3	171.4	129.9	155.1	135.1
3800	MW11	152.9	146.4	161.5	125	146.5	126.5
4000	MW12	134.1	123	136.9	105.8	125	105
5100	MW13	100.5	95.1	100.9	78.3	93.7	73.7
6800	MW14	43	50	53	62	72	52

Note: MW14 based on direct measurement of electrical conductivity

As previously described in Section 2.2.2 electrical resistivity soundings were conducted both near the center of the lens at Great Pond and along the median strip of Route 6 to gain some insight into the thickness of the fresh water layer of the lens. The results are:

Table 2.7. Fresh Water Layer Results from Electrical Resistivity Method

Distance from Center (feet)	Sounding Number (No.)	Layer Resistivity (ohm-ft)	Layer Thickness (feet)	Estimated Lens Thickness (feet)
0	1	1500	70	---
3800	2	750	95	115
3800	3	450	60	---
3800	4	1000	85	105
3800	5	625	115	135
3800	6	1600	60	---

Note: Estimated lens thickness is layer thickness plus 1/2 the estimated transition zone thickness.

Depths of 95 feet (No.2), 85 feet (No.4), and 115 feet (No.5) suggest an average thickness of the fresh water layer to the top of the transition zone of 98 feet. Exceptions in the sounding interpretations yield 63 feet (No.3) and 65 feet (No.6). These relatively shallow depths can be interpreted as a low resistivity sinking plume within the fresh water layer. The apparent resistivity values of 750 Ohm-feet for Sounding #2, and 625 Ohm-feet for Sounding #5 do indicate some mineralization, which was confirmed by water quality measurements for monitor well, MW11, which is near Sounding #2. Sounding #6 is unusual with respect to the fresh water resistivity and the depth to the bottom of the aquifer. Though the depth to the salt water is interpreted as only 65 feet, the aquifer resistivity is as high as 1600 Ohm-feet. The high resistivity excludes aquifer pollution, but there is no explanation for the relatively shallow depth to the apparent salt water layer.

Finally, direct water quality sampling using electrical conductivity gives at least the minimum thickness of the fresh water layer. The lower limit of the fresh water layer is taken as 1000 uS/cm. The results are presented in Table 2.8.

Table 2.8. Fresh Water Layer Results from Water Quality

Distance from Center feet	Monitor Well Location	Depth Below W. T. feet	Electrical Conductivity uS/cm	Minimum Fresh Water Thickness feet	Estimated Minimum Thickness feet
2000	MW10	82	245-404	82	102
3800	MW11	90	850-1210	90	110
4000	MW12	105	324-495	105	125
5100	MW13	102	425-689	102	122
6800	MW14	43	400	43	63
3800	MW15	104	1010-1200	104	124

To study the thickness of the fresh water lens at the shore margin the well set installed at the Johnson Street beach, MW14, was used to obtain water salinity measurements. The freshwater lens is thinner near the shoreline and consequently the transition zone was penetrated with an 80' deep well, MW14D. During the drilling of MW14D, five minipiezometers were installed at 10' intervals from 30 to 80 feet below the ground surface. These minipiezometers consisted of 3/16" outer diameter polypropylene tubing with a 4" slotted stainless steel well point. Samples were obtained with a K-V Analytical Sampling Kit which contained a hand piston pump, tubing, valves, and collection bottles. The samples were collected and field tested with a YSI Conductivity Meter for temperature, conductivity, and salinity. The thickness of the fresh water lens was then determined from the conductivity profiles obtained. The first sampling occurred in January 1991, shortly after installation. Figure 2.12 is the electrical conductivity profile created from this survey. The upper portion of the lens is slightly brackish. The mid portion of the lens is quite fresh producing a fresh water thickness of approximately 40 feet to the transition zone. In order to determine seasonal variation of the lens, profiles were again collected in August 1991, October 1991, and July 1992. These profiles, included in Appendix E, portray an increase in the fresh water thickness from 40 feet to 50 - 60 feet. It is normally expected that the lens thickness and its associated outflow would become thinner in the summer months because of the decrease in recharge during this season. This converse effect appears to be caused by the increase in aquifer recharge via septic field leachate during the summer tourist season when more water is being imported from Truro to meet the higher demand of a temporarily increased population.

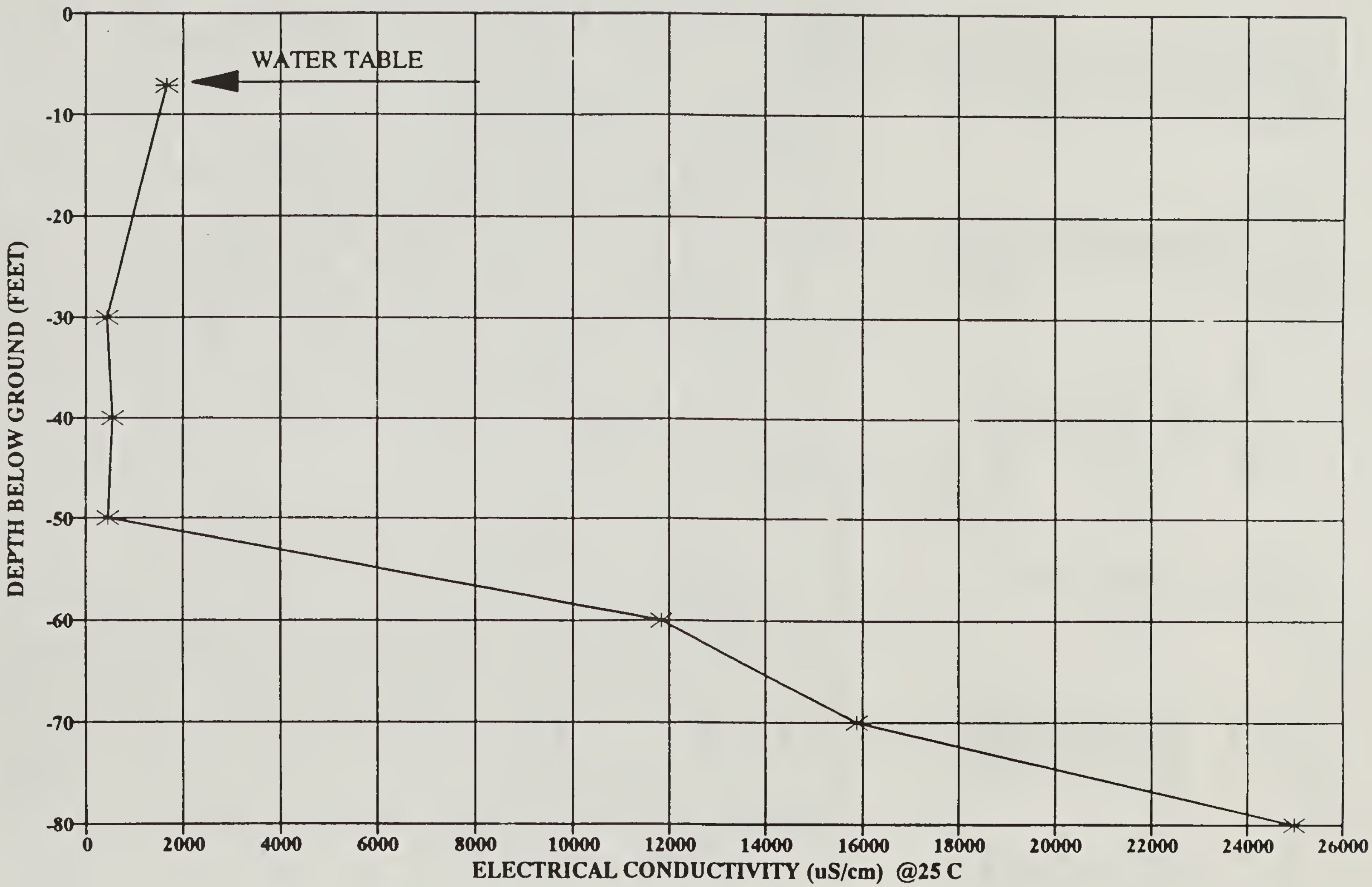


Fig. 2.12. Electrical conductivity profile for MW14 -1/20/91.

2.6 Beachface Dynamics

2.6.1 Groundwater Fluctuation

In order to determine the location and timing of potentially contaminated groundwater discharge in the beach zone it is necessary to examine the dynamics of tidal induced water movement in the beach. In Provincetown Harbor tides may be as great as 12 feet. The groundwater response to tidal dynamics was investigated at the Johnson Street town beach. Water table fluctuations were manually measured on February 28, 1991 by taking wetted tape measurements periodically over a tidal cycle at MW14S, MW14I, and MW14D. Tide measurements were also obtained from a bench mark established at the town pier.

These measurements are plotted on Figure 2.13. The midpoint of the water table elevation is about 2.2 feet higher than midtide elevation, largely due to the "pumping effect" of water moving up a sloping beach (Urish, 1989). It should be noted that the high tide water level in the harbor is over 3 feet higher than the highest point of the water table. This demonstrates that there is substantial wave attenuation which increases as the wave moves inland.

In addition to manual measurements, automatic data recording pressure transducers were used to measure the water table fluctuations over two tidal cycles. An Enviro-Labs Model DL-120, 8-Channel Data Logger and three Enviro-Labs Pressure Transducer probes of 0-5 psi and three of 0-15 psi were used to perform the surveys. The equipment was set to record water levels every 15 minutes. Manual measurements were taken periodically at the 6 stations to check the instrument and also at the town pier to measure the tide. The three 0-5 psi probes were placed in the MW14 multilevel well set to examine the effect of tidal fluctuation with depth. The three 0-15 psi probes were placed in temporary 2" diameter PVC well points, manually installed at 40-, 100-, and 150-feet distances from MW14 toward the shoreline. These stations, except for PT-150 which malfunctioned, were used to examine the effect of tidal fluctuation with distance from the shoreline. The sampling locations are shown in Figure 2.14.

This procedure was accomplished for two different tidal ranges to quantify the effect of time lag and attenuation. The initial study occurred on October 11, 1991 which had a maximum tidal range of 11.5 feet, and the second on November 15, 1991 which had a maximum tidal range of 6.7 feet. Fluctuation in the upper beach water table at MW14 was observed to be as much as 7.1 feet from the October 11, 1991 tide. In order to establish an effective position of the water table at the

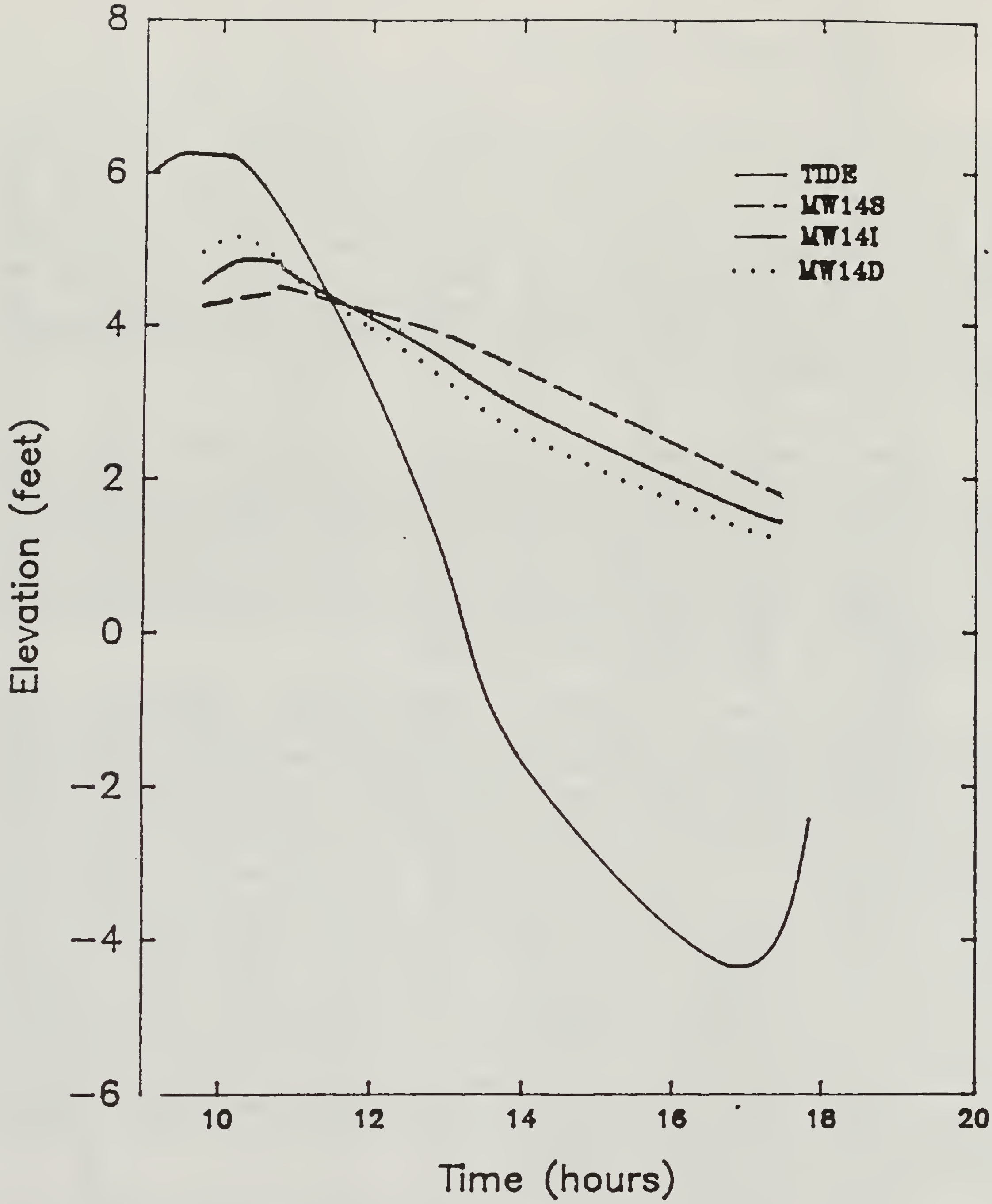


Fig. 2.13. Water table fluctuations at MW14 - 2/28/91.

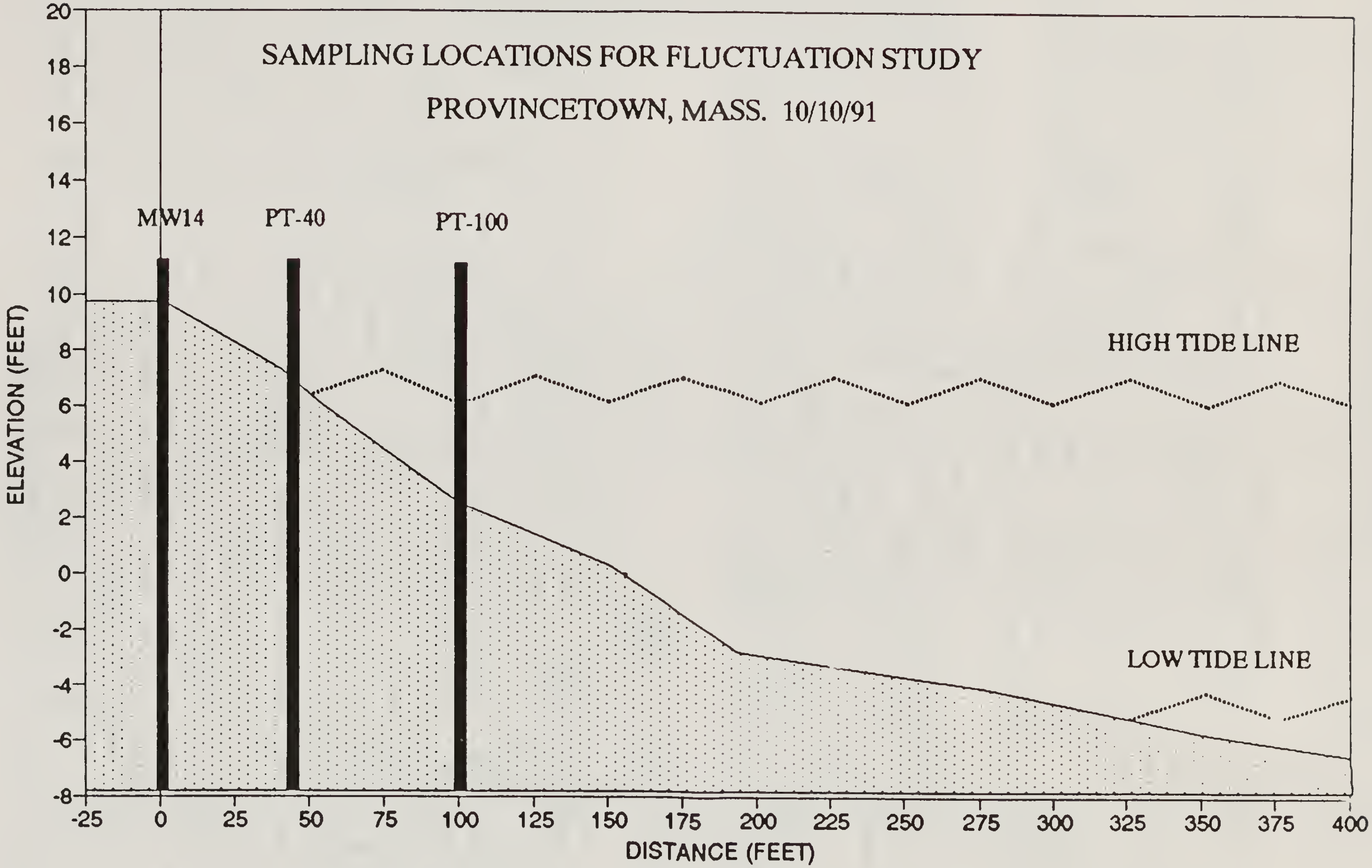


Fig. 2.14. Beach profile and sampling locations at Johnson St.

coastal margin, ground water measurements must be made over at least one tidal cycle and the average position used (Urish and Ozbiligin, 1989). Measurements for this study were taken over nearly four tidal cycles.

Due to the dynamic effect of wave runup on the beach the determined average elevation is always higher than mean sea level. This is illustrated in Figure 2.15 which shows ground water fluctuations at monitor well set 14 and the tidal fluctuations of sea level in the harbor. In the beach zone itself, extreme limits of this fluctuation can be shown as a water table envelope, which at low tide develops a very steep gradient, but at high tide creates a reverse gradient shoreward with consequent damming of ground water outflow. This is illustrated in Figure 2.16.

The water table fluctuation with distance from the upper beach is presented in Figure 2.17. The range of fluctuation decreases with distance from the shoreline. The range attenuates 42% from 7.1 feet at the 100' station to only 3 feet at MW14S, a distance of 100 feet. The water table elevation at each site mimics the sinusoidal wave pattern of the tidal fluctuations but are offset from its' cycle. This time lag effect increases with distance from the shoreline because it takes longer for the wave to travel further inland.

2.6.2 Beach Outflow

A 2" diameter stainless steel hand driven sampling probe was used to sample the groundwater with depth in a preliminary effort to map the fresh water outflow zone in the lower beach. During low tide the probe was driven 3' below the ground and samples were obtained with a manual vacuum pump at one foot increments. The samples were measured with a conductivity meter (YSI model 33 S-C-T) and a salinity refractometer. This routine was performed on three different occasions: July 19, 1991; August 15, 1991; and November 15, 1991. Sampling occurred along the beachface from Johnson Street southwest to the town pier. The salinity ranged from 10 ppt to 30 ppt which can be compared with normal sea water salinity of 34-35 ppt. The harbor water was also surveyed for fresh water outflow locations along this same transect. The salinity at high tide when fresh ground water discharge is obstructed is 32 ppt. At low tide when ground water flows freely through the beachface, the salinity is 28 ppt. The harbor water salinity is diluted by fresh water outflow during low tide. A discrete location for fresh water outflow was not established. It is suspected that due to mixing from the considerable tidal range in the harbor, the ground water quality that flows into the harbor is always slightly brackish.

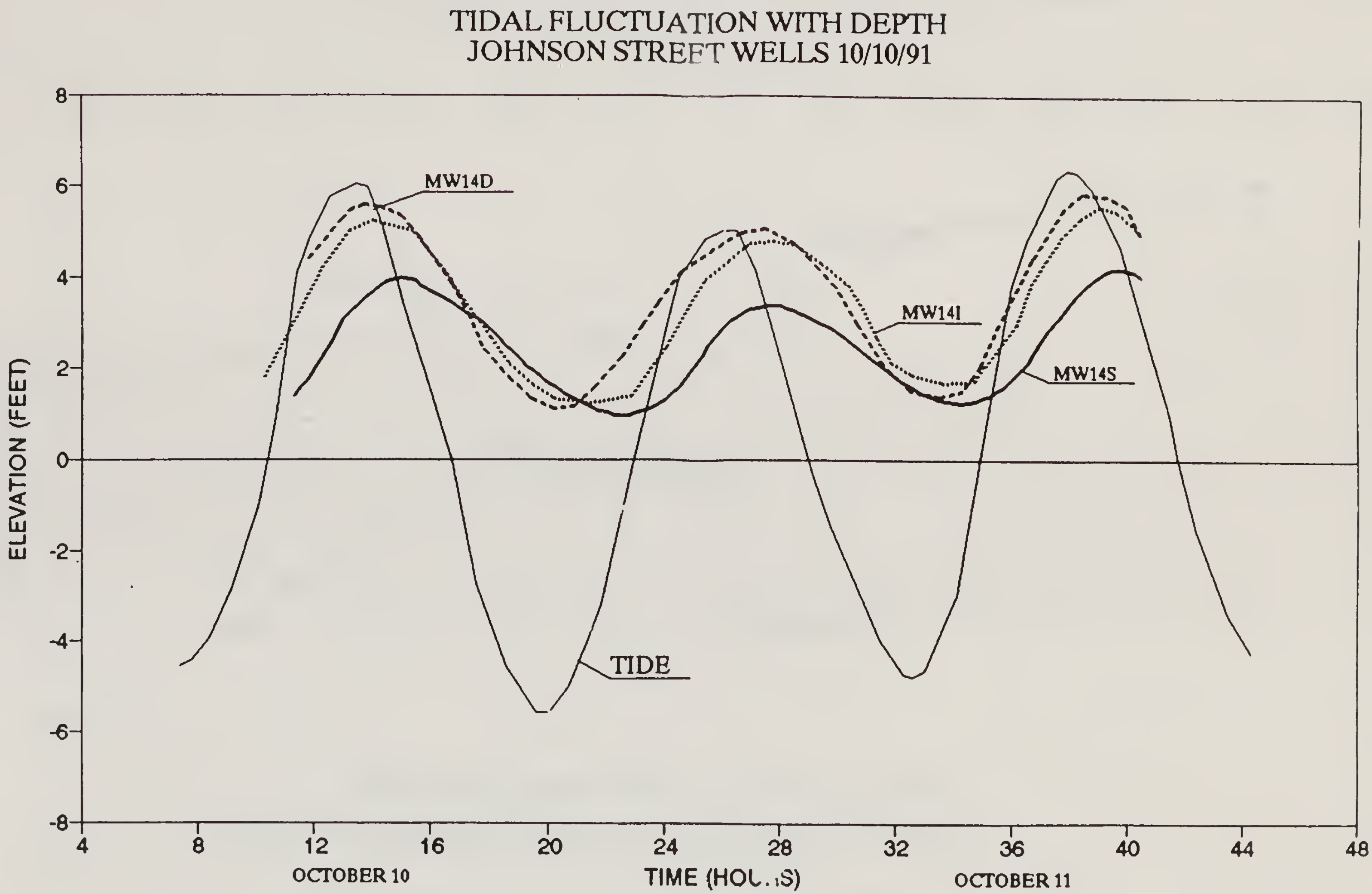


Fig. 2.15. Water table fluctuations with depth.

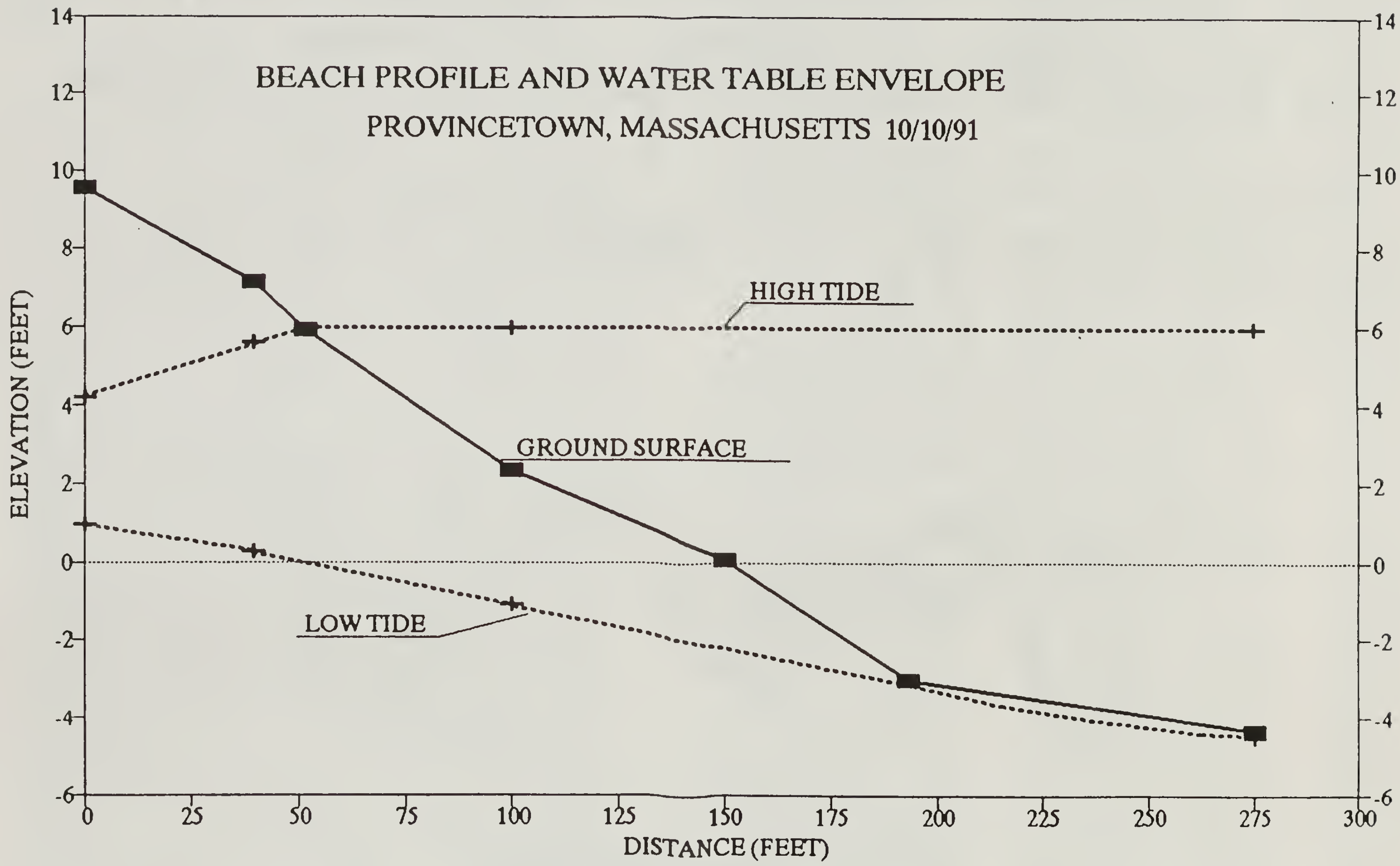


Fig. 2.16. Water table envelope for 10/10/91.

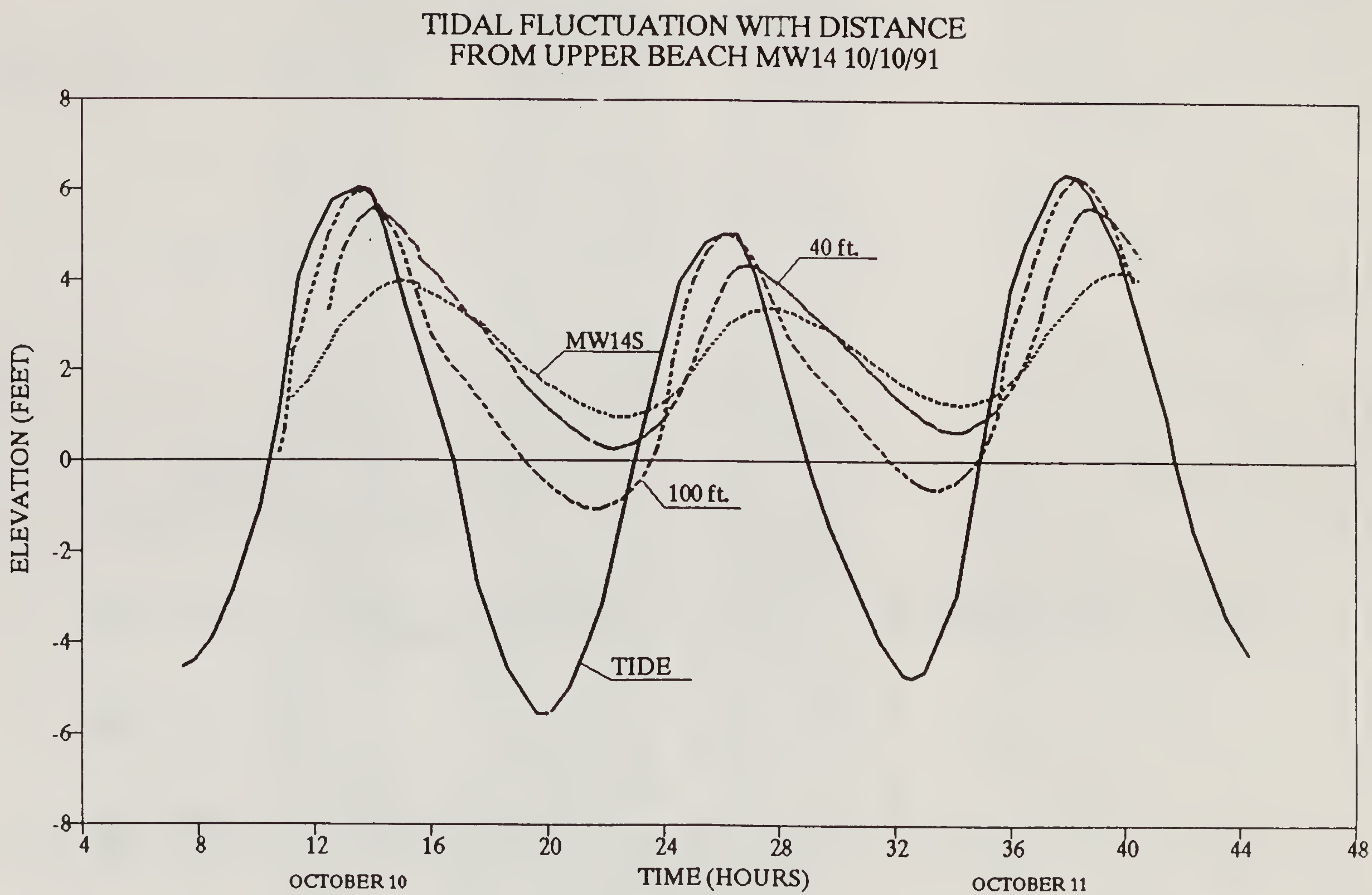


Fig. 2.17. Water table fluctuations with distance

The location of fresh water outflow was investigated during low tide at the upper and lower beach at locations of 35' and 150' from the MW14 site on May 28, 1992. These locations are shown in Figure 2.18. The KVA Rotary Hefty System, an electric rotary hammer, equipped with a screened well point and 3' nickel plated hardened steel shaft sections, was driven 8.5' below the water table. Samples were collected every foot with a hand piston pump and tested for temperature, electrical conductivity, and salinity. The electrical conductivity profiles are presented in Figure 2.19. In the upper beach profile the top of the water table is brackish due to salt water overwash during high tide, but at approximately 6 feet below the water table, the water quality becomes quite fresh. The water quality in the lower beach site is very salty throughout the 14-foot profile. This is probably a result of the site's proximity to mean low water.

2.6.3 Beach Profiling

The beachface was surveyed on October 10, 1991 and November 15, 1991 to measure the slope of the beach at the time the tidal fluctuation investigations were conducted. Profiles were also surveyed on March 28, 1991 and July 19, 1991 to determine the seasonal changes in the beach profile and slope. The profiles are included in Appendix F.

The beach slope gradually increases from 0.058 in July to 0.066 in November. In seasonal climates beaches go through a summer-winter cycle caused by differing wave types that occur in these seasons (Plummer and McGeary, 1979). During summer long, low waves wash sand from deeper water onto the beach and build out a wide berm. In winter, the short, high storm waves erode sand from the beach producing a narrower and steeper beachface.

The beach slope is an important parameter, along with the tidal range, in the determination of an effective mean sea level to use as a boundary condition (Urish and Ozbilgin, 1989). Field studies at Provincetown show an effective mean sea level generally 1.3 feet higher than mean sea level.

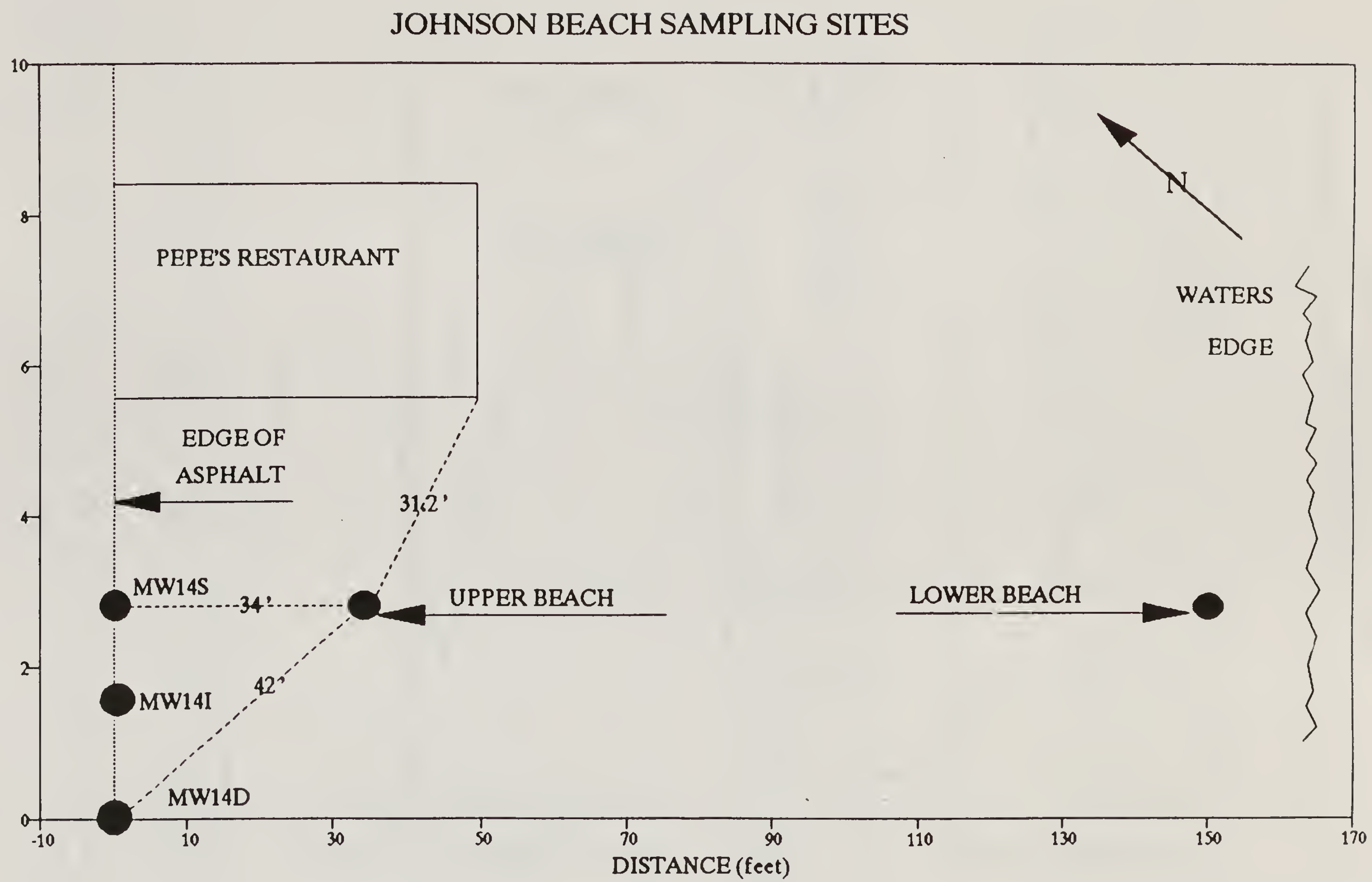
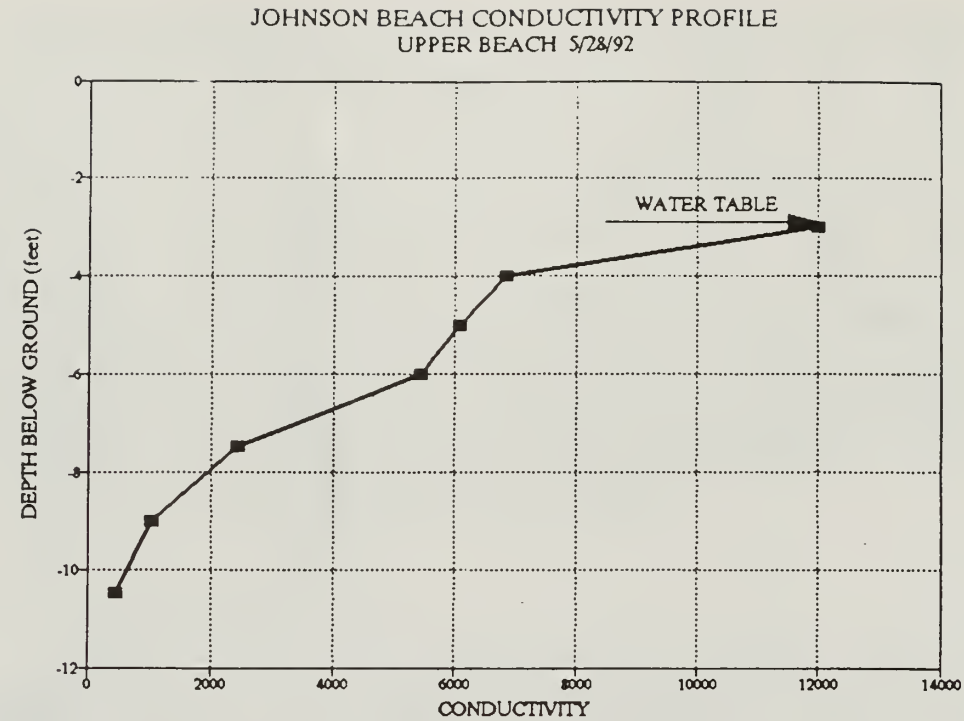


Fig. 2.18. Johnson Street beachface sampling locations.



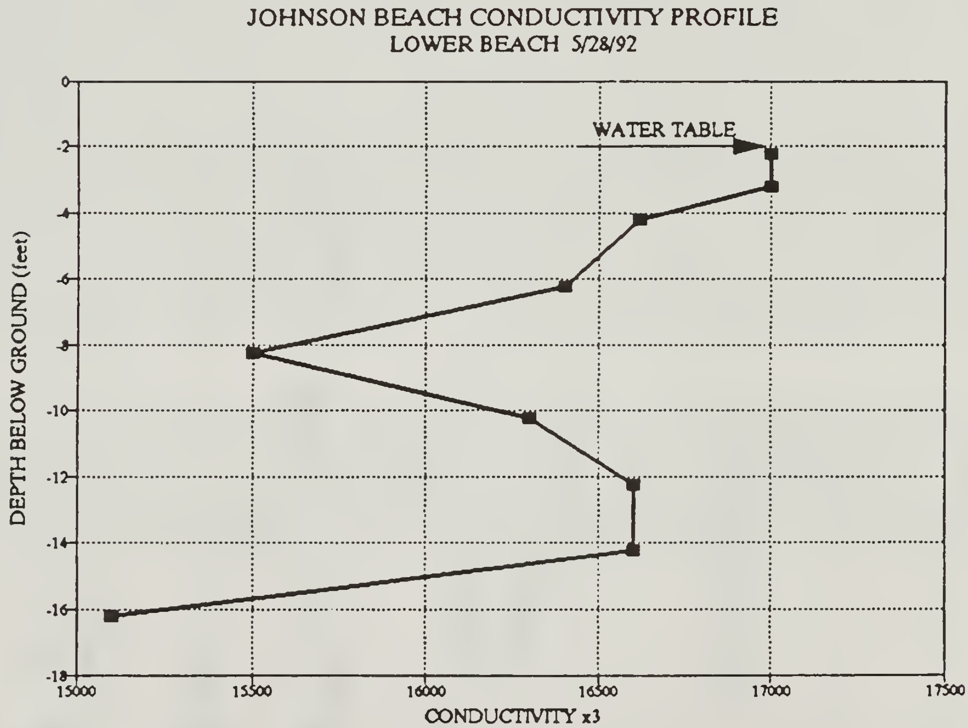


Fig. 2.19. Electrical conductivity profiles at Johnson Street May 28, 1992.

3. DISCUSSION

3.1 Groundwater Flow System

3.1.1 Fresh Water Layer Thickness

Horizontal boundaries for ground water flow are reasonably well defined at the harbor. The vertical boundary, however, includes the lower boundary of the floating fresh water lens which is much more difficult to determine. For this reason considerable attention, as described in Section 2.5.2, was given to this determination. The results from the four different methods of determining fresh water layer thickness, are summarized in Table 3.1.

Table 3.1. Fresh Water Layer Thickness Results

Distance from Center feet	Sampling Location	Fresh Water Layer Thickness (feet) Method			
		Analytical Model	Semi-empirical Method	Electrical Resistivity	Water Quality
0	Great Pond	120			
200	MW10	114	135		82
3800	MW11	97	127	98	97
4000	MW12		105		105
5100	MW13	76	74		102
6800	MW14		52		43

Note: The Water Quality Method represents a minimum thickness

From the foregoing summary it is probable that the bottom of the fresh water layer in the central part of the fresh water lens lies at a depth of 100 - 135 feet below the water table, most likely at about 120 feet, plus or minus 20 feet depending on seasonal fluctuation. The midpoint of the transition zone, which is analogous to the theoretical sharp interface, can be approximated by adding the half width of an estimated transition zone which gives the equivalent thickness of the fresh water lens as 140 feet. The only place in the Provincelands where the fresh water layer and the transition zone is ascertained directly is in MW14 near the upper beach at Provincetown Harbor. Based on measurements of electrical conductivity and chlorides, the fresh water layer thickness in the upper beach varies seasonally from 50 to 60 feet and the transition zone thickness at this location is approximately 40 feet. At one other location on Cape Cod, at Great Island (Strahler, 1972), the transition zone was found to be 58 feet thick. For the Provincelands area 40 feet is taken as a reasonable thickness for the transition zone. The fresh water-salt water boundary has been estimated from this information and is shown along with electrical conductivity in Figure 3.1, a vertical section extending from the landfill to the beach.

3.1.2 Groundwater Flow Path

Based on the measured water table elevations the water table divide of the fresh water lens lies somewhere to the northwest of the landfill, but the position is uncertain. All measurements taken during this study show regional flow to the southeast. Examination of the various water table maps show considerable variation in direction of flow. Additionally, it is very likely that localized water table mounding does occur, adding to the complexities of the flowpath determination. Unfortunately there are no water level measuring stations in the landfill itself.

The flow paths of water particles in a pollution plume within the fresh water lens are always three dimensional, consisting both of the horizontal trace of the plume and the vertical path unique to a fresh water lens in dynamic balance with the underlying sea water (Urish and Ozbilgin, 1989). In general this vertical flow begins with descending recharge water at a region where the recharge takes place. The flow continues into the lower reaches of the lens towards the coastline, then ascends to discharge at a relatively narrow margin at the sea water boundary (Strahler, 1972).

The horizontal trace of the flow path can be determined from analysis of the water table maps since flow lines under assumed homogeneous and isotropic water table conditions cross water table contours at right angles. Using this relationship and assuming no dispersion, flow lines can be drawn on each water table map from the boundaries of the landfill to discharge at Provincetown Harbor. These flowlines will change with the season, dispersing the plume from a single path. Figure 3.2 is a composite of the outer limits of each seasonal plume flow path and probably is a reasonable representation of the geographic extent of regional ground water contamination from the landfill. From this analysis it

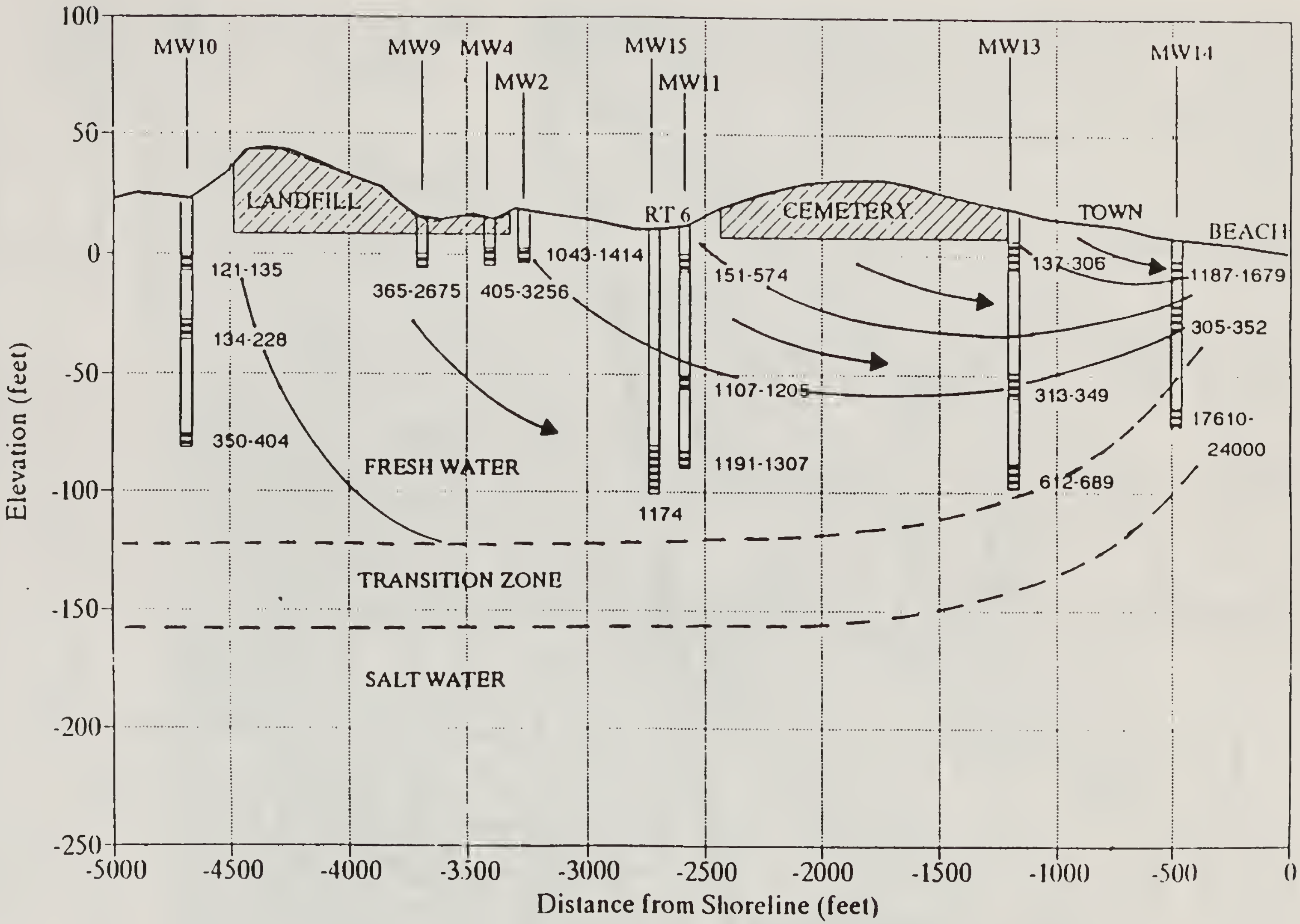


Fig. 3.1. Fresh water - salt water boundary relationship and range of electrical conductivity along flow path from landfill to beach, Provincetown, MA.

Fig. 3.2. Outer limits of plume flow path due to seasonal changes.

appears that the leachate plume is a part of the ground water discharge through the beach on both sides of the MacMillian's Wharf parking area, but more likely to be greater on the northwest side. Because of the constructed characteristics and geometry of the wharf parking area it is probable that most of the ground water flow is diverted around the parking area.

Flow path gradients range from 0.00030 to 0.00056, being about 25% less in the summer months. Using a hydraulic conductivity of 200 ft/day and a porosity of 0.35, the average flow velocity ranges from 0.04 to 1.08 ft/day along the flowpath. The time of travel from the landfill to the harbor, a distance of 2900 feet, is probably about 20 years, but could change by a factor of 2 depending primarily on the veracity of the estimated hydraulic conductivity. Figure 3.3 is a plot showing the variation of average ground water flow velocity with distance from the upgradient well set, MW10. This is based on the hydraulic gradients from the water table map of September 1992, a hydraulic conductivity of 200 feet/day determined by laboratory permeameter tests, and an effective porosity of 0.35 determined from laboratory soil tests.

The vertical flow at any location can be determined by comparison of hydraulic heads (water levels) in the three nested monitor wells at locations 10, 11, 12, 13 and 14. Figure 3.4 provides a plotted example of the hydraulic heads at MW11. In this plot there is a consistent component of vertical flow downward, indicating the descending flow path shown in Figure 3.1. Plots for other wells (Appendix D) are less marked in this characteristic, showing weaker downward flow for MW13 to very little vertical flow in MW12.

It seems likely that high evapotranspiration in the open water of ponds and wetlands to the west and southeast causes discharge to occur at these locations in the late summer. This is supported by pond monitor well water level measurements as shown in Figure 3.5. At Duck Pond in September the ground water levels are higher than the pond water levels indicating vertical flow into the pond. An equilibrium is reached in the fall as the pond level increases. Both pond and groundwater levels increase in winter. But in the spring, as overland runoff concentrates in the pond, the pond surface is higher than the groundwater creating an influent pond condition.

3.2 Water Quality

3.2.1 Introduction

As ground water moves along its pathway from the landfill to discharge in the harbor area, it receives not only fresh ground water recharge which tends to mitigate the effects of

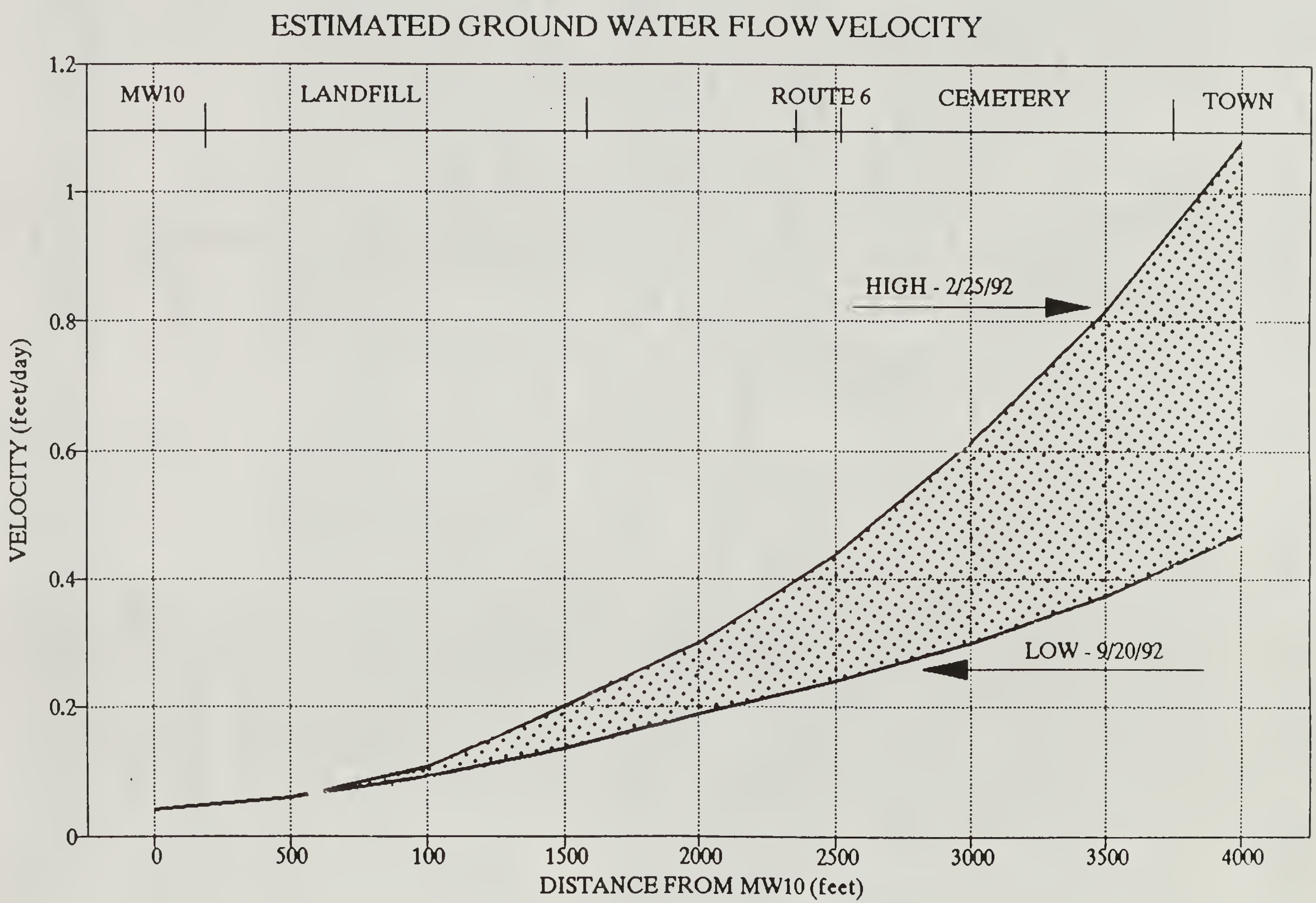


Fig. 3.3. Variation in ground water flow velocity.

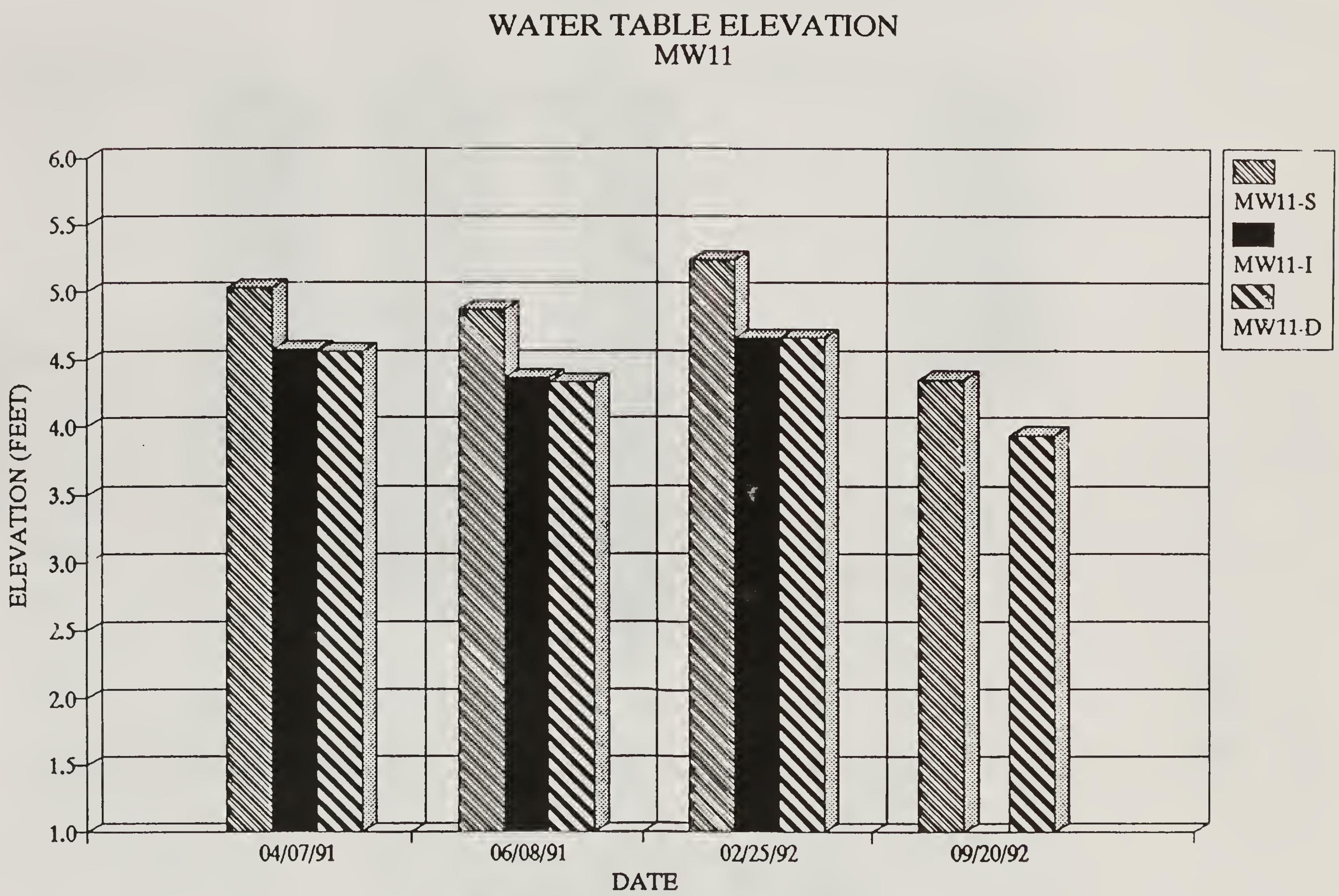


Fig. 3.4. Hydraulic heads at monitor well 11.

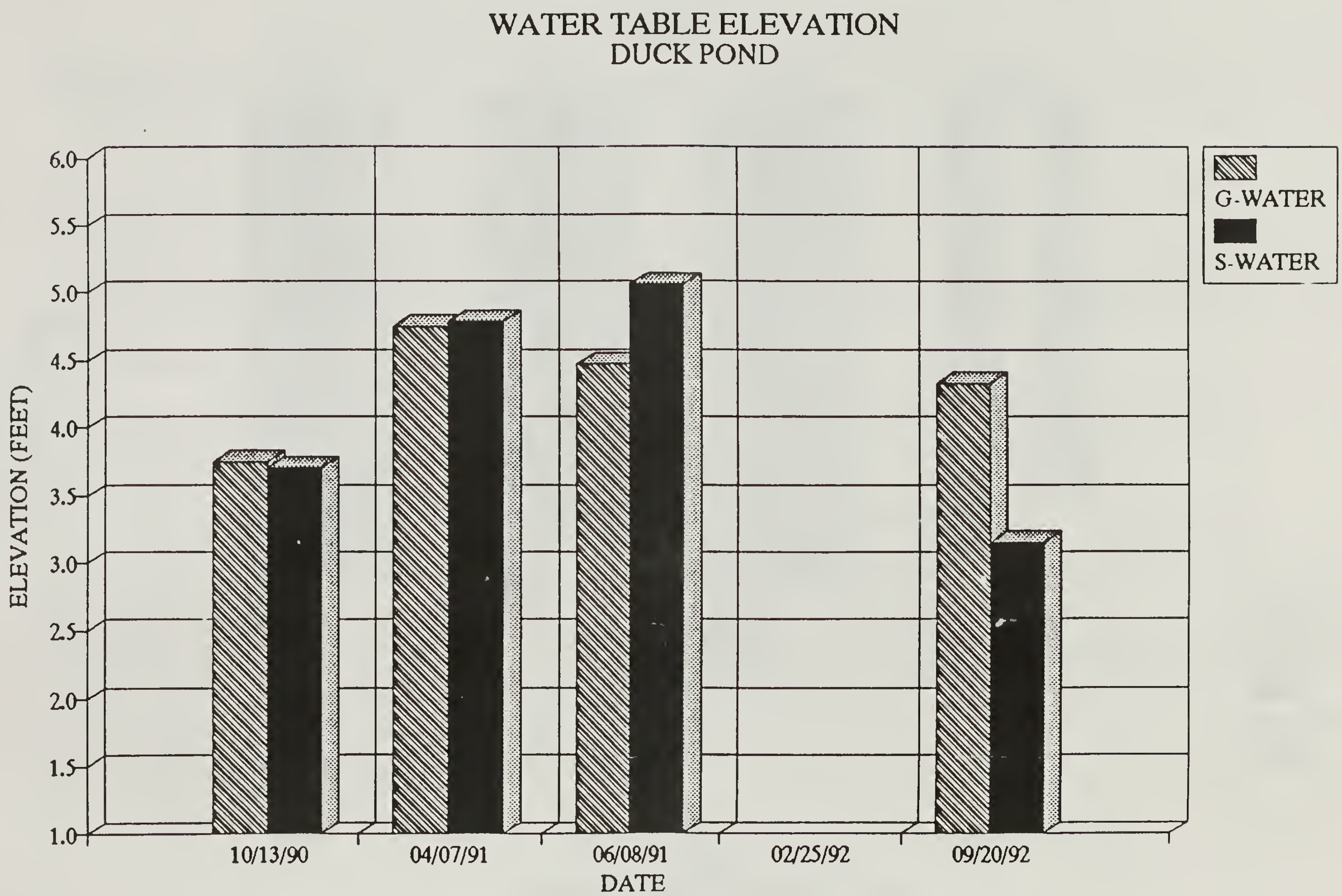


Fig. 3.5 Hydraulic heads at Duck Pond.

landfill and septage leachate, but also contaminants from several other sources: the Route 6 highway with automotive contaminants and road salting; the cemetery with its products from corpses, coffins, and embalming fluid decomposition; town on-site sewage disposal effluents, and the by-products of long buried fish processing and other marine activities now lost in the beachfront sands. All of these are merged into the mixture of ground water discharge through the beachface at low tide.

3.2.2 Landfill

From landfills there are a large number of contaminants introduced, as summarized in Table 3.2. The strongest evidence of landfill pollution is found in monitor wells 2, 4, and 9. These wells contain very high levels of electrical conductivity, alkalinity, bicarbonate, ammonia, nitrate, orthophosphate, calcium, COD, sulfate, chloride, metals and VOC's. With distance from the landfill the concentration of contaminants decreases due to adsorption, dispersion, and dilution. In MW15, which appears to be directly in the path of the landfill plume, there are elevated levels of electrical conductivity, ammonia, chloride, cadmium, COD, lead, and sodium, as well as the presence of VOC's. MW11, further to the east may also have some impact from the plume but this is inconclusive.

By the time the flow path from the landfill reaches the highway it is probably overlain by about 35 feet of fresh ground water recharge, hence the landfill effect is only evident in the deeper samples, generally shown by a significant rise in electrical conductivity (higher mineralization) at 35 feet below the water table. Measurements of electrical conductivity at MW15 both in winter (February 5, 1992) and summer (July 24, 1992) show a marked increase in mineralization starting at about 35 feet depth to a maximum value of 1260 uS/cm at 100 feet depth. Below this, the layer shows a tendency to become slightly less mineralized. The same electrical conductivity trend is evident in MW11 approximately 1200 feet to the northeast along Route 6.

The range of selected water quality parameters from water quality sampling in Monitor Wells 11, 12, and 15 is tabulated in Table 3.3. All of these wells are along Route 6 in a line generally transverse to the probable leachate plume flowpath. All show concentrations levels of water quality parameters greatly exceeding native water. Because of the distance downgradient from the landfill, it is believed the deeper wells are most indicative of possible landfill influence. The flowpath map (Figure 3.2) based on water table contours shows the approximate leachate plume width and range and indicates that MW15 lies near the center of the plume. This is supported

Table 3.2. Characteristics of Landfill Leachate

Constitutent	Range (mg/L)	
	van der Leeden, 1990	Provincetown
Chloride	34-2800	29-290
Iron	0.2-5500	0.5-182
Manganese	0.06-1400	0.08-3.6
Zinc	0-1000	0-1.6
Magnesium	16.5-15600	1.6-67.5
Calcium	5-4080	0.5-210
Potassium	2.8-3770	
Sodium	0-7700	13-180
Phosphate	0-154	0-0.27
Copper	0-9.9	0.8-11.3
Lead	0-5	0-9
Cadmium		0.13-15.
Sulfate	1-1826	0-182
Total N	0-1416	0-146
Conductivity (umhos)		115-3260
TDS	0-42276	
TSS	6-2685	
pH	3.7-8.5	4.8-7.2
Alkalinity	0-20850	0-1100
Hardness	0-22800	
BOD	9-54610	
COD	0-89520	7-137

Note: Provincetown landfill data from MW1 - MW9

Table 3.3 Ranges for Water Quality Parameter: Monitor Wells 11, 12, and 15 along Route 6

Monitor Well Number	12			15	11		
Distance West from intersection of Rte 6 & Race Pt. Rd (feet)	2000			900	100		
Well Description	S	I	D	D	S	I	D
Screen Elevation (feet)	-1.6	-48.4	-96.5	-87.9	-1.8	-51.9	-84.8
Parameters:							
elect. cond. (US/cm)	242-440	159-239	236-495	1174	151-574	1107-1205	1191-1307
alkalinity (mg/l)	48-135	20-43	79-144	37	8-13	27-47	81-112
ammonia (mg/l)	ND-0.3	0.2-0.3	0.1-0.4	40	0.1-0.4	0.2-0.5	0.4-1.2
bicarbonate	48-150	43-51	88-145	426	8-13	47-59	86-118
calcium	0.3-0.5	0.8-1.0	32-58	4.3	1.7-4.1	3-6.4	44-64
chloride	25-60	45-61	25-47	138	41-300	335-400	290-363
COD	17-29	11-31	11-41	74	15-95	12-31	4-31
iron	.1-4.2	5.9-20.8	.3-4.3	4.3	1.7-5.6	13.6-33.0	16.8-46.0
nitrate-N	ND-1-6	ND	ND-1-4.1	0.3	ND-1-1.8	N.D.	N.D.
sulfate (mg/l)	7-64	ND-13	3-45	44	16-19	ND-11	0.8-26
VOC (mg/l)	ND	ND	ND-4.9	1.1	ND	ND-0.5	0-4.8

Note: 1) Tabulation sequence is relative to location of wells looking north along Route 6.
2) All depths are to center of screen. See Table 2.2 for additional details.
3) Well description: **S (shallow), I (Intermediate) D (deep)**

by surface geophysical surveys as well as water quality data. It would appear that the westernmost monitor well along Route 6, MW12, is on the fringe of the possible flowpath and is also affected. Monitor Well 11 lies about 300' to the east of the plume limit, but shows strong contamination. This may be from the landfill, but also may be from other sources, namely salt storage and maintenance activity at the town maintenance facility approximately 800' upgradient of MW11.

The presence of high levels of VOC's in MW11I, MW11D, MW12D, and MW15D suggest the influence of landfill leachate in the deeper parts of the fresh water lens. Except for MW13S, VOC's are not found in upgradient or other down gradient wells distant from the landfill.

3.2.3 Highway Salting

The effect of highway salting on Route 6 is evident in the upper portion of the lens in MW15 (February sampling) as illustrated in Figure 3.6, and probably also in MW11 as illustrated in Figure 2.9. In MW11 higher chlorides in particular are observed in the shallow well of the February and April sampling as illustrated in Table 3.3.

As described in Section 1.4.3 road salting consisting of sodium chloride in the winter months during the study period averaged 7.84 tons per year for the 2400 foot long stretch of road along Route 6 between Race Point Road and Shank Painter Road. Assuming this mixes with an average recharge of 7.5 inches from precipitation during winter and considering a dispersion factor of 2, this amount of salt would create a theoretical layer of ground water 4 feet thick with a salinity of 1.17 ppt. This is roughly equivalent to an electrical conductivity of 1500 uS/cm which can be compared with an electrical conductivity of 910 uS/cm measured in February, 1992 in the upper 10 feet of the fresh water layer at monitor well 15. At 20-30 feet below the water table the electrical conductivity reduces to almost 500 uS/cm, then sharply rises again as the influence of the landfill leachate appears. This indicates that highway salting does influence the upper 10 feet, but is unlikely to extend much below that depth.

3.2.4 Cemetery

Over the 200 years that the Provincetown Cemetery has been in operation various burial and embalming practices have been used, ranging from no treatment in wooden boxes, to the use of arsenic and cast iron burial vaults at the turn of the century, to the more modern use of formaldehyde mixes and sealed vaults. Few studies have been done on the potential

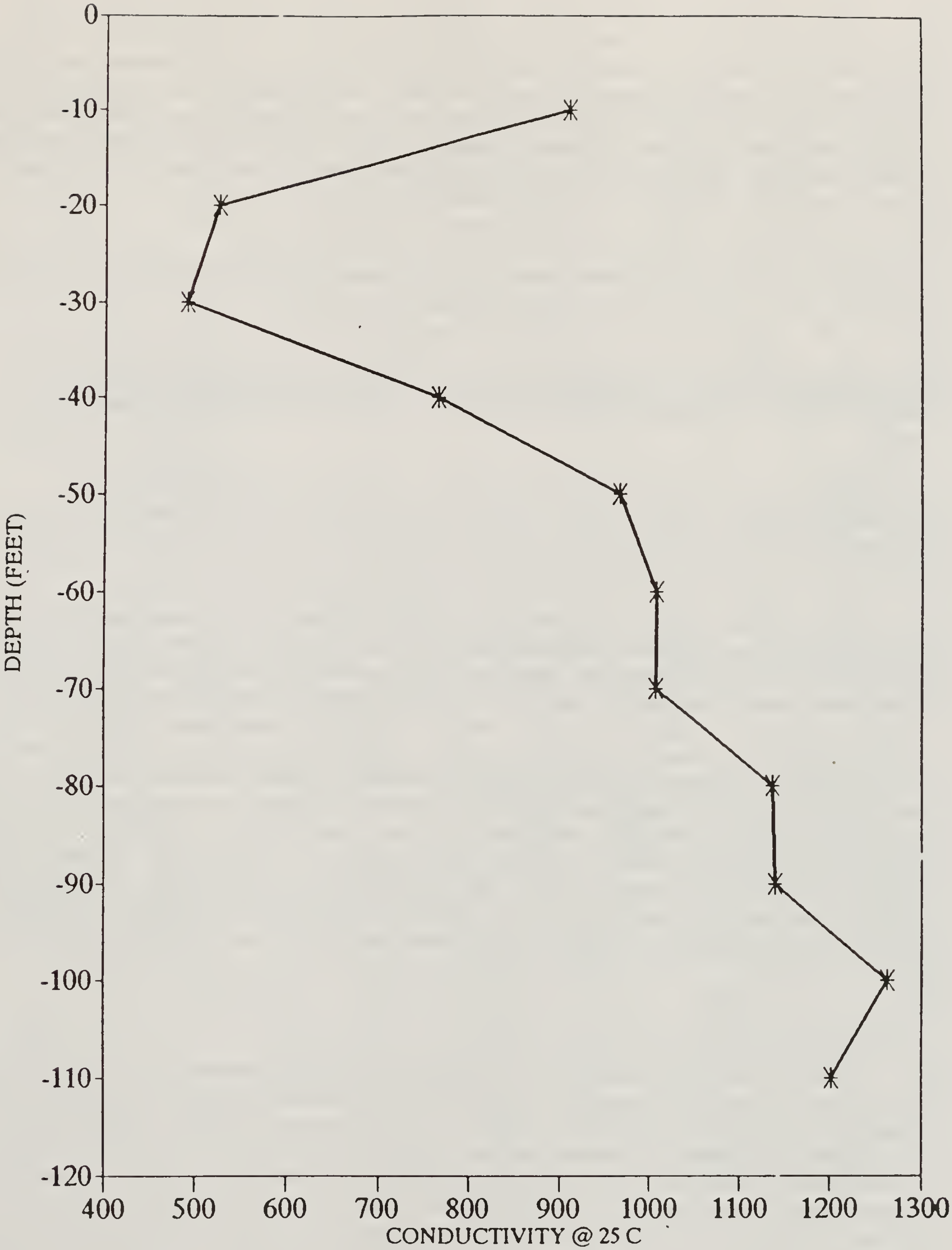


Fig 3.6. Electrical conductivity profile at MW15.

pollution effects of cemeteries, but it is apparent that potential contaminants include the decomposition products of the human body as well as the leached embalming chemical and metals used in the burial boxes. Bouwer (1978) cites average chemical parameters in shallow ground water below graves in the sandy soils of Holland as follows:

Table 3.3. Average Chemical Parameters below Grave Sites (Bouwer, 1978)

PARAMETER	CONCENTRATION
Electrical Conductivity	2300 uS/cm
COD	95 mg/L
Chloride	500 mg/L
Sulfate	300 mg/L
Bicarbonate	450 mg/L
Ammonia	45 mg/L

Monitor well set no. 13 was installed immediately down gradient from the cemetery. It is likely that the shallow well, MW13S, reflects some of the cemetery leaching products. The concentration of COD, which ranges from 20 to 175 mg/L, is the highest found in any well except the deep well at the Provincetown beach; electrical conductivity is approximately twice that expected from background; sulfate ranges from 1.8 to 43 mg/L, approximately twice the expected natural background level; ammonia-N was low, but nitrate-N was relatively high with a range of 2.8 to 4.8 mg/L, though this may be derived from grass fertilizer. It is most likely that the contamination in the shallow well is the result of cemetery activity, and not from landfill or highway effects.

3.2.5 On-Site Sewage Disposal

Since Provincetown is completely dependent on individual on-site sewage disposal systems, it is expected that at least the more shallow beach well, MW14S, would show effects from sewage effluent. Domestic sewage effluent is characterized by increased electrical conductivity, high levels of chloride, nitrogen (as ammonia, nitrite, or nitrate depending on the distance from the source and the redox potential), phosphate, and sulfate (Canter and Knox, 1985). Metals may be present from the movement of water through metal piping systems if the water has a low pH. The public water supply source for Provincetown, which is from Truro, has a pH of about 6.0.

It is apparent from a review of the chemical parameters measured in water samples from MW14S that there is a strong contribution of sewage effluent into the ground water. This would be apparent in the upper 20 feet of the fresh water layer. However, high levels of electrical conductivity and chloride are ambiguous since this can also come from upper beach wave and tidal salt water overwash. The contribution of nitrogen in the upper level beach well sample in the ammonia form is low, but in the nitrate form it is the highest of any samples. In MW14S nitrate-N averages 5.2 mg/L and is as high 8.0 mg/L. In MW14I nitrate-N averages 1.6 mg/L, rising as high as 5.7 mg/L. Orthophosphate (0.13-1.15 mg/L) and phosphate (0.49-1.01) in MW14S, as well as somewhat lesser amounts in MW14I, are also greater than in any other well. The presence of these chemicals is also a strong indicator of sewage effluent pollution. Sulfate was also quite high, but this could be ambiguous due to the decomposing seaweed and other organic material frequently mixed with the sand in the upper beach.

The import of water for the public water supply of Provincetown is an important hydrologic component. Water use data from the Provincetown Water Department indicates that 312,949,700 gallons of water was pumped to Provincetown during 1991. With an estimated water use service area of approximately 12,000,000 square feet, this represents the equivalent of 42 inches of ground water recharge into the area every year. Assuming an effective porosity of 0.35, this increases the fresh water layer in the Provincetown area by an average of 10 feet.

Since the 3-month summer population is approximately 4 to 5 times that of the permanent winter population, there is a much greater input of water in the summer; water records indicate the water usage in 1991 varied from a low of 14,269,000 gallons in February to a high of 47,904,500 in July. This results in a cyclic ground water recharge which is evident in the vertical electrical conductivity profiles taken in January 1991 and in August 1991 which are shown in Figure 3.7. The electrical conductivity can be used as a direct measurement of mineralization, viz. using a conductivity of 1000 uS/cm as a fresh water limit. Measurements show that in January the fresh water layer thickness is about 40 feet, but in August it increases to 50 feet. This 10-foot increase in the fresh water layer is a result of the greatly increase public water use during the summer which largely enters the water table through the individual sewage disposal systems. It is to be noted that this is in sharp contrast to the normal natural fresh water lens summer response, which is to shrink in thickness because of the decrease in recharge due to increased evapo-transpiration during these summer months.

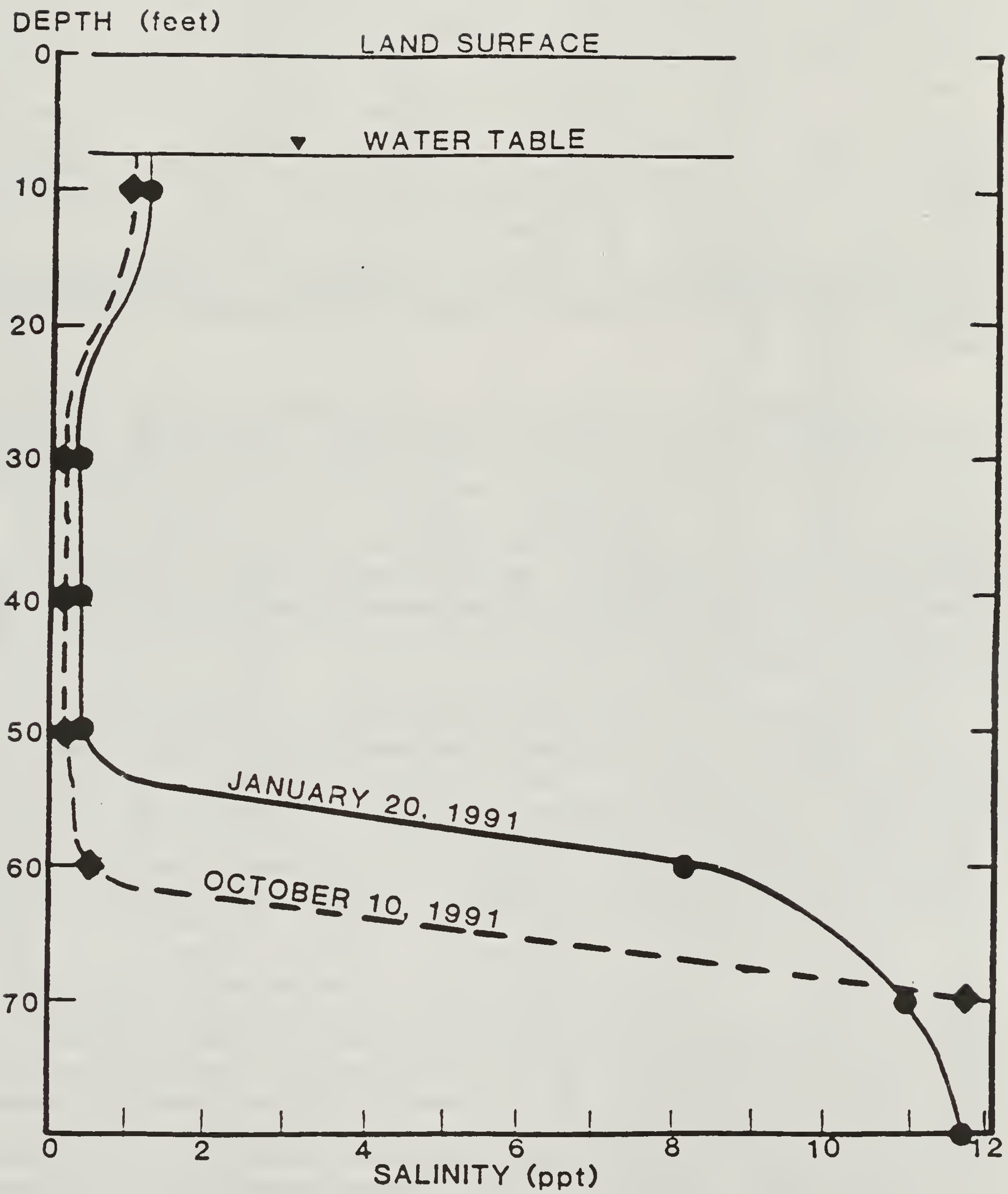


Figure 3.7. Electrical conductivity profiles taken at MW14.

3.3 Beach Dynamics

3.3.1 Groundwater Mixing

As described in Section 2.6.1, the beachface is a highly dynamic geohydrologic environment. As evidenced both by direct salinity measurements, and by the greatly increased slope of the water table near the beach, the fresh ground water lens decreases in thickness at the beach line as compared with much greater thickness at inland monitor wells. This, along with tidal dynamics, causes further mixing of the water in the lens at the beach zone.

The influence of the tide is reflected in the ground water levels at MW14. The upper beach is much more strongly influenced by tidal fluctuations than by seasonal changes, which cause the major water level differences in inland wells. It is also evident that the deep well, MW14D, is much more responsive to the tide than the shallow well, MW14S. As indicated in Figure 3.8, a high tide measurement taken on 2/25/92 exhibits a strong upward flow from MW14D to MW14S; at a low tide measurement taken on 9/20/92 the situation is reversed with vertical flow downward. This causes greater mixing both within the fresh water lens as well as in the transition zone as the fresh water and salt water strive to reach a dynamic equilibrium.

3.3.2 Groundwater Outflow

As the tide rises and moves shoreward there is a localized reversal of the ground water gradient from seaward to shoreward due to the much faster rise of the tide water than the ground water in the beach. This effect progresses shoreward for as much as 250 feet from high tide, effectively damming ground water outflow during an incoming tide. This process also introduces a large quantity of salt water into the beach, overlying the fresher ground water. With an outgoing tide the effect is reversed as a strong ground water gradient is created seaward. The ground water, with the recently introduced salt water then flows out of the beachface. Hence, the beach outflow is a cyclic process. The limits of ground water and tide water fluctuations are shown in Figure 3.9, a water table envelope for a tide of 11.5 feet.

The effect of the tide in creating a hydraulic damming of the fresh water lens at high tide is very important to ground water outflow timing and the mixing of the fresh water with the salt water in the intertidal zone. Inspection of the water level fluctuations in MW14 on October 10, 1991 (for an 11.5 ft tide) shows that for about 4 hours, from 3 hours before high

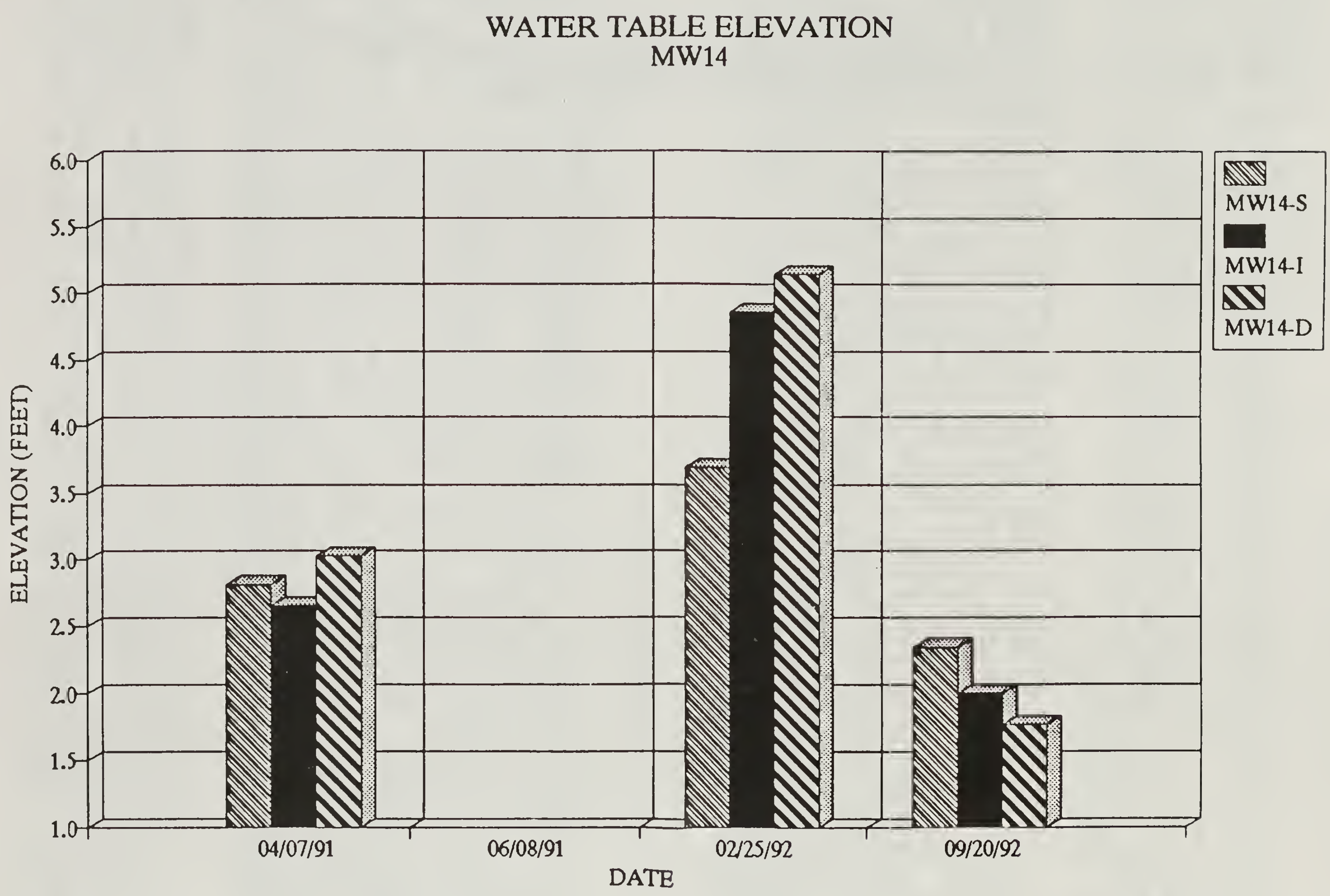


Figure 3.8. Effect of tide on hydraulic heads at MW14.

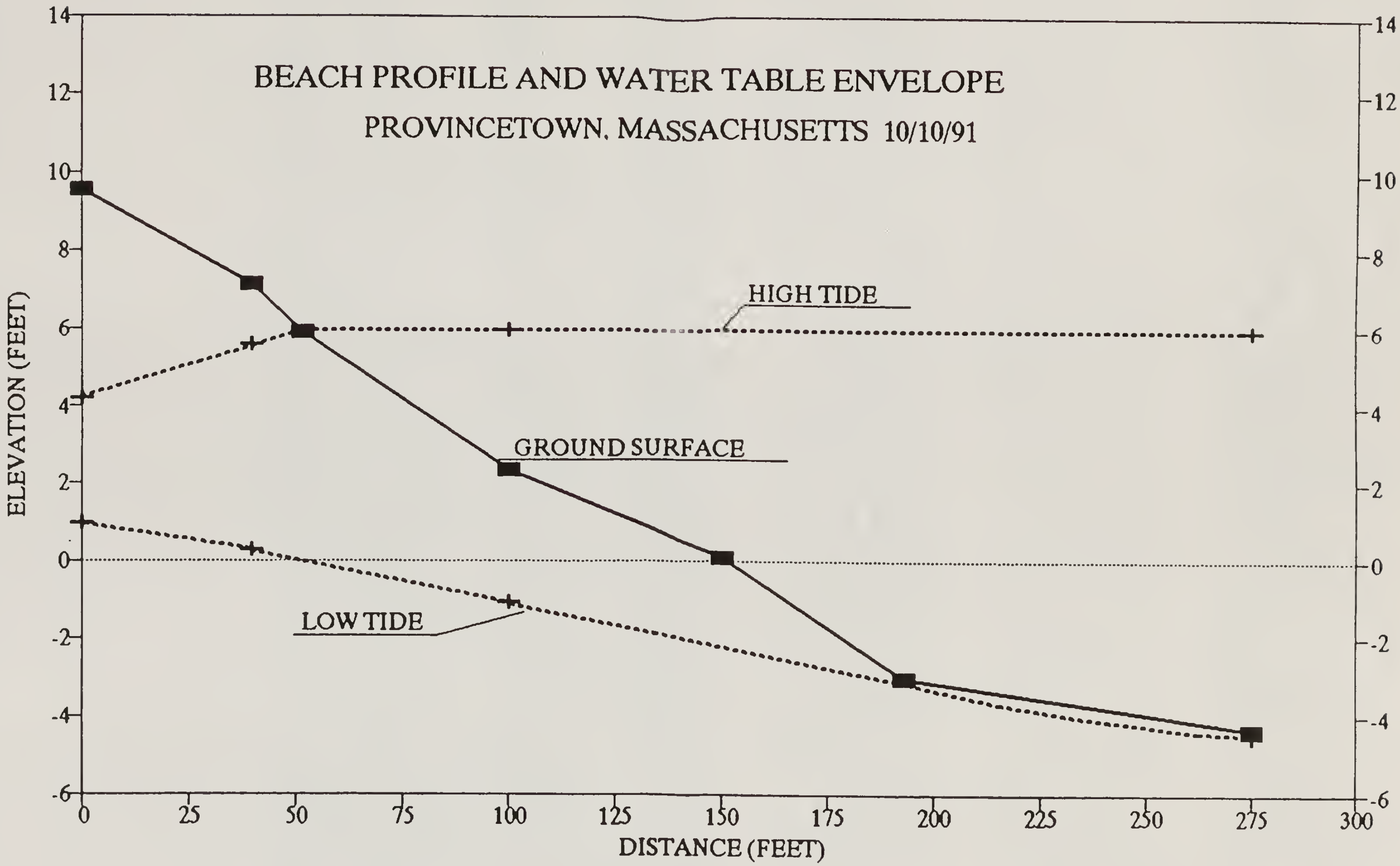


Fig. 3.9. Water table envelope at Johnson beach - 10/10/91.

tide to 1 hour after high tide, the tide level is higher than the water in the upper beach, and for almost 2 hours is actually higher than any surface or ground water level in the Provincetown area. As the tide goes out, both the dammed fresh water and the tidal induced salt water pour out, carrying with it all of the chemical constituents collected for years from a myriad of sources.

CHAPTER 4. CONCLUSIONS

1. A classic fresh water lens based on the Ghyben-Herzberg Principle exists in the Provincelands region with an estimated fresh water thickness of 100 to 135 feet in the central part of the landmass and a fresh water - salt water transition zone estimated at about 40 feet.

2. Field measurements indicate that leachate emanating from the landfill has impacted local ground water quality to the south and southeast of the landfill and to a lesser extent impacted surface water quality to the west and southeast of the landfill. Fresh water ponds in the immediate vicinity of the landfill show contamination from landfill surface runoff and groundwater discharge.

3. The leachate plume flows to the southeast in a descending flow path within the fresh water lens at a very slow pace, with an estimated travel time from the south edge of the landfill to the harbor beach of probably from 10-30 years. The travel time depends primarily on the veracity of the estimated hydraulic conductivity which could easily vary by a factor of 2.

4. Evidence of landfill leachate input to the ground water system is found in down gradient wells approximately 800 feet southeast of the nearest edge of the landfill, but is not identifiable in the more remote monitor wells.

5. Contaminant input from other sources, namely Route 6 highway salting, the cemetery, and town on-site sewage disposal, is evident in water samples taken from monitor wells located immediately down gradient of each of these sources.

6. The strong tidal dynamics at the harbor beach causes extensive mixing of all contaminants so that in the shallow ground water outflow evidence of landfill leachate could not be distinguished. Based on the flow path derived from water table elevation measurements, it appears that leachate plume discharge could occur through the beach area on both sides of the MacMillian Wharf parking area.

CHAPTER 5. RECOMMENDATIONS (referenced to project objectives)

A. Project Objective 1 (Delineation of the Groundwater Flow System).

A.1. Establish a more comprehensive water table measurement network in order to produce a water table map for a broader region of the Provincelands. This should include sufficient locations to the north and west to identify groundwater flow divides. These additional measuring points are necessary to provide a more complete understanding of the flow directions in the central part of the peninsula where very flat gradients exist. Specifically the locations should include.

a.) Additional locations for both surface and groundwater measurements in ponds.

b.) Additional shallow groundwater measuring points in selected areas of low topography for less expensive installation.

c.) Additional nested multilevel wells in selected areas both in the presumed flow path and in "clean" areas.

A.2. These would provide supplemental water level data for vertical flow determination and evaluating water quality with depth. Split spoon samples should be taken during drilling to provide subsurface data for possible modeling. These wells should extend to a depth of at least 150 feet, well into the sea water - fresh water transition zone.

A.3. Install system of nested wells along the Provincetown Harbor upper beach. These stations should be similar to Monitor Well 14 installed at the Johnson Street parking lot.

A.4. Obtain the services of the Denver Office of the U.S. Geological Survey to perform borehole geophysics in each deep well to augment subsurface information for possible groundwater modeling. Borehole geophysical surveys have been done for existing NPS deep wells subsequent to the completion of this study as an independent URI research project. These results will be provided to intersected parties at a later date. Preliminary analysis indicates that these surveys would provide very useful stratigraphic data.

A.5. With an expanded water level measuring network, obtain water measurements quarterly for an additional year to provide more time variant change.

A.6. Construct a fully calibrated and validated numerical-based computer groundwater flow model to simulate both winter and summer conditions. The detail and reliability of such a model depends on the coverage of groundwater information available. If expanded multilevel monitor wells are installed and associated three-dimensional data obtained, then a 3-D model is most desirable and most feasible. Such three-dimensional steady state regional flow models have been constructed by the U.S. Geological Survey for all Cape Cod areas except the Provincetown region. Such a model would complete the coverage and provide a much more complete understanding of probable landfill and septage leachate plume flow paths.

B. Project Objective 2 (Characterization of Water Quality).

B.1. Accomplish an additional year of quarterly water quality sampling utilizing all newly proposed wells. This will expand the data base into new areas for which no water quality information exists, to further explore the possibility of landfill/septage leachate migration outside of the expected plume flow path. This also establishes a longer more viable data base for the relatively new NPS multilevel wells.

C. Project Objective 3 (Composition and Dynamics of Beachface Groundwater Outflow).

C.1. Accomplish two comprehensive surveys (summer and winter) of groundwater discharge water quality at low tide at the Provincetown Harbor beach on both sides of MacMillians Wharf at 50' intervals for a distance of 2000'. These can be more feasibility collected using hand driven stainless steel sampling probes. In addition, collect similar water quality samples in a control section along a stretch of harbor beach outside of the probable influence of leachate plume discharge. The intention of this survey is to search for a pattern or variation in water quality outflow which may identify leachate discharge as well as to locate point sources of contamination which may be of concern to the environmental condition of beach and near shore harbor waters.

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APPENDIX A

GEOPHYSICAL RESULTS

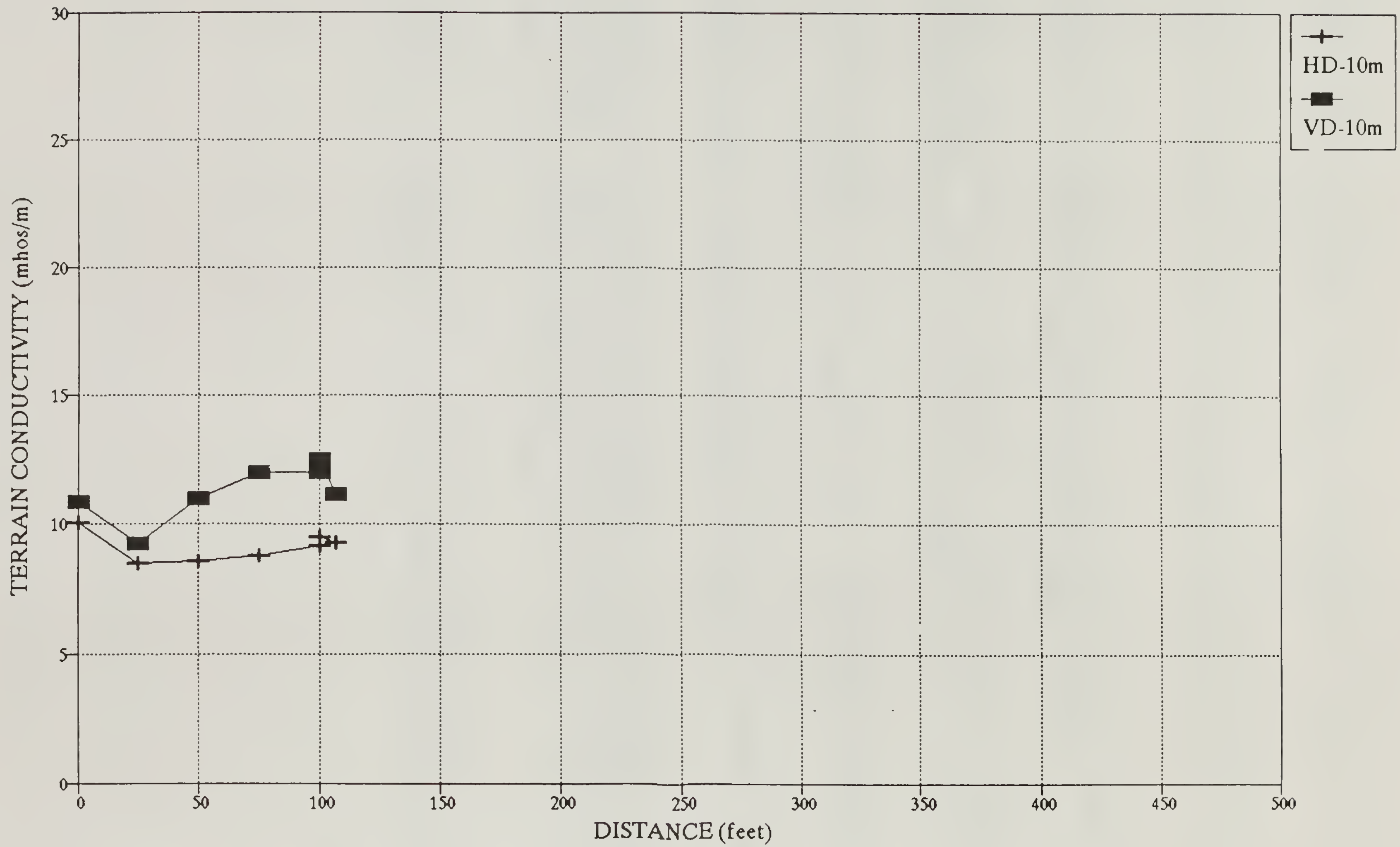


Fig. A-1. Electromagnetic survey # 2, Provincetown, MA.

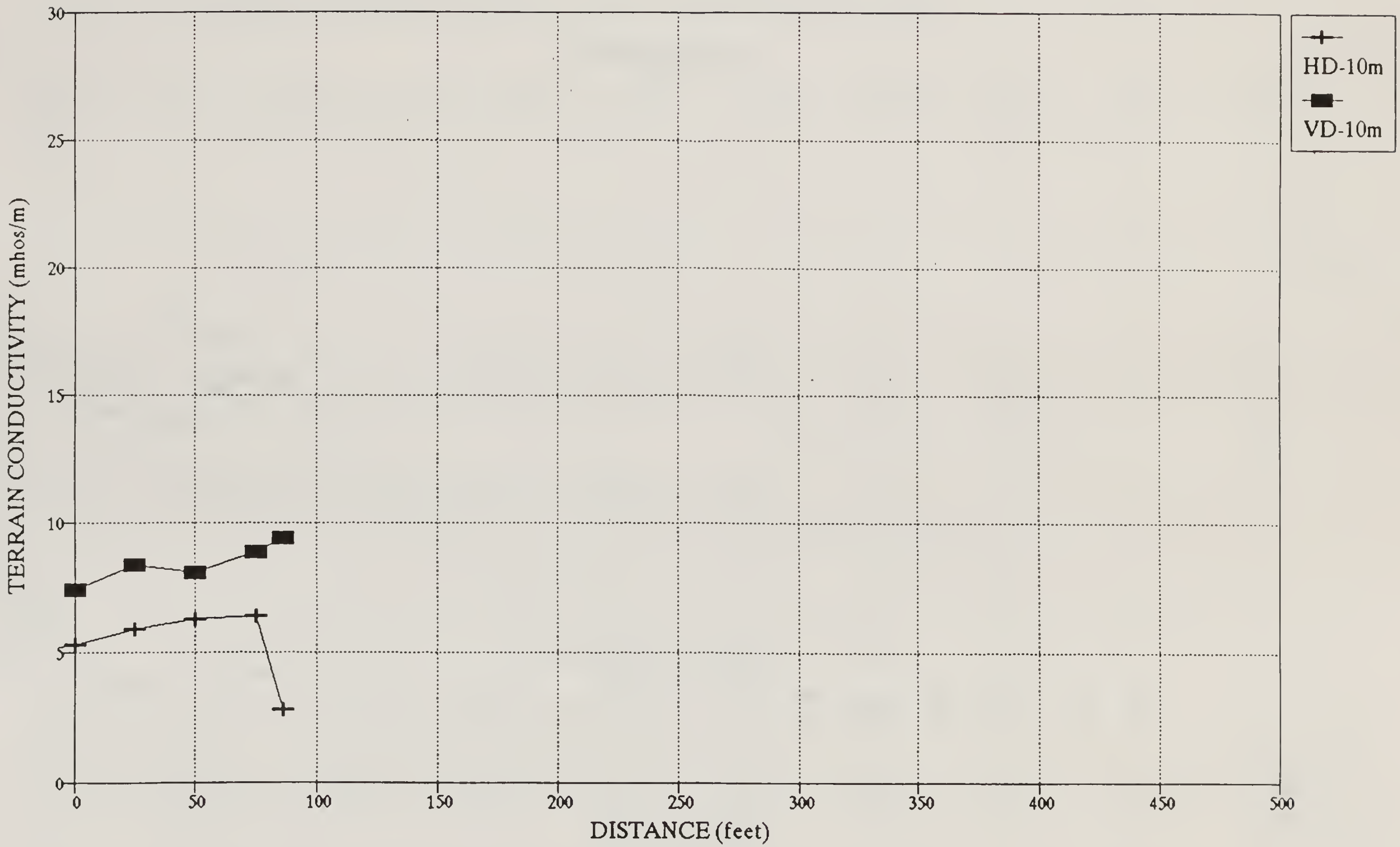


Fig. A-2. Electromagnetic survey # 3, Provincetown, MA.

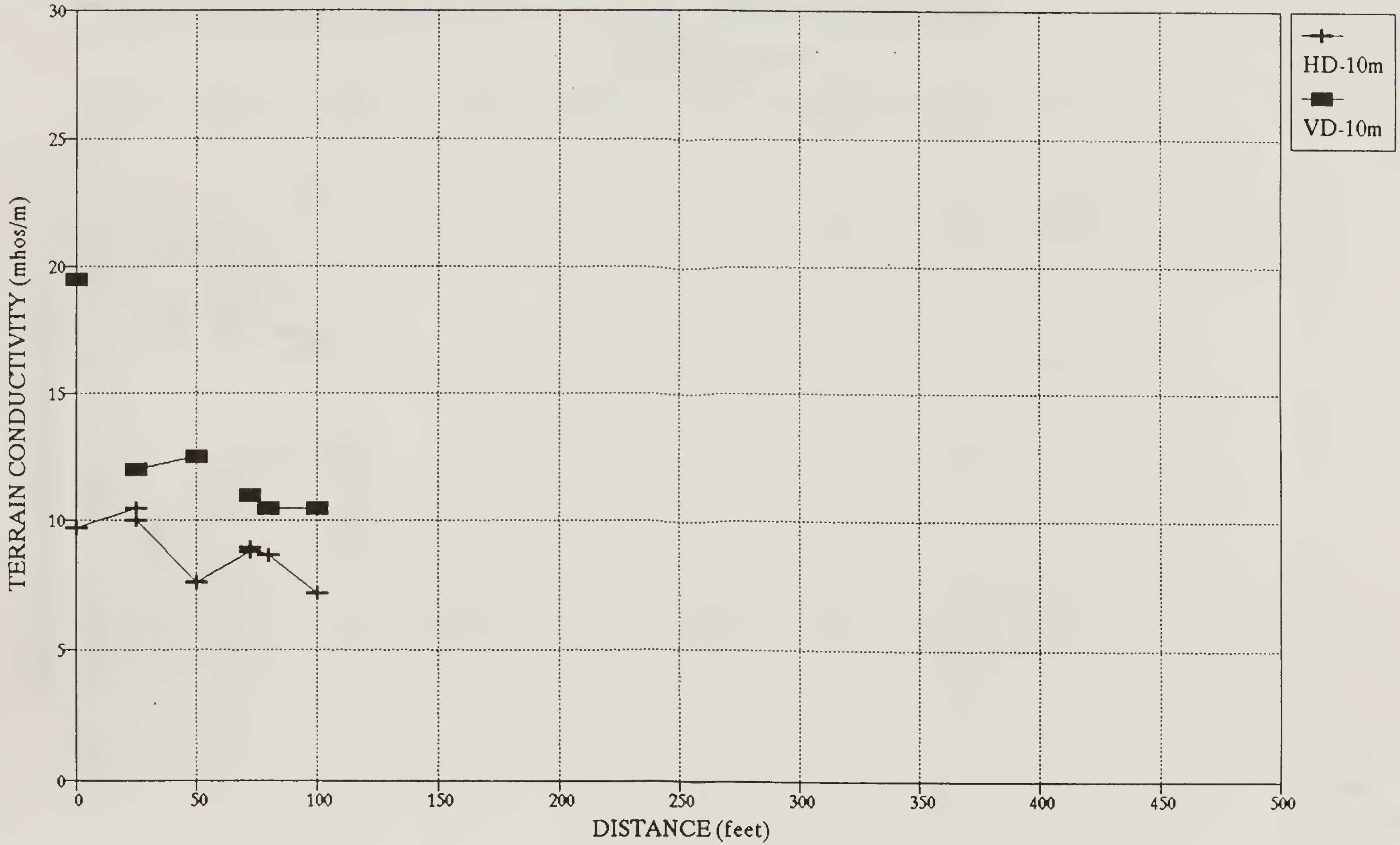


Fig. A-3. Electromagnetic survey # 4, Provincetown, MA.

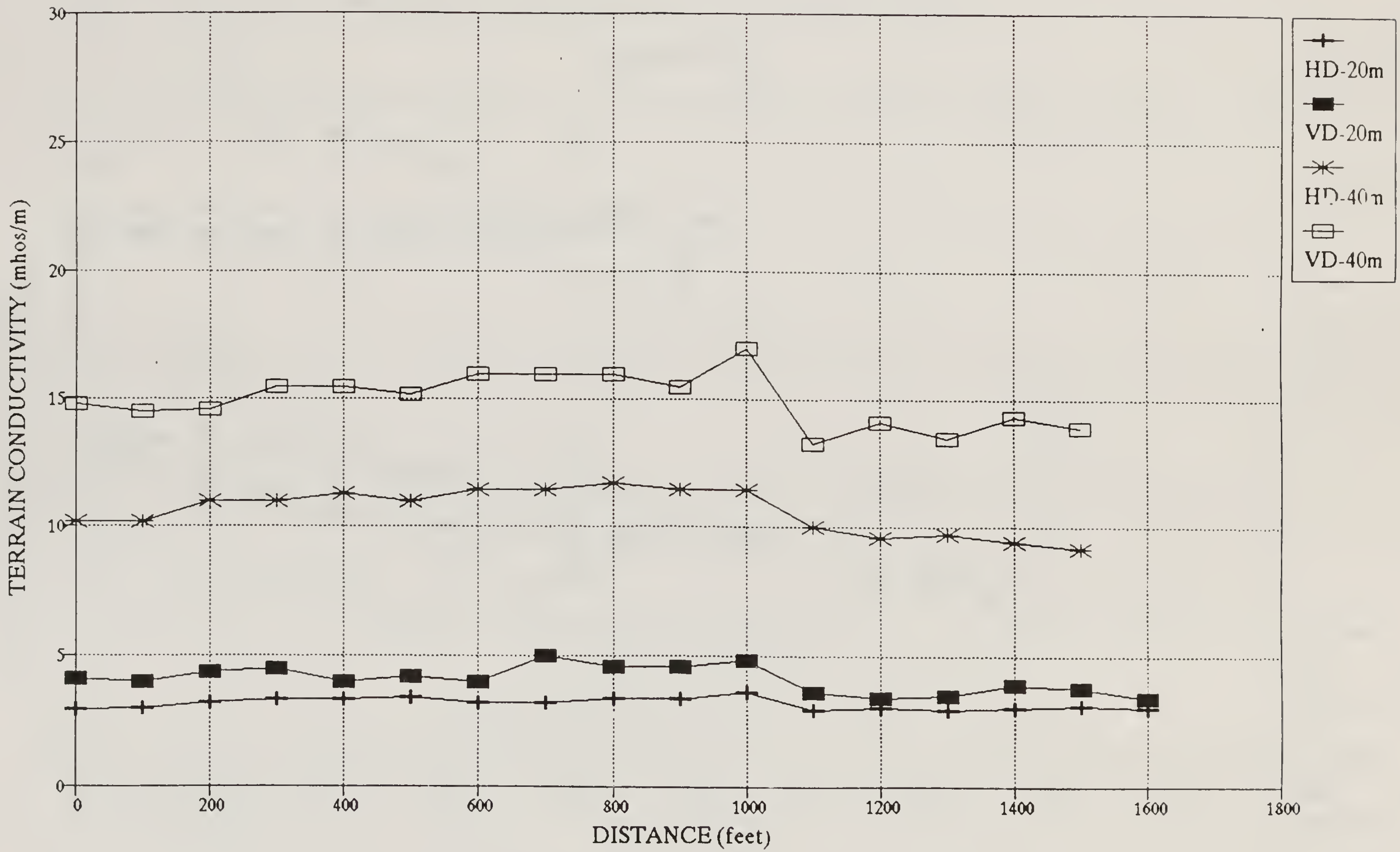


Fig. A-4. Electromagnetic survey # 5, Provincetown, MA.

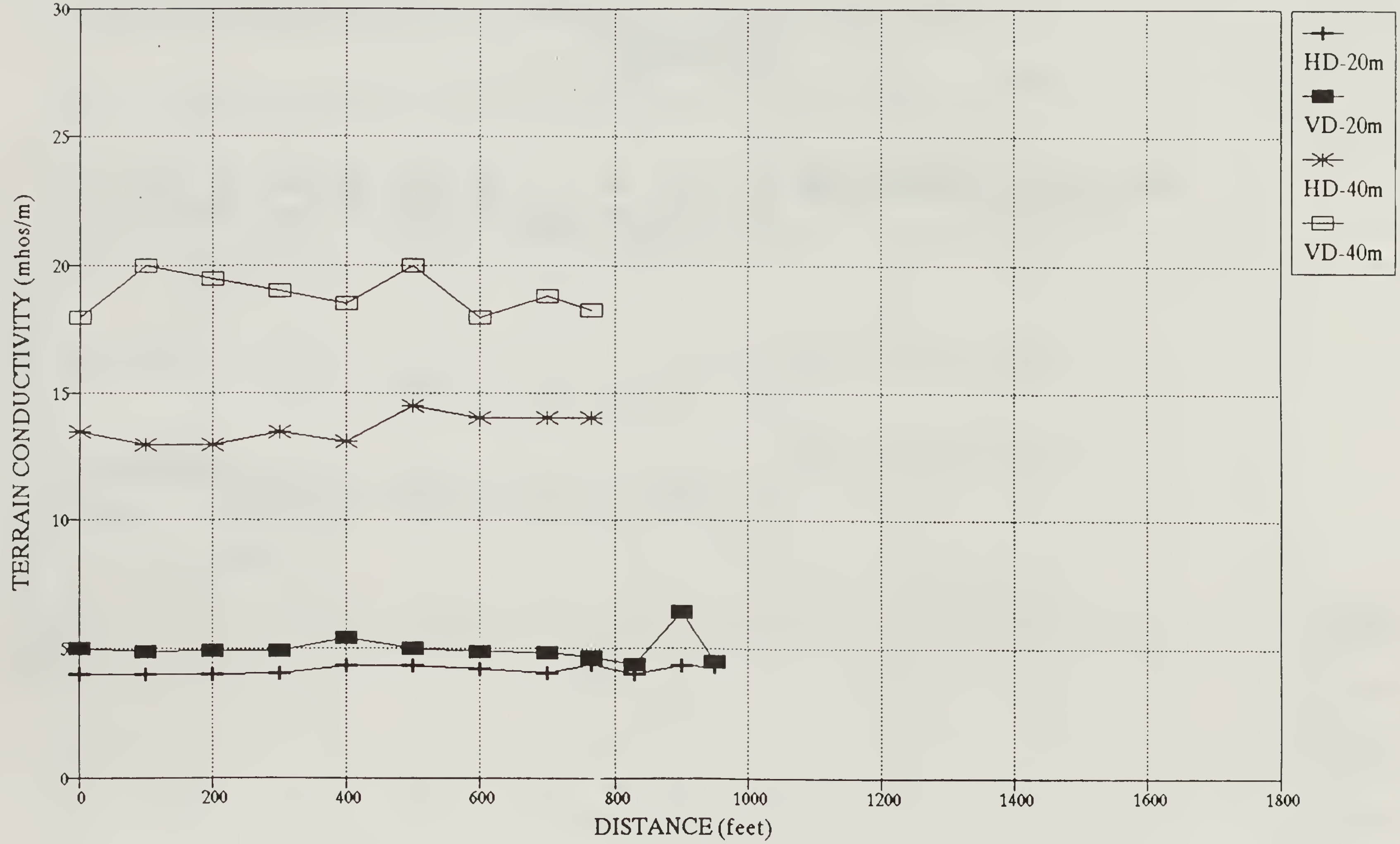


Fig. A-5. Electromagnetic survey # 6, Provincetown, MA.

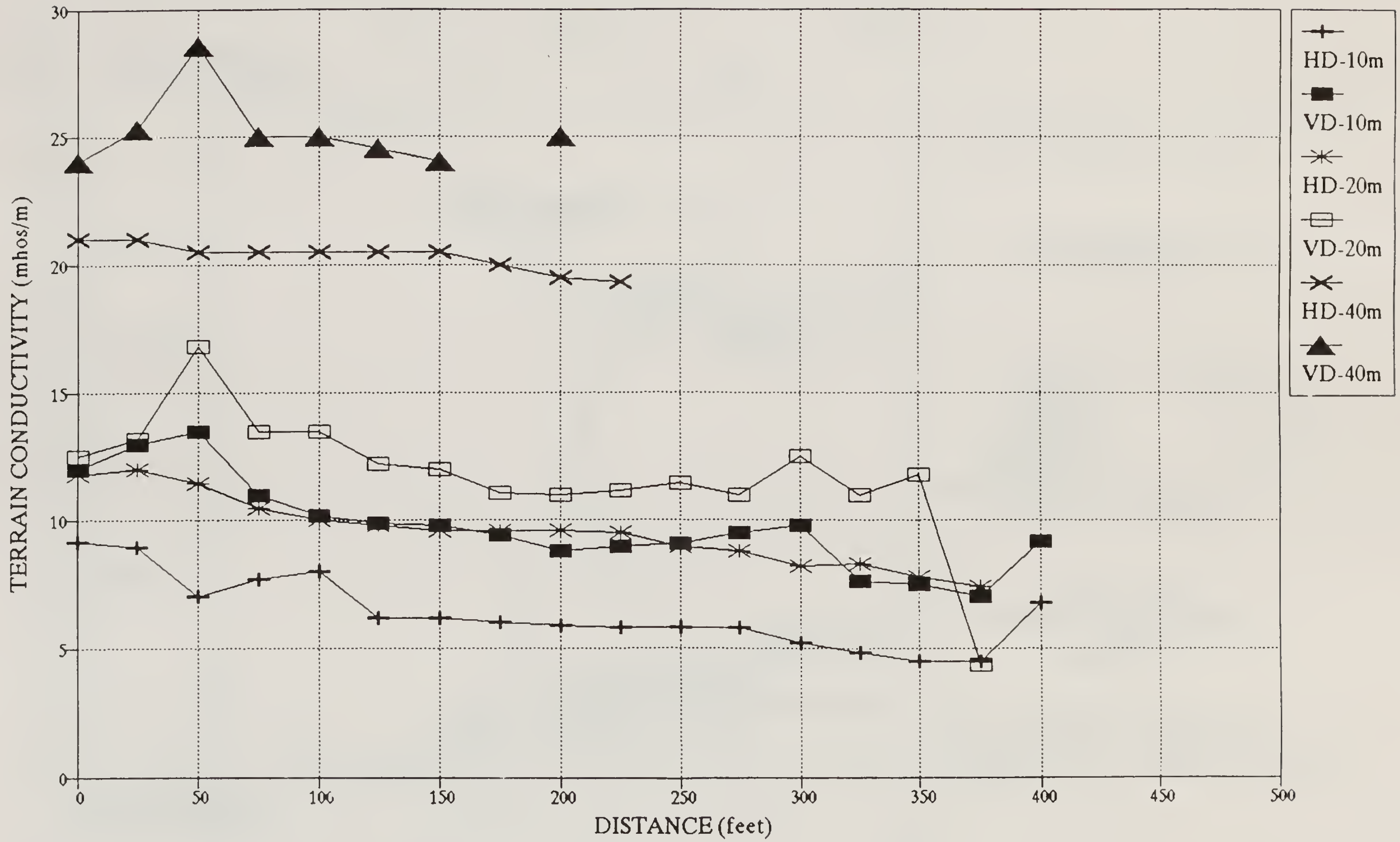


Fig. A-6. Electromagnetic survey # 7, Provincetown, MA.

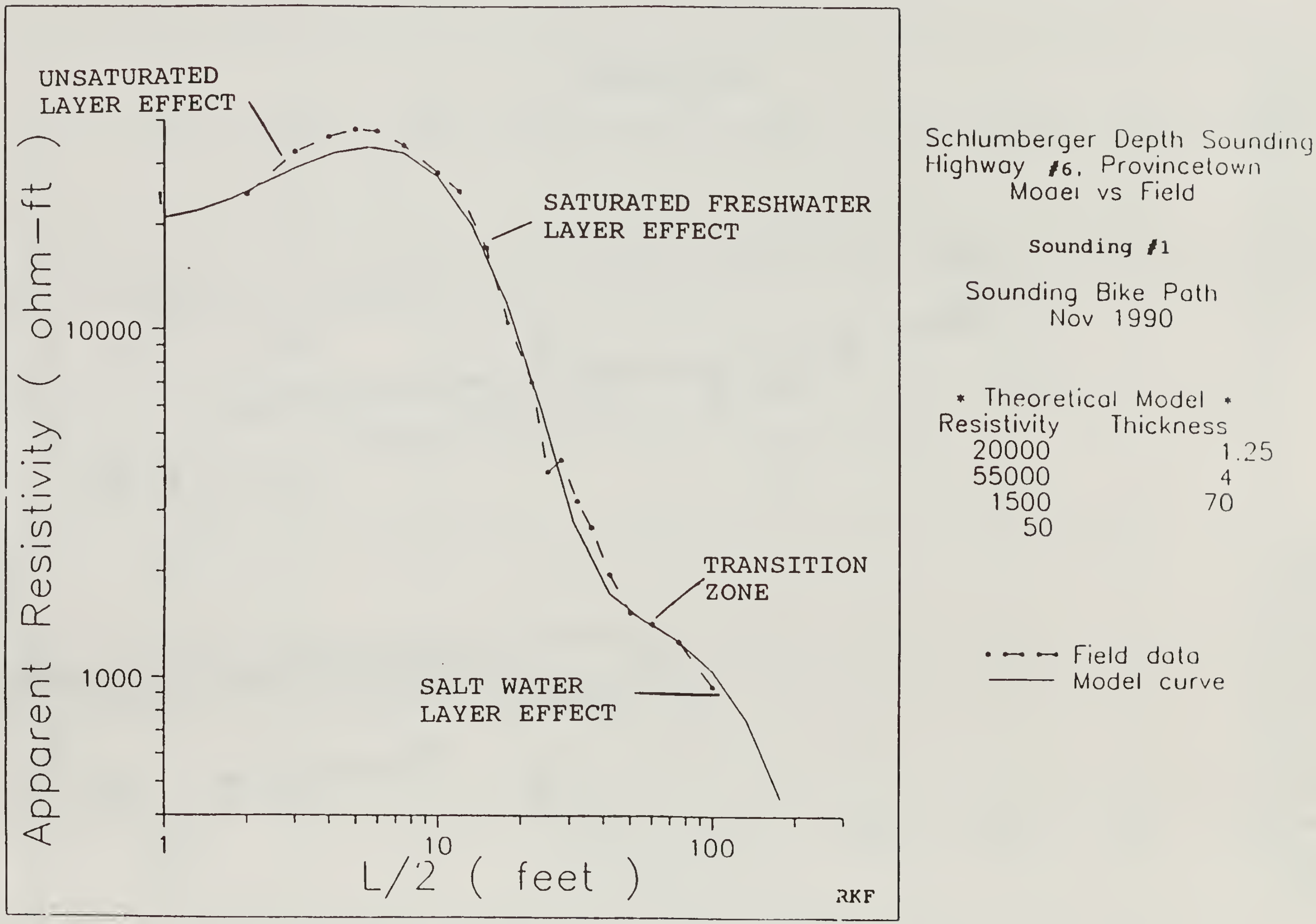


Fig. A-7. Electrical resistivity sounding #1, Provincetown, MA.

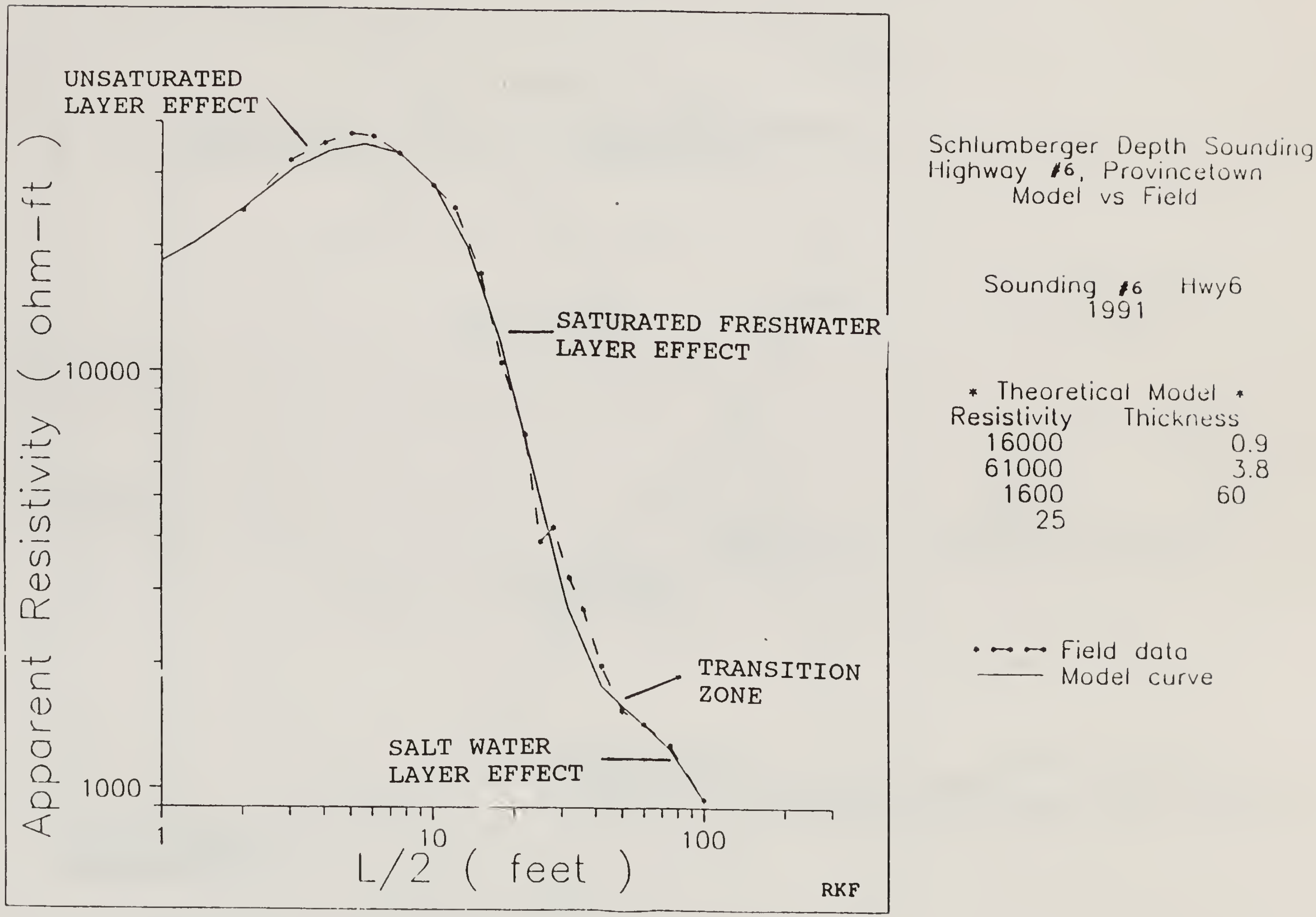


Fig. A-8. Electrical resistivity sounding # 2, Provincetown, MA.

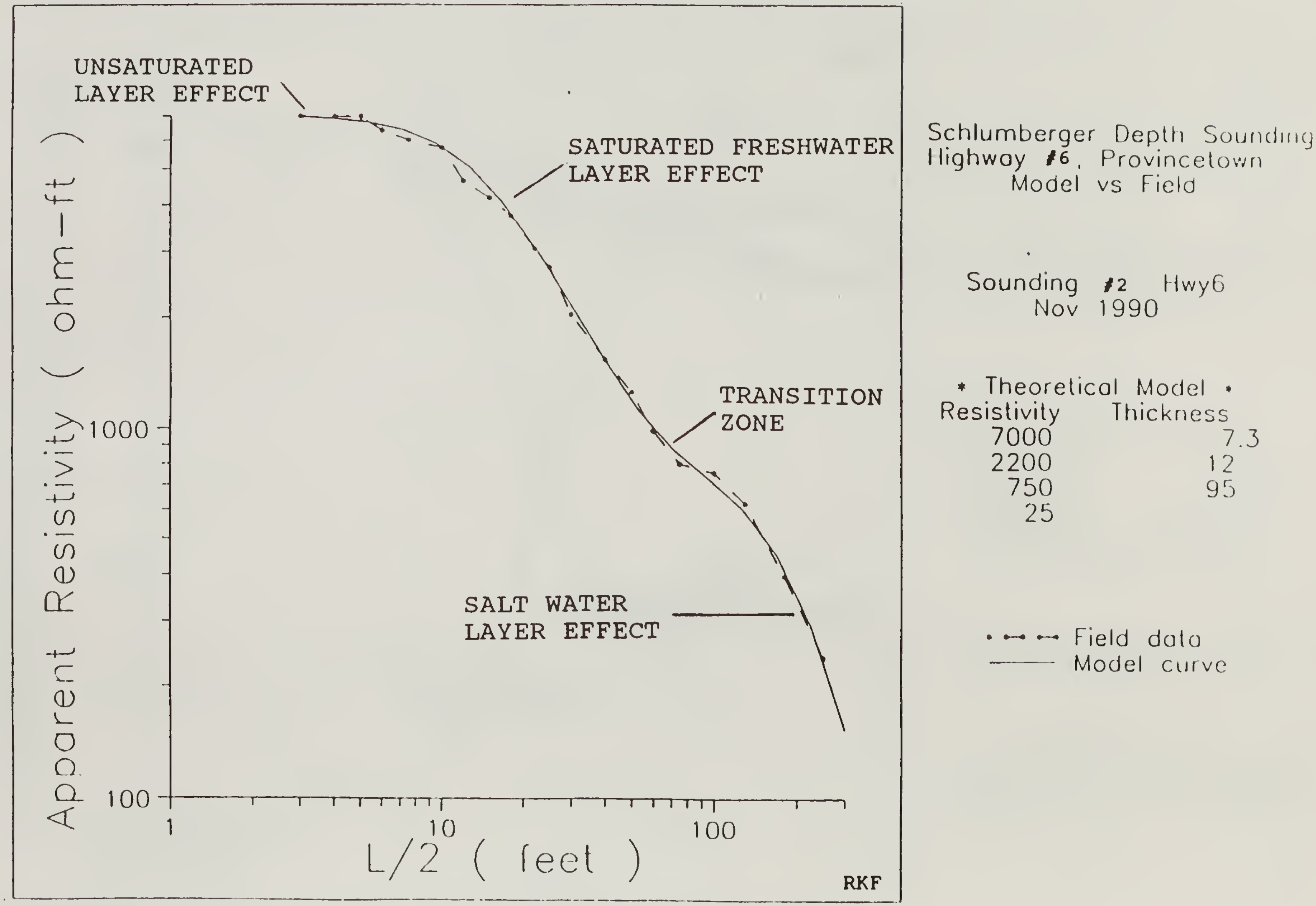


Fig. A-9. Electrical resistivity sounding # 3, Provincetown, MA.

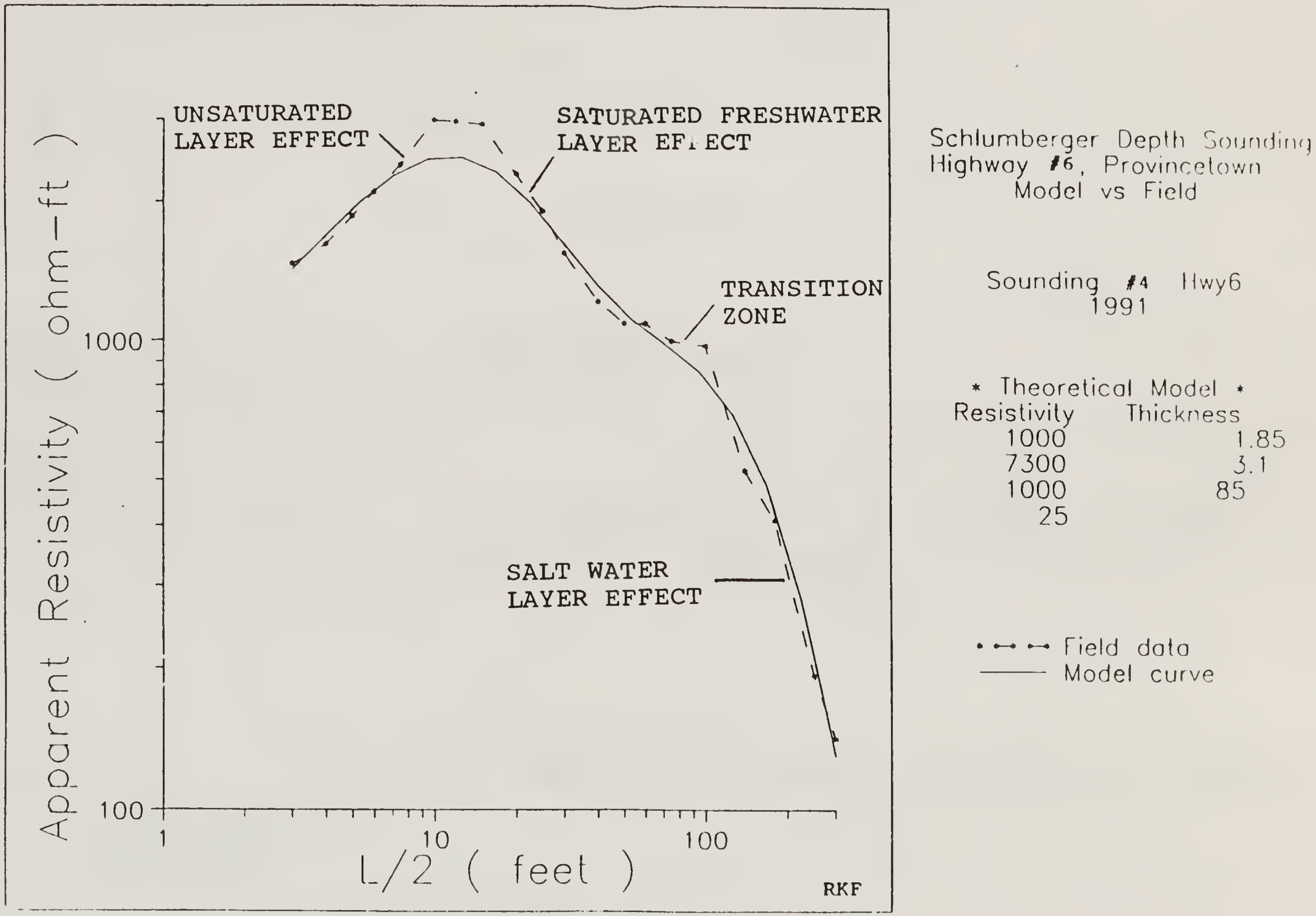


Fig. A-10. Electrical resistivity sounding # 4, Provincetown, Ma.

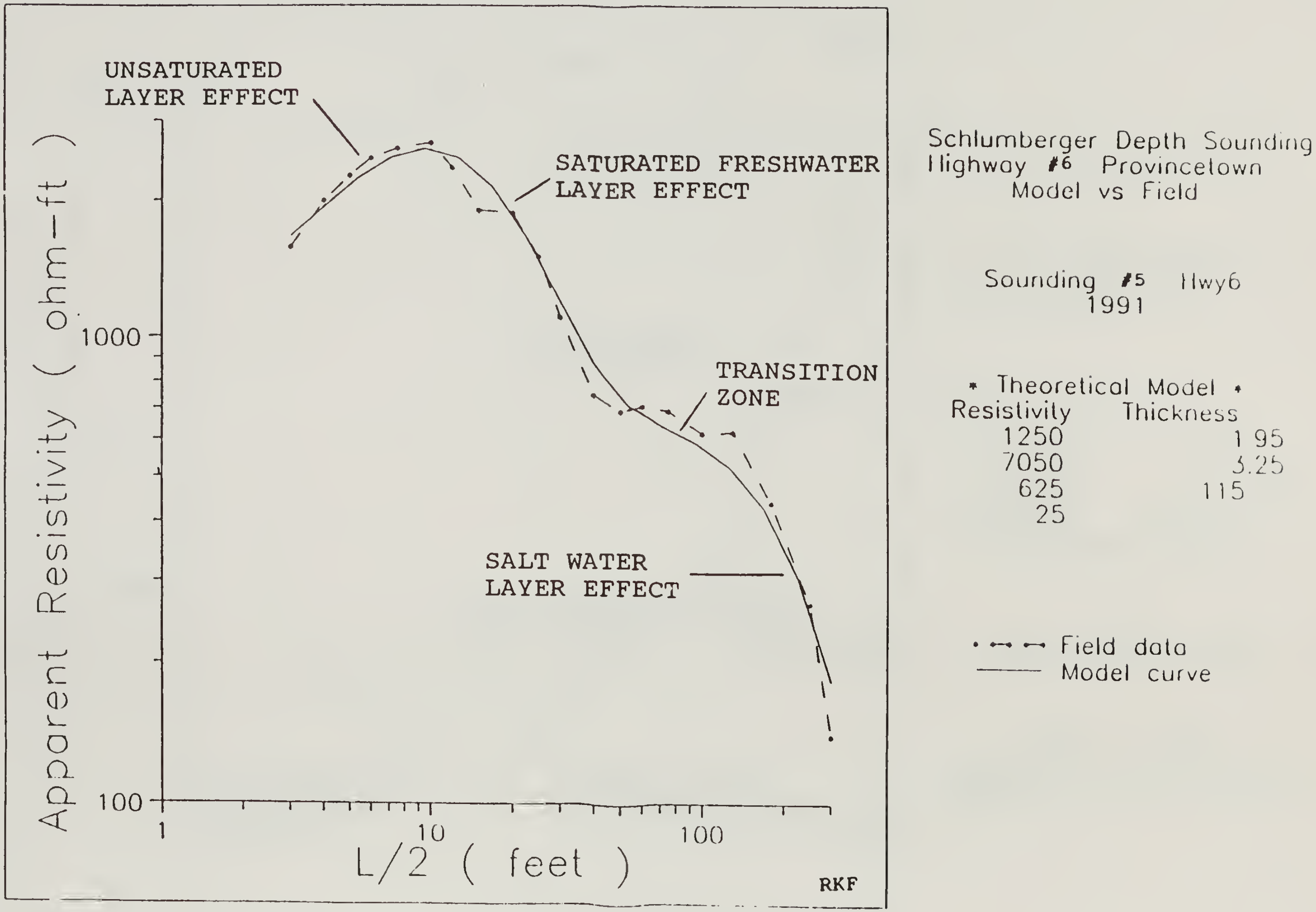


Fig. A-11. Electrical resistivity sounding # 5, Provincetown, Ma.

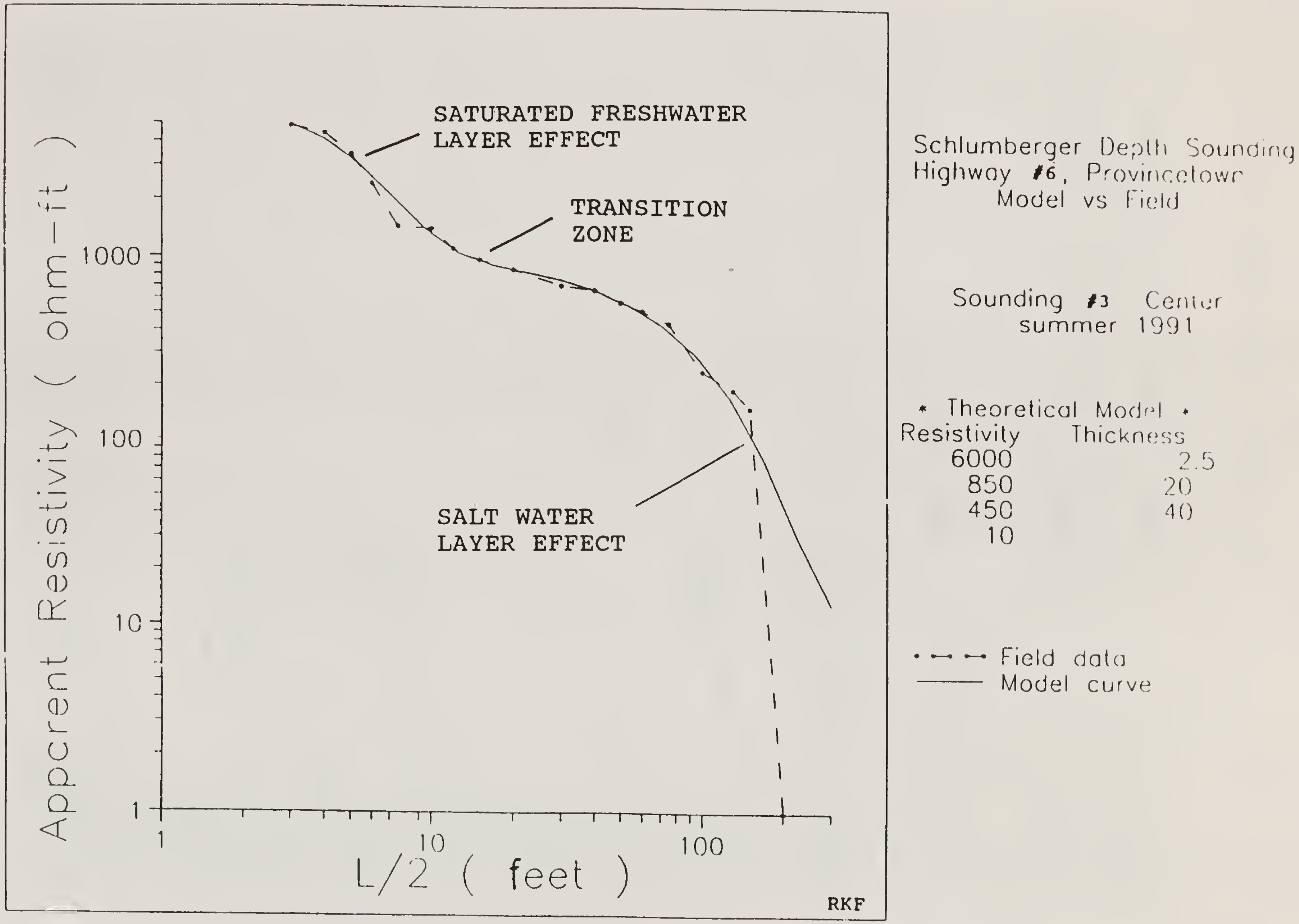


Fig. A-12. Electrical resistivity sounding # 6, Provincetown, MA.

APPENDIX B

WELL LOGS

Table B-1. Well Log for MW2

5

GUILD D ILLING CO., INC.
100 WATER STREET EAST PROVIDENCE R I

TO Town of Provincetown	ADDRESS Provincetown, Mass.
PROJECT NAME Obs. Wells @ Sanitary Land	LOCATION " "
REPORT SENT TO above / Fill & Septage Fac.	PROJ NO
SAMPLES SENT TO "	OUR JOB NO 83-325

SHEET 1 OF 1
DATE
HOLE NO MW-B
LINE & STA MW 2
OFFSET
SURF ELEV 16.91

GROUND WATER OBSERVATIONS		CASING	SAMPLER	CORE BAR		Date	Time
At 11'8" after ___ Hours	Rods-"NW" Type	HW	S/S		START	5/11/83	
	Size I D	4"	1 3/8"		COMPLETE	5/12/83	
At ___ after ___ Hours	Hammer Wt	300#	140#	BIT	TOTAL HRS.		
	Hammer Fall	24"	30"		BORING FOREMAN	T. Paquette	
					INSPECTOR		
					SOILS ENGR		

LOCATION OF BORING

DEPTH	Casing Blows per foot	Sample Depths From - To	Type of Sample	Blows per 6" on Sampler 0-6	6-12	12-18	Moisture Density or Consist	Strata Change Elev	SOIL IDENTIFICATION Remarks include color, gradation, Type of soil etc. Rock-color, type, condition, hardness, Drilling time, seams and etc	Sample No	Pen	Rec
	11	0'-2'	D	1	1	2	Dry		Brown medium to fine Sand	1	24"	18"
	14					2	loose		& Rubbish - FILL			
	11							3'				
	40											
	46											
	11	5'-7'	D	4	4	6	Dry		Light Brown medium to	2	24"	17"
	13					5	medium		fine SAND			
	13						dense					
	11											
	13											
	6	10'-12'	D	4	5	5	Wet		" trace of silt	3	24"	5"
	10					6	medium					
	9						dense					
	12											
	9											
	7	15'-17'	D	8	4	6	"		" "	4	24"	11"
	10					4						
	13											
	27											
	29											
	17	20'-22'	D	6	7	7	"		" "	5	24"	7"
	27					8		22'				
									Bottom of Boring 22'			
									Installed Observation Well at 22'			
									1 - 5' x 2" I.D. Well Screen			
									19' of 2" I.D. PVC			
									1 - 5' x 4" Steel Riser with Locking Cap & Padlock			
									½ Bag of Cement			
									1 Bag of Bentonite			

GROUND SURFACE TO ___ USED ___ CASING THEN ___

Sample Type	Proportions Used	140 lb Wt x 30" fall on 2" O D Sampler		SUMMARY
D=Dry C=Cored W=Washed	trace 0 to 10%	Cohesionless Density	Cohesive Consistency	Earth Boring 22'
UP=Undisturbed Piston	little 10 to 20%	0-10 Loose	0-4 Soft 30 + Hard	Rock Coring
TP=Test Pit A=Auger V=Vane Test	some 20 to 35%	10-30 Med Dense	4-8 M/Stiff	Samples 5

Table B-2. Well Log for MW4

GUILD DRILLING CO., INC

100 WATER STREET EAST PROVIDENCE, R. I.

SHEET 1 OF 1
DATE
HOLE NO MW-C
LINE & STA. MW4
OFFSET
SURF ELEV. 14.44

TO Town of Provincetown ADDRESS Provincetown, Mass.
PROJECT NAME Obs. Wells @ Sanitary Land LOCATION " "
REPORT SENT TO above / fill & Septage Fac. PROJ NO
SAMPLES SENT TO " OUR JOB NO 83-325

GROUND WATER OBSERVATIONS
At 9' after ____ Hours
At ____ after ____ Hours

Rods-"NW"	CASING	SAMPLER	CORE BAR
Type	HW	S/S	
Size I.D.	4"	1 3/8"	
Hammer Wt.	300#	140#	BIT
Hammer Fall	24"	30"	

	Date	Time
START	5/11/83	
COMPLETE	5/11/83	
TOTAL HRS.		

BORING FOREMAN T. Paquette
INSPECTOR
SOILS ENGR

LOCATION OF BORING

DEPTH	Casing Blows per foot	Sample Depths From - To	Type of Sample	Blows per 6" on Sampler 0-6	6-12	12-18	Moisture Density or Consist	Strata Change Elev	SOIL IDENTIFICATION Remarks include color, gradation, Type of soil etc. Rock-color, type, condition, hardness, Drilling time, seams and etc	SAMPLE No	Pen	Rec
	8	0'-1'	D	1	1		Dry	1'	Br. fine Sand & Rubbish-FILL	1	12"	7"
	16	1'-2'	D	4	4		loose		Brown medium to fine SAND	1A	12"	6"
	20											
	21											
	28											
	16	5'-7'	D	5	6	4	"			2	24"	19"
	15					4						
	11											
	13											
	13											
	8	10'-12'	D	6	5	4	Wet		" trace of silt	3	24"	16"
	9					7	medium					
	10						dense					
	12											
	11											
	10	15'-17'	D	1	0	2	"		" "	4	24"	7"
	12					9		17'				
	37											
	58											
	82								Brown Gray medium to fine			
		20'-22'	D	4	7	8	"		SAND (Hydrostatic) trace	5	24"	-
						8		22'	of silt			
									Bottom of Boring 22'			
									Installed Observation Well at 20'			
									1 - 5' x 2" Well Screen			
									17' of 2" I.D. Solid PVC			
									1 - 5' x 4" Steel Riser with Locking Cap & Padlock			
									½ Bag of Cement			
									1 Bag of Bentonite			

GROUND SURFACE TO ____ USED ____" CASING THEN ____

Sample Type
D=Dry C=Cored W=Washed
UP=Undisturbed Piston
TP=Test Pit A=Auger V=Vane Test

Proportions Used
trace 0 to 10%
little 10 to 20%
some 20 to 35%

140 lb Wt x 30" fall on 2" O.D. Sampler
Cohesionless Density: 0-10 Loose, 10-30 Med Dense
Cohesive Consistency: 0-4 Soft, 4-8 M/Stiff, 30 + Hard

SUMMARY
Earth Boring 22'
Rock Coring
Samples 5

Table B-3. Well Log for MW5

GUILD [illegible]RILLING CO., INC.
100 WATER STREET EAST PROVIDENCE, R. I.

TO: Town of Provincetown
ADDRESS: Provincetown, Mass.
PROJECT NAME: Obs. Wells @ Sanitary Land-
LOCATION: " "
REPORT SENT TO: above / fill & Septage Fac.
PROJ NO:
SAMPLES SENT TO: "
OUR JOB NO: 83-325

SHEET 1 OF 1
DATE:
HOLE NO: MW-D
LINE & STA.: MW5
OFFSET:
SURF ELEV: 6.70

GROUND WATER OBSERVATIONS
At 0.5' after Comp. Hours
At ______ after ______ Hours

Rods-"NW"	CASING	SAMPLER	CORE BAR
Type	HW	S/S	
Size I D	4"	1 3/8"	
Hammer Wt	300#	140#	BIT
Hammer Fall	24"	30"	

	Date	Time
START	5/10/83	
COMPLETE	5/10/83	

TOTAL HRS.:
BORING FOREMAN: T. Paquette
INSPECTOR:
SOILS ENGR.:

LOCATION OF BORING

DEPTH	Casing Blows per foot	Sample Depths From - To	Type of Sample	Blows per 6" on Sampler From To 0-6	6-12	12-18	Moisture Density or Consist	Strata Change Elev	SOIL IDENTIFICATION Remarks include color, gradation, Type of soil etc. Rock-color, type, condition, hardness, Drilling time, seams and etc	SAMPLE No	Pen	Rec
	5	0'-2'	D	2	4	3	Wet		Brown Gray medium to fine	1	24"	19"
	18					5	loose		SAND, trace of silt			
	20											
	17							3.5'				
	13											
	4	5'-7'	D	2	1	2	"		Brown medium to fine SAND,	2	24"	21"
	22					2			trace of silt			
	44											
	41											
	26											
	8	10'-12'	D	2	3	3	"			3	24"	16"
	8					3			(Sand Hydrostatic from 8'			
	17								to bottom of hole)			
	27							13.5'				
	36											
		15'-17'	D	6	7	8	Wet/m		Brown coarse to medium	4	24"	[illegible]
						11	dense	17'	SAND, trace of silt			
									Bottom of Boring 17'			
									Installed Observation Well at 15'			
									1 - 5' x 2" I.D. Wellpoint			
									12' of 2" I.D. Solid PVC			
									1 - 5' x 4" Steel Riser with Locking Cap & Padlock			
									½ Bag of Cement			
									1 Bag of Bentonite			

GROUND SURFACE TO ______ USED ______" CASING. THEN ______

Sample Type
D: Dry C: Cored W: Washed
UP: Undisturbed Piston
TP: Test Pit A: Auger V: Vane Test

Proportions Used
trace 0 to 10%
little 10 to 20%
some 20 to 35%

140 lb Wt x 30" fall on 2" O.D. Sampler
Cohesionless Density: 0-10 Loose; 10-30 Med Dense
Cohesive Consistency: 0-4 Soft; 4-8 M/Stiff; 30 + Hard

SUMMARY
Earth Boring 17'
Rock Coring ______
Samples 4

Table B-4. Well Log for MW6

GUILD [illegible]RILLING CO., INC.
100 WATER STREET EAST PROVIDENCE, R. I.

SHEET	1 OF 1
DATE	
HOLE NO	MW-E
LINE & STA.	MW6
OFFSET	
SURF ELEV.	9.16

TO: Town of Provincetown
ADDRESS: Provincetown, Mass.
PROJECT NAME: Obs. Wells @ Sanitary Land-
LOCATION: - " "
REPORT SENT TO: above / fill & Septage Fac.
PROJ NO:
SAMPLES SENT TO: -"-
OUR JOB NO: 83-325

GROUND WATER OBSERVATIONS
At 2.3' after ____ Hours
At ____ after ____ Hours

Rods-"NW"	CASING	SAMPLER	CORE BAR
Type	HW	S/S	
Size I.D.	4"	1 3/8"	-
Hammer Wt	300#	140#	BIT
Hammer Fall	24"	30"	

	Date	Time
START	5/10/83	
COMPLETE	5/10/83	
TOTAL HRS.		
BORING FOREMAN	T. Paquette	
INSPECTOR		
SOILS ENGR.		

LOCATION OF BORING

DEPTH	Casing Blows per foot	Sample Depths From - To	Type of Sample	Blows per 6" on Sampler From 0-6	To 6-12	12-18	Moisture Density or Consist	Strata Change Elev	SOIL IDENTIFICATION Remarks include color, gradation, Type of soil etc. Rock-color, type, condition, hardness, Drilling time, seams and etc	SAMPLE No	Pen	Rec
	5	0'-2'	D	1	1	2	Dry		Brown Rusty medium to	1	24"	11"
	10					3	loose		fine SAND			
	12							3'				
	11											
	14											
	4	5'-7'	D	4	5	3	Wet		Brown medium to fine	2	24"	17"
	5					4	loose		SAND, trace of silt			
	8											
	10											
	28											
	12	10'-12'	D	5	8	7	Wet			3	24"	19"
	19					8	medium					
	20						dense					
	30											
	46											
		15'-17'	D	7	9	11	"		(Sample #4 - Sand	4	24"	16"
						8		17'	Hydrostatic)			
									Bottom of Boring 17'			
									Installed Observation Well at 15'			
									1 - 5' x 2" I.D. Wellpoint			
									12' of 2" I.D. Solid PVC			
									1 - 5' x 4" Riser with locking Cap & Padlock			
									1 Bag of Bentonite			
									½ Bag of Cement			

GROUND SURFACE TO ____ USED ____ CASING. THEN ____

Sample Type
D=Dry C=Cored W=Washed
UP=Undisturbed Piston
TP=Test Pit A=Auger V=Vane Test

Proportions Used	
trace	0 to 10%
little	10 to 20%
some	20 to 35%

140 lb Wt x 30" fall on 2" O.D. Sampler

Cohesionless Density		Cohesive Consistency			
0-10	Loose	0-4	Soft	30 +	Hard
10-30	Med Dense	4-8	M/Stiff		

SUMMARY
Earth Boring 17'
Rock Coring ____
Samples 4

Table B-5. Well Log for MW8

GUILD DRILLING CO., INC.

100 WATER STREET EAST PROVIDENCE, R. I.

TO: Town of Provincetown	ADDRESS: Provincetown, Mass.	SHEET 1 OF 1	
PROJECT NAME: Obs. Wells @ Sanitary Land-	LOCATION: " "	DATE	
REPORT SENT TO: above / fill & Septage Fac.	PROJ NO	HOLE NO: MW-F	
SAMPLES SENT TO: "	OUR JOB NO: 83-325	LINE & STA.: MW8	
		OFFSET	
		SURF ELEV: 21.22	

GROUND WATER OBSERVATIONS	Rods-"NW"	CASING	SAMPLER	CORE BAR		Date	Time
At 14'8" after ___ hours	Type	HW	S/S		START	5/16/83	
At ___ after ___ Hours	Size I.D.	4"	1 3/8"		COMPLETE	5/16/83	
	Hammer Wt.	300#	140#	BIT	TOTAL HRS.		
	Hammer Fall	24"	30"		BORING FOREMAN	T. Paquette	
					INSPECTOR		
					SOILS ENGR.		

LOCATION OF BORING

DEPTH	Casing Blows per foot	Sample Depths From - To	Type of Sample	Blows per 6 on Sampler From To 0-6	6-12	12-18	Moisture Density or Consist	Strata Change Elev	SOIL IDENTIFICATION Remarks include color, gradation, Type of soil etc. Rock-color, type, condition, hardness, Drilling time, seams and etc	SAMPLE No	Pen	Rec
	7	0'-2'	D	2	2	3	Dry	1.5'	Dark & Light Brown medium	1	24"	19
	17					5	loose		to fine SAND, tr. vegetation			
	24											
	23											
	24											
	10	5'-7'	D	3	2	3	"		Light Brown medium to	2	24"	18
	17					4			fine SAND			
	26				-							
	44											
	41											
	25	10'-12'	D	7	9	11	Dry			3	24"	1-
	31					11	medium					
	23						dense					
	14											
	16											
	11	15'-17'	D	4	6	5	Wet		" trace of silt	4	24"	11
	16					5	loose					
	16											
	31											
	53											
	16	20'-22'	D	8	8	6	Wet		" "	5	24"	8
	18					7	medium					
	31						dense					
	25											
	45											
	56	25'-27'	D	4	8	8	"		" "	6	24"	-
	52					11						
	43											
	44											
	37											
		30'-32'	D	5	5	8	"		" "	7	24"	-
						5		32'				
									Bottom of Boring 32'			
									Installed Observation			
									Well at 30'			
									1 - 5' x 2" Well Screen			
									27' of 2" I.D. Solid PVC			
									1 - 5' x 4" Riser with			
									Locking Cap & Padlock			
									1 Bag of Cement & Bentonite			

GROUND SURFACE TO ___ USED ___ " CASING. THEN ___

Sample Type	Proportions Used	140 lb Wt x 30" fall on 2" O.D. Sampler		SUMMARY:
D: Dry C: Cored W: Washed	trace 0 to 10%	Cohesionless Density	Cohesive Consistency	Earth Boring 32
UP: Undisturbed Piston	little 10 to 20%	0-10 Loose	0-4 Soft 30 + Hard	Rock Coring -
		10-30 Med Dense	4-8 M/Stiff	Samples

Table B-6. Well Log for MW9

GUILD RILLING CO., INC
100 WATER STREET EAST PROVIDENCE R I

TO	Town of Provincetown
ADDRESS	Provincetown, Mass.
PROJECT NAME	Obs. Wells @ Sanitary Land-
LOCATION	" "
REPORT SENT TO	above / fill & Septage Fac.
PROJ NO	
SAMPLES SENT TO	"
OUR JOB NO	83-325
SHEET	1 OF 1
DATE	
HOLE NO.	MW-A
LINE & STA	MW9
OFFSET	
SURF ELEV	24.23

GROUND WATER OBSERVATIONS			CASING	SAMPLER	CORE BAR
At 10.2' after ___ Hours	Rods-"NW"	Type	HW	S/S	
At ___ after ___ Hours		Size I D	4"	1 3/8"	
		Hammer Wt	300#	140#	BIT
		Hammer Fall	24"	30"	

	Date	Time
START	5/12/83	
COMPLETE	5/12/83	
TOTAL HRS.		
BORING FOREMAN	T. Paquette	
INSPECTOR		
SOILS ENGR		

LOCATION OF BORING Note: Hole is 30' East of Stake - OK by Engineer

DEPTH	Casing Blows per foot	Sample Depths From - To	Type of Sample	Blows per 6" on Sampler 0-6	6-12	12-18	Moisture Density or Consist	Strata Change Elev	SOIL IDENTIFICATION Remarks include color, gradation, Type of soil etc. Rock-color, type, condition, hardness, Drilling time, seams and etc	SAMPLE No	Pen	Rec
	6	0'-2'	D	1	1	2	Dry		Dark Brown fine to medium	1	24"	16
	12					4	loose	2'	Sand, Rubbish & Topsoil			
	20								intermixed - FILL			
	20											
	15											
	5	5'-7'	D	2	2	3	"		Brown medium to fine SAND	2	24"	14
	12					4						
	12											
	12											
	14											
	3	10'-12'	D	2	2	3	Wet		" trace of silt	3	24"	18
	4					4	loose					
	5											
	6											
	7							15'				
	11	15'-17'	D	4	6	5	Wet		Brown Gray medium to fine	4	24"	18
	28					8	medium		SAND, trace of silt			
	46						dense					
	53											
	47							20'	(Sand Hydrostatic)			
	35	20'-22'	D	3	5	8	"		Brown medium to fine SAND,	5	24"	8
	45					6		22'	trace of silt			

Bottom of Boring 22'

Installed Observation Well at 21'

1 - 5' x 2" I.D. Screen
18' of 2" I.D. PVC
1 - 5' x 4" Riser with Locking Cap & Padlock
½ Bag of Cement
1 Bag of Bentonite

GROUND SURFACE TO ___ USED ___ CASING. THEN ___

Sample Type	Proportions Used	140 lb Wt x 30" fall on 2" O.D. Sampler		SUMMARY
D=Dry C=Cored W=Washed	trace 0 to 10%	Cohesionless Density	Cohesive Consistency	Earth Boring 22'
UP=Undisturbed Piston	little 10 to 20%	0-10 Loose	0-4 Soft 30 + Hard	Rock Coring
TP=Test Pit A=Auger V=Vane Test	some 20 to 35%	10-30 Med Dense	4-8 M/Stiff	Samples 5

Table B-7. Well Log for MW10-S

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling Inc	PROJECT Cape Cod National Seashore Contract NO. PX 1730-0295	BORING NO. a [illegible] - MW10 S SHEET 1 OF 1

DRILLER Thomas Desmond
HELPER David Pimenta
INSPECTOR John Portnoy, Mary O'Reilly, Dan Urist
BORING LOCATION Provincetown Landfill
GROUND SURFACE ELEVATION
DATE START 11 26/90 DATE END 11 27/90

SAMPLER: SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE 3 3/4" [illegible]
CASING SIZE 2"
SCREEN SIZE 2"x5' .01

Depth	Sample NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
					No samples taken.	
4'					Bentonite	bentonite
5'						
8'					Static. (should be 19')	▼
16'					Bentonite.	bentonite
18'						
30'					Well depth.	screen
35'					End of drilling. Protective concreted in place. Master Lock NO. 3447 key.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M. DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V. STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- SAND PACK
- SOIL BACKFILL
- BENTONITE
- SCREEN
- ▼ APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING BORING NO. DW75

Table B-8. Well Log for MW10-I

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract NO. PX 1730-0-0295	BORING NO Oh 1 I - MW10I SHEET 1 OF 2

DRILLER Thomas Desmond
HELPER David Pimenta
INSPECTOR John Portnov, Mary O'Reilly

BORING LOCATION Provincetown Landfill
GROUND SURFACE ELEVATION
DATE START 11/26/90 DATE END 11/27/90

SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB. HAMMER FALLING 30"

AUGER SIZE 3 3/4" ID
CASING SIZE 2"
SCREEN SIZE 2"x5' .01

D (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
					No samples taken.	
4'					Bentonite.	Bentonite
5'						
17'					Bentonite	Bentonite
19'						
20'					Static.	▼

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V LOOSE	<2	V SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY

■ - CEMENT
▨ - BENTONITE
□ - SAND PACK
≡ - SCREEN
□ - SOIL BACKFILL
▼ - APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING

BORING NO Oh 1I

Table B-8 continued. Well Log for MW10-I

Cape Cod Test Boring
5 Rayber Road, Orleans, MA 02653
(508) 240-1000
div Desmond Well Drilling, Inc.

PROJECT

BORING NO OW1 I -MW10 I
SHEET 2 OF 2

DRILLER
HELPER
INSPECTOR

BORING LOCATION
GROUND SURFACE ELEVATION
DATE START   DATE END

SAMPLER: SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE.
CASING SIZE.
SCREEN SIZE.

DEPTH	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
55'					Well Depth.	
60'					End of drilling.	
					Protective cover concreted in place. Master Lock key no. 3447.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V. STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED
Trace 0 - 10%
Little 10 - 20%
Some 20 - 35%
And 35 - 50%

CAPE COD TEST BORING   BORING NO

Table B-9. W·ll Log for MW10-D

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract No. PX 1730-0-0295	BORING NO OW 1D -MW10D SHEET 1 OF 3

DRILLER: Thomas Desmond
HELPER: David Pimenta
INSPECTOR: John Portnov, Mary O'Reilly, Dan Urish

BORING LOCATION: Provincetown Landfill
GROUND SURFACE ELEVATION
DATE START: 11/26/90 DATE END: 11/27/90

SAMPLER: SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE: 3 3/4" ID
CASING SIZE: 2"
SCREEN SIZE: 2"x5" .010

(ft)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
0	1	18/12	0 - 18"	1/1/2	2" top soil. Fine/medium sand.	
5'	2	18/13	5'-6'6"	1/2/2	Fine/medium brown sand.	bentonite
10'	3	18/15	10'-11'6"	1/1/1	Fine/medium sand.	
15'	4	18/14	15'-16'6"	1/1/2	Fine/medium sand.	bentonite
20'	5	18/4	20'-21'6"	2/2/2	Fine/medium sand.	approx. water level
25'	6	18/12	25'-26'6"	3/7/12	Fine/medium sand.	
30'	7	18/12	30'-31'6"	6/10/11	Fine/medium/coarse sand.	
35'	8	18/18	35'-35'6"	18/50/80	Fine/medium/coarse sand. Gravel/some very coarse sand. Trace silty material.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V. STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED
- Trace 0 - 10%
- Little 10 - 20%
- Some 20 - 35%
- And 35 - 50%

CAPE COD TEST BORING — BORING NO OW 1D

Table B-9 (continued). Well Log for MW10-D

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT	BORING NO Ch 1D - MW10D SHEET 2 OF 3

DRILLER
HELPER
INSPECTOR

BORING LOCATION
GROUND SURFACE ELEVATION
DATE START DATE END

SAMPLER: SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE
CASING SIZE
SCREEN SIZE

(FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
40'	9	18/12	40'-41'6"	15/37/60	Same.	
45'	10	18/0	45'-46'6"	30/75/90	No Recovery.	
50'	11	18/0-2	50'-51'6"	21/87/98	No recovery, first try. Washed auger. Resampled, 2" recovery. fine/medium sand.	
55'	12	18/0	55'-56'6"	40/105/185	No recovery.	
60'	13	18/0	60'-61'6"	30/76/115	No recovery.	
62'	14	18/9	62'-63'6"	130	Fine/medium sand.	
67'	15	18/0	67'-68'6"	100	No recovery.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V LOOSE	<2	V SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M STIFF
30-50	DENSE	8 - 15	STIFF
>50	V DENSE	15 - 30	V. STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- SAND PACK
- SOIL BACKFILL
- BENTONITE
- SCREEN
- APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING — BORING NO Ch 1D

Table B-9 (continued). Well Log for MW10-D

Cape Cod Test Boring
5 Rayber Road, Orleans MA 02653
(508) 240-1000
div Desmond Well Drilling, Inc.

PROJECT

BORING NO OW ID -MW10D
SHEET 3 OF 3

DRILLER
HELPER
INSPECTOR

BORING LOCATION
GROUND SURFACE ELEVATION
DATE START DATE END

SAMPLER: SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE
CASING SIZE
SCREEN SIZE

Depth	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
77'	16	18'15	77'-78'6"	50	Fine/medium sand. Little Grey color.	
92'					Fine/medium sand. Grey color, sample off auger.	
107'					End of drilling.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING

BORING NO OW ID

Table B-10. Well Log for MW11-S

Cape Cod Test Boring 5 Rayber Road, Orleans MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract No. PX 1730-0-0295	BORING NO Ch 2 S - MW11S SHEET 1 OF 1

DRILLER Thomas Desmond
HELPER David Pimenta
INSPECTOR John Portnov, Mary O'Reilly, Dan Urish

BORING LOCATION Route 6 & Race Point, Provincetown
GROUND SURFACE ELEVATION
DATE START 11/29/90 DATE END 11/29/90

SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE 3 3/4" ID
CASING SIZE 2"
SCREEN SIZE 2"x5' .010

D (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
					No samples taken.	
8'					Static.	▼
17'					Well depth.	screen
22'					End of drilling.	
					Protective cover 4"x5' concreted in place. Master lock key no. 3447.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V LOOSE	<2	V SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY

- ■ - CEMENT
- ▨ - BENTONITE
- □ - SAND PACK
- ≢ - SCREEN
- □ - SOIL BACKFILL
- ▼ - APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING — BORING NO Ch 2 S

Table B-11. Well Log for MW11-I

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract NO. PX 1730-0-0295	BORING NO OW 11 -MW11I SHEET 1 OF 1

DRILLER Thomas Desmond
HELPER David PImenta
INSPECTOR John Portnov, Mary O;Reilly, Dan Urish
BORING LOCATION Route 6 & Race Point, Provincetown
GROUND SURFACE ELEVATION
DATE START 11/28/90 DATE END 11/29/90

SAMPLER: SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE 3 3/4"
CASING SIZE 2"
SCREEN SIZE 2"x5' .01

D (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
					No samples taken.	
4'					Bentonite.	Bentonite
5'						
7'					Static.	Approx. water level
67'					Well Depth.	Screen
70'					End of drilling.	
					Protective cover concreted in place. 4"x5' Master lock key no. 3447.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V LOOSE	<2	V SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING BORING NO OW 11

Table B-12. Well Log for MW11-D

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract No. PX 1730-0-0295	BORING NO CW D - MW11D SHEET 1 OF 3

DRILLER Thomas Desmond
HELPER David Pimenta
INSPECTOR John Portnov, Mary O'Reilly, Dan Urish

BORING LOCATION Route 6 & Race Point, Provincetown
GROUND SURFACE ELEVATION
DATE START 11/28/90 DATE END 11/29/90

SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE 3 3/4" ID
CASING SIZE 2"
SCREEN SIZE 2"x5 .010

(FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
0	1	18/7	0-18"	8/4/4	Grass/ Black top. Fine sand.	
'6"	2	18/10.5"	2'6"→	2/3/4	Fine/medium sand.	
'6"	3	18/11	7'6"-9'	9/12/14	Fine/medium sand.	
12'6"	4	18/11	12'6"-14'	1/4/5	Fine/medium sand.	
'6"	5	18/11	17'6"-19'	2/2/7	Fine/medium sand.	
'6"	6	18/10	22'6"-24'	20/25/30	Washed. Fine/medium some coarse & very coarse.	
27'6"	7	18/18	27'6"-29'	9/24/50	Fine/medium/coarse sand. Trace small stone. Some very coarse sand.	
'6"	8	18/18	32'6"-34'	15/20/28	Fine/medium/coarse sand. Trace of small stone.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING — BORING NO CW D

Table B-12 (continued). Well Log for MW11-D

Cape Cod Test Boring
5 Rayber Road, Orleans, MA 02653
(508) 240-1000
div Desmond Well Drilling, Inc.

PROJECT

BORING NO OW D -MW11D
SHEET 2 OF 3

DRILLER
HELPER
INSPECTOR

BORING LOCATION
GROUND SURFACE ELEVATION
DATE START DATE END

SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE
CASING SIZE
SCREEN SIZE

(FT)	SAMPLE NO	SAMPLE PEN / REC	SAMPLE DEPTH (FT)	SAMPLE BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
37'6"	9	18/15	37'6"-39'	19/50/50+	Fine/medium/coarse sand w/trace small stone.	
2'6"	10	18/6.5"	42'6"-44'	10/13/22	Fine/medium coarse sand.	
7'6"	11	18/14	47'6"-49'	28/78/90	Fine/medium coarse sand.	
52'6"	12	18/11	52'6"-54'	53/ infinite	Fine/medium/coarse. Some very coarse sand.	
'6"	13	18/	57'6"-59'	51/85/infinite	Fine/medium sand.	
'6"					Sample grab.	
67'6"					Sample grab.	
'6"	14	18/0	72'6"-74'	22/58/75	Fine/medium grey sand (grab).	

GRANULAR SOILS BLOWS/FT	GRANULAR SOILS DENSITY	COHESIVE SOILS BLOWS/FT	COHESIVE SOILS DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY

- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING

BORING NO OW D

Table B-12 (continued). Well Log for MW11-D

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	PROJECT	BORING NO CWD -MW11D SHEET 3 OF 3

DRILLER HELPER INSPECTOR	BORING LOCATION: GROUND SURFACE ELEVATION DATE START DATE END
SAMPLER: SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"	AUGER SIZE CASING SIZE SCREEN SIZE

DEPTH (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
77'6"	15	18/6	77'6"-79'	infini.	Fine/medium sand.	
102'					End of drilling.	

GRANULAR SOILS		COHESIVE SOILS	
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY
0 - 4	V LOOSE	<2	V SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY

- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED

Trace 0 - 10%
Little 10 - 20%
Some 20 - 35%
And 35 - 50%

CAPE COD TEST BORING — BORING NO CWD

Table B-13. Well Log for MW12-S

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract NO. PX 1730-C-0295	BORING NO ___ -MW12S SHEET 1 OF 1

DRILLER Thomas Desmond	BORING LOCATION Jerome Smith Parking Lot
HELPER Robert Ford	GROUND SURFACE ELEVATION
INSPECTOR John Portnov, Mary O'Reilly	DATE START 12/17/90 DATE END 12/18/90
SAMPLER: SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"	AUGER SIZE 3 3/4" ID CASING SIZE 2" SCREEN SIZE 2"x15' .0

DEPTH (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
					No samples taken.	
7'					Bentonite	bentonite
9'					Static	▼
22'					Well depth	screen
					Protective cover concreted in place.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V LOOSE	<2	V SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY: ■ - CEMENT; ▨ - BENTONITE; □ - SAND PACK; ⩸ - SCREEN; □ - SOIL BACKFILL; ▼ - APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING — BORING NO MW12S

Table B-14. Well Log for MW12-I

Cape Cod Test Boring 5 Rayber Road Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract No. PX 1730-0-0295	BORING NO MW 3I - MW12 I SHEET 1 OF 1

DRILLER Thomas Desmond
HELPER Robert Ford
INSPECTOR John Portnov, Mary O'Reilly

BORING LOCATION Jerome Smith Parking Lot
GROUND SURFACE ELEVATION
DATE START 12/17/90 DATE END 12/18/90

SAMPLER: SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE: 3 3/4" ID
CASING SIZE: 2"
SCREEN SIZE: 2'x5' .010

Depth (ft)	Sample NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
					No samples taken.	
5'					Bentonite	Bentonite
7'						
9'					Static	▼
					Well depth.	Screen
					Protective cover concreted in place. 4"x5'	

GRANULAR SOILS		COHESIVE SOILS	
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V. STIFF
		>30	HARD

WELL INSTALLATION KEY

- ■ - CEMENT
- ▨ - BENTONITE
- □ - SAND PACK
- ⌗ - SCREEN
- □ - SOIL BACKFILL
- ▼ - APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING — BORING NO MW 3 I

Table B-15. Well Log for MW12-D

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract No. PX 1730-0-0295	BORING NO W 3 D -MW12D SHEET 1 OF 2

DRILLER Thomas Desmond
HELPER Robert Ford
INSPECTOR John Portnov, Mary O'Reilly
BORING LOCATION Jerome Smith Parking Lot
GROUND SURFACE ELEVATION
DATE START 12/17/90 DATE END 12/18/90

SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE 3 3/4" ID
CASING SIZE 2"
SCREEN SIZE 2"x5'.010

(ft)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION
0					Sandy fill.
5'					
7'					
9'	1	18	9'-10'6"	3/3/4	Fine/medium/coarse w/trace of small stone.
19'	2	18	19'-20'6"	8/3/6	Fine/ Medium/coarse sand, trace small stone.
29'	3	18	29'-30'6"	6/15/25	Washed (Orleans Town Water). Fine/medium/coarse sand, trace small stone possible wash.
34'	4	18/14	34'-35'6"	5/14/28	Fine/medium/trace coarse sand & small stone.

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V LOOSE	<2	V SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	5 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- SAND PACK
- SOIL BACKFILL
- BENTONITE
- SCREEN
- APPROX. WATER LEVEL

PROPORTIONS USED
Trace 0 - 10%
Little 10 - 20%
Some 20 - 35%
And 35 - 50%

CAPE COD TEST BORING

BORING NO W 3 D

Table B-15 (continued). Well Log for MW12-D

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT	BORING NO 4 3D -MW12D SHEET 2 OF 2

DRILLER
HELPER
INSPECTOR

BORING LOCATION
GROUND SURFACE ELEVATION
DATE START DATE END

SAMPLER: SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE
CASING SIZE
SCREEN SIZE

DEPTH (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
44'	5	18/10	44'-45'6"	14/25/43	Fine/medium/coarse sand, trace gravel 1/2" some very coarse sand.	
4'	6	18/0	54'-55'6"	45/20/30	Trace fine/medium sand in shoe of spoon.	
59'	7	18/16	59'-60'6"	6/20/22	Fine/medium sand.	
9'	8	18			No sample. Very fine/fine/medium sand, grey color to 110', sample off augers.	
12'					Well depth.	

GRANULAR SOILS		COHESIVE SOILS	
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING BORING NO 4 3D

Table B-16. Well Log for MW13-S

Cape Cod Test Boring 5 Rayber Road, Orleans MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract No. PX 1730-0-0295	BORING NO 4W 4S -MW13S SHEET 1 OF 1

DRILLER Thomas Desmond
HELPER Robert Ford
INSPECTOR John Portnov, Dan Ursih

BORING LOCATION End of Standish Ave., Provincetown
GROUND SURFACE ELEVATION
DATE START 1/9/91/ DATE END 1/9/91

SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE 3 3/4" I
CASING SIZE 2"
SCREEN SIZE 2"x10' .(

D (ft)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
					No samples taken.	
4'					Bentonite	Bentonite
5'						
10'					Bentonite	Bentonite
12'						
17'					Static.	Approx. water level
25'					Well Depth.	Screen
28'					End of drilling.	
					Protective cover concreted in place.	

GRANULAR SOILS		COHESIVE SOILS	
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY
- ■ - CEMENT
- ▨ - BENTONITE
- □ - SAND PACK
- ⩩ - SCREEN
- □ - SOIL BACKFILL
- ▼ - APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING

BORING NO 4W 4S

Table B-17. Well Log for MW13-I

Cape Cod Test Boring Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract No.PX 1730-0-0295	BORING NO MW-I -MW13I SHEET 1 OF 2

DRILLER Thomas Desmond
HELPER Robert Ford
INSPECTOR John Portnov, Dan Urish
BORING LOCATION End of Standish Ave. Entr. to Cemetary
GROUND SURFACE ELEVATION
DATE START 1/7/91 DATE END 1/9/91

SAMPLER: SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE 3 3/4" ID
CASING SIZE 2"
SCREEN SIZE 2"x10' .010

DEPTH (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
			0-29'		Fine/medium some coarse sand. No split spoon samples until 29'0".	
29'	1	24/24	29'-31'	15 total	Washed out augers. Sand, fine/medium/coarse Trace of wood, possible trace shells.	
34'	2	18/7	34'-35'6"		Washed out augers. Fine/medium/coarse sand.	

GRANULAR SOILS		COHESIVE SOILS	
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED
- Trace 0 - 10%
- Little 10 - 20%
- Some 20 - 35%
- And 35 - 50%

CAPE COD TEST BORING — BORING NO MW-I

Table B-17 (continued). Well Log for MW13-I

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT	BORING NO MW I -MW13 I SHEET 2 OF 2

DRILLER
HELPER
INSPECTOR

BORING LOCATION
GROUND SURFACE ELEVATION
DATE START DATE END

SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB. HAMMER FALLING 30"

AUGER SIZE.
CASING SIZE.
SCREEN SIZE

DEPTH (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
44'	3	12/22	44'-45'	25/50	Some sand in auger. Fine/medium/coarse sand.	
54'	4	12/0 12/9	54'-55'	25/50+	Washed 5' sand out of augers. 2' still left in auger. First sample, no recovery. Second sample, 9" recovery, fine medium sand one 3/4" stone.	
64'	5	12/13	64'-65'	25/50+	Fine/medium sand.	
74'	6	12/23	74'-75'	20/58	Fine/medium sand.	
80'					End of drilling.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY

- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING BORING NO MW I

Table B-18. Well Log for MW13-D

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract No. PX 1730-0-0295	BORING NO MW 4D -MW13D SHEET 1 OF 2

DRILLER Thomas Desmond
HELPER Robert Ford
INSPECTOR John Portnov, Dan Urish

BORING LOCATION End of Standish Ave. Entr. to Cemetary
GROUND SURFACE ELEVATION
DATE START 1/8/91 DATE END 1/8/91

SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE. 3 3/4" ID
CASING SIZE. 2"
SCREEN SIZE 2"x10' .0

(FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
					Drilled with plate to 84'.	
84'	1	18/0	84'-85'6"		Fine/medium/grey sand.	
95'					Grab sample. Same.	
105'					Grab sample. Same.	
115'					Grab sample. Same.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V LOOSE	<2	V SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED
Trace 0 - 10%
Little 10 - 20%
Some 20 - 35%
And 35 - 50%

CAPE COD TEST BORING — BORING NO MW 4D

Table B-18 (continued). Well Log for MW13-D

Cape Cod Test Boring 6 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	PROJECT	BORING NO MW13D SHEET OF

DRILLER HELPER INSPECTOR	BORING LOCATION GROUND SURFACE ELEVATION DATE START DATE END

SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB. HAMMER FALLING 30"	AUGER SIZE. CASING SIZE SCREEN SIZE

DEPTH (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
120'					Grab sample. Same.	(screen)
123'					Grab sample. Same. End of drilling.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V. STIFF
		>30	HARD

WELL INSTALLATION KEY

- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING BORING NO MW-4D

Table B-19. Well Log for MW14-S

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract No. PX 1730-0-0295	BORING NO MW 5S -MW14S SHEET 1 OF 1

DRILLER Thomas Desmond
HELPER Robert Ford
INSPECTOR John Portnov
BORING LOCATION Johnson St. Parking Lot. Provincetown
GROUND SURFACE ELEVATION
DATE START 1.9.91 DATE END 1/9/91

SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB. HAMMER FALLING 30"

AUGER SIZE 3 3/4" ID
CASING SIZE 2"
SCREEN SIZE 2"x10' .010

D (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
7'						▼
13'	1	18/24	13'-14'6"	6/11/12	Fine/medium coarse, some very coarse sand.	
						screen
17' 18'	2	18/15	18'-19'6"	4/8/12	Fine/medium coarse sand, some very coarse sand.. End of drilling.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V LOOSE	<2	V SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- ▼ - APPROX. WATER LEVEL

PROPORTIONS USED
Trace 0 - 10%
Little 10 - 20%
Some 20 - 35%
And 35 - 50%

CAPE COD TEST BORING BORING NO MW 5S

Table B-20. Well Log for MW14-D

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Contract No. PX 1730-0-0295	BORING NO MW 5D - MW14D SHEET 1 OF 2

DRILLER Thomas Desmond
HELPER Robert Ford
INSPECTOR Dan Urish

BORING LOCATION Johnson St. Parking Lot Provincetown
GROUND SURFACE ELEVATION
DATE START 1/10/91 DATE END 1/10/91

SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"

AUGER SIZE 3 3/4" ID
CASING SIZE 2"
SCREEN SIZE 2" 5' .010

DEPTH (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
					Washed augers.	
23'	3				Started sampling at 23'. Washed sample. Fine/medium/coarse sand.	
28'	4	18/15	28'-29'6"	13/22/37	Fine/medium.coarse brown sand. Small gravel.	
38'	5	18/6	38'-39'6"	16/38/50+	Fine/medium coarse sand, some small gravel. 1- 1 /2" gravel end of spoon, brown sand.	
48'	6	12/20	48'-49'	24/76	Fine/medium/coarse sand, some very coarse brown sand.	
58'	7	12/18	58'-59'	12/67	Fine/medium/trace coarse& small stone. Green	

GRANULAR SOILS		COHESIVE SOILS	
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V DENSE	15 - 30	V. STIFF
		>30	HARD

WELL INSTALLATION KEY
- CEMENT
- BENTONITE
- SAND PACK
- SCREEN
- SOIL BACKFILL
- APPROX. WATER LEVEL

PROPORTIONS USED
- Trace 0 - 10%
- Little 10 - 20%
- Some 20 - 35%
- And 35 - 50%

CAPE COD TEST BORING BORING NO MW 5D

Table B-20 (continued). Well Log for MW14-D

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div Desmond Well Drilling, Inc.	PROJECT	BORING NO WD-MW14D SHEET 2 OF 2
DRILLER HELPER INSPECTOR	BORING LOCATION GROUND SURFACE ELEVATION DATE START DATE END	
SAMPLER SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 LB HAMMER FALLING 30"		AUGER SIZE CASING SIZE SCREEN SIZE

DEPTH (FT)	SAMPLE NO	PEN / REC	DEPTH (FT)	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
68'	8				Fine/medium sand off auger.	
78'	9				FIne/medium sand off auger.	screen
85'	10				Grab sample, fine/medium brown sand.	
88'	11				Grab sample, fine/medium brown sand. End of drilling.	

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY

- CEMENT
- SAND PACK
- SOIL BACKFILL
- BENTONITE
- SCREEN
- APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING BORING NO WD

Table B-21. Well Log for MW15-D

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	PROJECT Cape Cod National Seashore Provincetown, MA Race Point/Conwell St. Area	BORING NO mw 5 SHEET 1 OF 1

DRILLER: Thomas Desmond HELPER: Paul Young INSPECTOR: Dan Urish Mary O'Reilly	BORING LOCATION: Route 6 Median Strip GROUND SURFACE ELEVATION: DATE START: 1/10/92 DATE END: 1/10/92

SAMPLER: SAMPLER CONSISTS OF A TWO INCH SPLIT SPOON DRIVEN USING A 140 LB. HAMMER FALLING THIRTY INCHES.	NOTES No Split Spoon Soil Samples Taken, Grabs Only.	AUGER SIZE: 3.75" ID HSA CASING SIZE: 2" Sch40 PVC SCREEN SIZE: 2"x20'x.010 fjt

DEPTH (FT)	SAMPLE NO.	PEN / REC	DEPTH / FT	BLOWS 6"	SAMPLE DESCRIPTION	WELL INSTALLATION
0			3'-5'		Protective Cover Concrete Bentonite	Cement, Bentonite
						Z
50					Fine Medium Coarse/Grabs (0-50)	Z
60			50-60		Fine Medium Coarse/Very Coarse	Z
90'						20' screen
110			60-110		Fine Medium Coarse Greyer in color	
115					End of Drilling.	

GRANULAR SOILS		COHESIVE SOILS	
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V. SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M DENSE	4 - 8	M. STIFF
30-50	DENSE	8 - 15	STIFF
>50	V. DENSE	15 - 30	V STIFF
		>30	HARD

WELL INSTALLATION KEY

■ - CEMENT
▨ - BENTONITE
SAND PACK
≡ - SCREEN
Z - SOIL BACKFILL
▼ - APPROX. WATER LEVEL

PROPORTIONS USED

Trace	0 - 10%
Little	10 - 20%
Some	20 - 35%
And	35 - 50%

CAPE COD TEST BORING

BORING NO. mw5

APPENDIX C

SOIL TEST RESULTS

Table C-1. Soil Test Results for MW15

Sample Number: MW15 (composite sample)

Sample Section: Diameter- 3.5 cm
Area of Section- 9.62 cm^2
Length- 11.55 cm
Volume (total)- 111.11 cm^3
Dry Weight- 190 gms
Volume (solids)- 71.70 cm^3
Volume (voids)- 39.41 cm^3
Porosity- 0.355

Water Reservoir: Diameter- 3.5 cm
Area of Section- 9.62 cm^2
Temperature- 27°C

Run 1:

Ho- 5.6 cm	Ho- 5.6 cm	Ho- 5.6 cm
H1- 3.5 cm	H1- 2.1 cm	H1- 1.0 cm
Time- 60 sec	Time- 110 sec	Time- 180 sec
K(lab)- 256 ft/day	K(lab)- 291 ft/day	K(lab)- 313 ft/day

Run 2:

Ho- 6.6 cm	Ho- 6.6 cm	Ho-
H1- 3.1 cm	H1- 1.7 cm	H1-
Time- 100 sec	Time- 150 sec	Time-
K(lab)- 247 ft/day	K(lab)- 296 ft/day	K(lab)-

Average K(lab)- 281 ft/day
Porosity- 0.355

Temperature Adjustment: Temperature (lab)- 27°C
Temperature (field)- 11.5°C
Viscosity (lab)- 0.88
Viscosity (field)- 1.28

K (field): 193.2 ft/day

Table C-2. Soil Test Results for MW14I

Sample Number: MW14 (23-24.5')

Sample Section: Diameter- 3.5 cm
Area of Section- 9.62 cm^2
Length- 10.20 cm
Volume (total)- 98.12 cm^3
Dry Weight- 160.94 gms
Volume (solids)- 60.73 cm^3
Volume (voids)- 37.39 cm^3
Porosity- 0.38

Water Reservoir: Diameter-
Area of Section-
Temperature-

Run 1:

Ho-	Ho-	Ho-
H1-	H1-	H1-
Time-	Time-	Time-
K(lab)-	K(lab)-	K(lab)-

Run 2:

Ho-	Ho-	Ho-
H1-	H1-	H1-
Time-	Time-	Time-
K(lab)-	K(lab)-	K(lab)-

Average K(lab)-
Porosity- 0.38

Temperature Adjustment: Temperature (lab)-
Temperature (field)-
Viscosity (lab)-
Viscosity (field)-

K (field):

Table C-3. Soil Test Results for MW14S

Sample Number: MW14 (13-14.5')

Sample Section: Diameter- 3.5 cm
Area of Section- 9.62 cm^2
Length- 10.70 cm
Volume (total)- 102.93 cm^3
Dry Weight- 176.92 gms
Volume (solids)- 66.76 cm^3
Volume (voids)- 36.17 cm^3
Porosity- 0.35

Water Reservoir: Diameter-
Area of Section-
Temperature-

Run 1:

Ho-	Ho-	Ho-
H1-	H1-	H1-
Time-	Time-	Time-
K(lab)-	K(lab)-	K(lab)-

Run 2:

Ho-	Ho-	Ho-
H1-	H1-	H1-
Time-	Time-	Time-
K(lab)-	K(lab)-	K(lab)-

Average K(lab)-
Porosity- 0.35

Temperature Adjustment: Temperature (lab)-
Temperature (field)-
Viscosity (lab)-
Viscosity (field)-

K (field):

Table C-4. Sieve Analysis for MW15

Project Provincetown Landfill Job No. ____

Location of Project Provincetown, MA Boring No. ____ Sample No. MW1

Description of Soil Medium sand Depth of Sample ____

Tested By M.J. O. Date of Testing Sept. 92

Soil Sample Size (ASTM D1140-54)

Nominal diameter of largest particle	Approximate minimum mass of sample, g
No. 10 sieve	200
No. 4 sieve	500
3/4 in.	1500

Mass of dry sample + dish	1507.6 gm
Mass of dish	167.4 gm
Mass of dry sample, M_s	1340.2 gm

Sieve analysis and grain shape

Sieve no.	Diam. (mm)	Mass retained	% retained	% passing
4	4.75	15.6	1.17	98.83
10		29.5	2.21	96.62
20	0.840	149.8	11.20	85.42
30	0.600	429.0	32.08	53.34
50	0.300	666.0	49.81	3.53
60	0.250	23.0	1.72	1.81
100	0.150	18.2	1.36	0.45
200	0.075	4.2	0.31	0.14
Bottom		1.8	0.14	0
Total		1337.1	100.0	

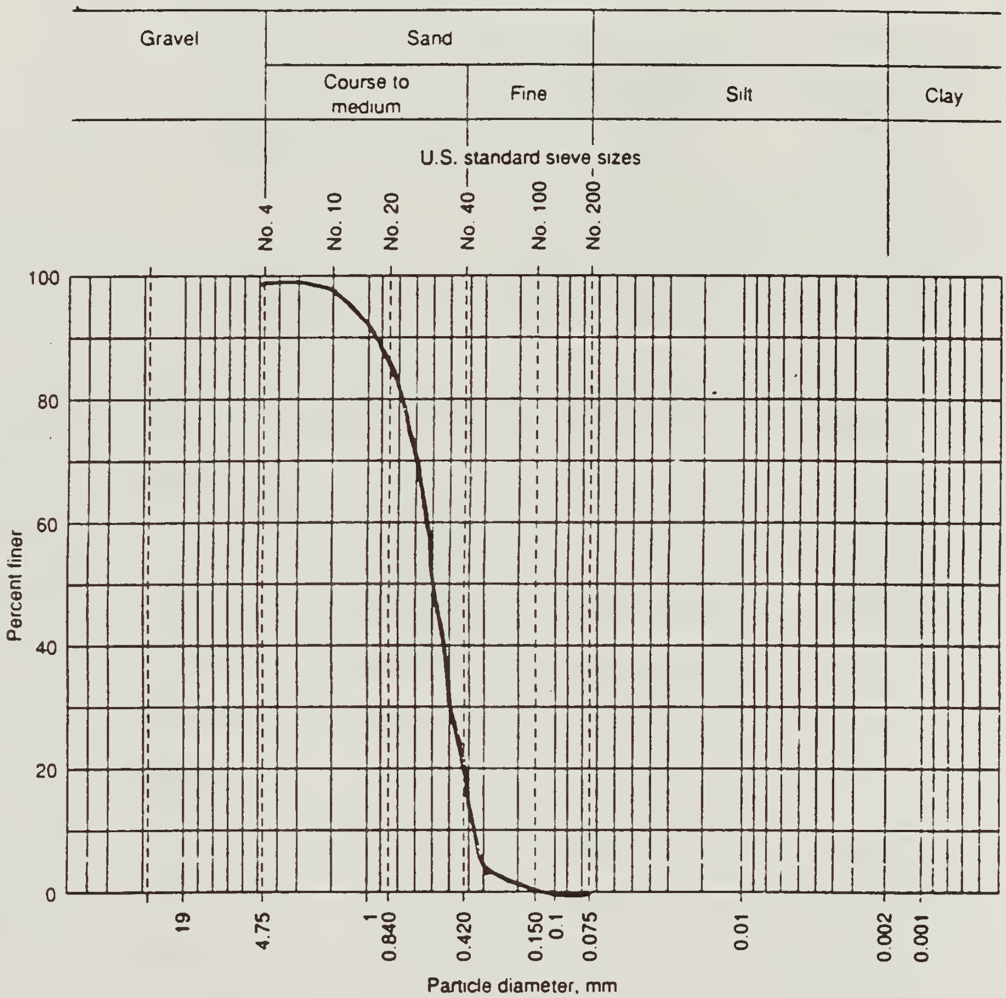
% passing = 100 − Σ % retained.

loss during sieve analysis = 0.23%

Project Provincetown Landfill Job No.

Location of Project Provincetown, MA Boring No. Sample No. MW15D

Tested By Mary J. O'Reilly Date of Testing Septembe- 1992



Visual soil description medium sand

Soil classification

System

Fig. C-1. Grain size distribution curve for MW15.

Table C-5. Grain Size Analysis for MW15

From grain size distribution curve

Percent Finer	Particle diameter (cm)
10	0.39
30	0.50
50	0.58
60	0.67

Uniformity Coefficient - Cu: %60/%10 = 1.72

Coefficient of Gradation - Cc: $(\%30)^2/(\%60 \times \%10) = 0.96$

Estimate of Hydraulic Conductivity - K: $(\%10)^2$ = 430.9 ft/day

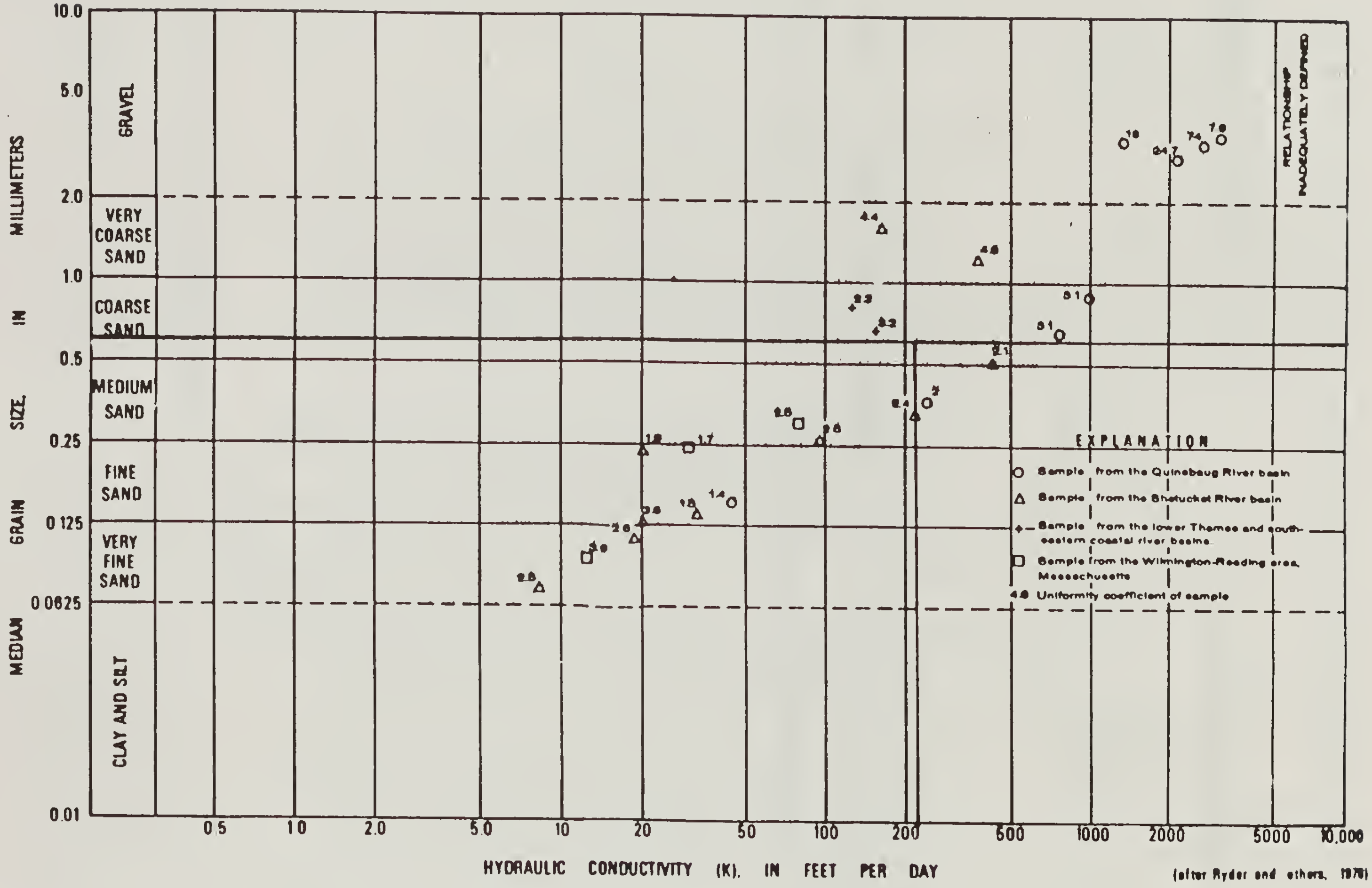


Fig. C-2. Hydraulic conductivity as a function of grain size (Mazzaferro,et. al, 1979).

APPENDIX D

WATER TABLE DATA AND MAPS

Table D-1. Provincetown Water Table Measurements

WATER TABLE ELEVATION (feet)

STATION	SAMPLING DATES					
	09/12/90	10/13/90	04/07/91	06/08/91	02/25/92	09/20/92
MW1	3.83	3.7	4.75	4.45	4.79	3.97
MW2	6.01	3.76	4.86	4.56	4.9	4.05
MW3						
MW4	2.99	3.89	5.01	4.69	6.46	
MW5	3.96	3.84	4.97	4.48	4.94	4.12
MW6	4.01	3.87	5.06	4.77	5.08	
MW7	3.92	3.94	5.16		5.29	
MW8	4.09	3.95	5.15	4.85	5.37	4.2
MW9	3.79	3.79	4.96	4.57	6.4	
MW10-S			5.35	5.04	5.48	4.47
MW10-I			4.69	5.04	5.48	
MW10-D			5.34	5.03	5.75	4.47
MW11-S			5.03	4.87	5.24	4.35
MW11-I			4.57	4.36	4.66	
MW11-D			4.55	4.33	4.66	3.94
MW12-S			4.57	4.3	4.64	3.88
MW12-I			4.67	4.38	4.61	
MW12-D			4.6	4.3	4.63	3.83
MW13-S			3.75	3.62	3.76	3.21
MW13-I			3.43	3.37	3.74	3.11
MW13-D			3.53	3.37	3.86	3.04
MW14-S			2.81		3.69	2.34
MW14-I			2.65		4.86	2
MW14-D			3.03		5.14	1.76
MW15-D						3.86
S1			4.67	4.38		3.76
S2						
S3						
P4		3.97	5.07	4.79		4.31
S5		3.75	5.11			
S6			5.55			
S6B	4.51	4.34		5.33		4.55
P6-in						4.34
P6-out						4.29

Table D-1 (continued). Water Table Measurements

WATER TABLE ELEVATION (feet)

STATION	SAMPLING DATES					
	09/12/90	10/13/90	04/07/91	06/08/91	02/25/92	09/20/92
S7			4.91	4.64		4.48
S7A		3.06	4.01	3.77		
S8A		4.83	6.11	5.8		
P8	4.15	3.98				
S9						
S9B	5.1	4.95	5.53	5.26		4.58
P10	4.5	4.24	5.48	5.2		4.64
S11		2.59				
S12			4.47	4.16		
S12B-in	4.56	4.42		4.81		3.88
S12B-out						3.88
S12C-in						
S12C-out						
P13	3.05					3.71
P14	2.8			4.72		4.11
P15	3.56		4.78	4.51		3.93
P16	3.71	3.63	4.63	4.29		
S16B-in	3.8	3.75	4.75	4.47		4.33
S16B-out		3.7	4.79	5.06		3.15
S16C-in		3.7	4.75	4.46		3.97
S16C-out			4.79	4.59		3.98
P17						
P18	3.69	3.63	4.56	4.27		3.83
P19	3.64	3.71	4.71	4.41		3.8
P20	3.97	3.8	4.89	4.64		
P21	3.85	3.74	4.76	4.53		
Oak-in						3.59
Oak-out						3.59
Court-in						3.4
Court-out						3.4
Skank						3.45

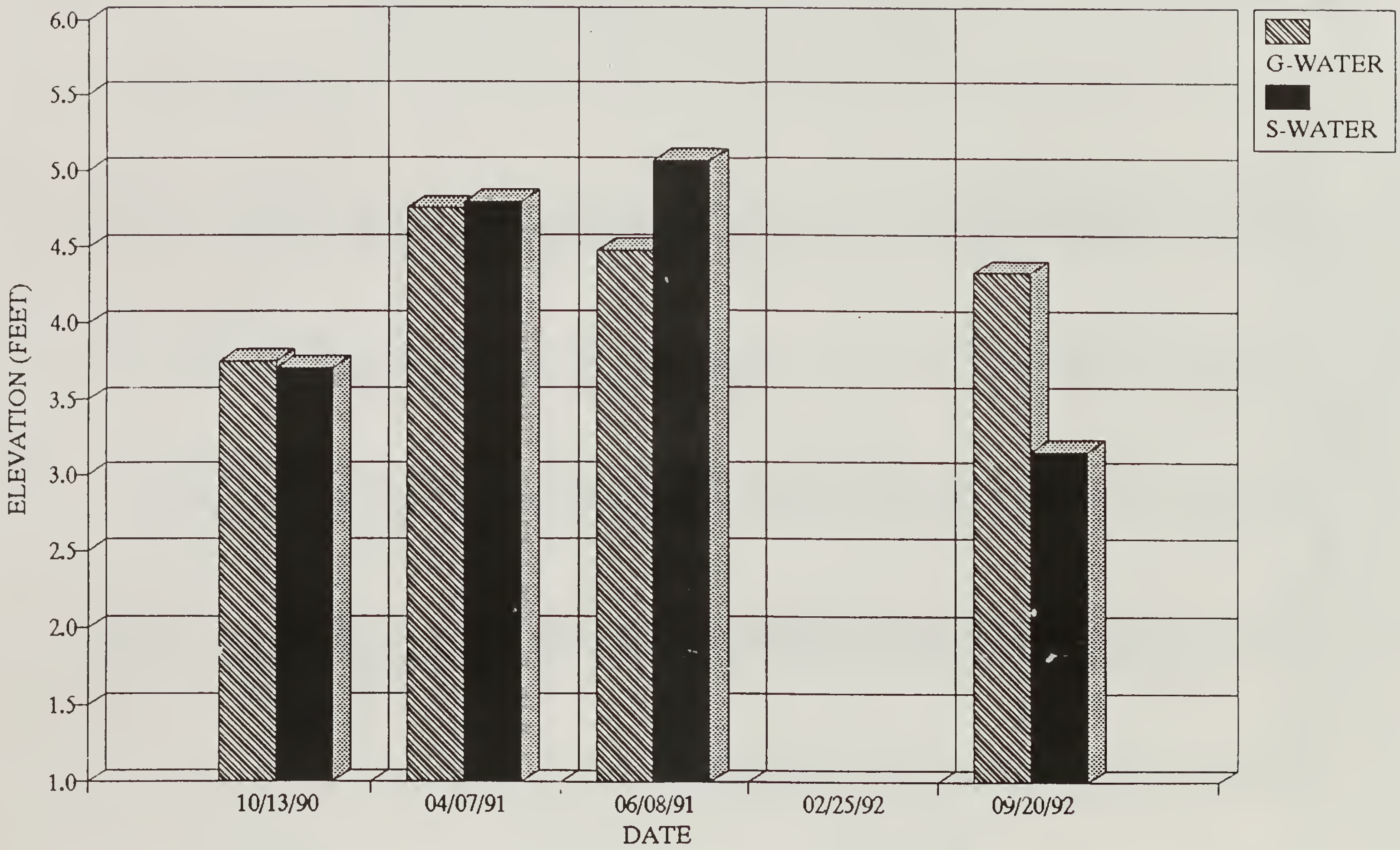


Fig. D-1. Water table elevations for Duck Pond, Provincetown, MA.

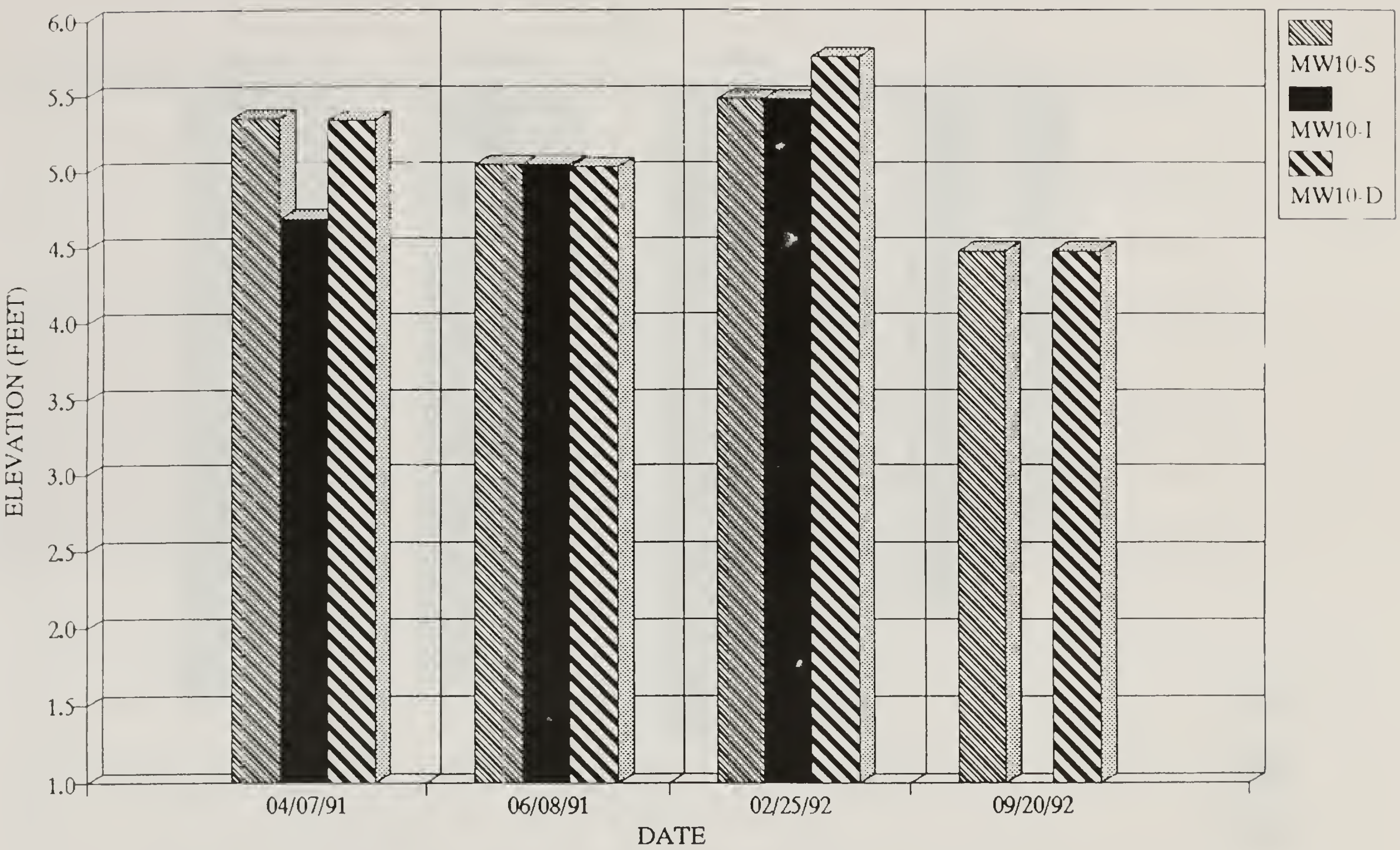


Fig. D-2. Water table elevations for MW10, Provincetown, MA.

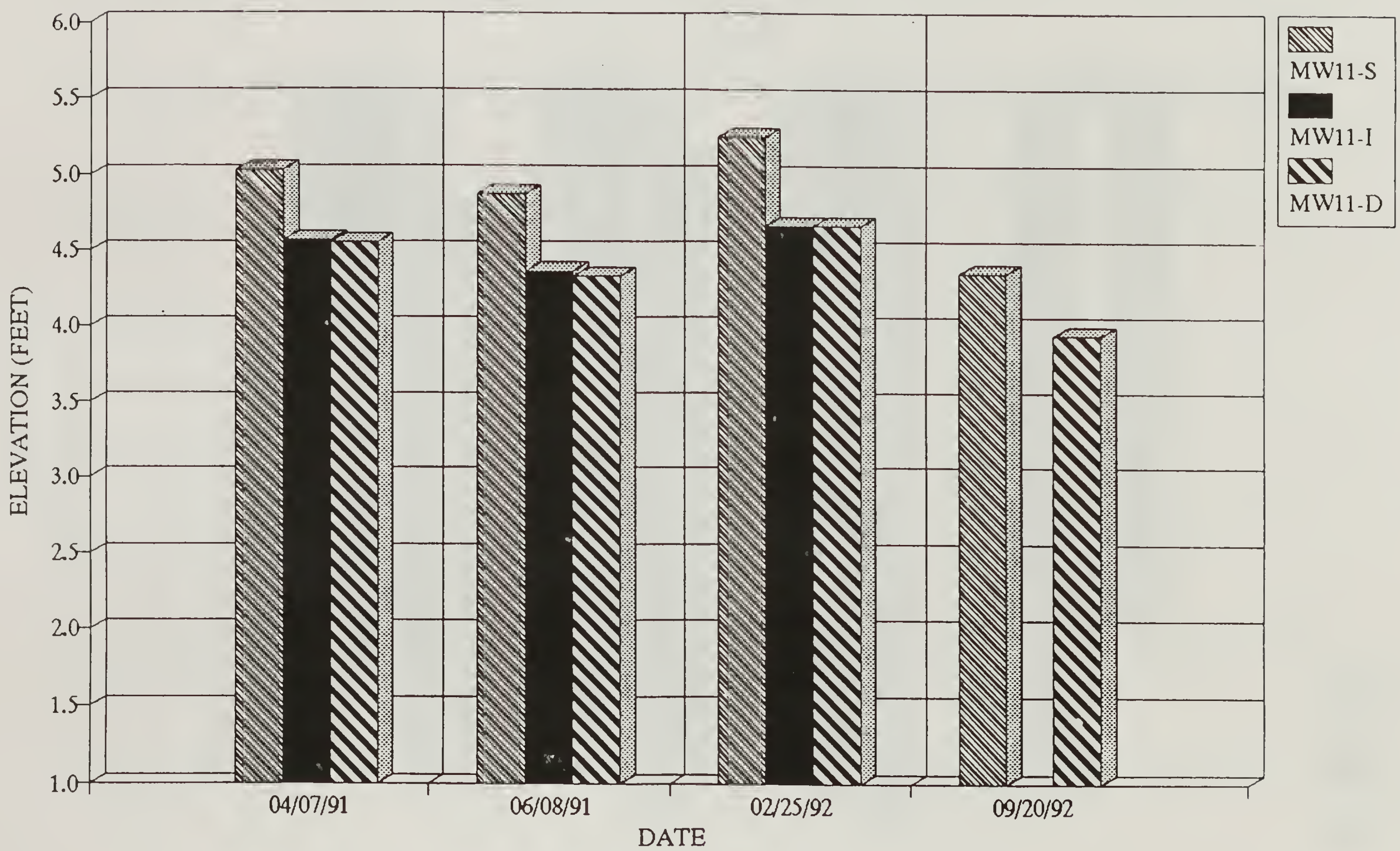


Fig. D-3. Water table elevations for MW11, Provincetown, MA.

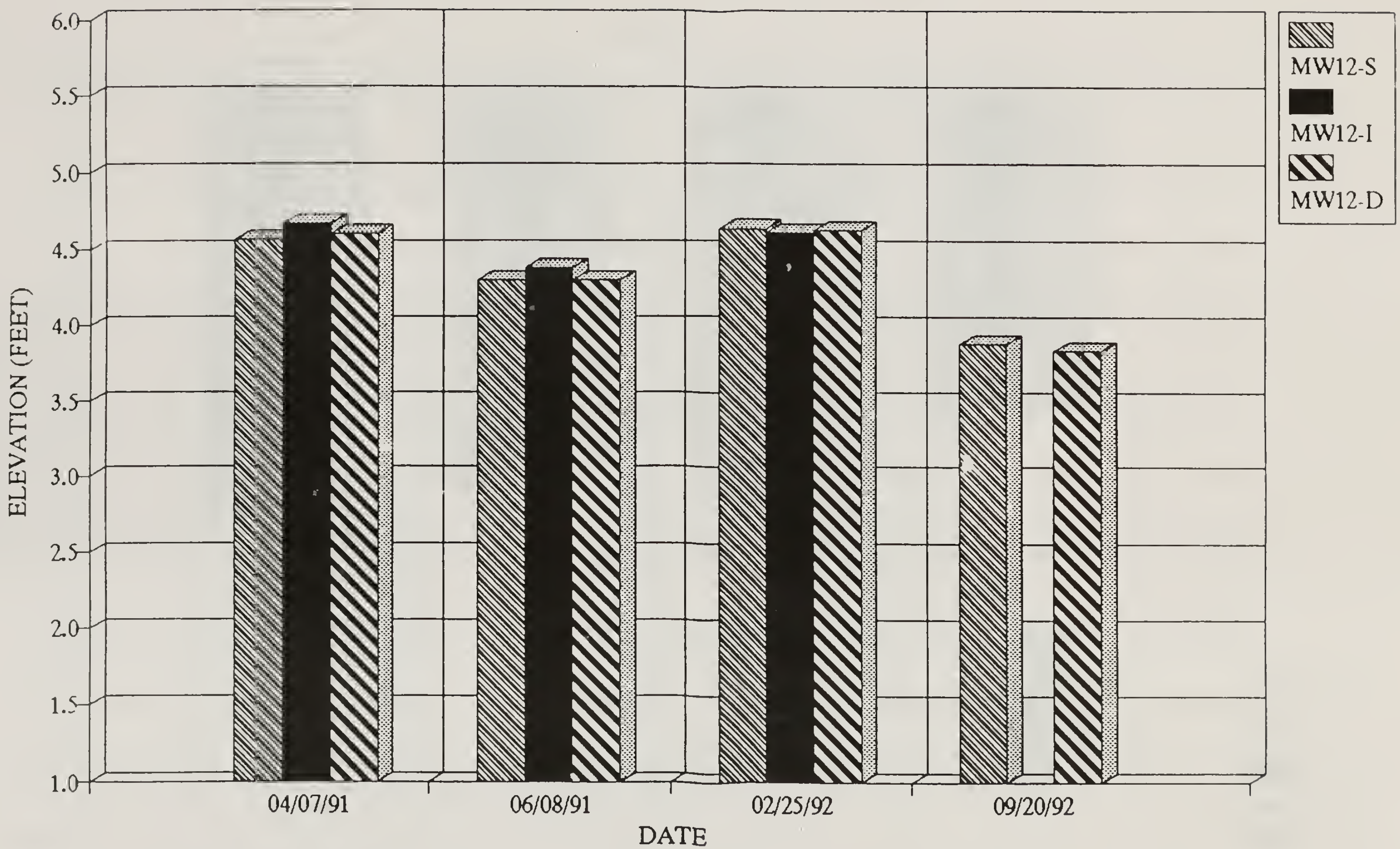


Fig. D-4. Water table elevations for MW12, Provincetown, MA.

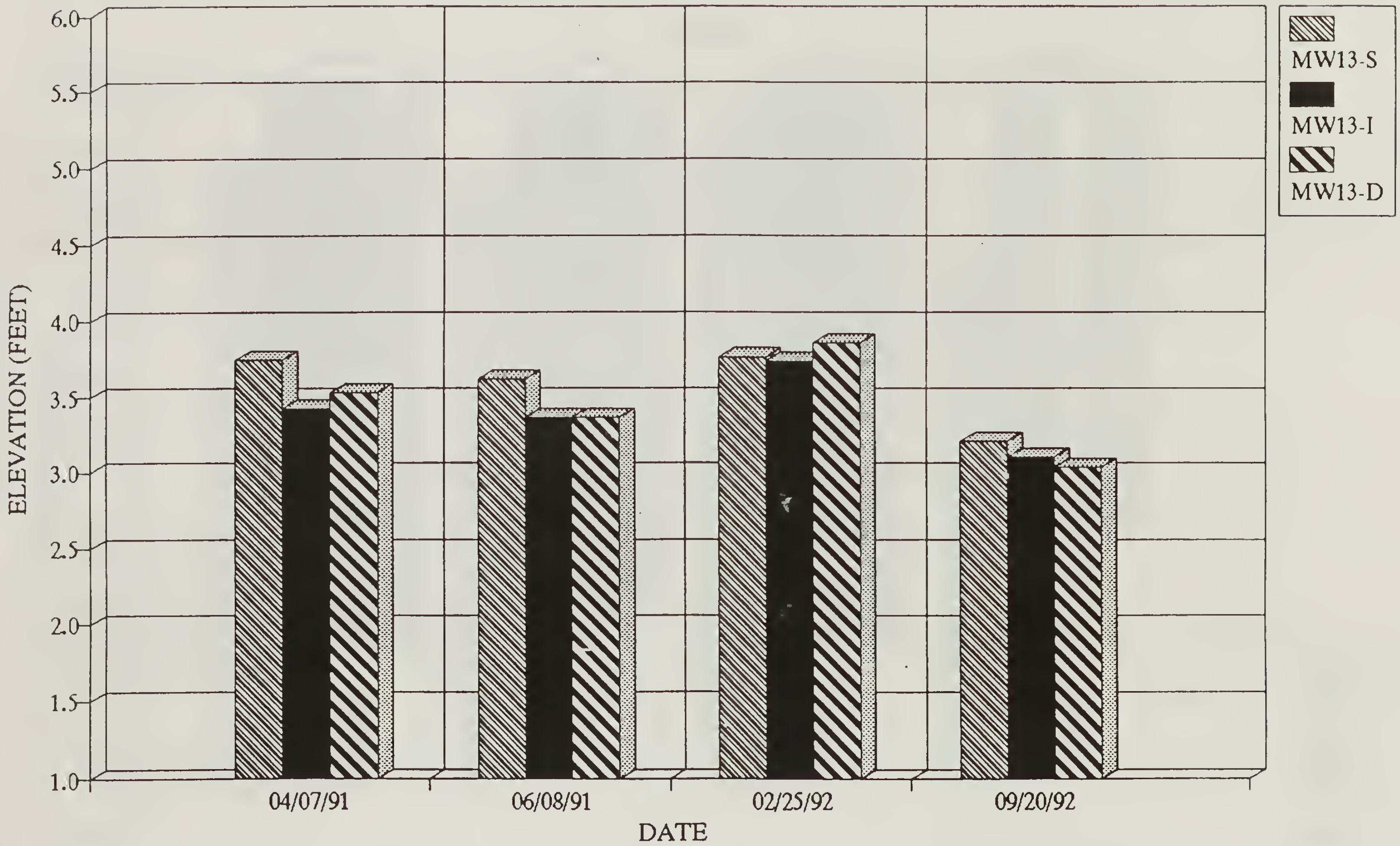


Fig. D-5. Water table elevations for MW13, Provincetown, MA.

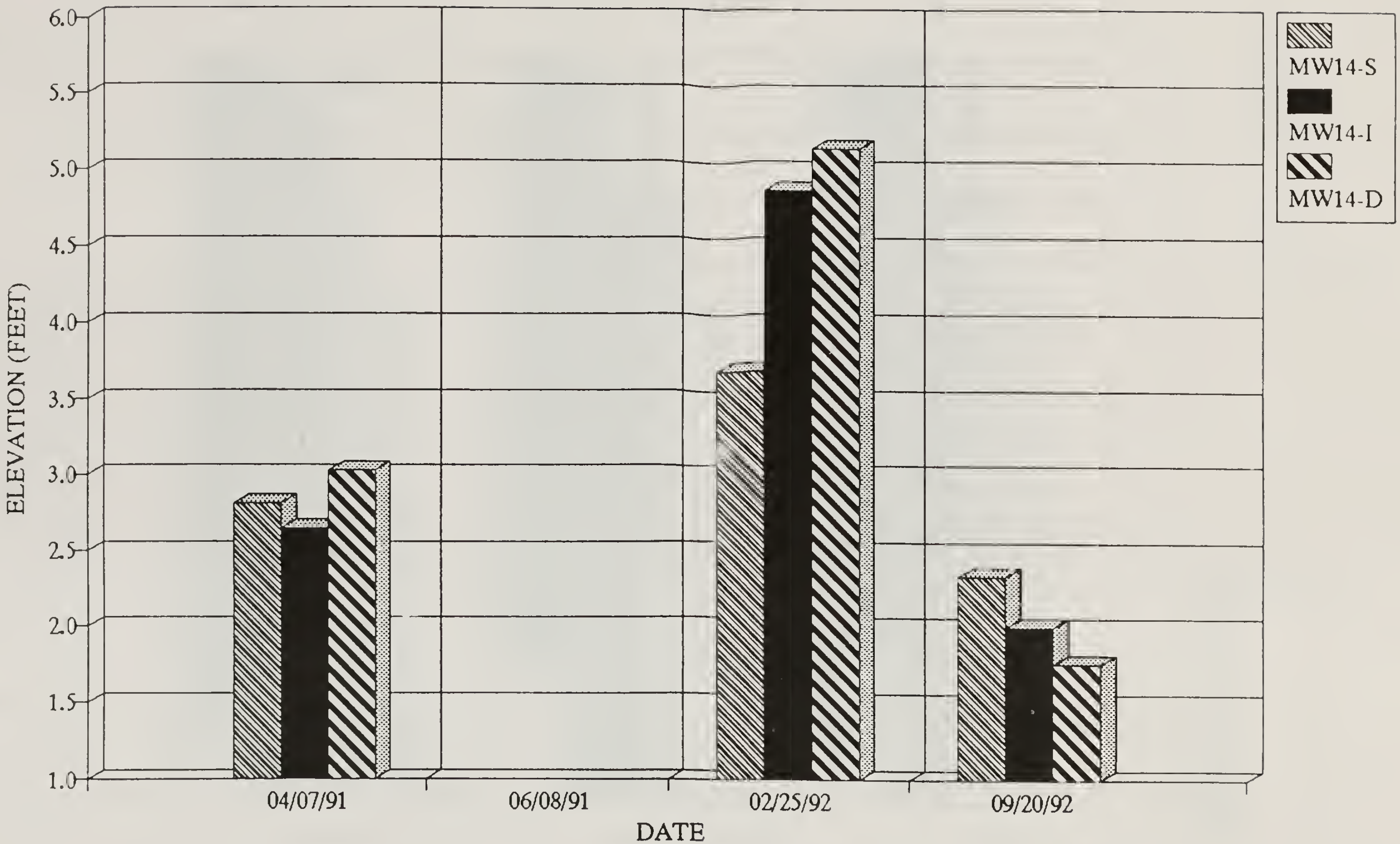


Fig. D-6. Water table elevations for MW14, Provincetown, MA.

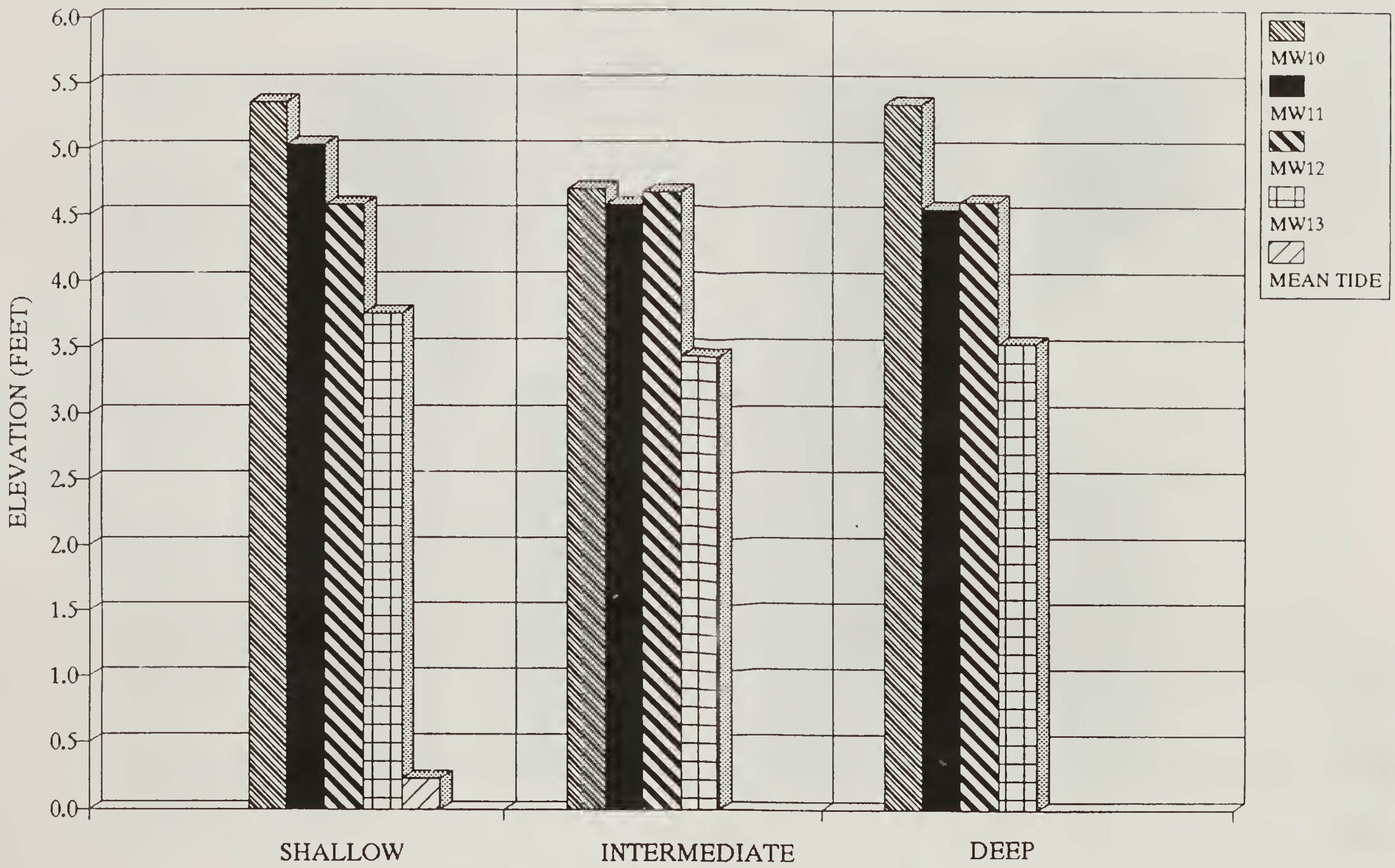


Fig. D-7. Water table elevations - 4/7/91, Provincetown, MA.

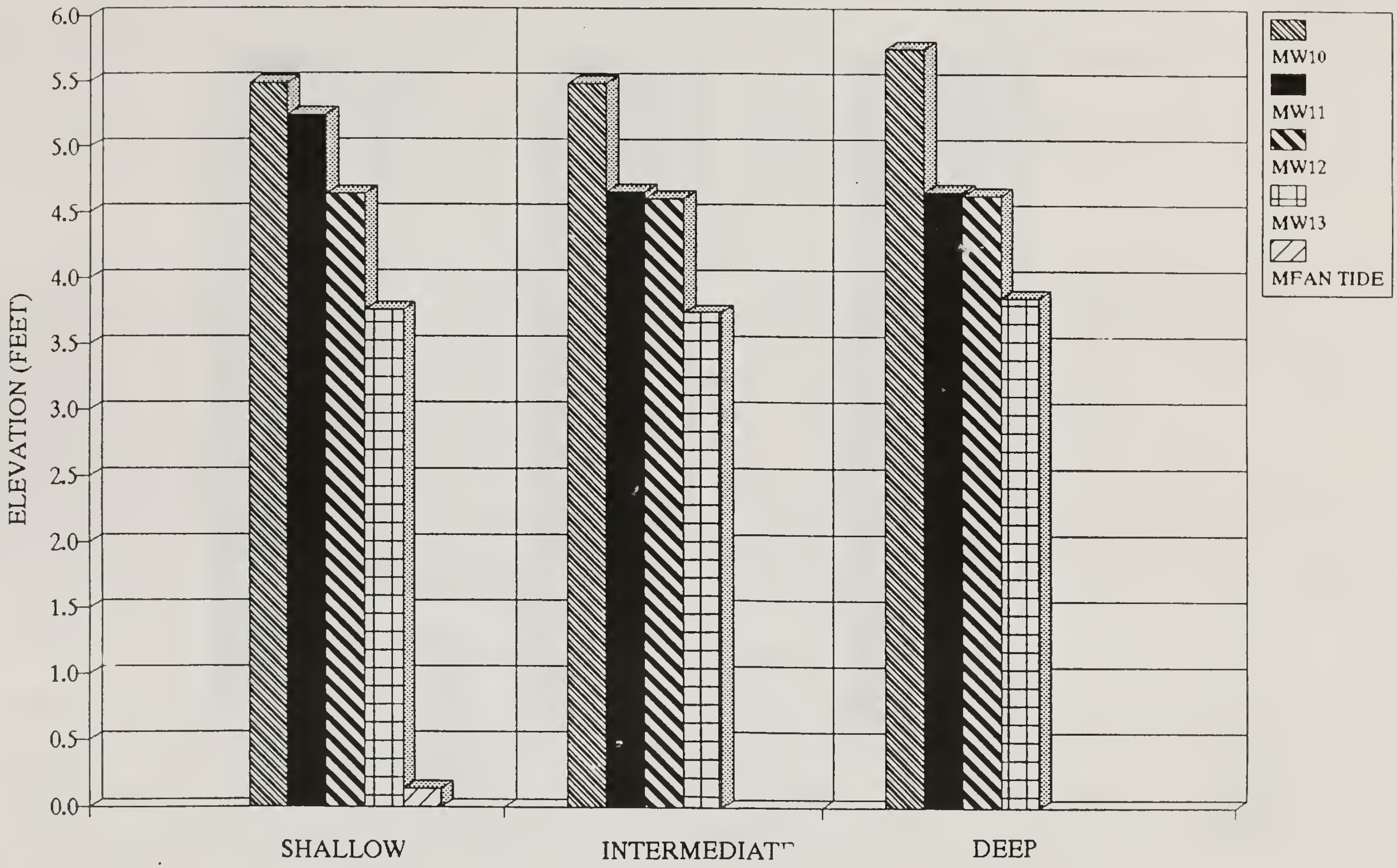


Fig. D-8. Water table elevations - 6/8/91, Provincetown, MA.

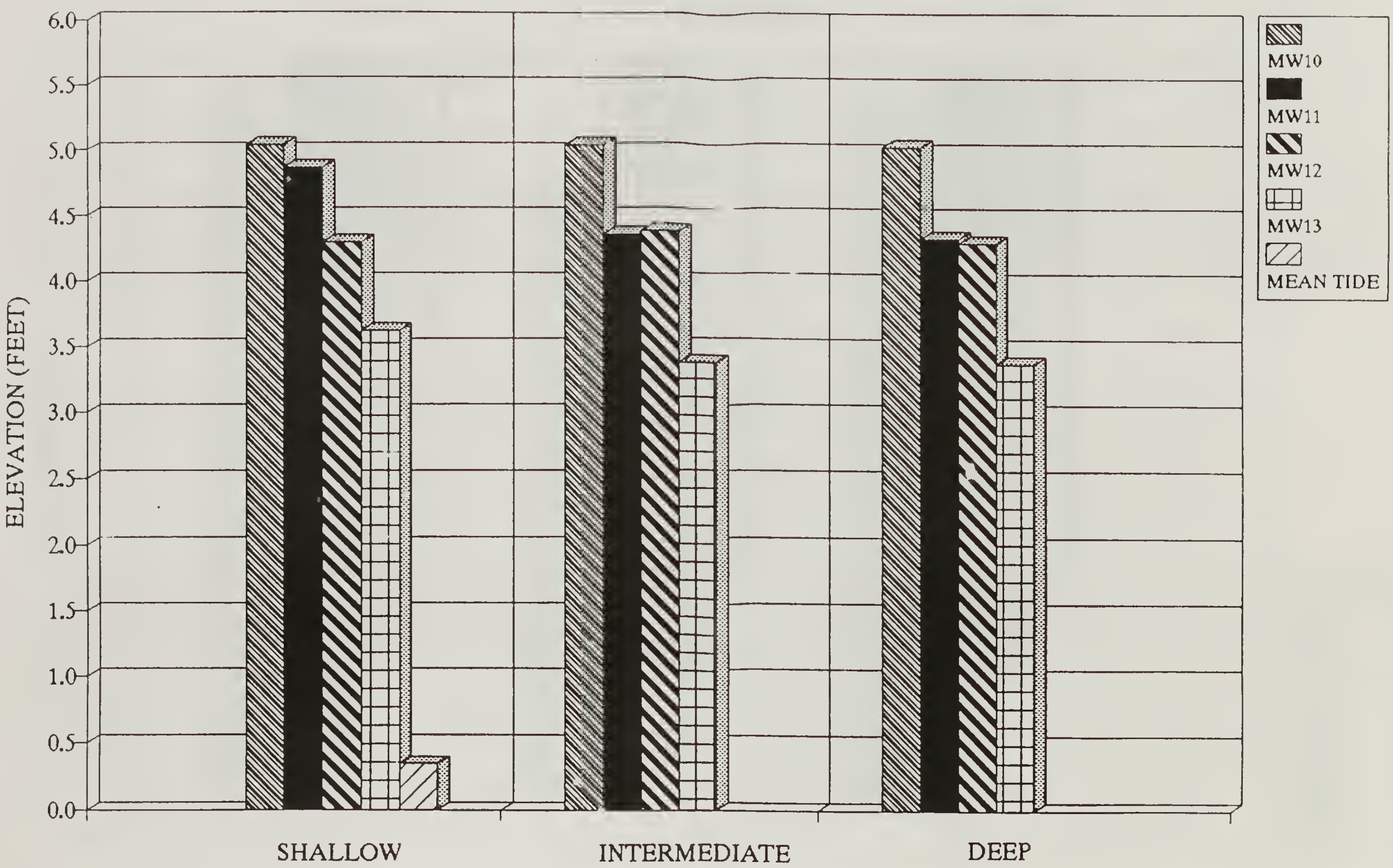


Fig. D-9. Water table elevations - 2/25/92, Provincetown, MA.

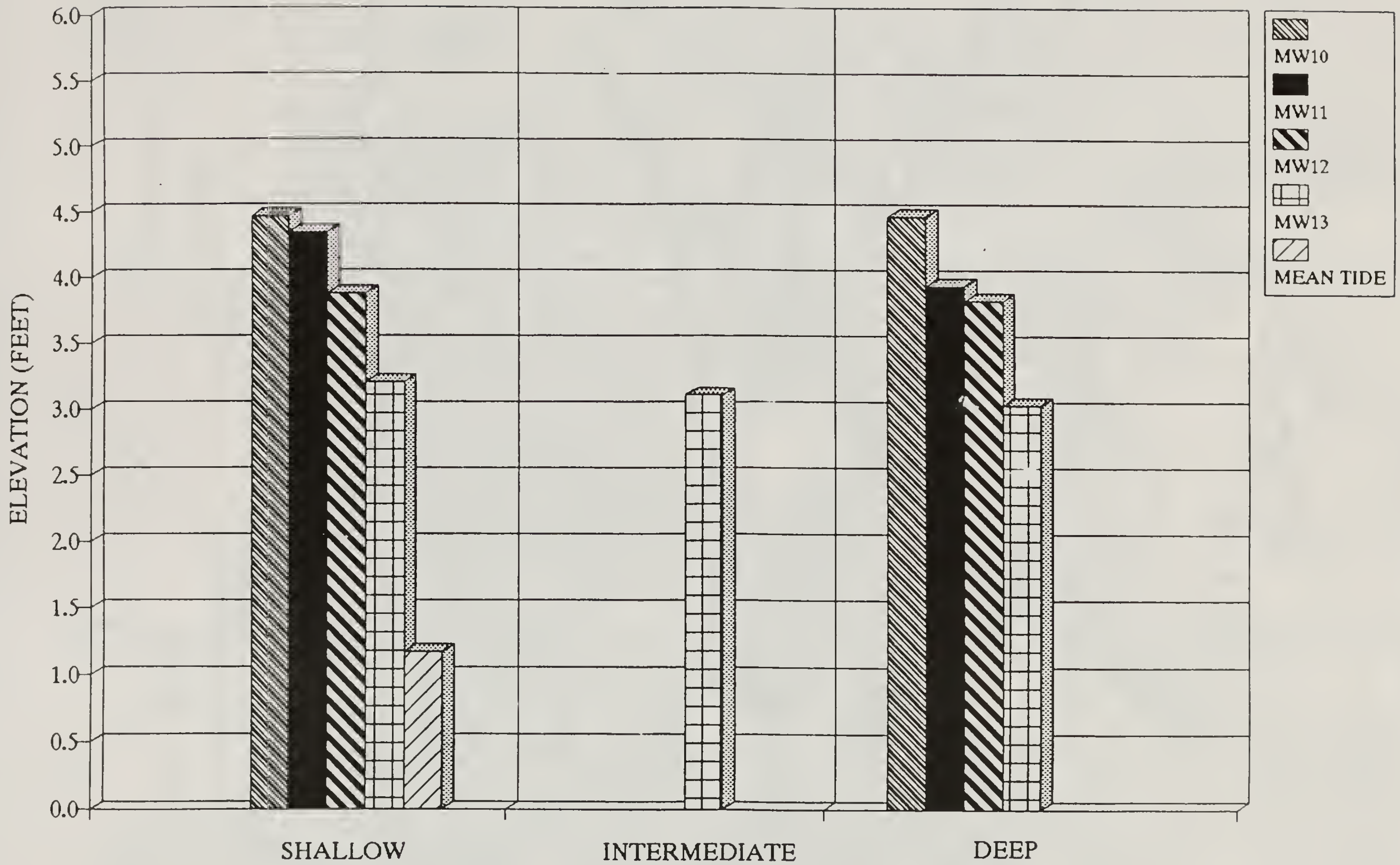


Fig. D-10. Water table elevations - 9/20/92, Provincetown, MA.

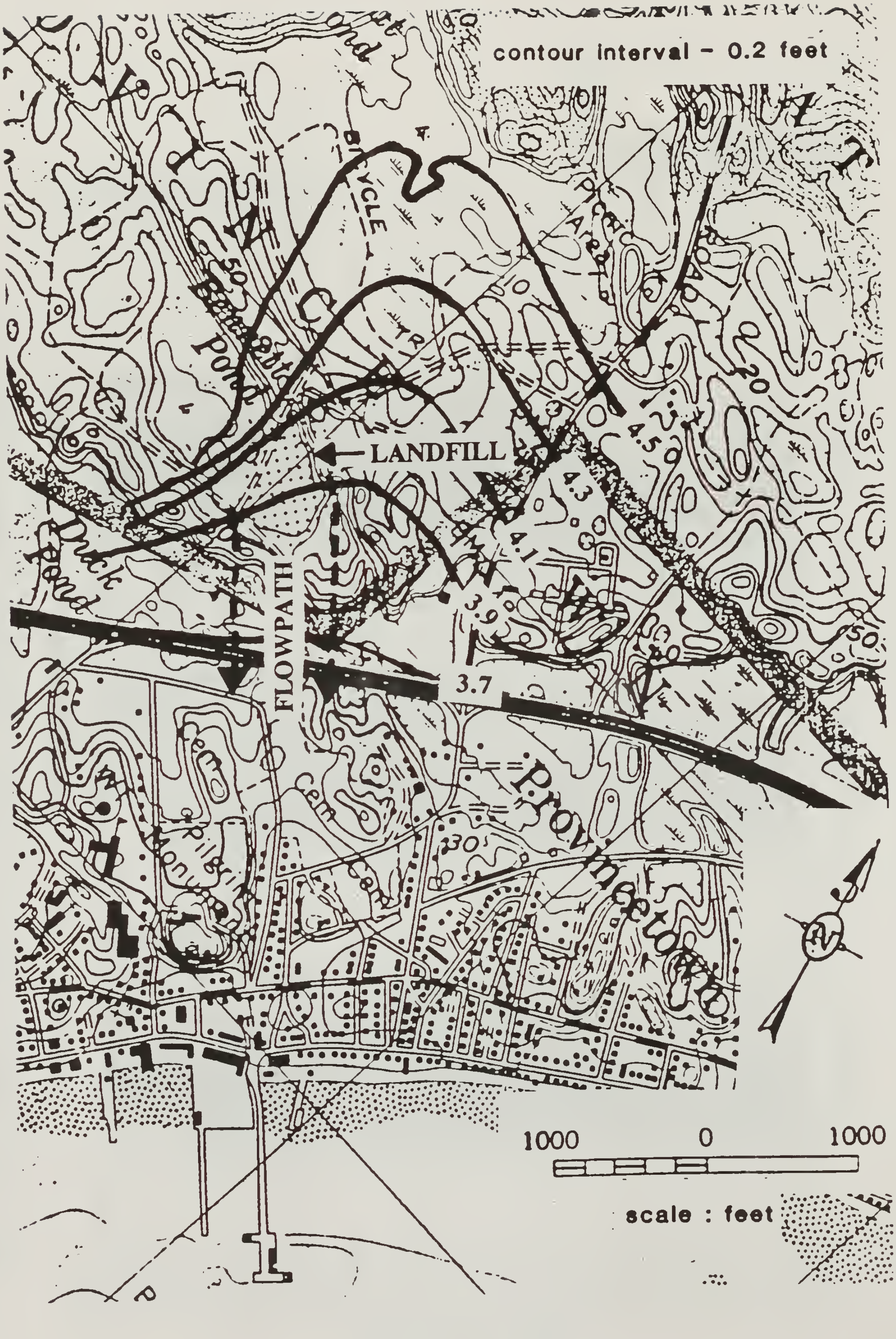


Fig. D-11. Water table map - 9/12/90, Provincetown, MA.

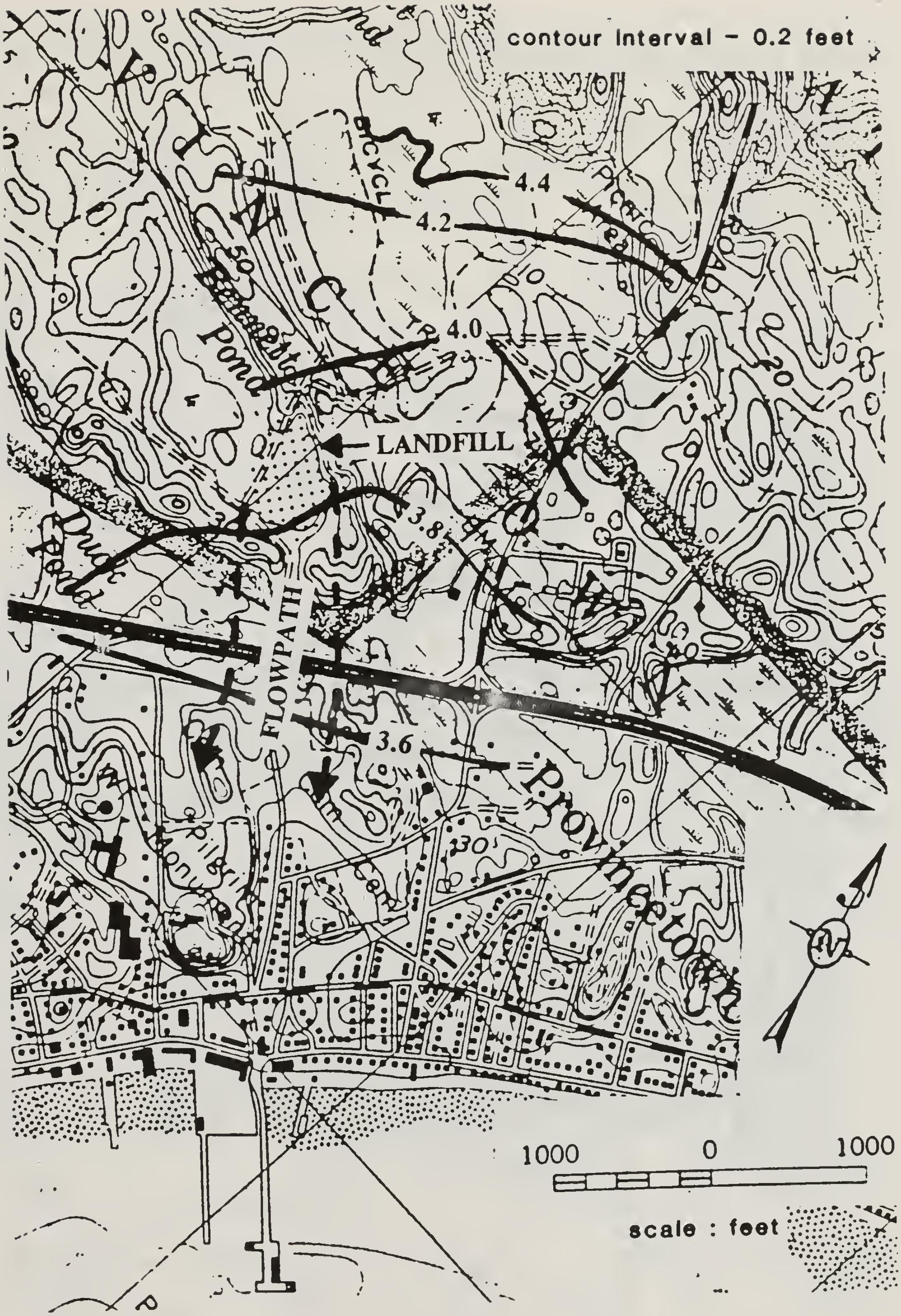


Fig. D-12. Water table map - 10/13/90, Provincetown, MA.

Fig. D-13. water table map - 4/7/91, Provincetown, MA.

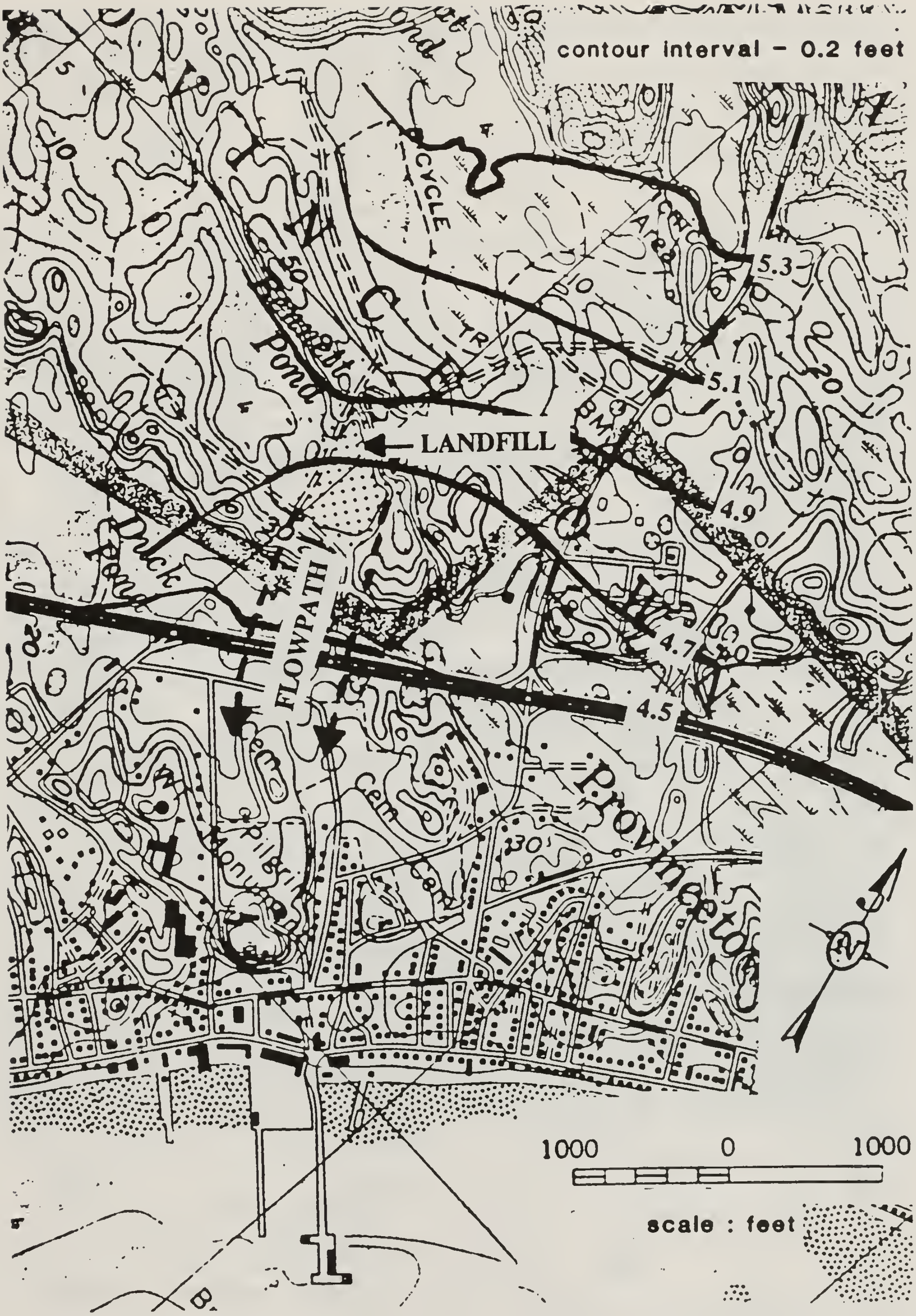


Fig. D-14. Water table map - 6/8/91, Provincetown, MA.

Fig. D-15. Water table map - 2/25/92, Provincetown, MA.

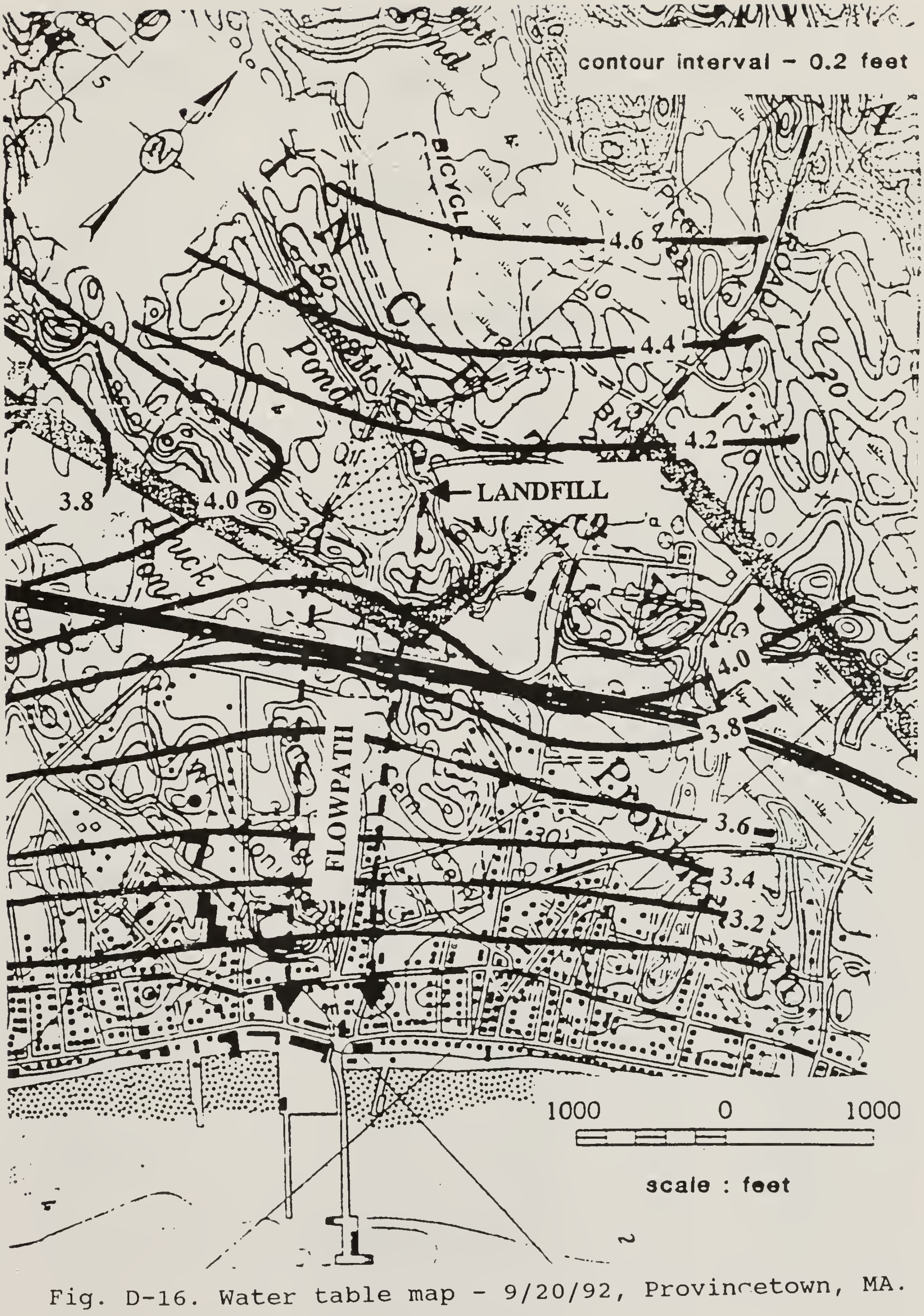


Fig. D-16. Water table map - 9/20/92, Provincetown, MA.

APPENDIX E

WATER QUALITY RESULTS

Table E-1. Water Quality Results for MW1, Provincetown, MA.

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92
Alkalinity (mg/l)	100	99.8	208	44
Bicarbonate (mg/l)	104	129.2	208	80
Ammonia (mg/l)	6.6	5.5	10	8
Nitrate-N (mg/l)	<0.4	<0.4	<0.1	<0.1
Ortho-P (mg/l)	0.02	0.07	0.04	<0.01
Phosphorus (mg/l)	NA	0.28	0.1	0.12
Chloride (mg/l)	29	32	63	49
Sulfate (mg/l)	33	3.3	53.2	20.1
COD (mg/l)	31	31	41	48
BCHED Metals				
Ca (mg/l)	24	19.5	39	9
Fe (mg/l)	18.5	20	28.6	16.6
Mg (mg/l)	5.5	4.8	10.5	3.4
Mn (mg/l)	0.36	0.42	0.44	0.22
Na (mg/l)	17	17	13	13
Zn (mg/l)	0.1	<0.1	NA	NA
URI Metals				
Cr (ug/l)	NA	1.2	1.2	2.2
Cu (ug/l)	NA	2.3	9.7	1
Cd(ug/l)	NA	0.33	0.67	0.75
Ni (ug/l)	NA	1.1	2.6	6.9
Pb (ug/l)	NA	0.5	3.7	<0.1
pH (Field)	6.3	6.3	6.6	6.25
Temp. (Field) C	12.6	9.6	11.0	10.4
Cond. (Field)	357	385	444	191
Cond. @ 25 C	357.0	385.0	606.1	264.9
DO (Field)	2.2	2.95	2.4	3.6
VOC (ug/l)				
Chloroform	0.6	<0.5	<0.5	<0.5

NA: NOT ANALYSED

Table E-2. Water Quality Results for MW2, Provincetown, MA.

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)	350.6	345	722	359
Bicarbonate (mg/l)	NA	578.3	722	531.2
Ammonia (mg/l)	37.4	35.6	59.7	68.5
Nitrate-N (mg/l)	<0.4	<0.5	<0.1	0.9
Ortho-P (mg/l)	0.06	0.18	0.02	<0.01
Phosphorus (mg/l)	NA	0.76	0.15	0.18
Chloride (mg/l)	42	56	94	64
Sulfate (mg/l)	120	47.5	1.4	8.6
COD (mg/l)	95	106	87.7	48
BCHED Metals				
Ca (mg/l)	100	95	74	52
Fe (mg/l)	182	160	169	29.3
Mg (mg/l)	16	18.6	29	14
Mn (mg/l)	1.84	1.61	0.95	1.07
Na (mg/l)	22	29	30	26
Zn (mg/l)	0.1	<0.1	NA	NA
URI Metals				
Cr (ug/l)	NA	1.7	0.9	2.7
Cu (ug/l)	NA	1	3	1.3
Cd(ug/l)	NA	0.4	0.16	3.73
Ni (ug/l)	NA	3.7	3.7	5
Pb (ug/l)	NA	0.6	1.1	2.3
pH (Field)	6.1	6.45	6.6	6.45
Temp. (Field)	12.8	10.1	11.1	11.3
Cond. (Field)	1319	1414	975	770
Cond. @ 25 C	1319.0	1414.0	1327.4	1042.9
DO (Field)	1.7	3.8	3.3	3.5
VOC (ug/l)				
Benzene	2.1	2.4	1.9	1.3
Chlorobenzene	1.9	2.3	3.2	2
Dichlorodifluoro-methane	4.5	2.3	2.4	<0.5

NA: NOT ANALYSED

Table E-3. Water Quality Results for MW3, Provincetown, MA.

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)	4.2	12	73.4	7
Bicarbonate (mg/l)	14	NA	73.4	15.8
Ammonia (mg/l)	1.4	1.3	2.7	1.3
Nitrate-N (mg/l)	<0.1	<0.2	<0.1	<0.1
Ortho-P (mg/l)	0.02	0.03	0.01	<0.01
Phosphorus (mg/l)	NA	0.24	0.07	0.04
Chloride (mg/l)	66	64	49.5	69
Sulfate (mg/l)	33.6	24.6	78	35.4
COD (mg/l)	20	31	7.6	21
BCHED Metals				
Ca (mg/l)	4	2.8	18	2.7
Fe (mg/l)	11.5	10.4	59.8	15.3
Mg (mg/l)	5	4.3	7.3	7
Mn (mg/l)	0.19	0.15	0.55	0.22
Na (mg/l)	34	28	19	27
Zn (mg/l)	0.1	<0.1	NA	NA
URI Metals				
Cr (ug/l)	NA	0.4	0.7	2
Cu (ug/l)	NA	1.3	12.3	1.8
Cd(ug/l)	NA	0.17	15.66	2.95
Ni (ug/l)	NA	7	5.7	7.4
Pb (ug/l)	NA	1.3	4.5	4.4
pH (Field)	6.4	6.3	6.1	6
Temp. (Field)	10	10.8	12.1	9.2
Cond. (Field)	680	198	288	195
Cond. @ 25 C	680	271.7	382.2	279.3
DO (Field)	4	3.25	3.65	3.55
VOC (ug/l)				
Chlorobenzene	<0.5	<0.5	0.5	<0.5

NA: NOT ANALYSED

Table E-4. Water Quality Results for MW4, Provincetown, MA.

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)	381	547	>800	1096
Bicarbonate (mg/l)	NA	558.8	>800	1300
Ammonia (mg/l)	98.5	2.4	88	144
Nitrate-N (mg/l)	0.5	0.4	<0.1	<0.1
Ortho-P (mg/l)	0.12	0.27	0.02	0.04
Phosphorus (mg/l)	NA	0.26	0.22	0.06
Chloride (mg/l)	89	42	290	260
Sulfate (mg/l)	163.5	170.1	5.6	<1.0
COD (mg/l)	128	62	NA	137
BCHED Metals				
Ca (mg/l)	200	180	62.5	210
Fe (mg/l)	75	70	96	19.7
Mg (mg/l)	47	38	38	67.5
Mn (mg/l)	0.97	3.64	0.14	1.55
Na (mg/l)	58	26	175	180
Zn (mg/l)	0.1	<0.1	NA	NA
Pb (ug/l)	57	NA	NA	NA
URI Metals				
Cr (ug/l)	NA	0.9	2.1	5.8
Cu (ug/l)	NA	3.4	5.4	3.8
Cd(ug/l)	NA	0.13	0.48	14.3
Ni (ug/l)	NA	2	8.6	8.5
Pb (ug/l)	NA	0.6	1.7	2.7
pH (Field)	5.95	6.2	6.8	6
Temp. (Field)	11.4	12.2	13	12
Cond. (Field)	1600	1150	2510	305
Cond. @ 25 C	1600	1522.1	3256.4	405.7
DO (Field)	1.6	2.6	2.65	3

Table E-4 (continued). Water Quality Results for MW4, Provincetown, MA.

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
VOC (ug/l)				
Benzene	3.5	2.6	5	5.8
Chlorobenzene	40	29	66	67
Ethyl Chloride	1.7	0.9	1.5	0.6
Total Xylenes	3.9	<0.5	21	<0.5
Dichlorodifluoro-methane	1.2	1.4	<0.5	<0.5
Dichlorobenzene	<0.5	1.1	<0.5	<0.5
Bromobenzene	<0.5	<0.5	<0.5	2.1
Isopropylbenzene	<0.5	<0.5	<0.5	2.4

NA: NOT ANALYSED

Table E-5. Water Quality Results for MW5, Provincetown, MA.

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)	37	23.2	23.8	24
Bicarbonate (mg/l)	40	28.8	23.8	29
Ammonia (mg/l)	2.1	1.8	2.9	2.2
Nitrate-N (mg/l)	<0.1	<0.5	<0.1	<0.1
Ortho-P (mg/l)	0.06	0.07	0.02	0.02
Phosphorus (mg/l)	NA	0.17	0.11	0.2
Chloride (mg/l)	40	39	39	43
Sulfate (mg/l)	182	69.7	68.8	59
COD (mg/l)	51	46	25	15
BCHED Metals				
Ca (mg/l)	16	24	25	18
Fe (mg/l)	2.2	4.8	6.5	4.4
Mg (mg/l)	3.5	5.9	4.9	4.7
Mn (mg/l)	0.19	0.37	0.46	0.26
Na (mg/l)	20	19	17	19
Zn (mg/l)	0.1	<0.1	NA	NA
URI Metals				
Cr (ug/l)	NA	0.4	1.2	2
Cu (ug/l)	NA	1.1	0.8	10
Cd(ug/l)	NA	0.22	0.29	5.23
Ni (ug/l)	NA	1	0.6	5
Pb (ug/l)	NA	0.6	1.4	9
pH (Field)	6.6	6	6.15	6.4
Temp. (Field)	8.9	10.5	10.5	7.3
Cond. (Field)	574	240	230	163
Cond. @ 25 C	574	331.9	318.1	246.2
DO (Field)	2.5	2.4	3.18	2.75
VOC (ug/l)	<0.5	<0.5	<0.5	<0.5

NA: NOT ANALYSED

Table E-6. Water Quality Results for MW6, Provincetown, MA.

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)	3.2	8.2	20.9	9
Bicarbonate (mg/l)	8	13.3	20.9	14.4
Ammonia (mg/l)	2	0.7	1.5	1.5
Nitrate-N (mg/l)	<0.4	<0.4	<0.1	<0.1
Ortho-P (mg/l)	0.07	0.24	0.21	0.12
Phosphorus (mg/l)	NA	0.19	0.14	0.38
Chloride (mg/l)	33	27	30	48
Sulfate (mg/l)	150	77.6	87	72.5
COD (mg/l)	41	31	26	26
BCHED Metals				
Ca (mg/l)	38	15.5	24	10.2
Fe (mg/l)	8	3.2	4.8	4.7
Mg (mg/l)	11	6.8	6.8	6.5
Mn (mg/l)	1.13	1.03	1.12	0.74
Na (mg/l)	18	15	16	15
Zn (mg/l)	0.1	0.1	NA	NA
URI Metals				
Cr (ug/l)	NA	0.4	1.4	1.6
Cu (ug/l)	NA	9.8	1.7	1.8
Cd(ug/l)	NA	0.4	4.05	2.49
Ni (ug/l)	NA	1.7	6.1	1.8
Pb (ug/l)	NA	1.2	1.2	0.8
pH (Field)	6.5	6.1	6.1	6
Temp. (Field)	9.4	10.5	11.3	7.7
Cond. (Field)	762	183	232	169
Cond. @ 25 C	762	253.1	314.2	252.4
DO (Field)	2.4	3.05	2.63	2.25
VOC (ug/l)	<0.5	<0.5	<0.5	<0.5

NA: NOT ANALYSED

Table E-7. Water Quality Results for MW7, Provincetown, MA.

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)	>0.1	NA	NA	<0.1
Bicarbonate (mg/l)	8	NA	NA	1.1
Ammonia (mg/l)	0.4	NA	NA	0.3
Nitrate-N (mg/l)	1.6	NA	NA	<0.1
Ortho-P (mg/l)	0.01	NA	NA	<0.01
Phosphorus (mg/l)	NA	NA	NA	0.15
Chloride (mg/l)	38	NA	NA	49
Sulfate (mg/l)	NA	NA	NA	78.4
COD (mg/l)	31	NA	NA	26
BCHED Metals				
Ca (mg/l)	55	NA	NA	6.8
Fe (mg/l)	11.5	NA	NA	0.7
Mg (mg/l)	16.8	NA	NA	9.6
Mn (mg/l)	2.32	NA	NA	0.88
Na (mg/l)	19	NA	NA	18
Zn (mg/l)	1.6	NA	NA	NA
Ni (mg/l)	0.1	NA	NA	NA
URI Metals				
Cr (ug/l)	NA	NA	NA	1.2
Cu (ug/l)	NA	NA	NA	4.5
Ni (ug/l)	NA	NA	NA	2.3
Pb (ug/l)	NA	NA	NA	0.75
Cd (ug/l)	NA	NA	NA	0.63
pH (Field)	5.8	NA	NA	4.8
Temp. (Field)	9	NA	NA	10
Cond. (Field)	825	NA	NA	349
Cond. @ 25 C	825.0	NA	NA	489.1
DO (Field)	7	NA	NA	NA
VOC (ug/l)	<0.5	NA	NA	<0.5

NA: NOT ANALYSED

Table E-8. Water Quality Results for MW8, Provincetown, MA.

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)	<0.1	3	7.6	1
Bicarbonate (mg/l)	6	NA	7.6	8.4
Ammonia (mg/l)	0.3	0.2	0.2	<0.1
Nitrate-N (mg/l)	<0.1	<0.5	<0.1	0.4
Ortho-P (mg/l)	0.06	0.07	0.06	0.07
Phosphorus (mg/l)	NA	0.22	0.09	0.13
Chloride (mg/l)	30	31	31	11
Sulfate (mg/l)	176.5	14.1	11.2	2.7
COD (mg/l)	51	41	33	48
BCHED Metals				
Ca (mg/l)	0.6	0.5	2	0.5
Fe (mg/l)	7.8	7.8	0.5	8
Mg (mg/l)	2.1	1.6	5.1	1.8
Mn (mg/l)	0.09	0.09	0.11	0.08
Na (mg/l)	19	16	18	14
Zn (mg/l)	0.1	<0.1	NA	NA
URI Metals				
Cr (ug/l)	NA	1.4	1.4	2.3
Cu (ug/l)	NA	1.2	3.6	1.3
Cd(ug/l)	NA	0.46	2.19	1.16
Ni (ug/l)	NA	2.7	3.5	2.2
Pb (ug/l)	NA	0.4	7	0.9
pH (Field)	6.2	5.5	5.85	6.1
Temp. (Field)	9.6	9.4	9.8	9.2
Cond. (Field)	500	136	95	80
Cond. @ 25 C	500	136.0	133.9	114.6
DO (Field)	1.9	2.75	3.08	2.85
VOC (ug/l)	<0.5	<0.5	<0.5	<0.5

NA: NOT ANALYSED

Table E-9. Water Quality Results for MW9, Provincetown, MA.

PARAMETER	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)	107	98	98.6	106
Bicarbonate (mg/l)	138	109.2	98.6	121.8
Ammonia (mg/l)	7.7	2	6.2	10.5
Nitrate-N (mg/l)	4	1	<0.1	3
Ortho-P (mg/l)	0.02	0.09	0.01	0.05
Phosphorus (mg/l)	NA	0.26	0.07	0.08
Chloride (mg/l)	52	63	45	41
Sulfate (mg/l)	26.7	35.5	23.7	20.8
COD (mg/l)	41	46	29	12
BCHED Metals				
Ca (mg/l)	45	32	26	38
Fe (mg/l)	9.6	12	7.6	13.9
Mg (mg/l)	5.2	4.1	26	6
Mn (mg/l)	0.54	0.49	0.76	0.7
Na (mg/l)	28	33	17	20
Zn (mg/l)	0.1	<0.1	NA	NA
URI Metals				
Cr (ug/l)	NA	0.7	1.6	3.6
Cu (ug/l)	NA	4.1	4.7	11.3
Cd(ug/l)	NA	0.22	0.28	10.34
Ni (ug/l)	NA	3	4.7	4.5
Pb (ug/l)	NA	2.9	2.2	68.4
pH (Field)	6.1	6.2	6.15	7.15
Temp. (Field)	12.2	13	11.2	11
Cond. (Field)	970	340	269	1960
Cond. @ 25 C	970	441.1	365.3	2675.4
DO (Field)	1.6	2.2	2.6	3.4
VOC (ug/l)				
Dichloroethane	<0.5	0.8	<0.5	0.8
Chlorobenzene	<0.5	<0.5	<0.5	1.6

NA: NOT ANALYSED

Table E-10. Water Quality Results for MW10-S,I,D, Provincetown, MA.

PARAMETER:	FEBRUARY 1991			APRIL 1991			AUGUST 1991			FEBRUARY 1992		
	S	I	D	S	I	D	S	I	D	S	I	D
Alkalinity (mg/l)	<0.1	9	101.2	<0.1	11	102.1	0.3	27.8	138.5	<0.1	7	97
Bicarb (mg/l)	2	20	118	0.4	28.3	149	0.3	27.8	138.5	<0.1	27	150.2
Ammonia (mg/l)	0.1	0.3	0.8	<0.1	0.3	0.7	0.2	0.5	1	0.1	0.6	1.2
Nitrate-N (mg/l)	<0.1	<2.0	<2.0	<0.1	<1.0	<1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ortho-P (mg/l)	0.02	0.09	0.08	0.05	0.14	0.11	0.01	0.07	0.1	0.04	0.1	0.05
Phosphorus (mg/l)	NA	NA	NA	0.32	0.31	0.37	0.09	0.09	0.12	0.06	0.11	0.12
Chloride (mg/l)	30	33	29	27	28	28	32.8	35.5	28.5	42	34	33
Sulfate (mg/l)	9.5	18.2	12.3	12.1	<1.0	2.4	4.4	13.3	<1.0	18	7.6	<1.0
COD (mg/l)	20	62	41	10	51	41	15	49	26	19	45	43
BCHED Metals												
Ca (mg/l)	0.5	0.9	40	0.3	0.8	32	0.5	0.9	34	0.3	1	58
Fe (mg/l)	3	14	40	2.6	14.5	40	3	12.5	41	3.4	18	66
Mg (mg/l)	2	2.7	3.9	1.8	2.7	3.9	2.1	2.6	3.9	2.2	2.6	3.7
Mn (mg/l)	0.09	0.11	0.14	0.06	0.09	0.13	0.09	0.11	0.15	0.05	0.08	0.12
Na (mg/l)	16	14	15	15	15	16	15	13	15	19	13	14
Zn (mg/l)	0.1	0.1	0.1	<0.1	<0.1	<0.1	NA	NA	NA	NA	NA	NA
URI Metals												
Cr (ug/l)	NA	NA	NA	0.4	5	1.2	0.9	4.2	0.7	2.5	6.2	2.1
Cu (ug/l)	NA	NA	NA	2.3	1.5	1.4	3.2	3.3	1.4	2	0.9	1.7
Cd(ug/l)	NA	NA	NA	0.62	0.36	0.79	0.66	0.19	0.59	0.47	0.56	0.5
Ni (ug/l)	NA	NA	NA	2.3	0.8	3.5	5.6	3.4	2.5	2.8	1.1	1.5
Pb (ug/l)	NA	NA	NA	0.4	0.6	0.2	1.8	42.1	1.3	0.7	0.8	0.5
pH (Field)	5.5	6.1	7.04	5.2	6.2	7.1	5.4	6.4	6.9	4.65	5.8	6.91
Temp. (Field)	10.4	10.1	10.7	9.7	10	10.8	8	8	7.8	9.9	9.7	9.3
Cond. (Field)	134	163	395	121	164	404	91	113	270	100	95	245
Cond. @ 25 C	134	228	395	121	164	404	135	167	402	141	134	350
DO (Field)	2.2	1.6	2	3.5	2.3	2.15	3.28	3.65	1.93	4.25	1.15	0.85
VOC (ug/l)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

NA: NOT ANALYSED

Table E-11. Water Quality Results for MW11-S,I,D, Provincetown, MA.

PARAMETER:	FEBRUARY 1991			APRIL 1991			AUGUST 1991			FEBRUARY 1992		
	S	I	D	S	I	D	S	I	D	S	I	D
Alkalinity (mg/l)	4	46	81	4.2	39	90	13.3	47.3	100	7	27	112
Bicarb (mg/l)	8	52	86	8.6	59.4	106.3	13.3	47.3	100	9.6	57.4	118
Ammonia (mg/l)	0.4	0.3	0.6	0.2	0.2	0.4	0.1	0.3	0.5	0.2	0.5	1.2
Nitrate-N(mg/l)	1.8	<0.5	<0.1	0.5	<0.4	<0.1	<0.1	<0.1	<0.1	0.5	<0.1	<0.1
Ortho-P (mg/l)	0.02	0.11	0.02	0.03	0.11	0.07	0.03	0.08	0.01	0.03	0.05	<0.01
Phosphorus (mg/l)	NA	NA	NA	0.26	0.43	0.24	0.09	0.08	0.07	0.03	0.1	0.15
Chloride (mg/l)	300	335	290	122	341	363	73	342	342	41	400	342
Sulfate (mg/l)	16.3	10.3	26.3	18.9	<1.0	3	16.6	11	0.8	15	6.6	2.1
COD (mg/l)	95	31	31	20	20	20	15	12	4	19	25	22
BCHED Metals												
Ca (mg/l)	4.1	3.2	50	2.6	3	44	1.7	4.1	58	2.7	6.4	64
Fe (mg/l)	5.6	13.6	46	2.2	15.5	16.8	2.5	14.8	22.1	1.7	33	21
Mg (mg/l)	1.6	3.6	5.1	1.1	4.2	3.3	1	5.5	4.2	1.2	6.2	4.4
Mn (mg/l)	0.08	0.1	0.16	0.05	0.13	0.1	0.07	0.19	0.13	0.03	0.19	0.08
Na (mg/l)	88	192	150	70	184	208	35	225	200	21	250	190
Zn (mg/l)	0.2	0.1	0.1	0.2	<0.1	<0.1	NA	NA	NA	NA	NA	NA
URI Metals												
Cr (ug/l)	NA	NA	NA	0.3	1	<0.1	0.6	1.6	0.1	5	2.4	1.5
Cu (ug/l)	NA	NA	NA	10.9	1.2	7.9	6.5	1.4	3.2	8.2	0.3	6.4
Cd(ug/l)	NA	NA	NA	1.36	0.21	0.37	5.1	0.65	1.07	0.67	0.06	0.28
Ni (ug/l)	NA	NA	NA	3.6	<0.1	1.1	3.2	1.6	0.7	4.8	1.2	1.6
Pb (ug/l)	NA	NA	NA	1.6	0.3	5	2.7	1.3	1.3	2	<0.1	1.5
pH (Field)	6.1	6.7	7	5.65	6.2	7.4	6.2	6.5	7.1	5.74	6.27	7
Temp. (Field)	8.5	9.6	10.1	9.2	11.4	10.7	16	10	10	9	10.5	10.9
Cond. (Field)	574	1107	1210	527	1205	950	215	790	850	105	850	880
Cond. @ 25 C	574	1107	1210	527	1205	1307	260	1107	1191	151	1176	1204
DO (Field)	3.9	1.6	1.3	4.9	2.75	1.3	2.25	2.03	1.95	[illegible]25	1.2	1.35
VOC (ug/l)												
Toluene	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
para-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5	1.9	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
meta-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5	2.4	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chloroform	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	<0.5

NA: NOT ANALYSED

Table E-12. Water Quality Results for MW12-S,I,D, Provincetown, MA.

PARAMETER:	FEBRUARY 1991			APRIL 1991			AUGUST 1991			FEBRUARY 1992		
	S	I	D	S	I	D	S	I	D	S	I	D
Alkalinity (mg/l)	134.8	31.8	79	72.2	33.4	135.6	48.1	43.1	141.6	112	20	144
Bicarb (mg/l)	150	44	88	65.5	48.5	133	48.1	43.1	141.6	116.1	50.9	144.6
Ammonia (mg/l)	0.3	0.3	0.1	<0.1	0.2	0.3	<0.1	0.2	0.3	0.2	0.3	0.4
Nitrate-N (mg/l)	<0.1	<0.2	<4.0	6	<0.4	<0.2	<0.1	<0.1	<0.1	2.1	<0.1	<0.1
Ortho-P (mg/l)	NA	0.07	0.03	0.07	0.11	0.11	0.01	0.15	0.09	0.27	0.07	0.03
Phosphorus (mg/l)	NA	NA	NA	0.19	0.21	0.17	0.09	0.17	0.09	0.31	0.33	0.01
Chloride (mg/l)	25	49	47	33	45	25	60	51	30.5	30	61	26
Sulfate (mg/l)	NA	12.8	45.3	64	3.5	NA	7	<1.0	3.3	34.6	<1.0	6.3
COD (mg/l)	20	31	41	41	70	31	17	11	11	29	29	22
BCHED Metals												
Ca (mg/l)	50	1.5	50	45	1	48	22	1.2	45	43	1.4	44
Fe (mg/l)	4.2	17	0.3	0.1	16.5	4.6	0.2	20.8	2.3	0.3	5.9	4.8
Mg (mg/l)	4.3	4.6	3.5	4.2	4.4	4.2	2.3	4.3	4.4	4.1	5	4.5
Mn (mg/l)	0.11	0.11	0.02	0.02	0.11	0.11	0.03	0.11	0.11	0.01	0.1	0.1
Na (mg/l)	16	24	31	33	25	15	33	19	11	14	24	14
Zn (mg/l)	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	NA	NA	NA	NA	NA	NA
URI Metals												
Cr (ug/l)	NA	NA	NA	0.2	3	<0.1	0.7	2.3	0.2	2.4	4.2	1
Cu (ug/l)	NA	NA	NA	2.1	1.7	4.1	14.4	3.9	3.3	4.9	1.1	1
Cd(ug/l)	NA	NA	NA	0.23	1.37	0.35	14.97	3.44	0.52	0.39	0.09	0.27
Ni (ug/l)	NA	NA	NA	2.3	6.3	1.6	4	1.5	3.4	2	0.8	<0.1
Pb (ug/l)	NA	NA	NA	1.9	1.5	1.6	3.9	1.5	1.1	2.4	0.7	0.4
pH (Field)	7.6	6.1	6.7	6.4	5.8	7.6	6.5	6.05	7.1	6.7	5.94	7.47
Temp. (Field)	10.9	12.1	12	9	11.1	10.8	12.8	9.5	9.3	8.9	10.7	10.5
Cond. (Field)	371	239	495	440	255	236	242	159	238	281	161	240
Cond. @ 25 C	371	239	495	440	225	324	316	226	340	406	221	332
DO (Field)	1.3	2.8	2	2.5	2.45	1.2	2.7	2.03	2.1	3.15	1.4	1.5
VOC (ug/l)												
Chloroform	<0.5	<0.5	<0.5	<0.5	<0.5	4.9	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

NA: NOT ANALYSED

Table E-13. Water Quality Results for MW13-S,I,D, Provincetown, MA.

PARAMETER:	FEBRUARY 1991			APRIL 1991			AUGUST 1991			FEBRUARY 1992		
	S	I	D	S	I	D	S	I	D	S	I	D
Alkalinity (mg/l)	<0.1	38.4	149.6	7.4	91.8	155	8.2	94.4	146.4	60	84	156
Bicarb (mg/l)	6	100	166	9.9	99.1	155.3	8.2	94.4	146.4	7.2	103.2	158
Ammonia (mg/l)	0.1	0.5	0.8	<0.1	0.4	0.8	0.1	0.3	0.6	0.1	0.6	0.8
Nitrate-N (mg/l)	<7.0	<0.1	<0.1	4	<0.2	<0.1	2.8	<0.1	<0.1	4.8	<0 1	<0.1
Ortho-P (mg/l)	0.01	0.02	0.01	0.03	0.09	0.09	<0.1	0.03	0.01	0.01	<0.01	0.03
Phosphorus (mg/l)	NA	NA	NA	0.37	0.17	0.32	0.8	0.09	0.09	0.12	0.06	0.06
Chloride (mg/l)	49	47	105	30	50	109	24.5	47.5	162	53	50	115
Sulfate (mg/l)	43	<1.0	115	3.1	1.9	2	1.8	1.6	1.1	9.3	<1.0	2.7
COD (mg/l)	62	20	10	175	20	20	20	8.4	8.2	26	32	19
BCHED Metals												
Ca (mg/l)	22	35	75	8.2	34	70	8.4	35	56	12.8	46	78
Fe (mg/l)	0.2	14	6.8	0.2	14	7.4	0.2	22.1	7.9	0.1	23	0.1
Mg (mg/l)	4.8	2.8	8.2	2.1	2.8	7.4	2.4	2.9	7.3	2.6	2.9	6.3
Mn (mg/l)	0.1	0.13	0.28	0.01	0.13	0.27	0.04	0.13	0.23	<0.01	0.11	0.23
Na (mg/l)	20	22	52	17	20	47	3	5.5	75	17	18	53
Zn (mg/l)	0.2	0.1	0.1	0.1	<0.1	<0.1	NA	NA	NA	NA	NA	NA
URI Metals												
Cr (ug/l)	NA	NA	NA	0.5	<0.1	0.2	0.2	0.8	1	3	0.6	0.9
Cu (ug/l)	NA	NA	NA	7.4	3.9	12.2	6	2.5	4.6	4	1.6	2.8
Cd(ug/l)	NA	NA	NA	0.29	0.26	0.58	0.38	0.37	0.31	0.15	0.09	0.13
Ni (ug/l)	NA	NA	NA	2.4	0.4	2.5	0.6	2	2.1	1.6	<0.1	0.9
Pb (ug/l)	NA	NA	NA	0.8	1.5	1.1	6.2	0.9	0.6	1.4	0.3	3.9
pH (Field)	5.4	7.1	7.3	6.1	7.2	7.7	6	6.75	7.26	5.93	6.96	7.21
Temp. (Field)	12.8	12.3	12.9	10	10.6	10.5	10.9	9	9	10.9	11.5	10.8
Cond. (Field)	306	349	689	118	239	483	100	220	425	158	232	475
Cond. @ 25 C	306	349	689	165	330	668	137	317	612	216	313	652
DO (Field)	5.6	1.8	1.5	5.5	1	1.15	5.45	2.55	1.85	3.2	1.05	1.35
VOC (ug/l)												
Chloroform	<0.5	<0.5	<0.5	1.3	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

NA: NOT ANALYSED

Table E-14. Water Quality Results for MW14-S,I,D, Provincetown, MA.

PARAMETER:	FEBRUARY 1991			APRIL 1991			AUGUST 1991			FEBRUARY 1992		
	S	I	D	S	I	D	S	I	D	S	I	D
Alkalinity (mg/l)	67.2	30	45	74.4	23	45	102.5	30.7	91.4	57	20	68
Bicarb (mg/l)	88	36	66	74.2	30.1	97.4	102.5	30.7	91.4	82.6	38	124.6
Ammonia (mg/l)	3.1	0.6	2.9	2.3	0.4	2.1	2.1	0.4	1.3	8.5	0.6	2.1
Nitrate-N (mg/l)	8	<0.5	0.4	<0.2	5.7	0.3	5	<0.1	<0.1	7.9	<0.1	NA
Ortho-P (mg/l)	1.13	0.22	0.01	0.84	0.14	0.03	1.15	0.11	<0.01	0.13	0.13	0.03
Phosphorus (mg/l)	NA	NA	NA	1.01	0.23	0.32	0.57	0.1	0.09	0.49	0.02	0.3
Chloride (mg/l)	235	80	7600	203	70	>1000	600	91	5400	360	83	8000
Sulfate (mg/l)	56.5	97	1425	48	13.2	1173	85.2	2.4	1074	62.2	8.6	1057
COD (mg/l)	10	62	530	10	51	573	9.2	9.8	5.7	26	36	>150
BCHED Metals												
Ca (mg/l)	10.2	3.4	225	11.4	3.6	230	16	3.2	164	24	2.8	198
Fe (mg/l)	0.2	8.7	51	0.2	6.4	46	<0.1	14.3	62.4	0.1	15	62.5
Mg (mg/l)	20	3.5	530	13	3.6	550	30	4.1	380	26	4.1	655
Mn (mg/l)	0.09	0.09	0.9	0.09	0.08	0.79	0.18	0.11	0.72	0.1	0.07	0.66
Na (mg/l)	150	48	4200	130	40	4300	350	50	>4500	190	42	5925
Zn (mg/l)	0.1	0.1	0.1	0.1	<0.1	0.1	NA	NA	NA	NA	NA	NA
Ni (mg/l)	<0.1	<0.1	0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pb (ug/l)	<50.0	<50.0	142	NA	NA	NA	NA	NA	NA	NA	NA	NA
URI Metals												
Cr (ug/l)	NA	NA	NA	<0.1	1.1	0.1	0.4	0.1	0.1	1.3	2	1.2
Cu (ug/l)	NA	NA	NA	3.6	1.1	0.7	3.7	3.1	1.7	9.1	1	4.4
Cd (ug/l)	NA	NA	NA	0.17	0.75	0.2	0.22	0.03	<0.1	1.06	0.12	0.19
Ni (ug/l)	NA	NA	NA	4.4	2.8	2.5	1.6	0.5	0.5	2.2	<0.1	1.2
Pb (ug/l)	NA	NA	NA	2.5	0.8	<0.1	1	0.1	<0.1	1.8	1	<0.1
pH (Field)	6.5	6.3	6.8	6.3	6.4	6.4	6.4	6.5	6.85	6.43	6.22	7.04
Temp. (Field)	12.4	12.9	9.6	11.5	13	12.5	16.3	11.5	10.7	11.5	13	12
Cond. (Field)	1187	352	24000	1017	345	>2000	1400	250	12800	1000	235	15500
Cond. @ 25 C	1187	352	24000	1370	345	>2627	1679	337	17610	1347	305	20620
DO (Field)	2.5	2.1	1.8	3.2	2.75	2.6	2.5	2.15	2.4	1.75	1.2	1.85
VOC (ug/l)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

NA: NOT ANALYSED

Table E-15. Water Quality Results for MW15-D, Provincetown, M

PARAMETER:	FEBRUARY 1992
Alkalinity (mg/l)	37
Bicarbonate (mg/l)	426.4
Ammonia (mg/l)	40.5
Nitrate-N (mg/l)	0.3
Ortho-P (mg/l)	0.04
Phosphorus (mg/l)	0.19
Chloride (mg/l)	138
Sulfate (mg/l)	44.4
COD (mg/l)	74
BCHED Metals	
Ca (mg/l)	4.3
Fe (mg/l)	0.3
Mg (mg/l)	24
Mn (mg/l)	0.17
Na (mg/l)	82
URI Metals	
Cr (ug/l)	2.8
Cu (ug/l)	0.8
Cd(ug/l)	0.86
Ni (ug/l)	<0.1
Pb (ug/l)	0.2
pH (Field)	6.94
Temp. (Field)	11
Cond. (Field)	860
Cond. @ 25 C	1173.9
DO (Field)	1.6
VOC (ug/l)	
Benzene	0.5
Dichloroethane	0.6

NA: NOT ANALYSED

Table E-16. Water Quality Results for Washdown Well, Provincetown Landfill

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)			73	139
Bicarbonate (mg/l)			73	163
Ammonia (mg/l)			1	44.2
Nitrate-N (mg/l)			<0.1	<0.1
Ortho-P (mg/l)			<0.01	0.01
Phosphorus (mg/l)			0.07	<0.01
Chloride (mg/l)			57	78
Sulfate (mg/l)			<1.0	7.6
COD (mg/l)			95.4	91
BCHED Metals				
Ca (mg/l)			12.5	8.2
Fe (mg/l)			45.5	28.6
Mg (mg/l)			6.2	7.1
Mn (mg/l)			0.53	0.57
Na (mg/l)			75	39
URI Metals				
Cr (ug/l)			1.8	4.6
Cu (ug/l)			4.8	71.3
Cd(ug/l)			0.17	2.38
Ni (ug/l)			6.8	17.8
Pb (ug/l)			2.1	11.1
pH (Field)			6.2	6.6
Temp. (Field)			20.2	10
Cond. (Field)			420	480
Cond. @ 25 C			462.4	672.7
DO (Field)			5.2	7.6

Table E-16 continued. Water Quality Results for Washdown Well, Provincetown, MA.

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
VOC (ug/l)				
Benzene			<0.5	1.6
Dichloroethane			5.5	0.5
Dichloromethane			5.2	<0.5
Trichloroethane			0.6	<0.5
Ethyl Chloride			2.1	1.3
Toluene			<0.5	0.5

NA: NOT ANALYSED

Table E-17. Water Quality Results for Bennett Pond - East, Provincetown, MA.

PARAMETER:	NOV. 90'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)		<0.1	0.6	<0.1
Bicarbonate (mg/l)		<0.1	0.6	<0.1
Ammonia (mg/l)		<0.1	0.4	0.2
Nitrate-N (mg/l)		<0.1	<0.1	<0.1
Ortho-P (mg/l)		0.07	0.51	0.04
Phosphorus (mg/l)		0.19	0.12	0.49
Chloride (mg/l)		27	54	37
Sulfate (mg/l)		<1.0	11.4	8.3
COD (mg/l)		62	39	32
BCHED Metals				
Ca (mg/l)		1.6	3.4	1.6
Fe (mg/l)		0.5	0.2	2.1
Mg (mg/l)		1.6	3.4	2.1
Mn (mg/l)		0.04	0.1	0.03
Na (mg/l)		11	18	13
Zn (mg/l)		NA	NA	NA
URI Metals	Total	Total	Total	T/D
Cr (ug/l)	0.6	0.2	0.7	1.2/2.1
Cu (ug/l)	2	2.6	8.1	5.8/2
Cd(ug/l)	0.09	0.15	0.55	3.68/2.84
Ni (ug/l)	0.8	2	7.9	2.4/1.7
Pb (ug/l)	9	2.8	17.2	6.6/4.3
pH (Field)		5.2	5.5	5
Temp. (Field)		11	28	3.8
Cond. (Field)		78	175	52
Cond. @ 25 C		106.5	165.5	87.4
DO (Field)		10.6	7.35	6.8
VOC (ug/l)		<0.5	<0.5	<0.5

NA: NOT ANALYSED

T/D: TOTAL/DISSOLVED

Table E-18. Water Quality Results for Bennett Pond - West, Provincetown, MA.

PARAMETER:	NOV. 90'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)		<0.1	<0.1	<0.1
Bicarbonate (mg/l)		<0.1	<0.1	<0.1
Ammonia (mg/l)		0.2	1.3	0.03
Nitrate-N (mg/l)		<0.1	<0.1	<0.1
Ortho-P (mg/l)		0.05	0.37	0.02
Phosphorus (mg/l)		0.23	0.12	0.14
Chloride (mg/l)		28	56	26
Sulfate (mg/l)		<1.0	7.8	7.6
COD (mg/l)		73	39	45
BCHED Metals				
Ca (mg/l)		1.4	3.8	1.6
Fe (mg/l)		0.6	2.2	0.5
Mg (mg/l)		1.7	3.6	2
Mn (mg/l)		0.05	0.13	0.03
Na (mg/l)		12	26	13
Zn (mg/l)		0.1	NA	NA
URI Metals	Total	Total	T/D	T/D
Cr (ug/l)	0.5	0.5	NA	1/2.5
Cu (ug/l)	3.1	11.9	NA	3.1/9
Cd(ug/l)	0.06	1.27	NA	1.52/9.01
Ni (ug/l)	0.3	2.8	NA	1.9/3.2
Pb (ug/l)	7.4	8.3	NA	2/5.2
pH (Field)		5.3	5	5.7
Temp. (Field)		11	27	1.5
Cond. (Field)		70	200	58
Cond. @ 25 C		95.6	192.6	105.2
DO (Field)		8.5	6.25	3
VOC (ug/l)				
Toluene		0.8	<0.5	<0.5

NA: NOT ANALYSED

T/D: TOTAL/DISSOLVED

Table E-19. Water Quality Results for Duck Pond, Provincetown, MA.

PARAMETER:	NOV. 90'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)		0.2	3.1	<0.1
Bicarbonate (mg/l)		1	3.1	0.9
Ammonia (mg/l)		<0.1	0.3	0.1
Nitrate-N (mg/l)		<0.1	<0.1	<0.1
Ortho-P (mg/l)		0.05	0.01	<0.01
Phosphorus (mg/l)		0.26	0.09	0.01
Chloride (mg/l)		27	57	25
Sulfate (mg/l)		<1.0	3.5	<1.0
COD (mg/l)		73	42	39
BCHED Metals				
Ca (mg/l)		2.3	2.4	2.1
Fe (mg/l)		1.1	0.7	1
Mg (mg/l)		1.9	3.3	1.4
Mn (mg/l)		0.05	0.06	0.06
Na (mg/l)		16	23	11
Zn (mg/l)		0.1	NA	NA
URI Metals	Total	Total	T/D	T/D
Cr (ug/l)	2.1	<0.1	1.6/0.7	1.7/1.5
Cu (ug/l)	2.6	1.5	1.3/0.7	6/2.4
Cd(ug/l)	6.4	0.78	2.16/0.1	0.65/0.63
Ni (ug/l)	31.6	2.3	1.8/0.9	2.7/0.2
Pb (ug/l)	0.42	1.9	1.2/0.2	4.1/3.9
pH (Field)		9	5.45	4.9
Temp. (Field)		20	20.2	4.8
Cond. (Field)		119	162	78
Cond. @ 25 C		131.6	178.4	127.0
DO (Field)		5.7	6.7	10.9
VOC (ug/l)		<0.5	<0.5	<0.5

NA: NOT ANALYSED

T/D: TOTAL/DISSOLVED

Table E-20. Water Quality Results for Great Pond, Provincetown, MA.

PARAMETER:	NOV. 90'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)		<0.1	1.6	2
Bicarbonate (mg/l)		0.6	1.6	2.3
Ammonia (mg/l)		0.1	0.1	0.1
Nitrate-N (mg/l)		<0.4	<0.1	0.2
Ortho-P (mg/l)		0.03	0.04	0.05
Phosphorus (mg/l)		0.28	0.09	0.07
Chloride (mg/l)		29	43	31
Sulfate (mg/l)		16.8	15.7	<1.0
COD (mg/l)		31	12	32
BCHED Metals				
Ca (mg/l)		2.8	4.1	1.8
Fe (mg/l)		0.7	0.4	1
Mg (mg/l)		1.7	2.6	1.6
Mn (mg/l)		0.02	0.04	0.02
Na (mg/l)		12	15	9
Zn (mg/l)		<0.1	NA	NA
URI Metals	Total	Total	T/D	T/D
Cr (ug/l)	0.6	0.1	0.4/0.4	1.5/2.4
Cu (ug/l)	2.3	3.3	3.2/5.1	5.1/4.4
Cd(ug/l)	0.09	0.21	0.44/0.43	0.82/1.06
Ni (ug/l)	0.7	1.8	8.2/2.7	2.1/1.5
Pb (ug/l)	11.9	8.9	4.5/4.4	13.5/8.9
pH (Field)		5.7	6.2	4.9
Temp. (Field)		12.5	28	2.5
Cond. (Field)		78	182	54
Cond. @ 25 C		102.5	172.1	94.7
DO (Field)		12.7	10.2	11
VOC (ug/l)				
Chloroform		<0.5	<0.5	1.6

NA: NOT ANALYSED

T/D: TOTAL/DISSOLVED

Table E-21. Water Quality Results for Little Bennett Pond, Provincetown, MA.

PARAMETER:	NOV. 90'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)		<0.1	<0.1	<0.1
Bicarbonate (mg/l)		1.9	<0.1	<0.1
Ammonia (mg/l)		<0.1	0.4	0.1
Nitrate-N (mg/l)		<0.2	<0.1	0.3
Ortho-P (mg/l)		<0.01	0.01	0.04
Phosphorus (mg/l)		0.24	0.08	<0.01
Chloride (mg/l)		24	51	20
Sulfate (mg/l)		<1.0	9.3	6.6
COD (mg/l)		51	92	19
BCHED Metals				
Ca (mg/l)		0.8	1.8	1
Fe (mg/l)		0.8	9.1	0.3
Mg (mg/l)		1.8	3.4	1.2
Mn (mg/l)		0.05	0.11	0.03
Na (mg/l)		12	20	8
Zn (mg/l)		<0.1	NA	NA
URI Metals	Total	Total	T/D	T/D
Cr (ug/l)	0.3	0.4	0.9/0.4	1.1/1.5
Cu (ug/l)	4.2	7.6	2.7/13.1	3.3/7.2
Cd(ug/l)	0.11	0.8	0.72/1.34	0.13/0.87
Ni (ug/l)	ND	41.8	1.6/4.4	2.4/1.9
Pb (ug/l)	2	7.1	10.2/8.9	1.9/3.4
pH (Field)		5.4	5.1	4.9
Temp. (Field)		15.5	22.5	1.9
Cond. (Field)		73	155	40
Cond. @ 25 C		89.2	162.8	71.6
DO (Field)		12.2	10.6	10.8
VOC (ug/l)				
Chloroform		<0.5	<0.5	0.6

NA: NOT ANALYSED

T/D: TOTAL/DISSOLVED

Table E-22. Water Quality Results for Station 7, (unnamed pond)

PARAMETER:	FEB. 91'	APR. 91'	AUG. 91'	FEB. 92'
Alkalinity (mg/l)		<0.1	<0.1	<0.1
Bicarbonate (mg/l)		<0.1	<0.1	<0.1
Ammonia (mg/l)		<0.1	0.2	0.1
Nitrate-N (mg/l)		<0.2	<0.1	<0.1
Ortho-P (mg/l)		0.01	<0.01	<0.01
Phosphorus (mg/l)		0.28	0.07	0.04
Chloride (mg/l)		30	60	18
Sulfate (mg/l)		9.1	8.2	4.7
COD (mg/l)		41	19	15
BCHED Metals				
Ca (mg/l)		0.7	1.9	0.9
Fe (mg/l)		0.8	0.3	0.1
Mg (mg/l)		1.7	3.2	1.8
Mn (mg/l)		0.05	0.07	<0.01
Na (mg/l)		12	16	13
Zn (mg/l)		<0.1	NA	NA
URI Metals		Total	T/D	T/D
Cr (ug/l)		ND	0.4/0.1	0.9/1.8
Cu (ug/l)		3.2	1.8/5.3	4.2/2.6
Cd(ug/l)		0.24	0.23/0.47	0.72/0.59
Ni (ug/l)		6.5	1.9/3.7	7.6/2
Pb (ug/l)		2.9	3.9/3.3	1.4/3.5
pH (Field)		5.1	4.4	4.7
Temp. (Field)		13	26.2	6
Cond. (Field)		65	205	202
Cond. @ 25 C		84.3	200.4	317.1
DO (Field)		9.9	6.8	9.4
VOC (ug/l)		<0.5	<0.5	<0.5

NA: NOT ANALYSED

T/D: TOTAL/DISSOLVED

Table E-23. Water Quality Results for Truro Tap Water, Town Hall, Provincetown, MA.

PARAMETER:	FEBRUARY 1992
Alkalinity (mg/l)	9
Bicarbonate (mg/l)	0.76
Ammonia (mg/l)	0.2
Nitrate-N (mg/l)	0.5
Ortho-P (mg/l)	0.03
Phosphorus (mg/l)	0.19
Chloride (mg/l)	96
Sulfate (mg/l)	10.6
COD (mg/l)	8
BCHED Metals	
Ca (mg/l)	4.5
Fe (mg/l)	0.1
Mg (mg/l)	6
Mn (mg/l)	0.05
Na (mg/l)	29
URI Metals	
Cr (ug/l)	1.3
Cu (ug/l)	291
Cd(ug/l)	1.93
Ni (ug/l)	4.5
Pb (ug/l)	4.6
pH (Field)	6.01
Temp. (Field)	9.5
Cond. (Field)	178
Cond. @ 25 C	252.9
DO (Field)	5.6
VOC (ug/l)	
Chloroform	0.9

NA: NOT ANALYSED

Table E-24. Water Quality Results for Cape Cod Bay Water, Provincetwon, MA.

PARAMETER:	FEBRUARY 1992	
	HARBOR - H.T.	HARBOR - L.T.
Alkalinity (mg/l)	103	107
Bicarbonate (mg/l)	104.3	107.2
Ammonia (mg/l)	0.1	0.6
Nitrate-N (mg/l)	NA	NA
Ortho-P (mg/l)	0.06	0.05
Phosphorus (mg/l)	0.1	0.13
Chloride (mg/l)	18500	17000
Sulfate (mg/l)	1956	2060
COD (mg/l)	>150	>150
BCHED Metals		
Ca (mg/l)	322	345
Fe (mg/l)	0.2	0.6
Mg (mg/l)	1105	1112
Mn (mg/l)	0.03	0.05
Na (mg/l)	14500	14200
URI Metals		
Cr (ug/l)	0.6	1.8
Cu (ug/l)	1	1.1
Cd(ug/l)	>6.0	0.44
Ni (ug/l)	<0.1	<0.1
Pb (ug/l)	<0.1	<0.1
pH (Field)	8.24	7.88
Temp. (Field)	1.11	2
Cond. (Field)	25200	23200
Cond. @ 25 C	46349.0	41376.9
DO (Field)	13.2	13.2
VOC (ug/l)	<0.5	<0.5

NA: NOT ANALYSED

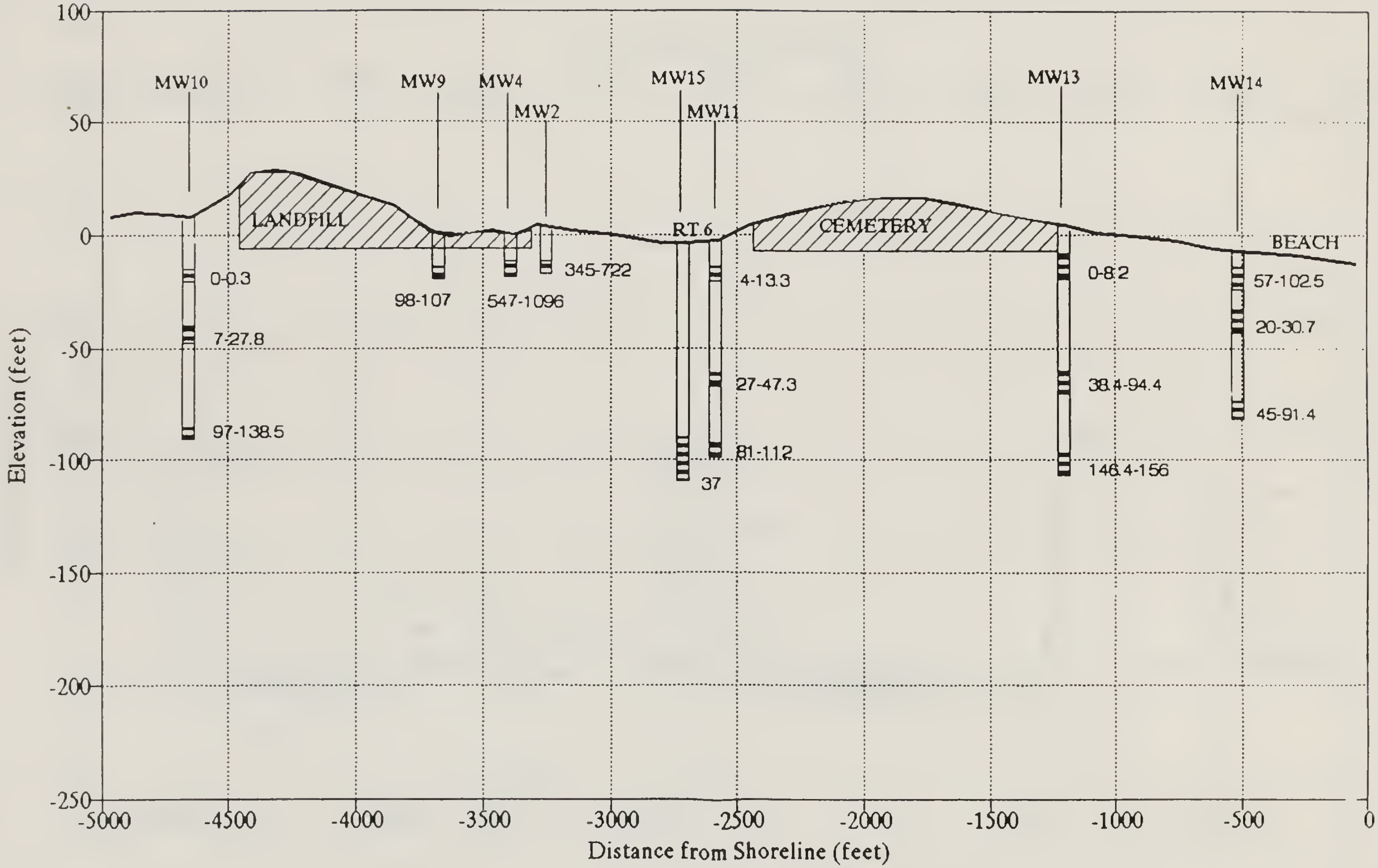


Fig. E-1. Alkalinity (mg/L) concentrations along the flowpath.

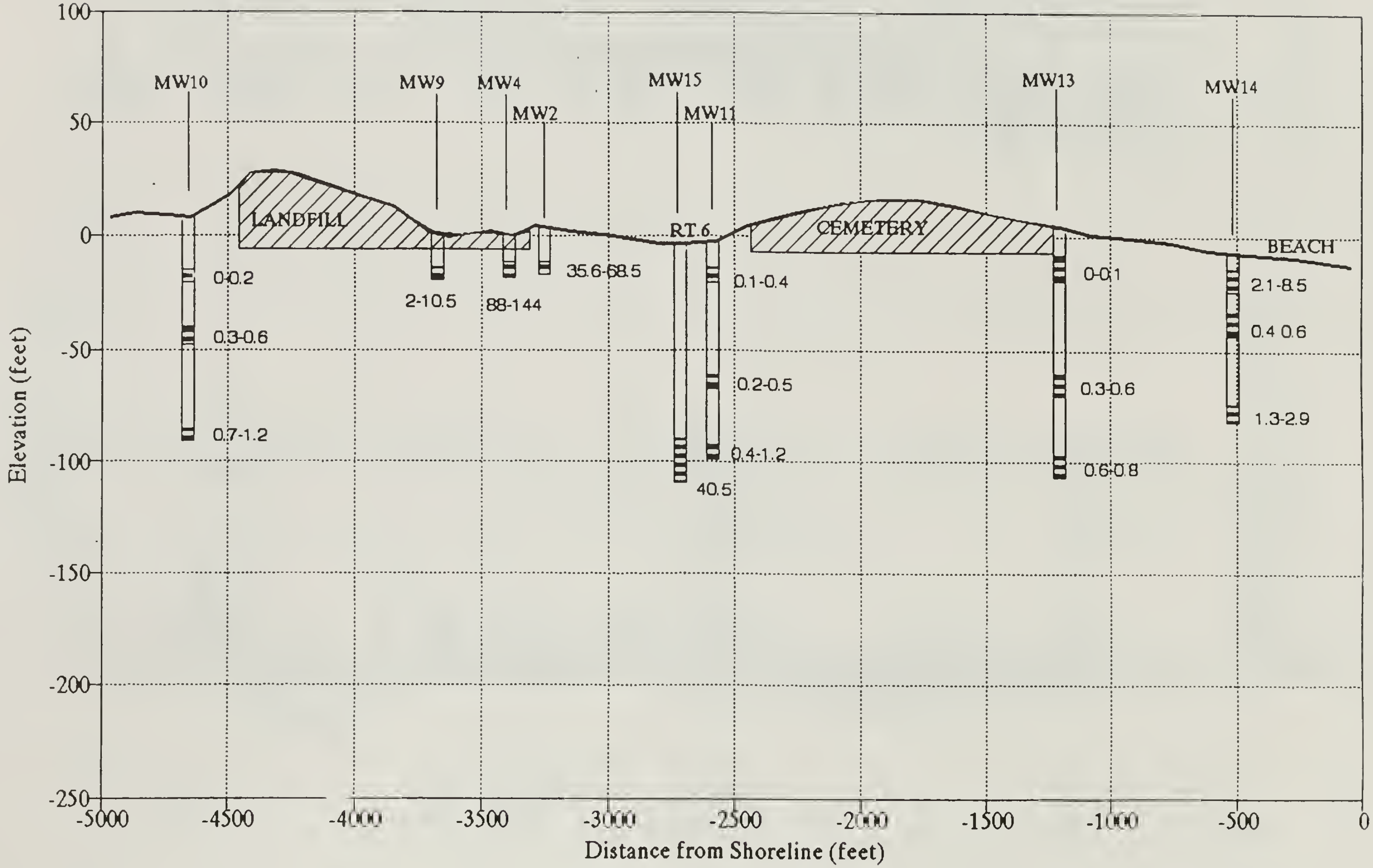


Fig. E-2. Ammonia-N (mg/L) concentrations along the flowpath.

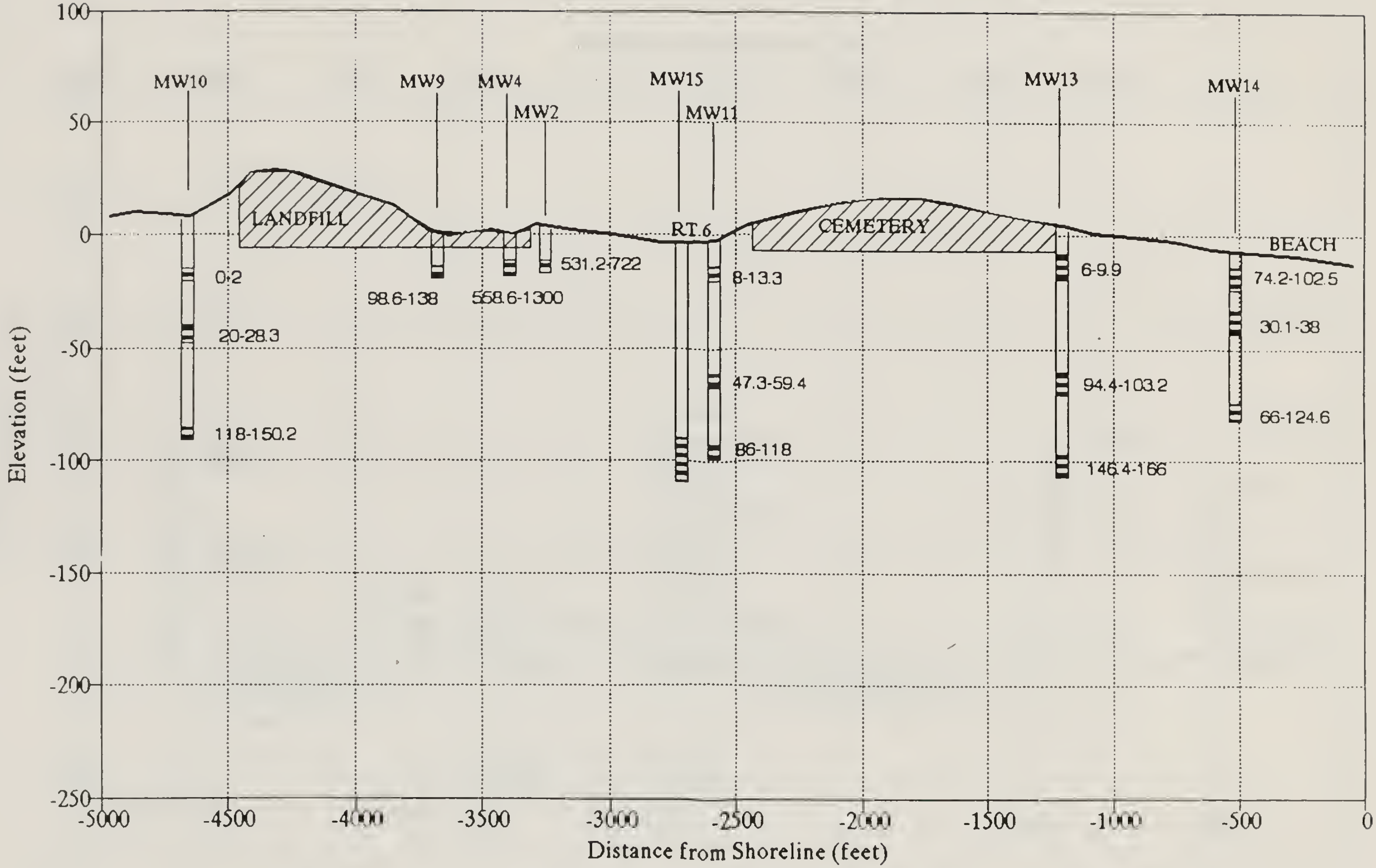


Fig. E-3. Bicarbonate (mg/L) concentrations along the flowpath.

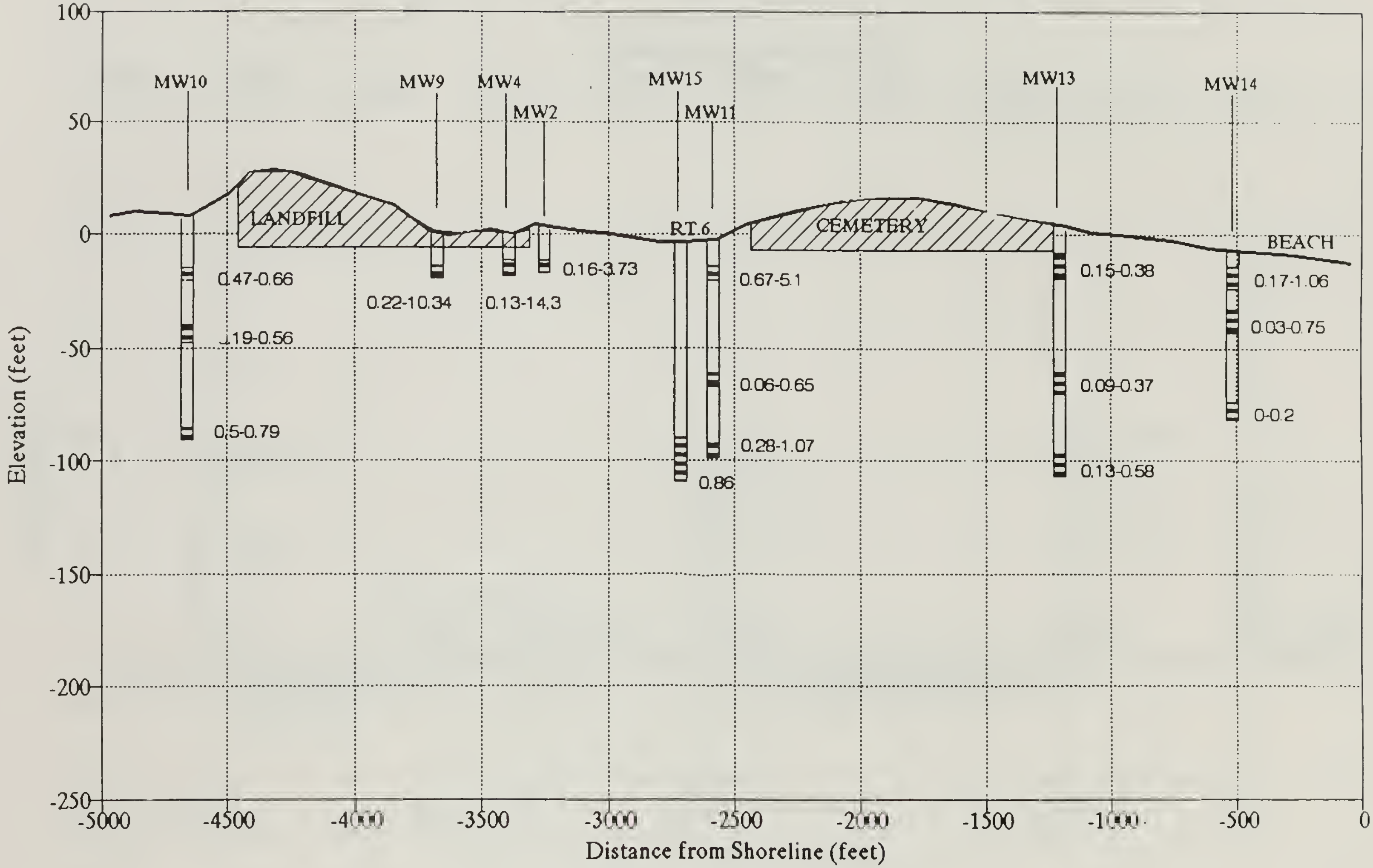


Fig. E-4. Cadmium (ug/L) concentrations along the flowpath.

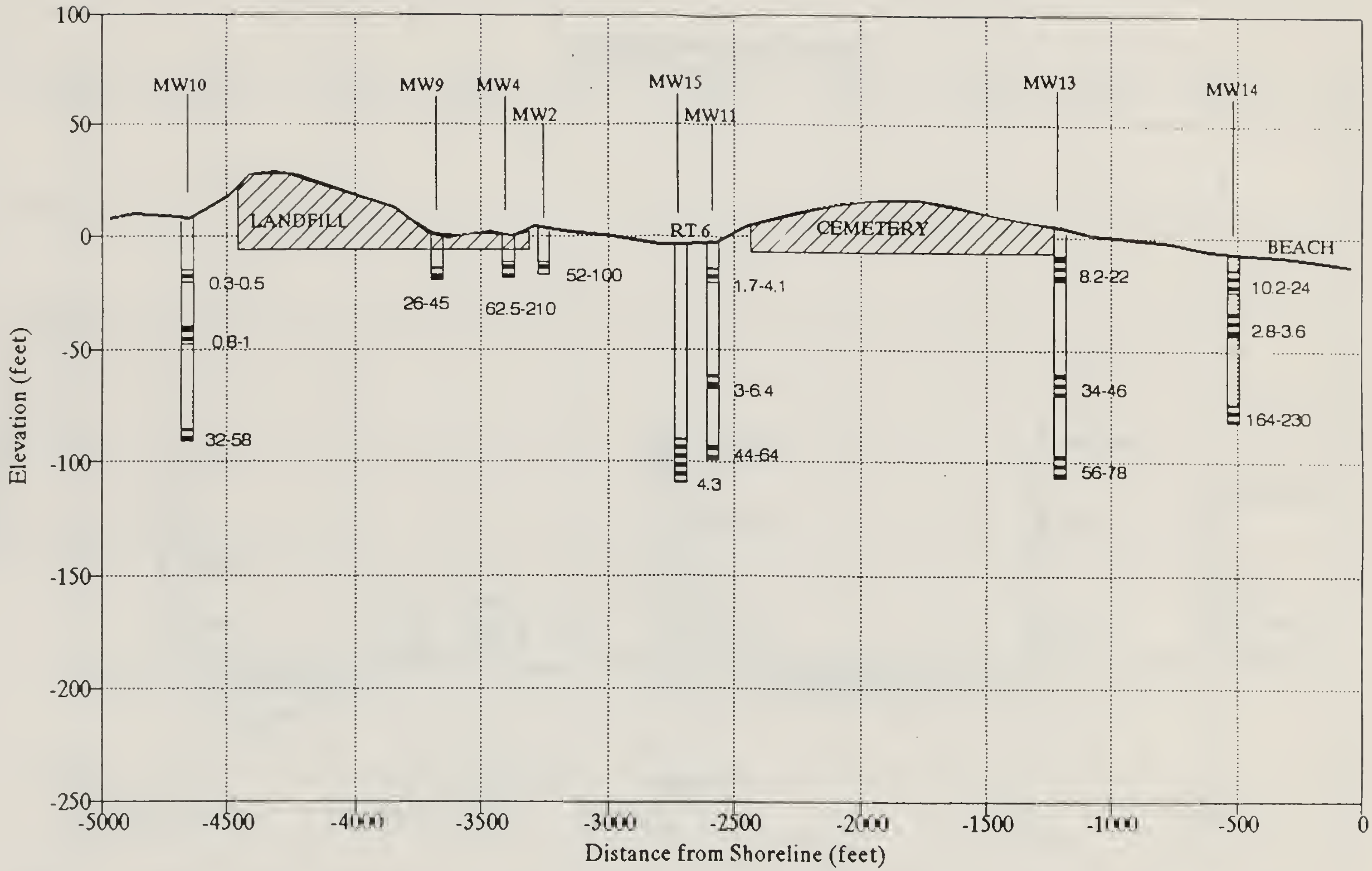


Fig. E-5. Calcium (mg/L) concentrations along the flowpath.

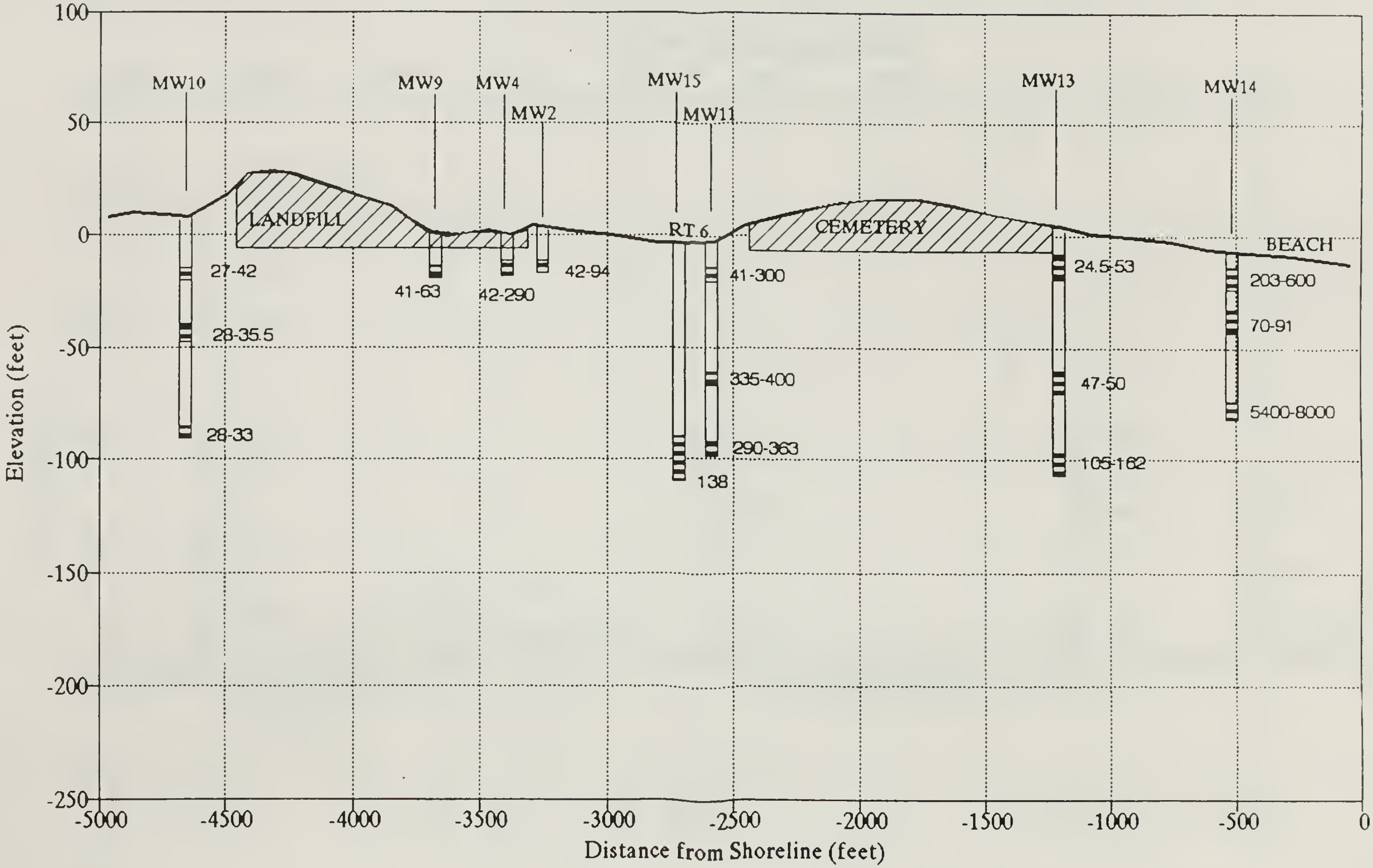


Fig. E-6. Chloride (mg/L) concentrations along the flowpath.

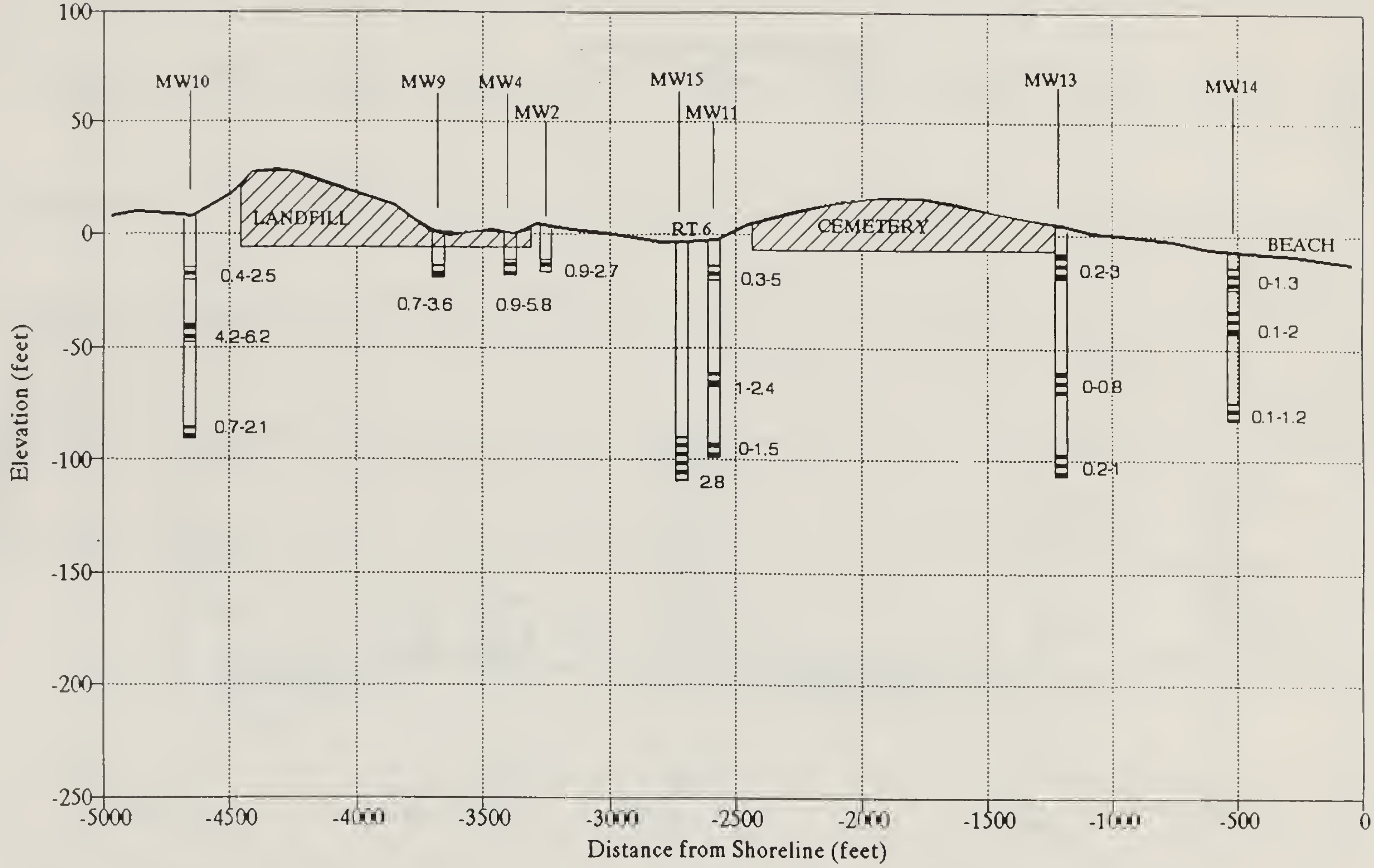


Fig. E-7. Chromium (ug/L) concentrations along the flowpath.

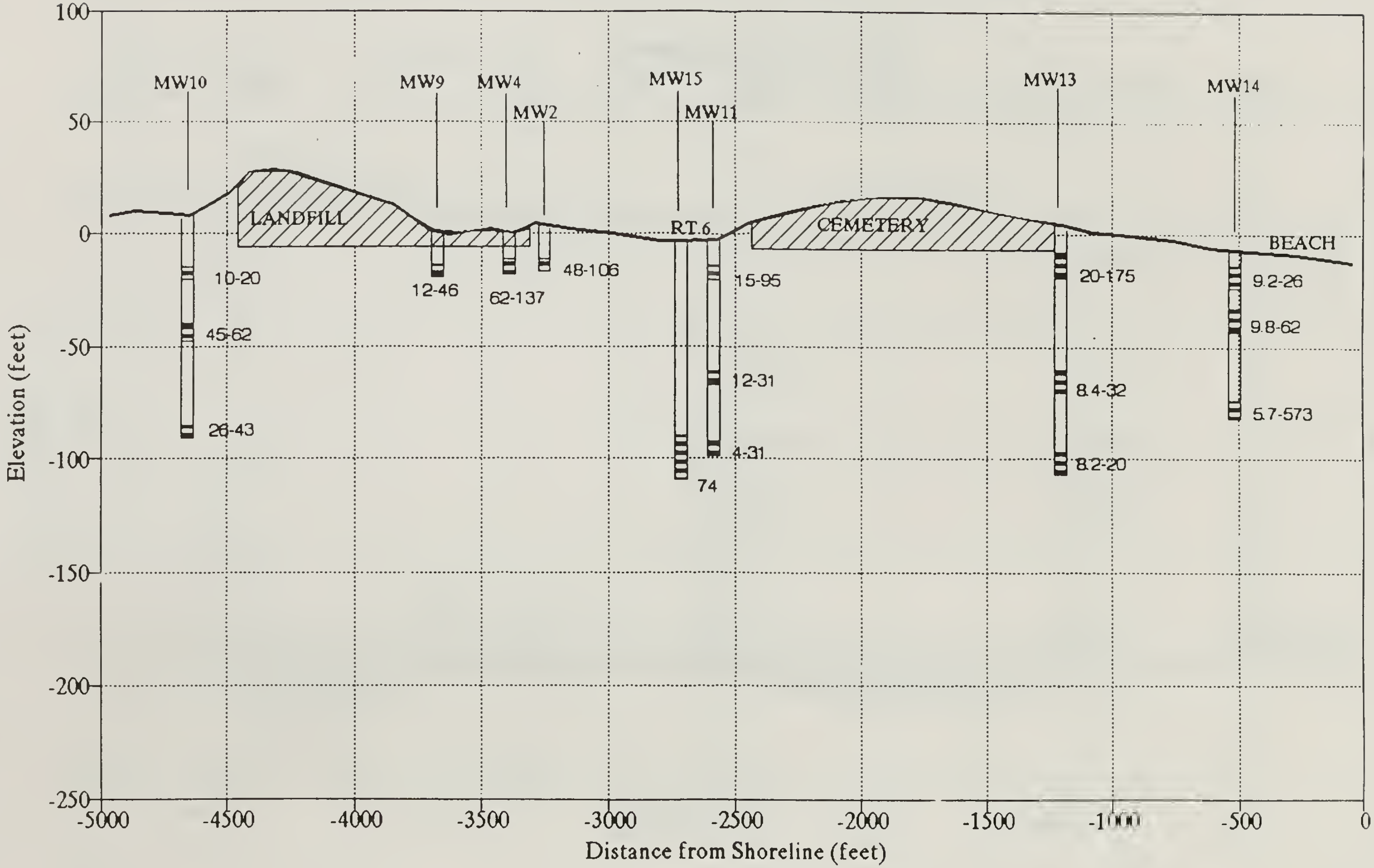


Fig. E-8. COD (mg/L) concentrations along the flowpath.

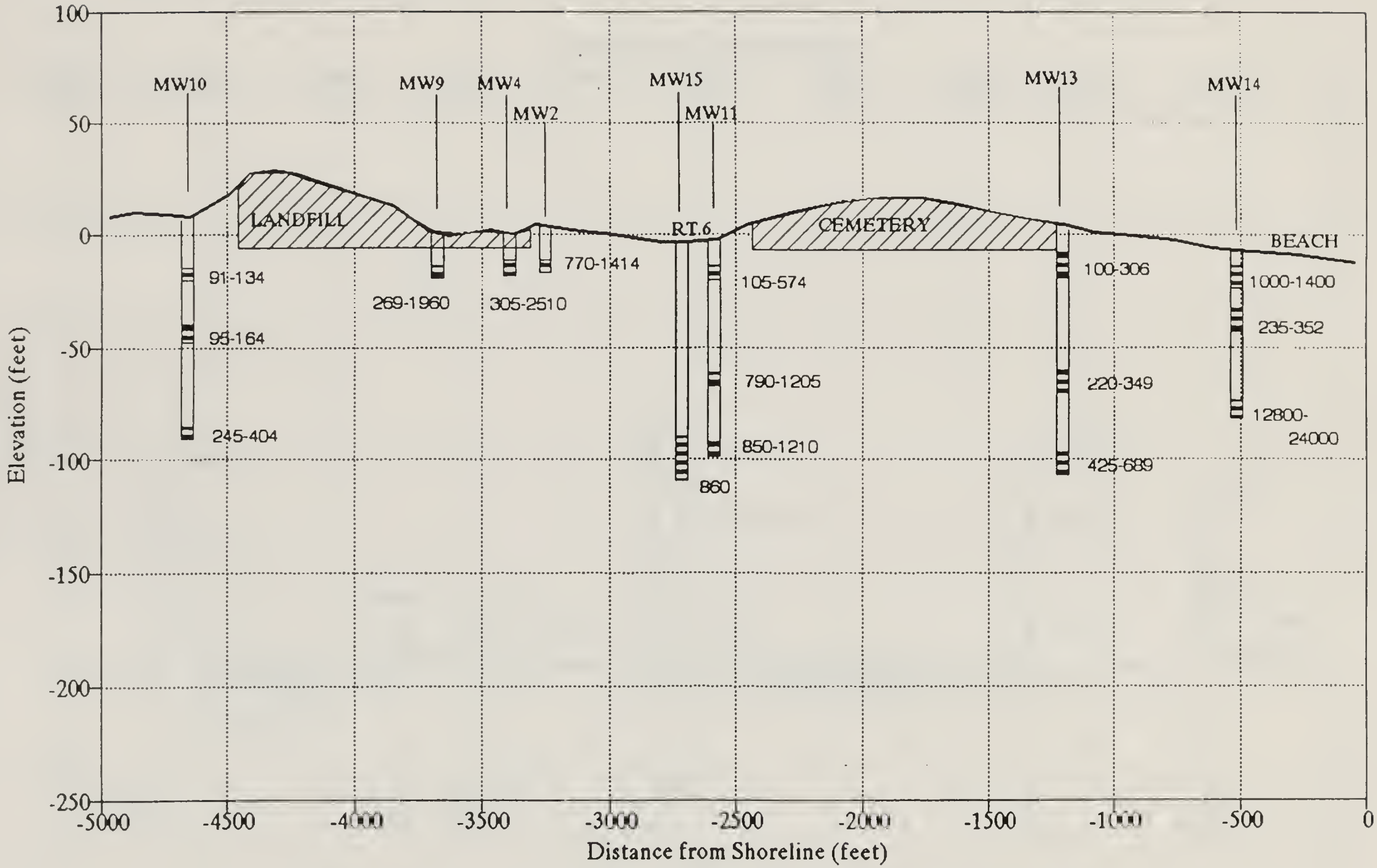


Fig. E-9. Conductivity (uS/cm) concentrations along the flowpath.

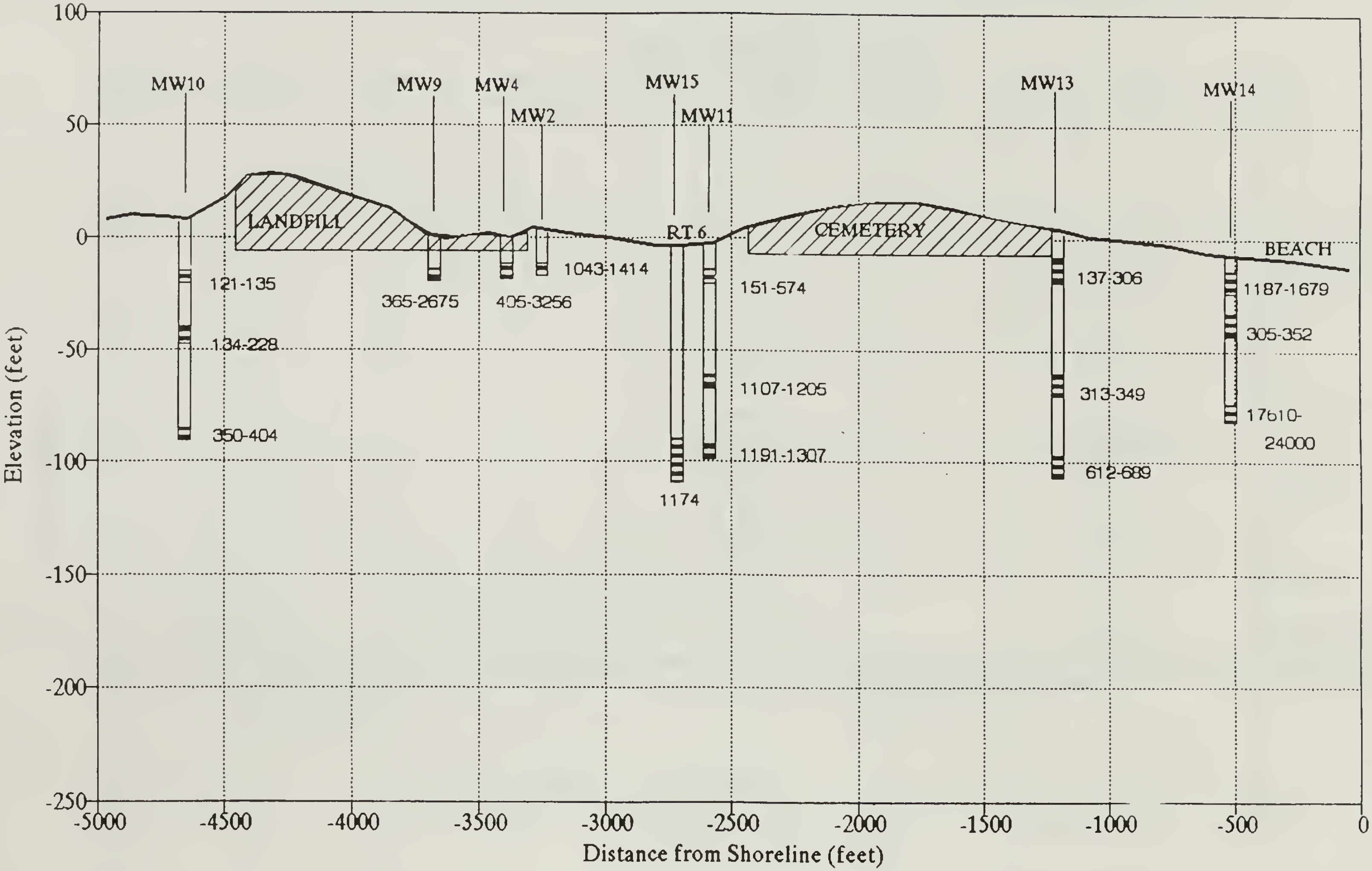


Fig. E-10. Conductivity (uS/cm) @ 25 C concentrations along the flowpath.

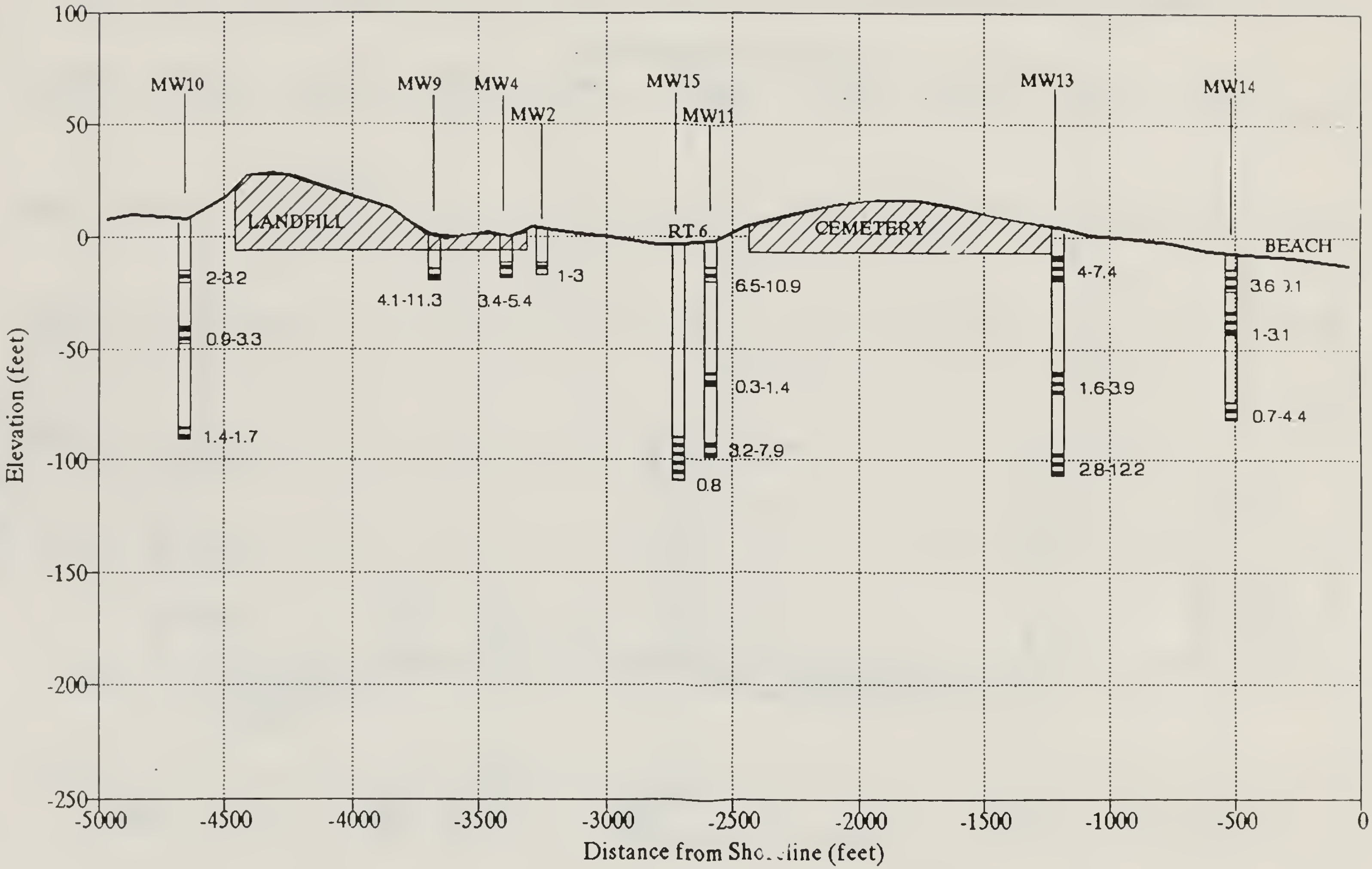


Fig. E-11. Copper (ug/L) concentrations along the flowpath.

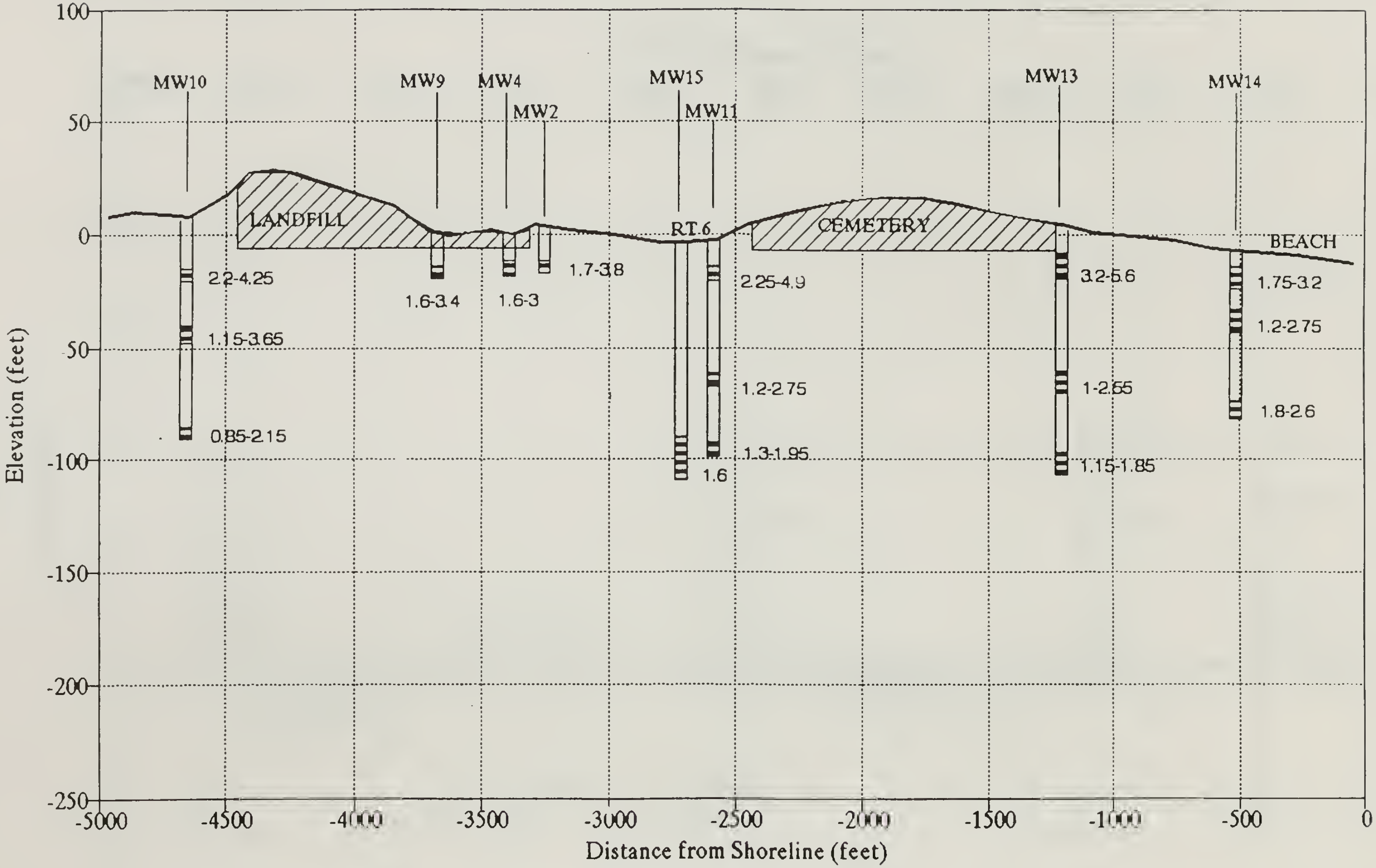


Fig. E-12. Dissolved oxygen (mg/L) concentrations along the flowpath.

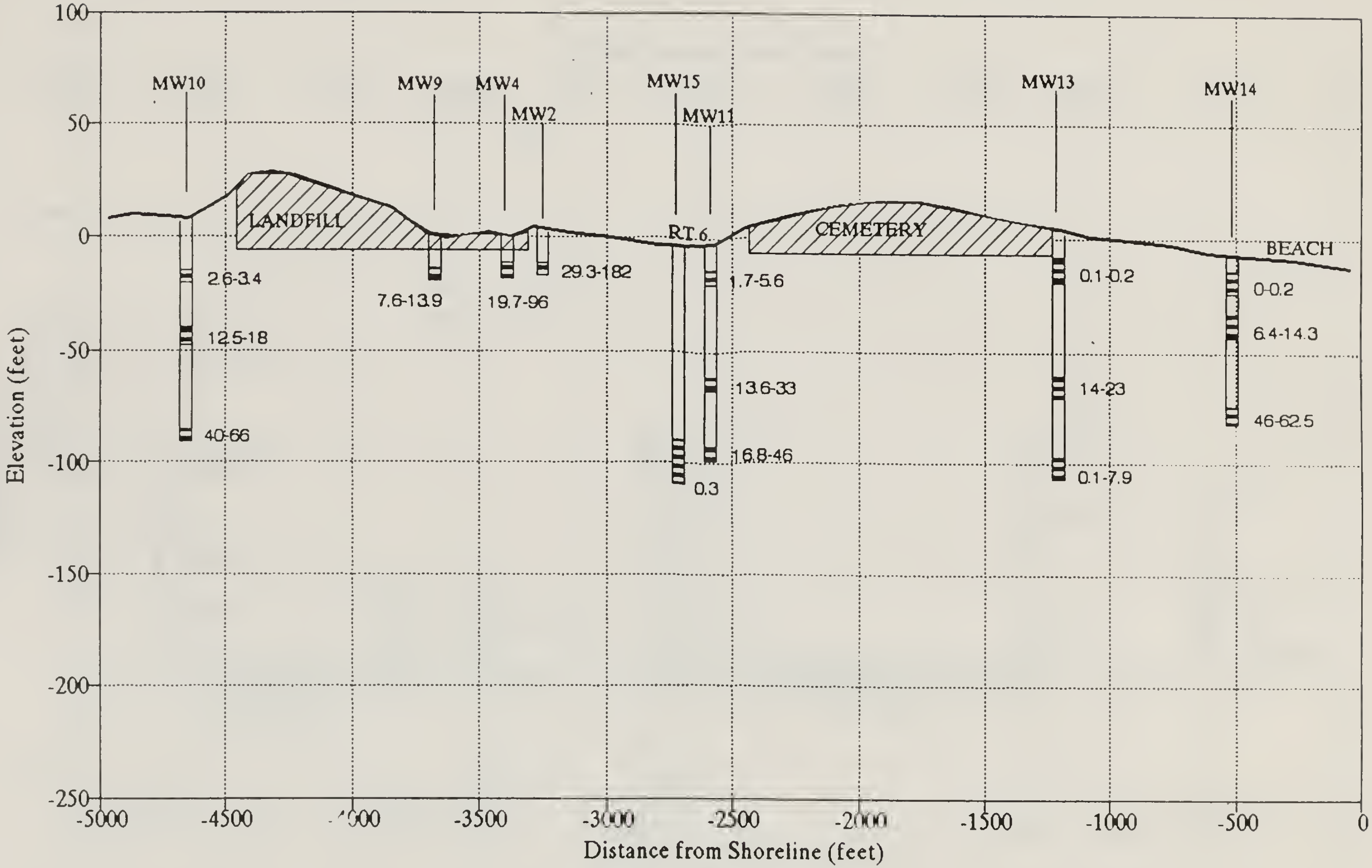


Fig. E-13. Iron (mg/L) concentrations along the flowpath.

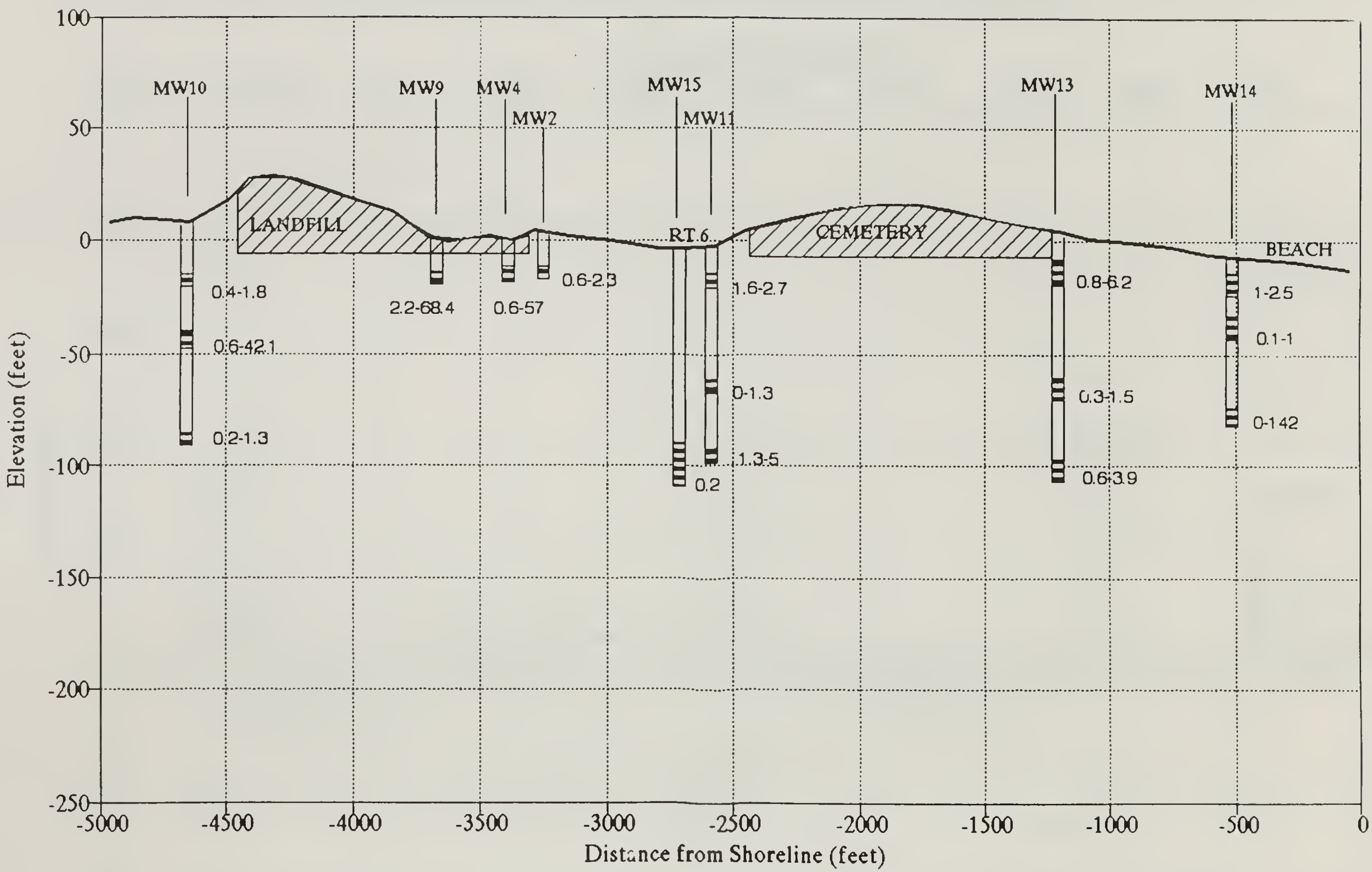


Fig. E-14. Lead (ug/L) concentrations along the flowpath.

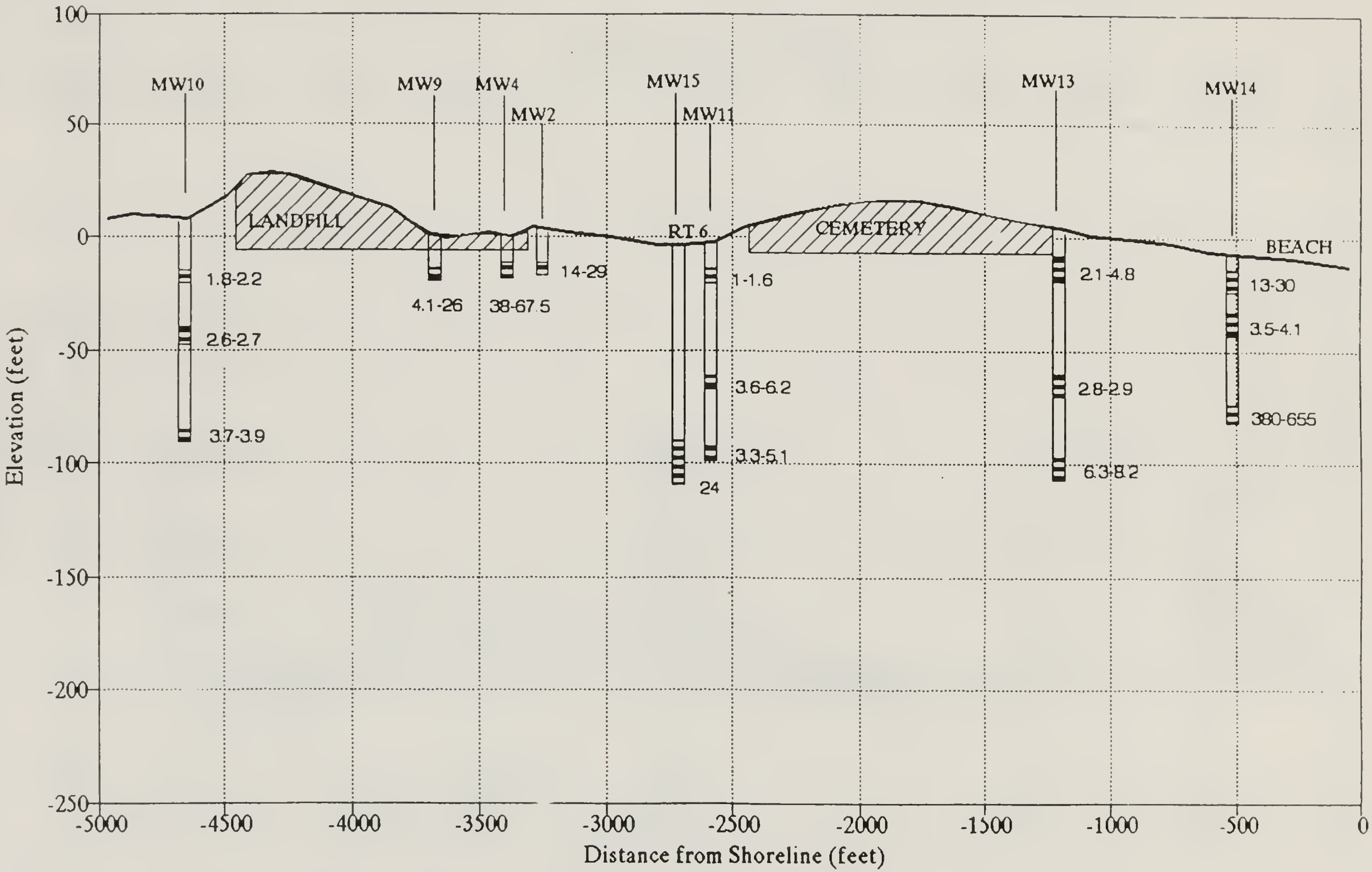


Fig. E-15. Magnesium (mg/L) concentrations along the flowpath.

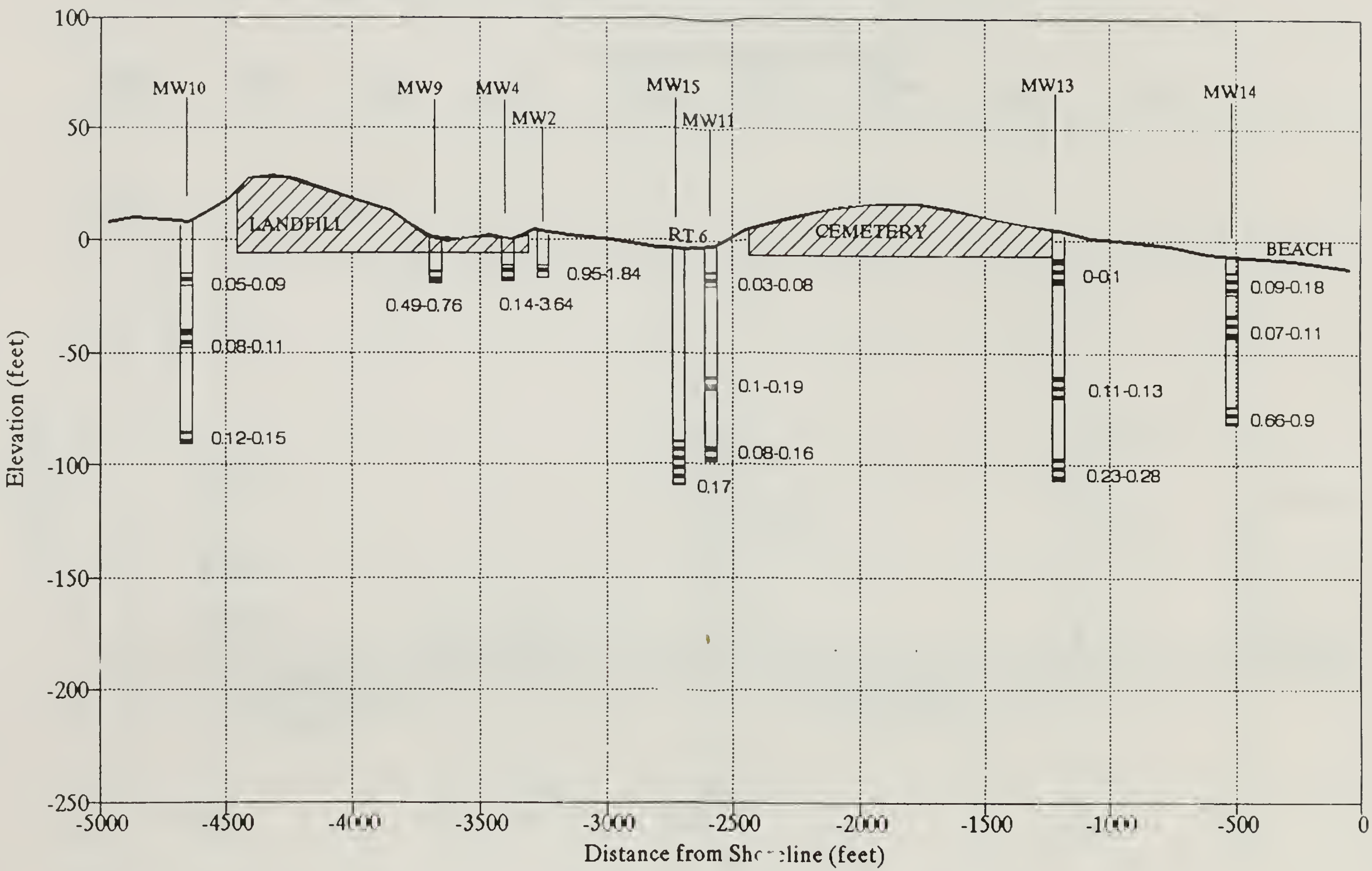


Fig. E-16. Manganese (mg/L) concentrations along the flowpath.

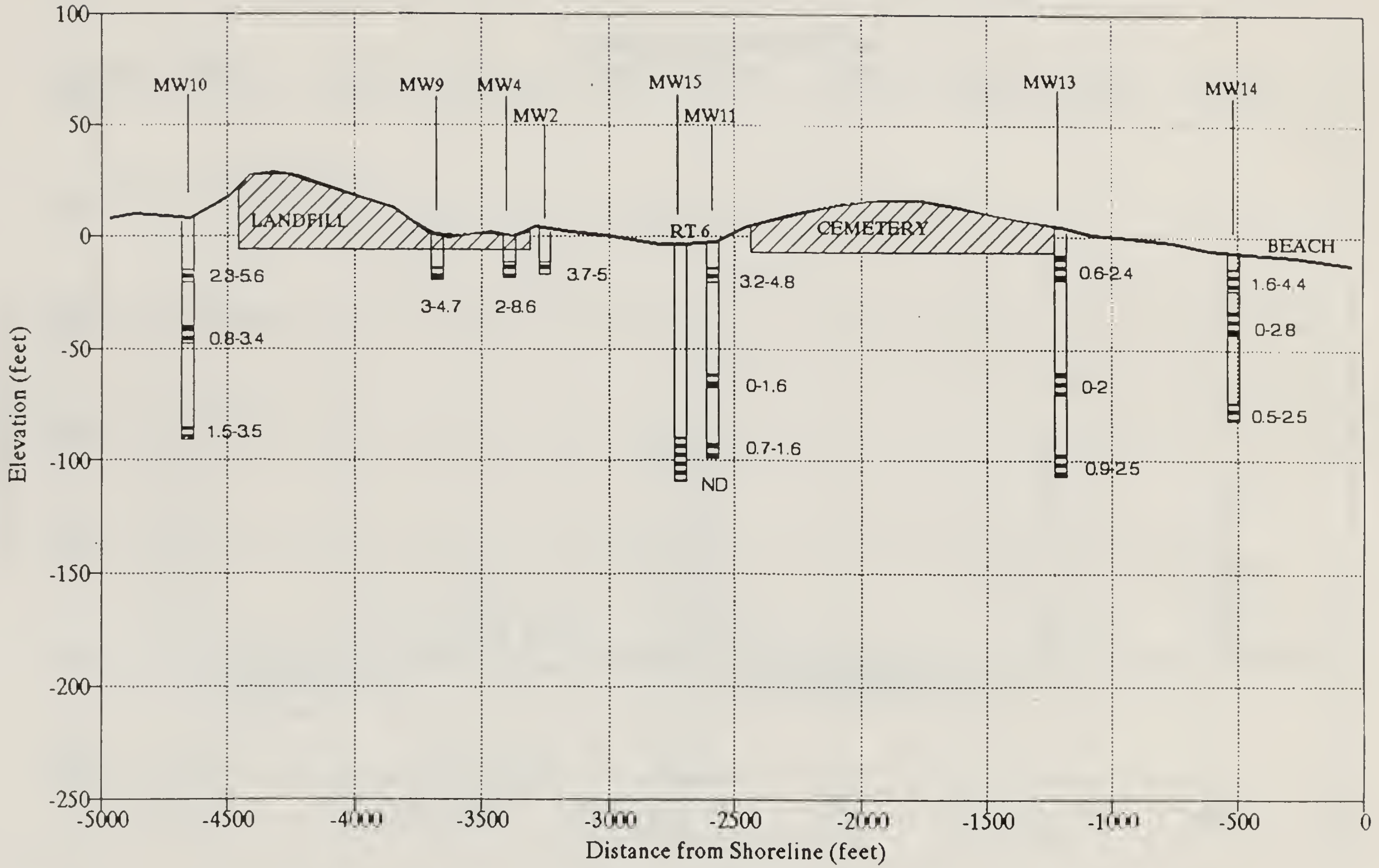


Fig. E-17. Nickel (ug/L) concentrations along the flowpath.

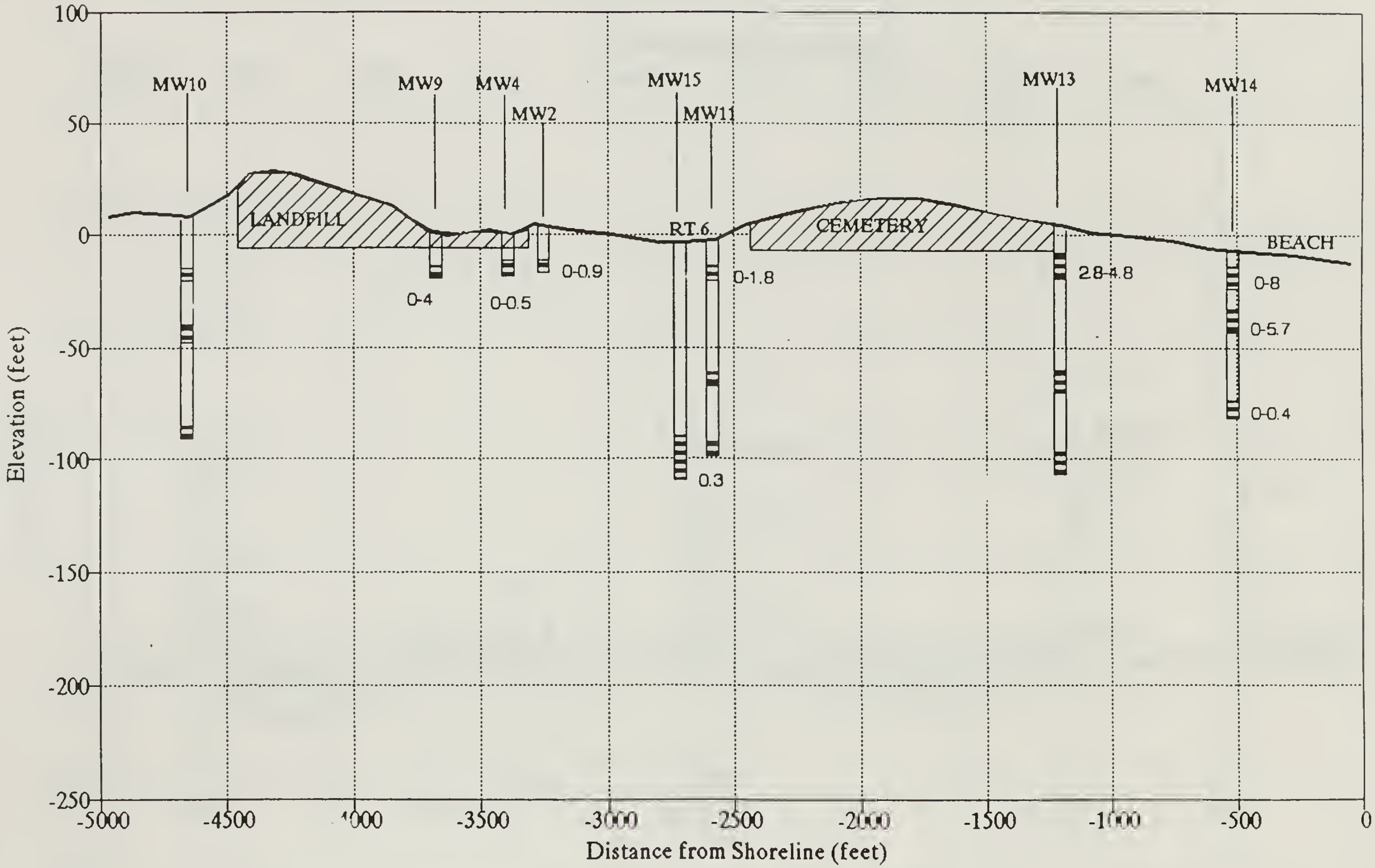


Fig. E-18. Nitrate-N (mg/L) concentrations along the flowpath.

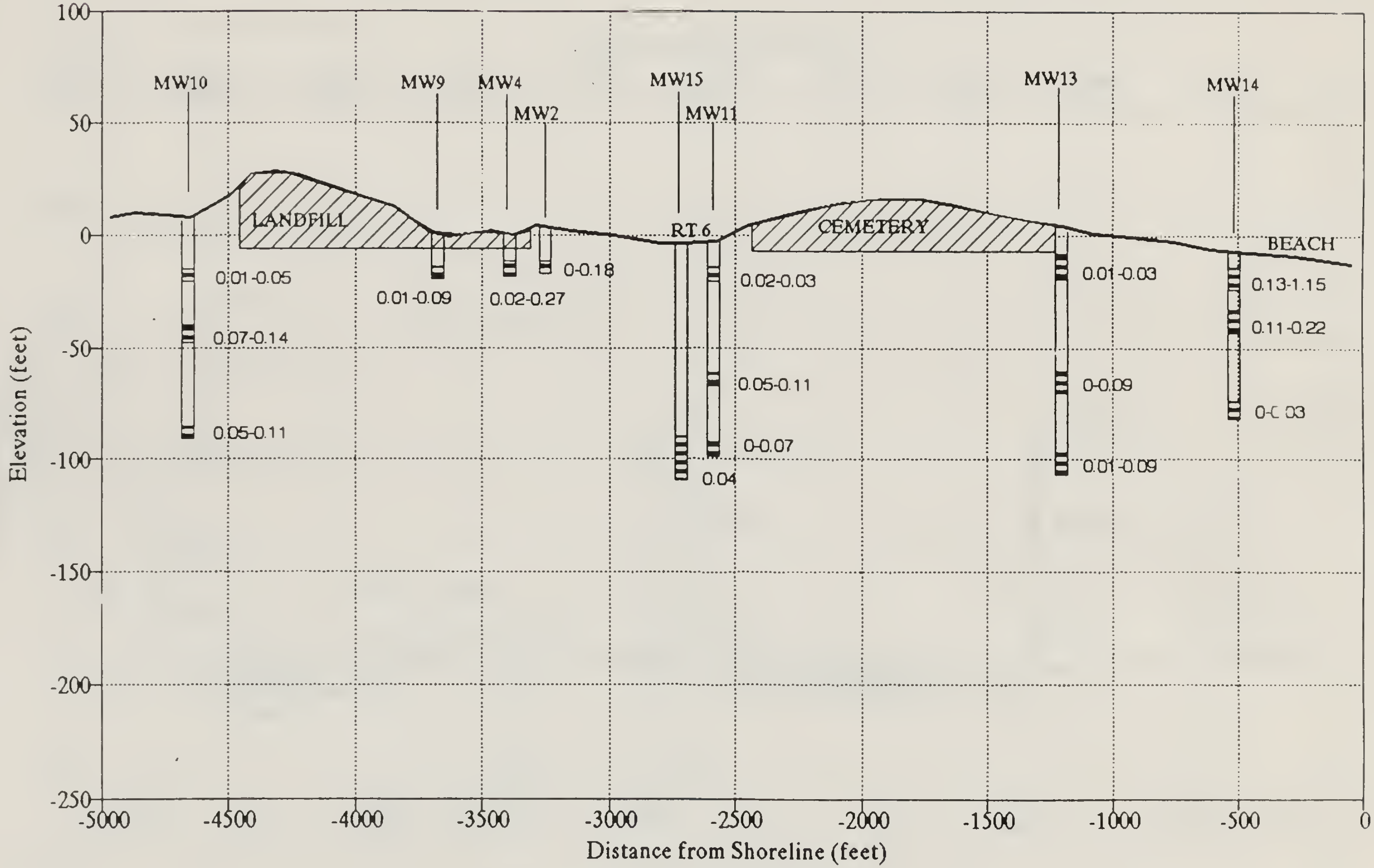


Fig. E-19. Ortho-P (mg/L) concentrations along the flowpath.

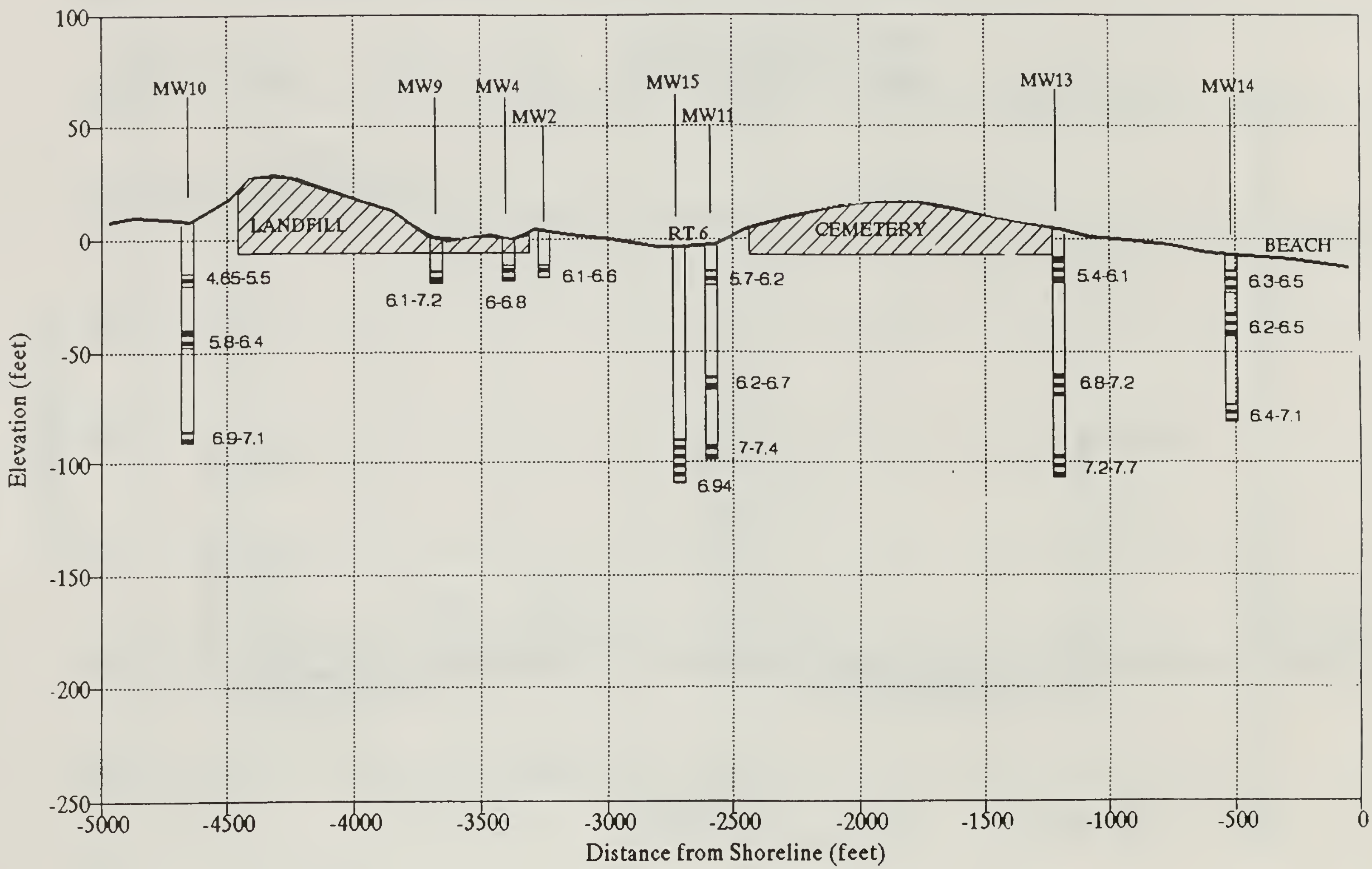


Fig. E-20. pH concentrations along the flowpath.

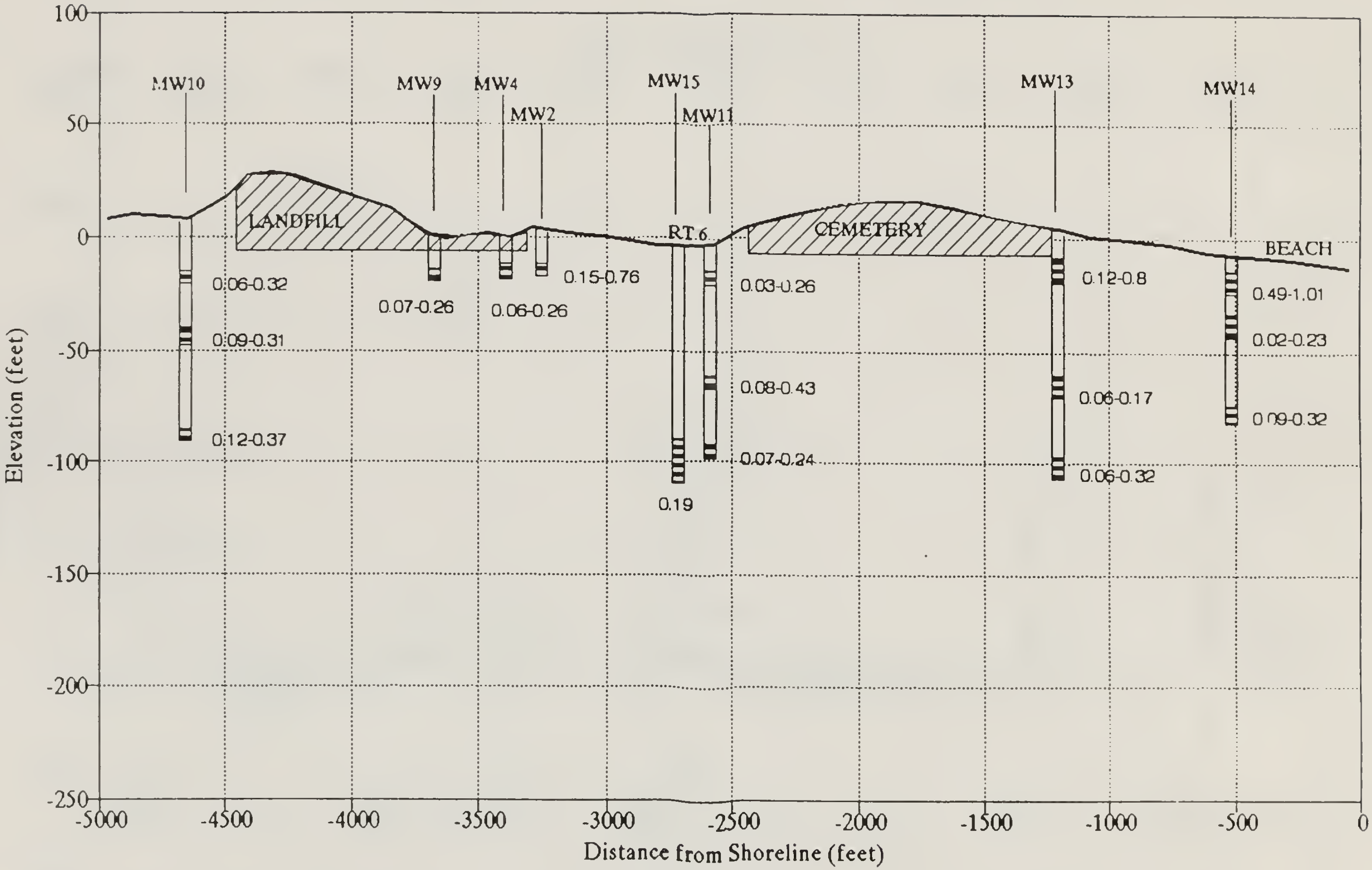


Fig. E-21 Phosphorus (mg/L) concentrations along the flowpath.

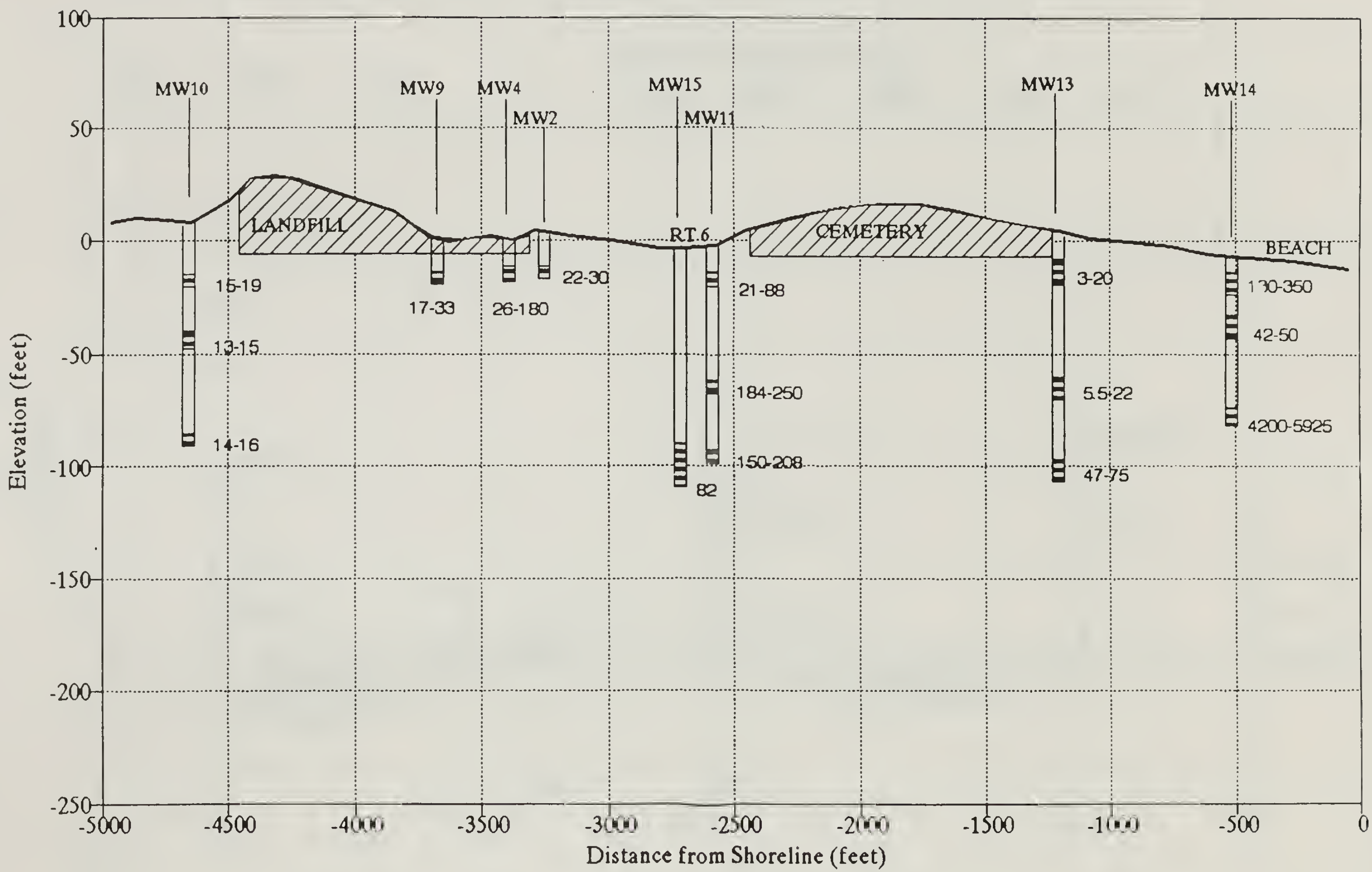


Fig. E-22. Sodium (mg/L) concentrations along the flowpath.

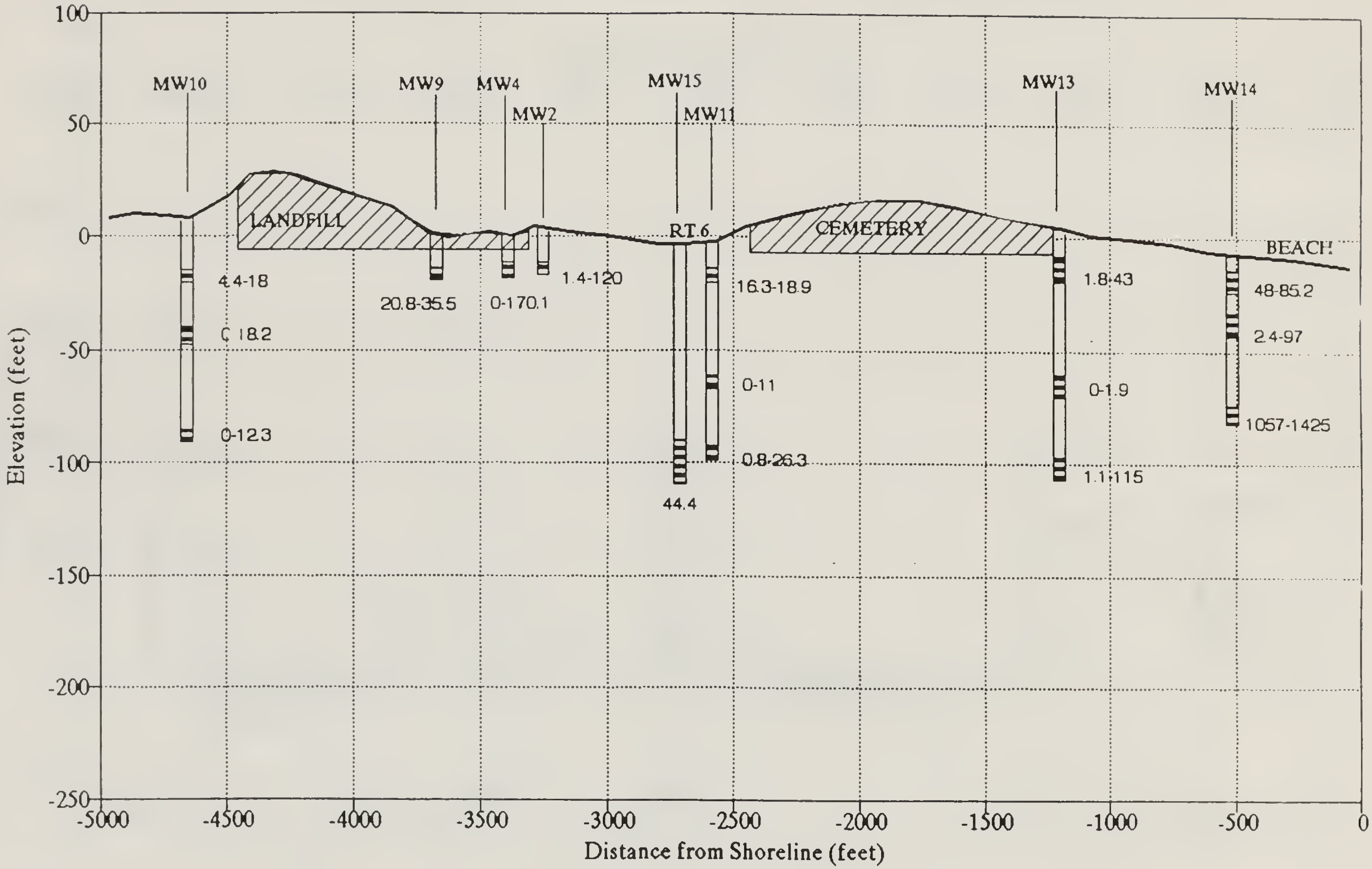


Fig. E-23. Sulfate (mg/L) concentrations along the flowpath.

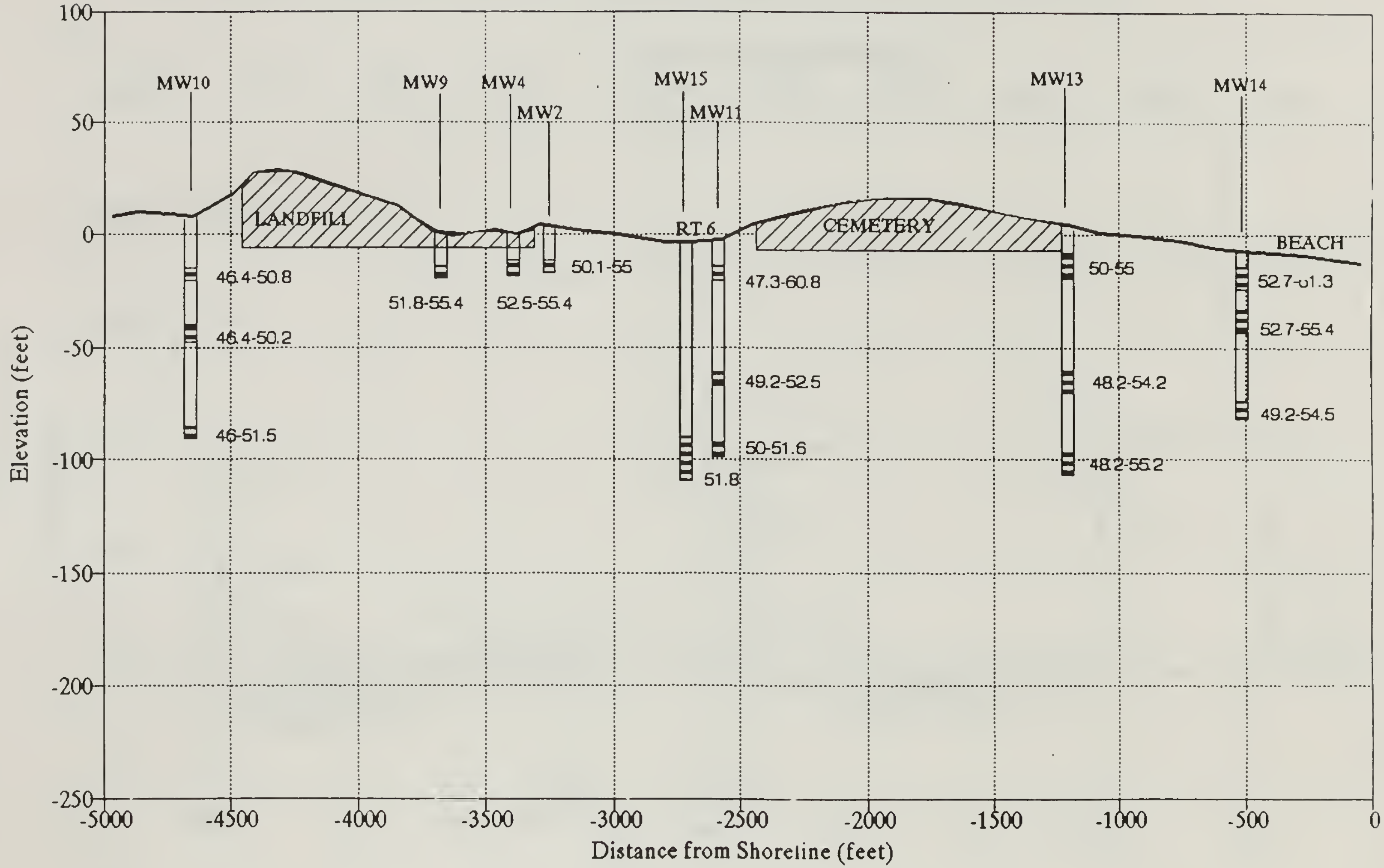


Fig. E-24. Temperature (C) concentrations along the flowpath.

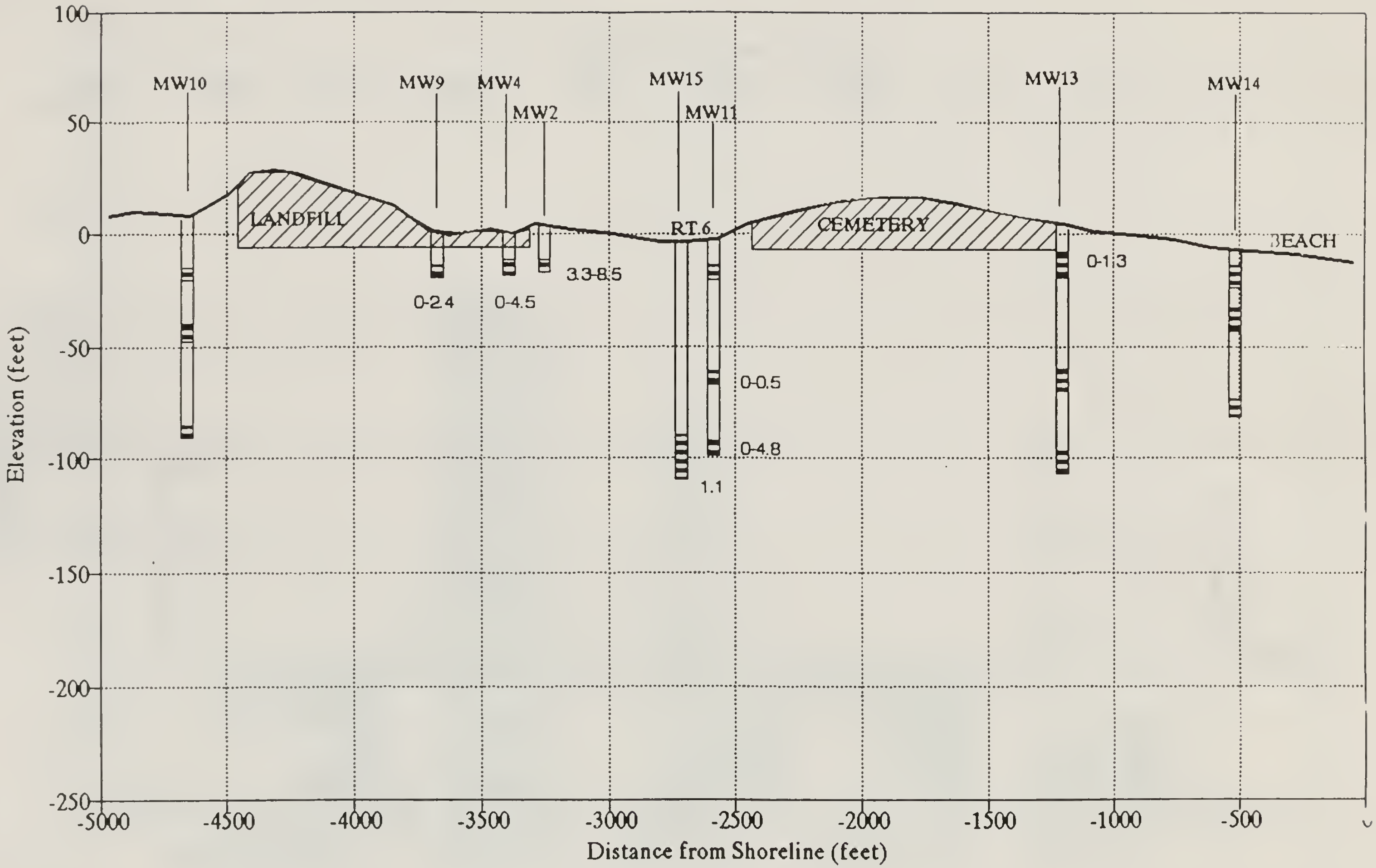


Fig. E-25. VOC (ug/L) concentrations along the flowpath.

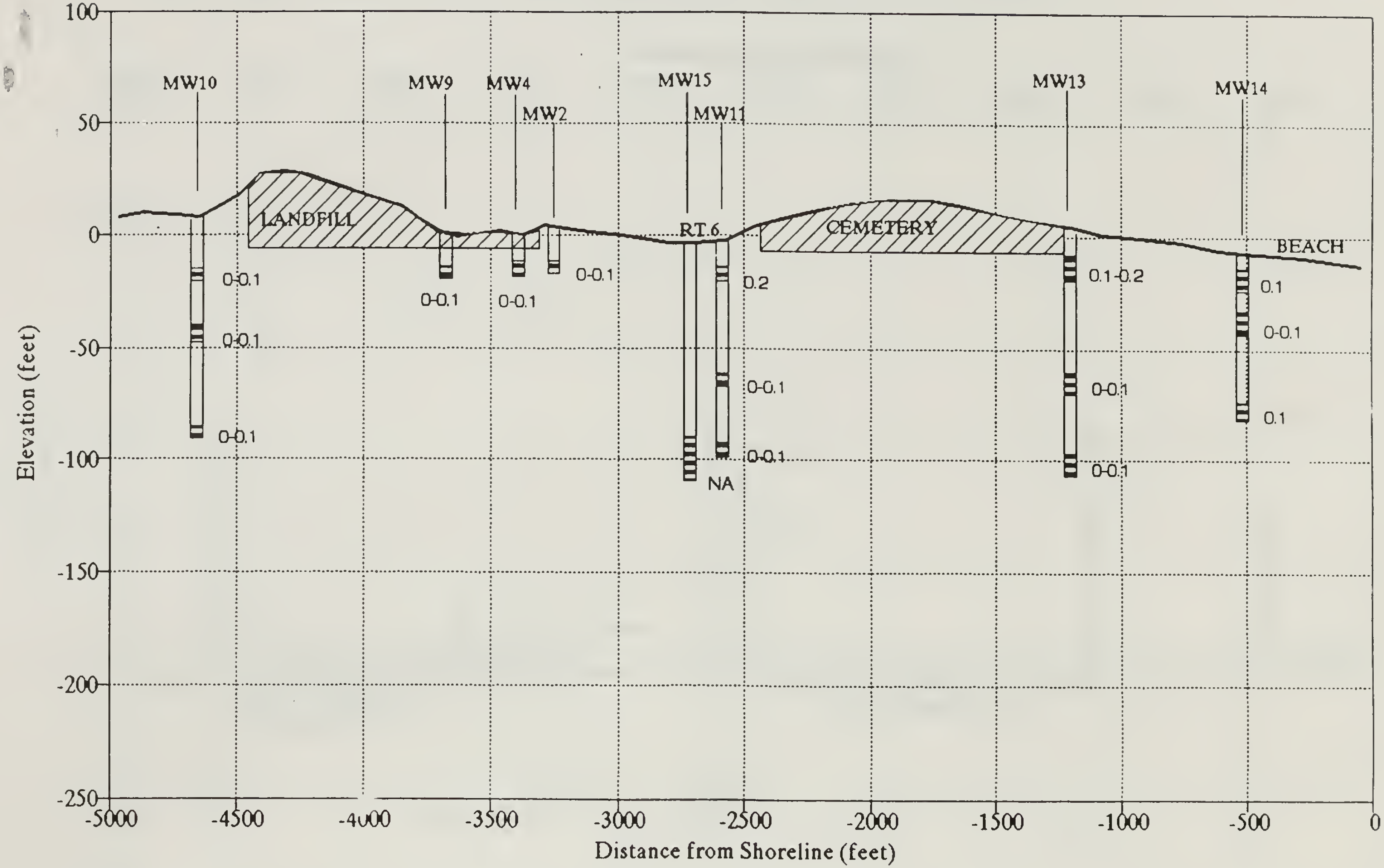


Fig. E-26. Zinc (mg/L) concentrations along the flowpath.

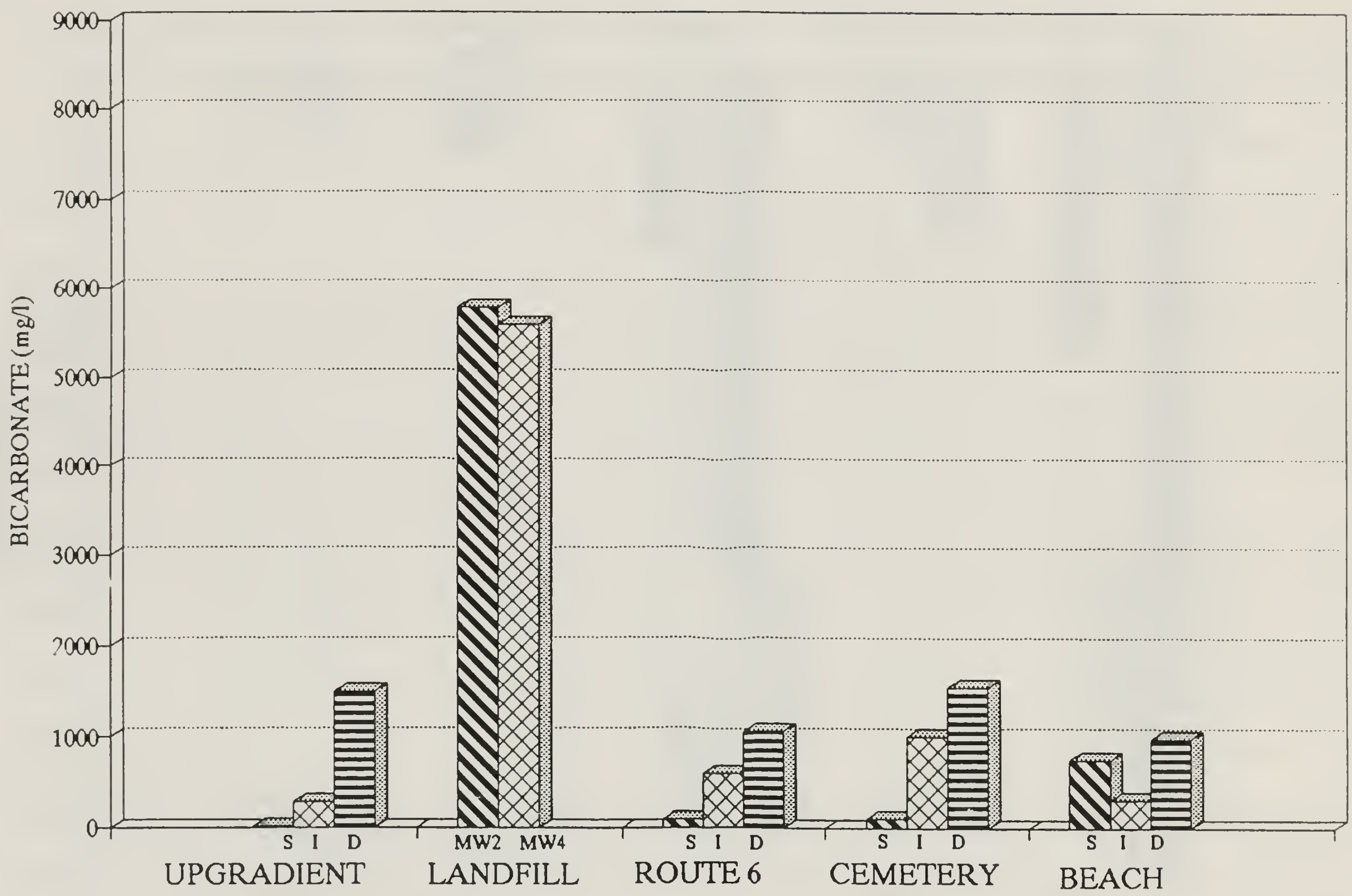


Fig. E-27. Bicarbonate (mg/L) concentrations - 4/91.

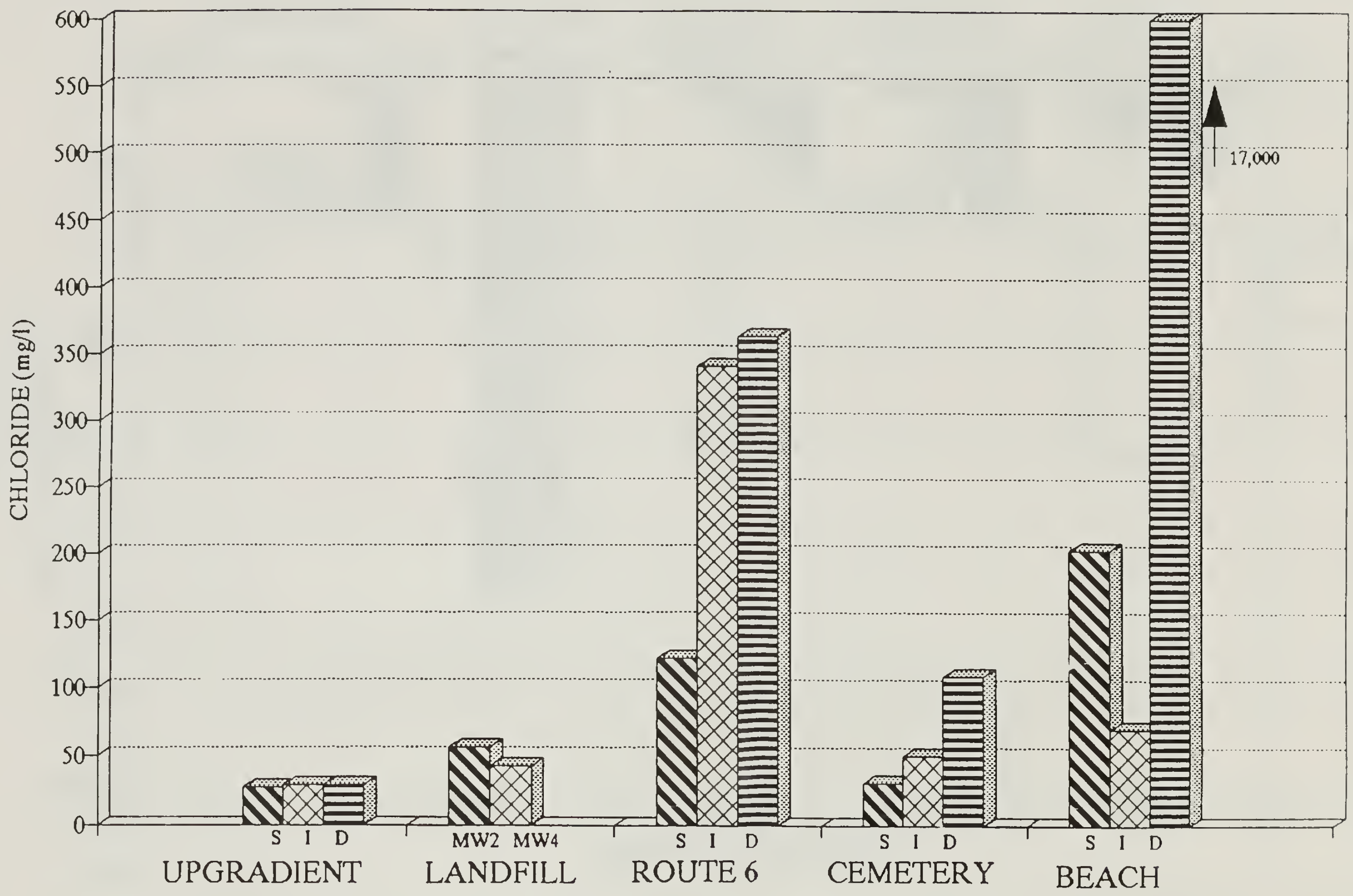


Fig. E-28. Chloride (mg/L) concentrations - 4/91.

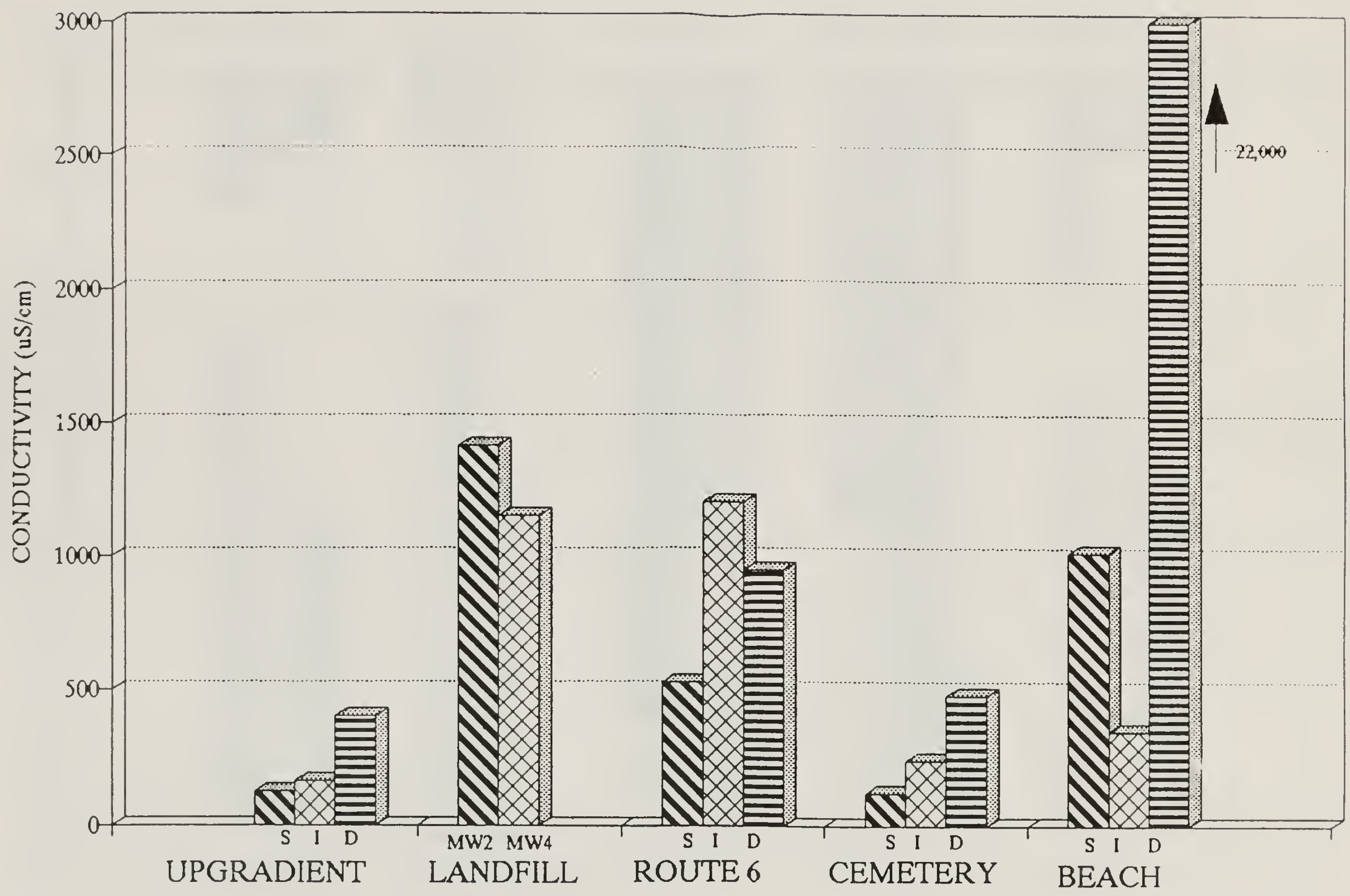


Fig. E-29. Conductivity (uS/cm) concentrations - 4/91.

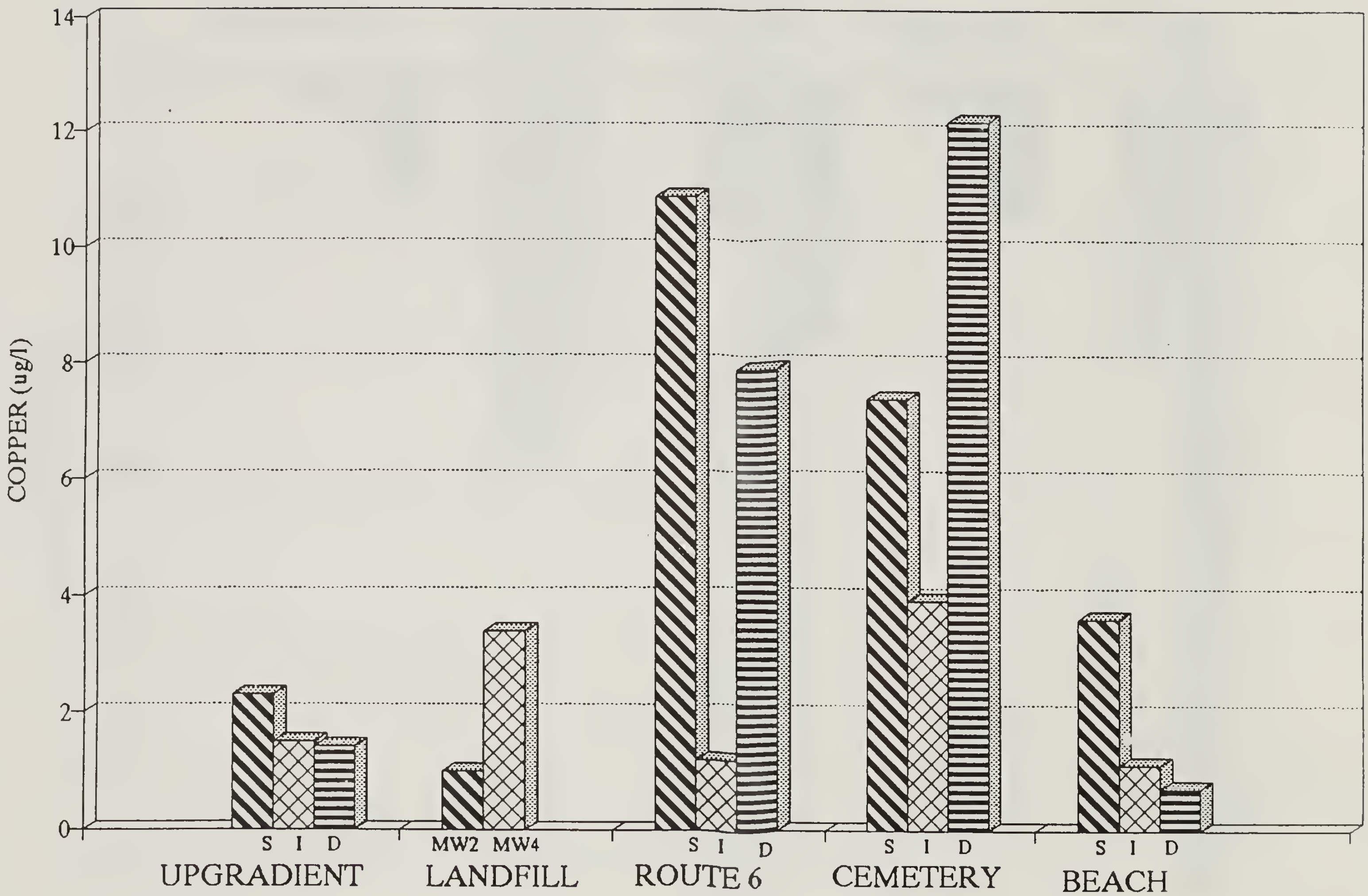


Fig. E-30. Copper (ug/L) concentrations - 4/91.

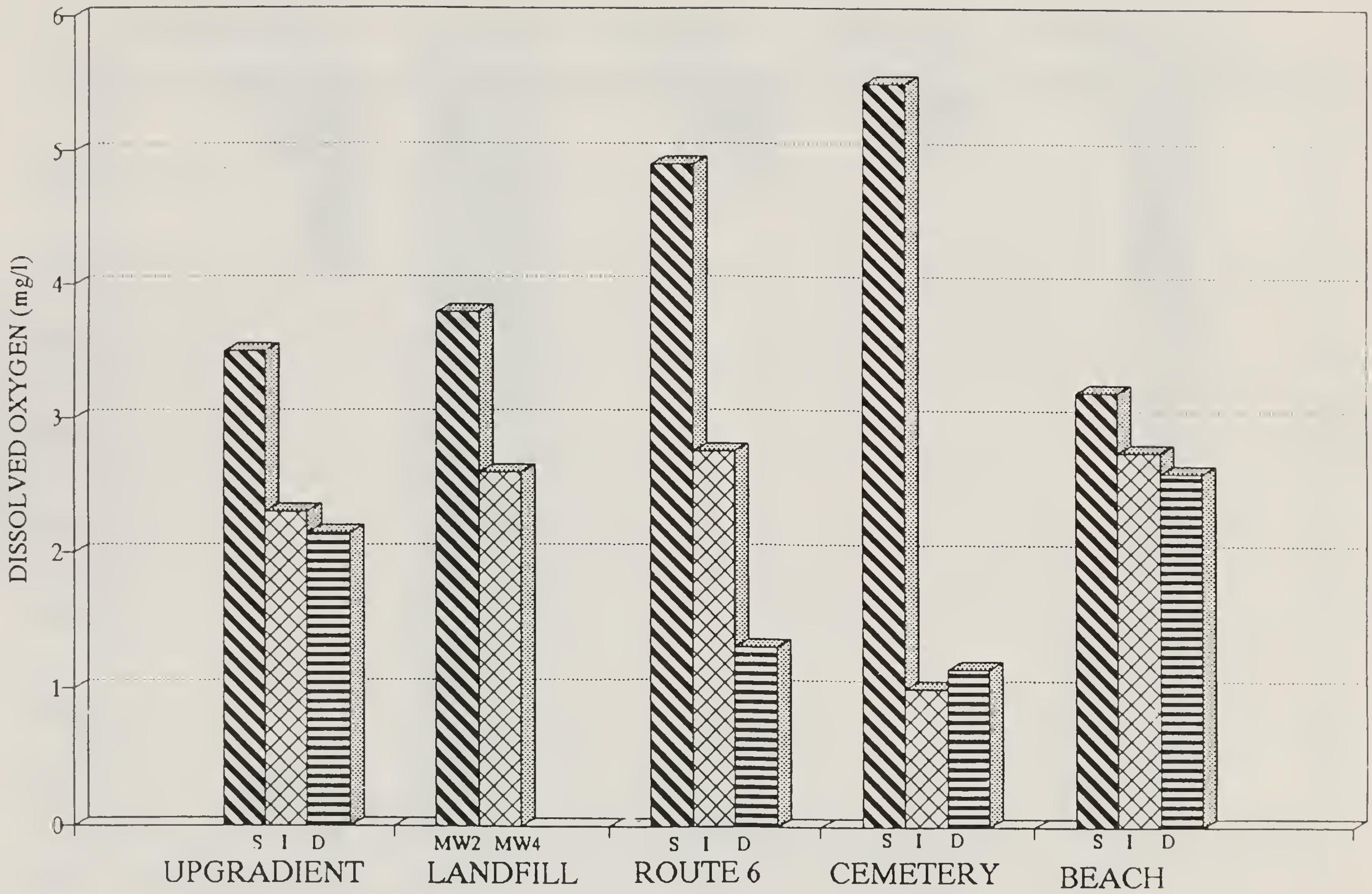


Fig. E-31. Dissolved oxygen (mg/L) concentrations - 4/91.

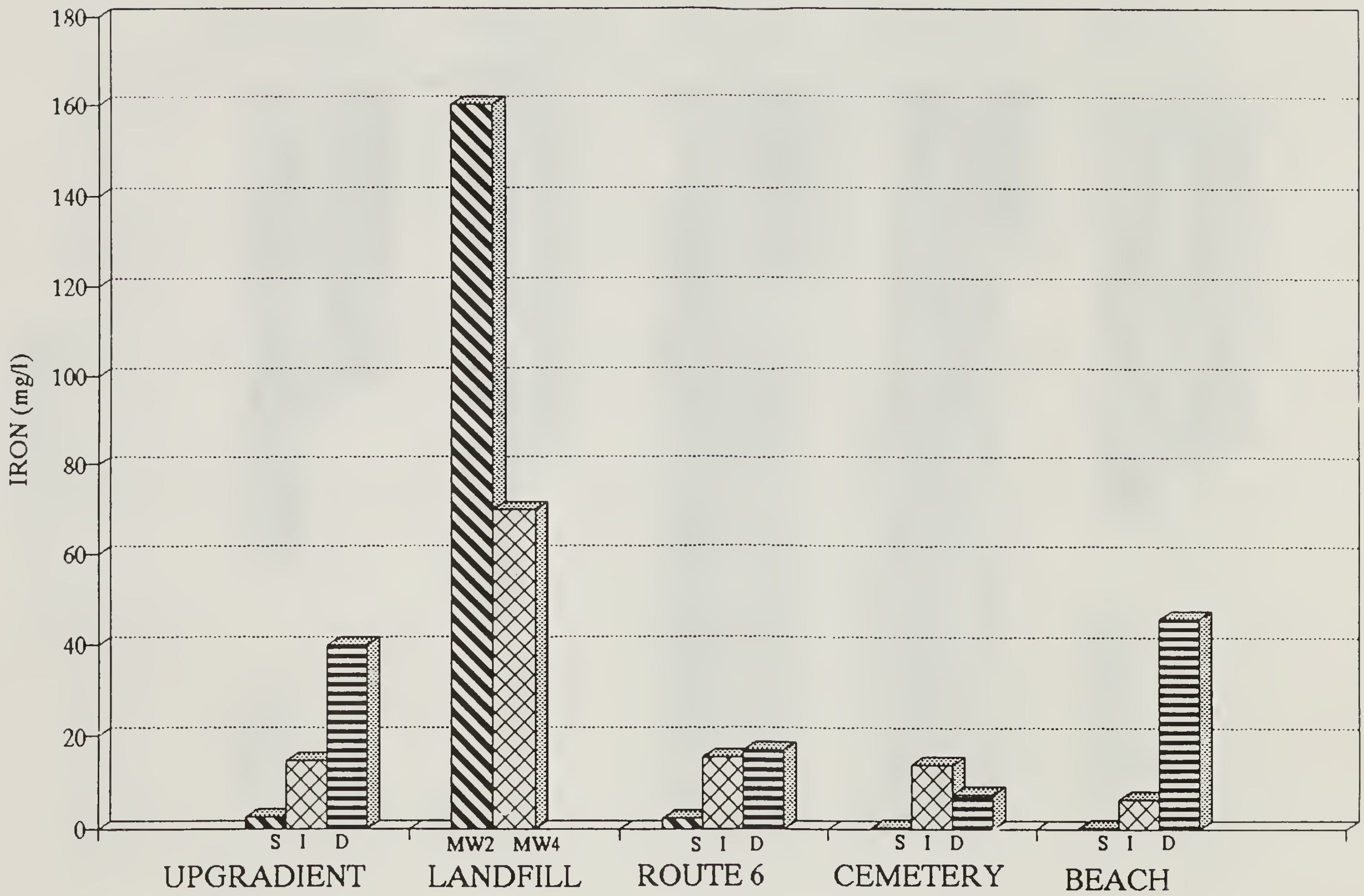


Fig. E-32. Iron (mg/L) concentrations - 4/91.

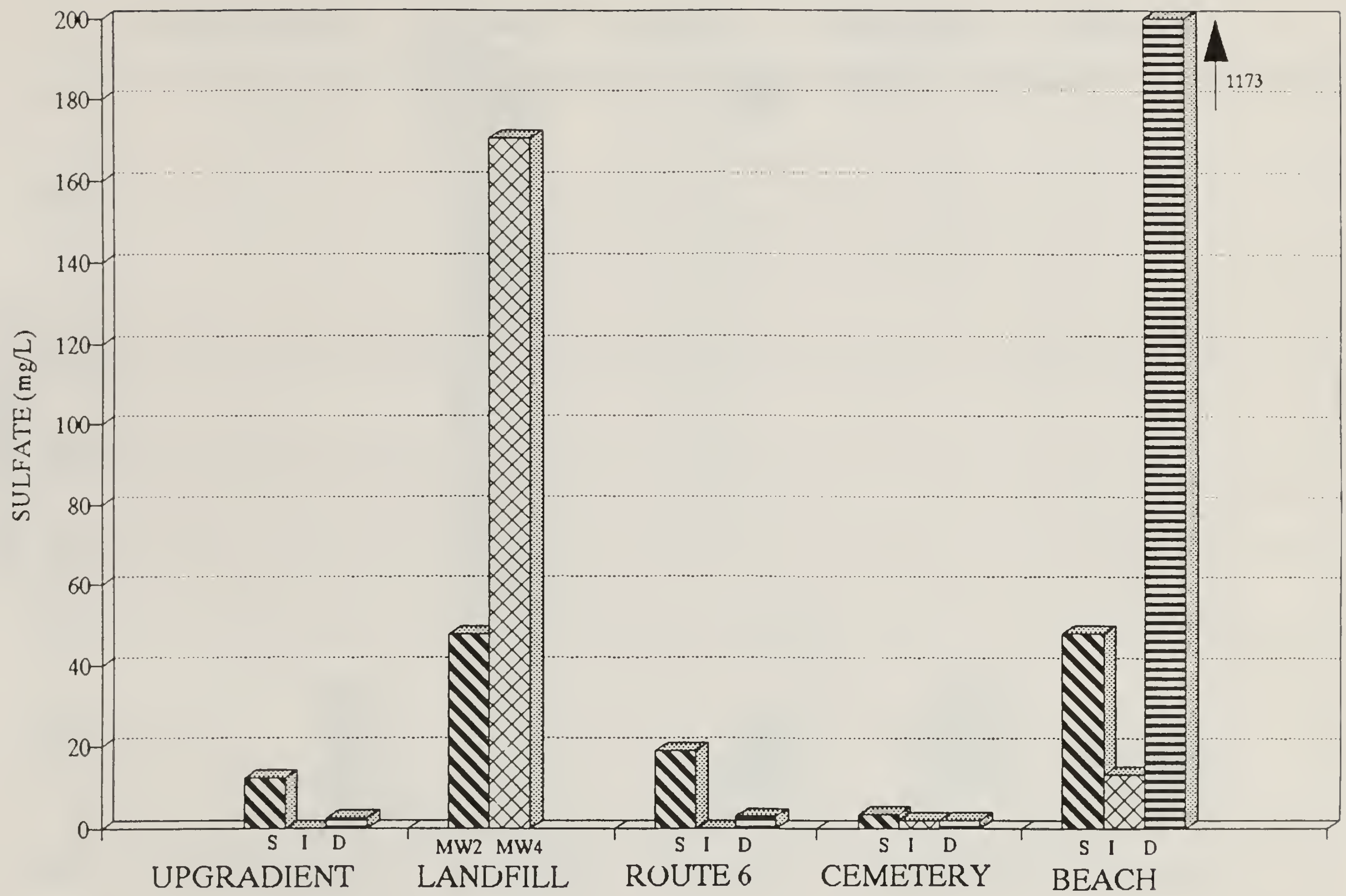


Fig. E-33. Sulfate (mg/L) concentrations - 4/91.

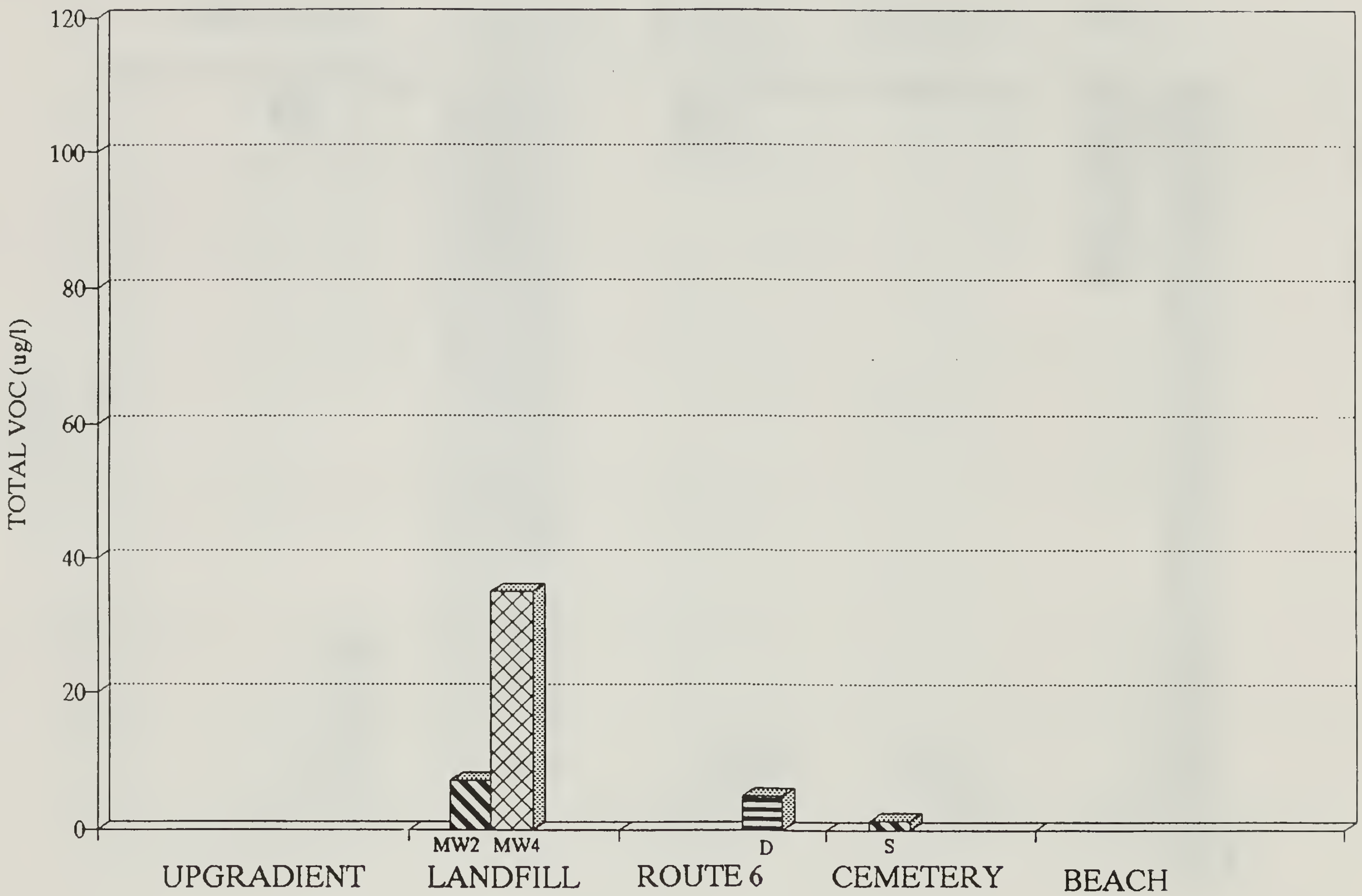


Fig. E-34. VOC (ug/L) concentrations - 4/91.

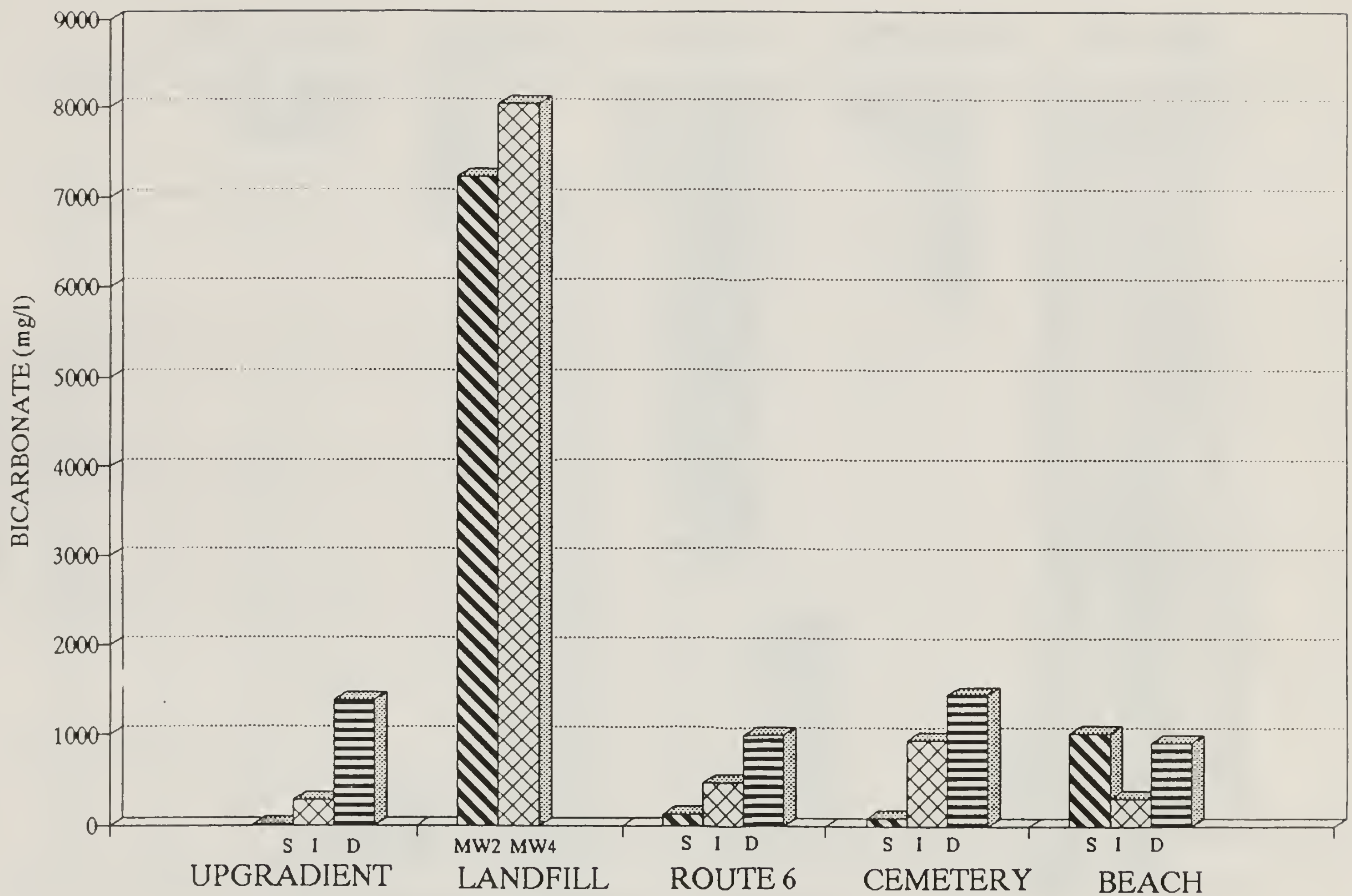


Fig. E-35. Bicarbonate (mg/L) concentrations 8/91.

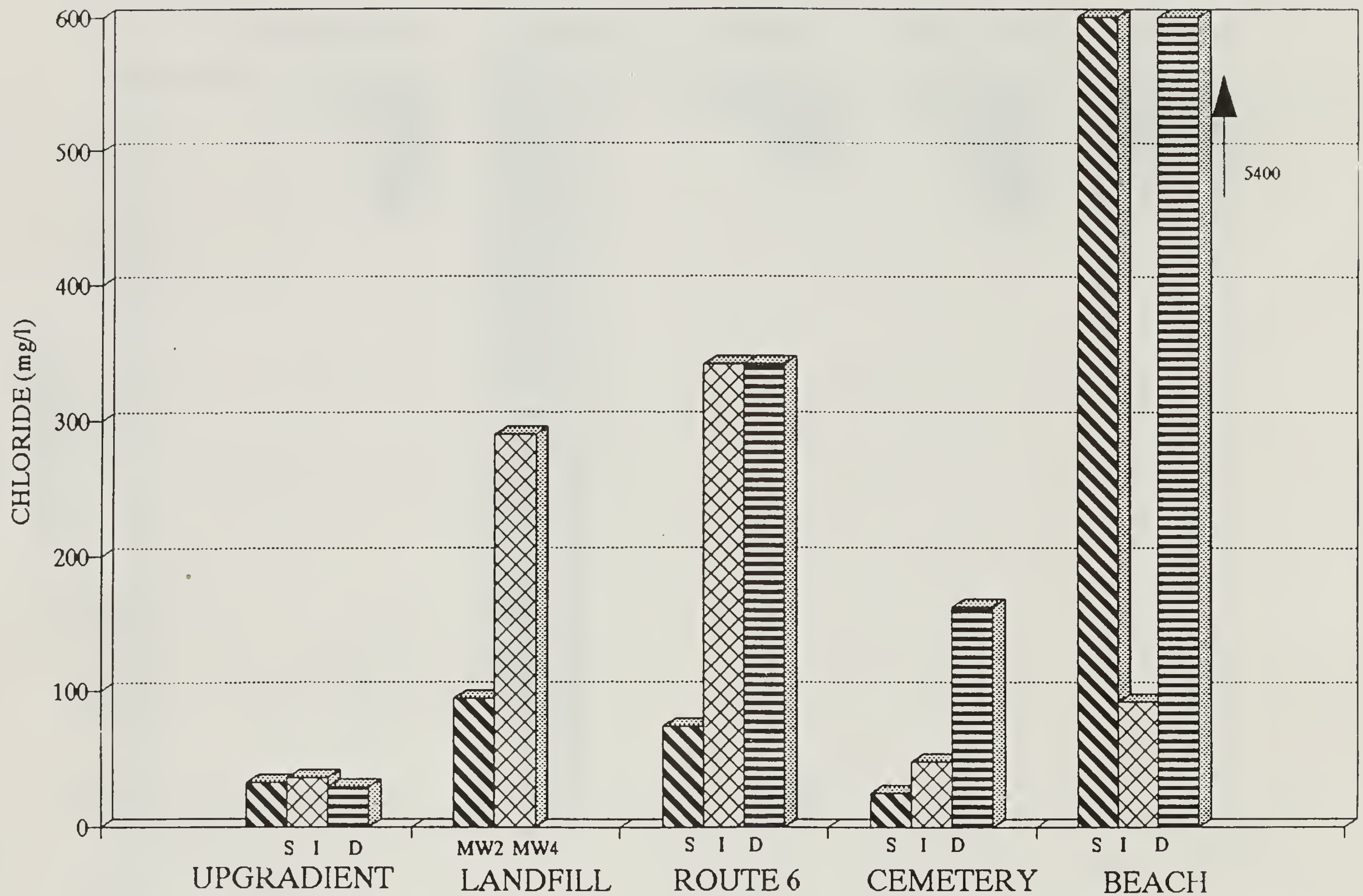


Fig. E-36. Chloride (mg/L) concentrations - 8/91.

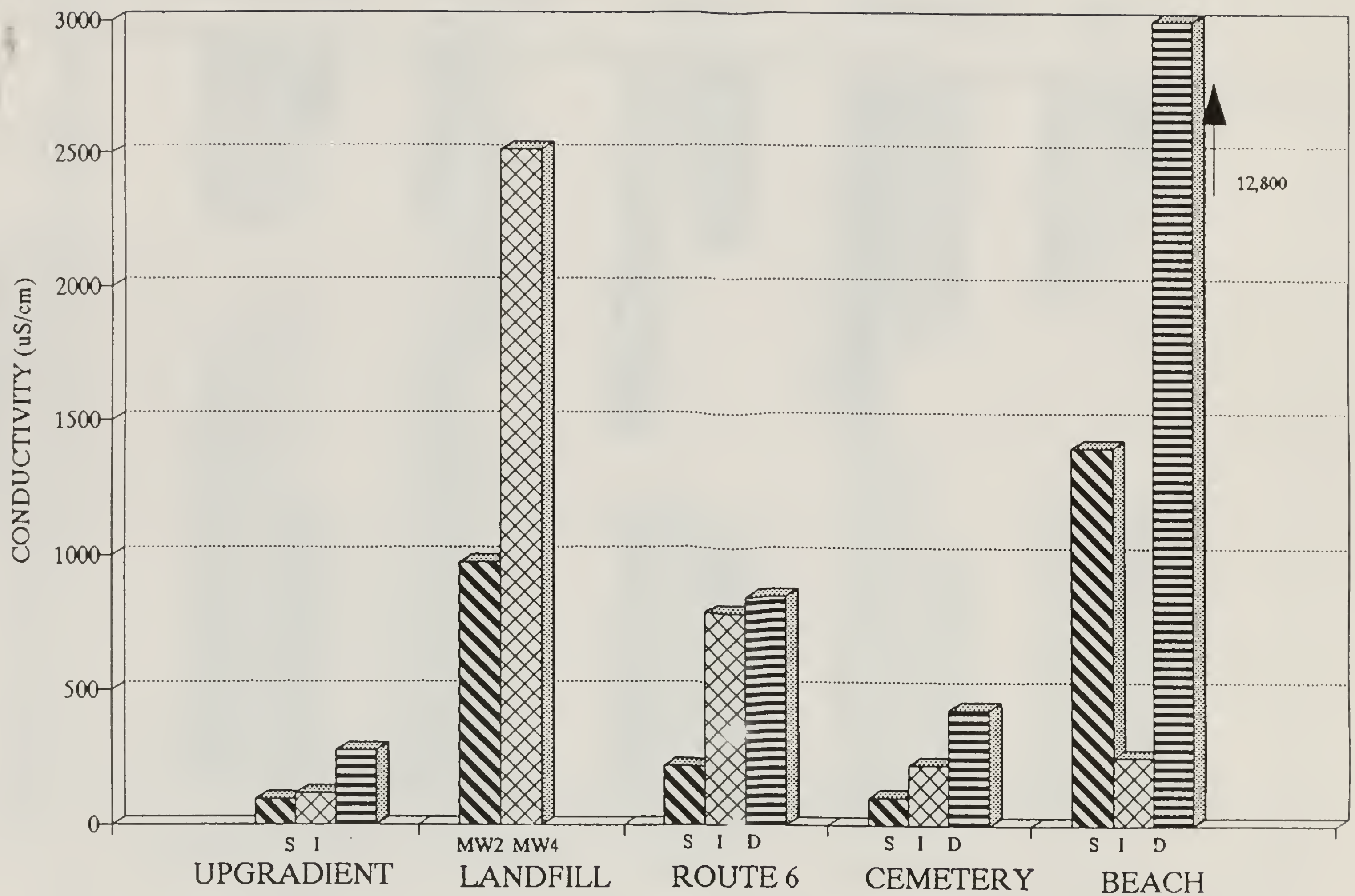


Fig. E-37. Conductivity (uS/cm) concentrations - 8/91.

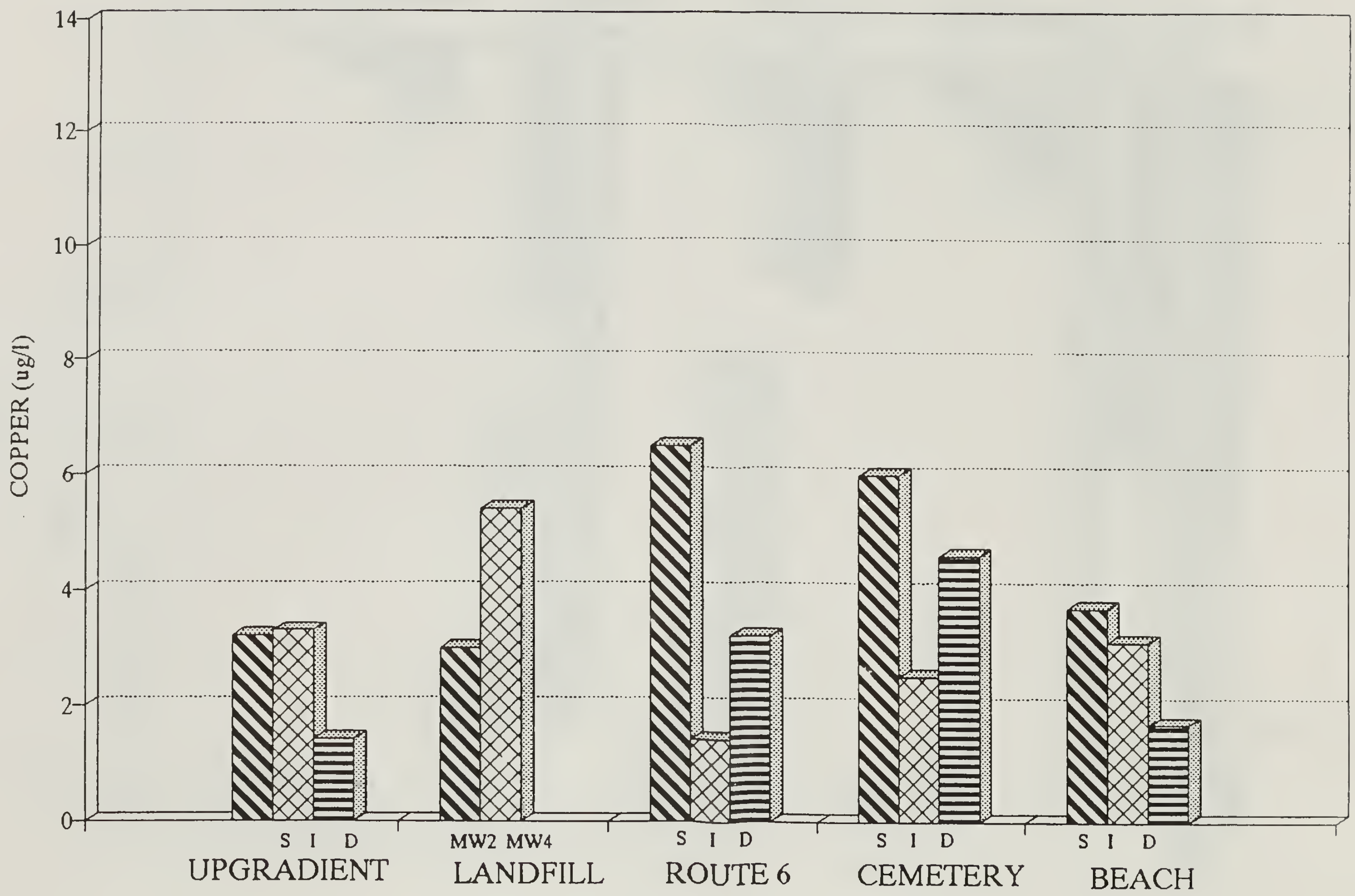


Fig. E-38. Copper (ug/L) concentrations - 8/91.

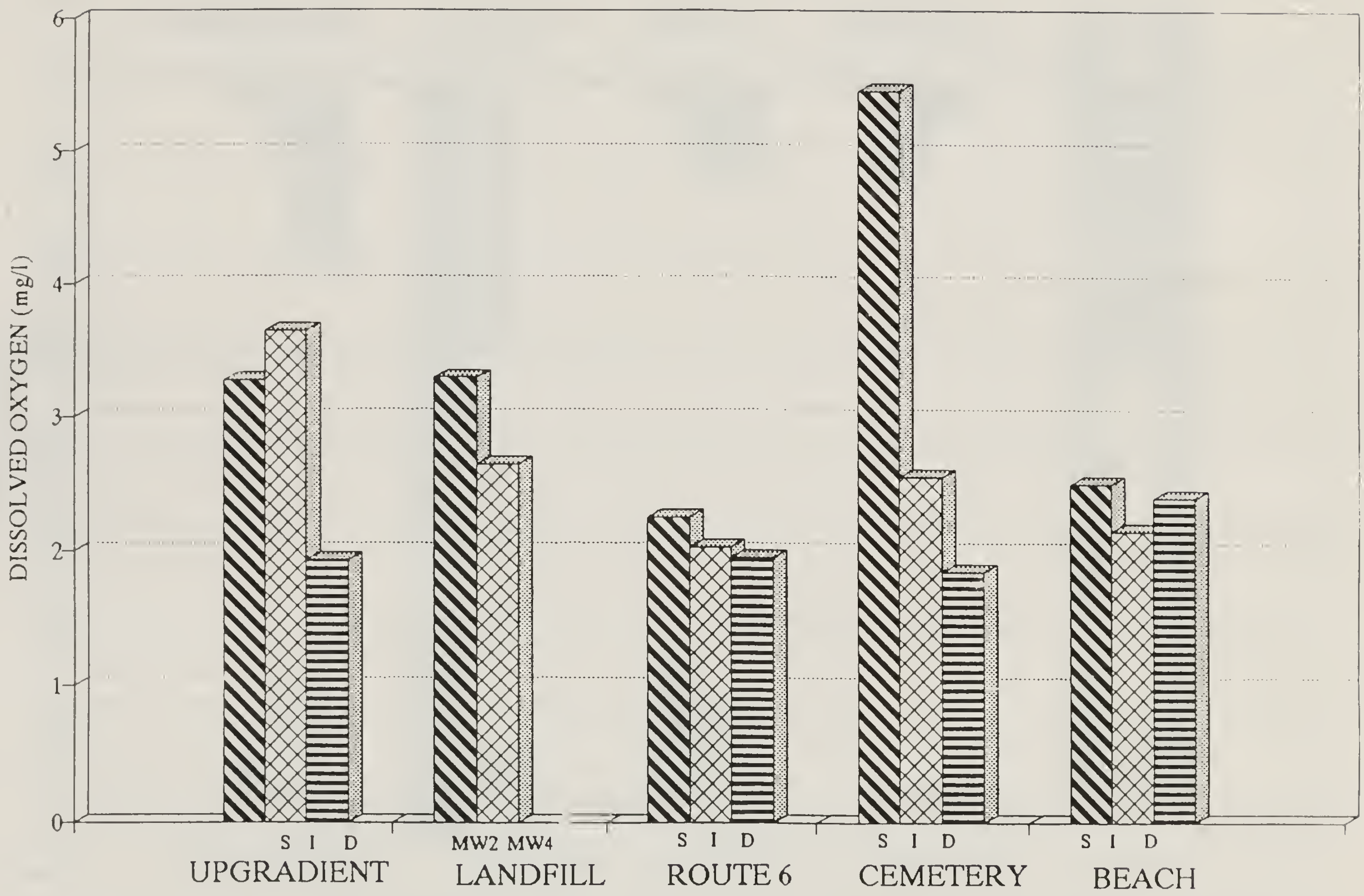


Fig. E-39. Dissolved oxygen (mg/L) concentrations - 8/91.

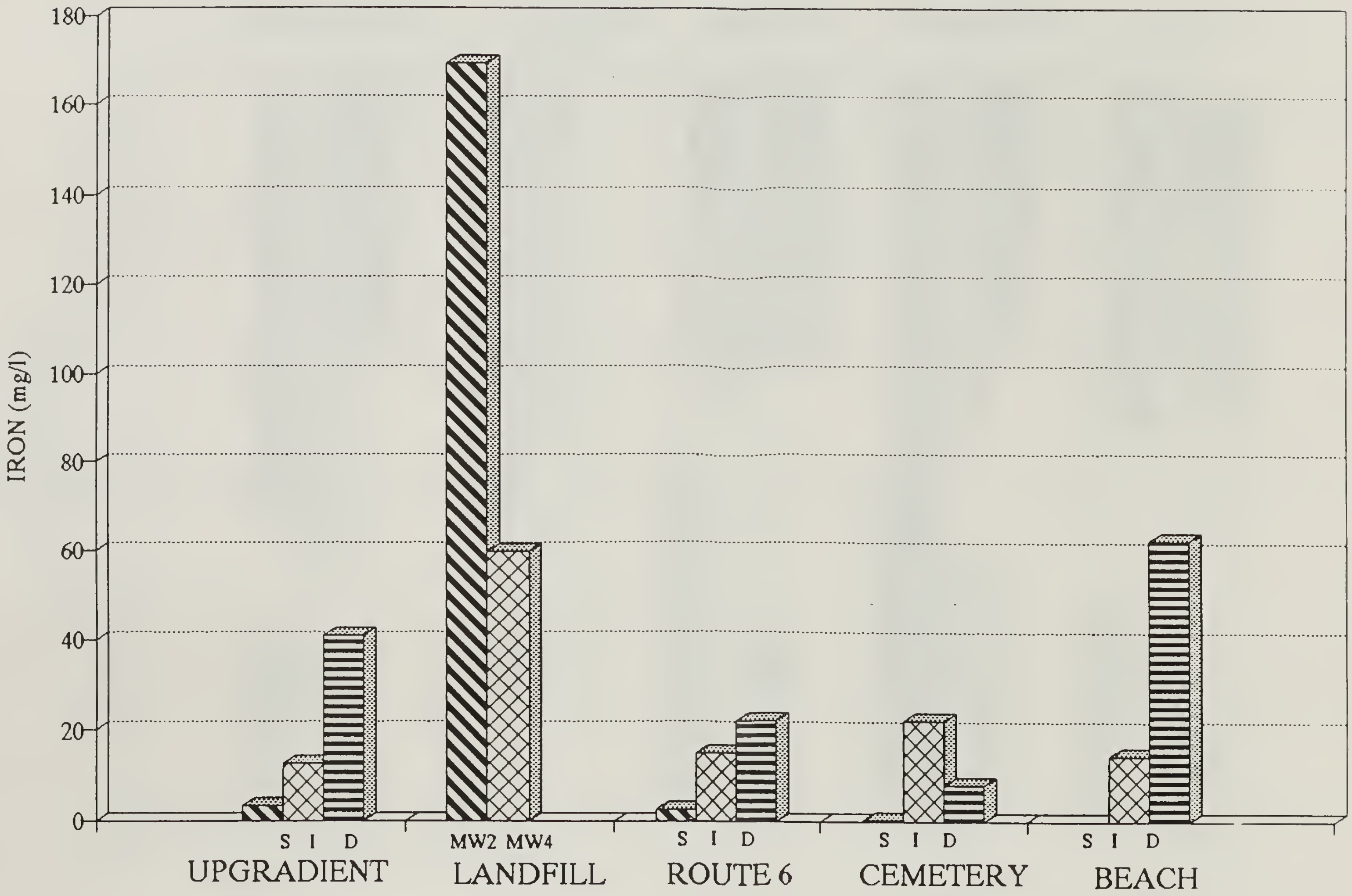


Fig. E-40. Iron (mg/L) concentrations - 8/91.

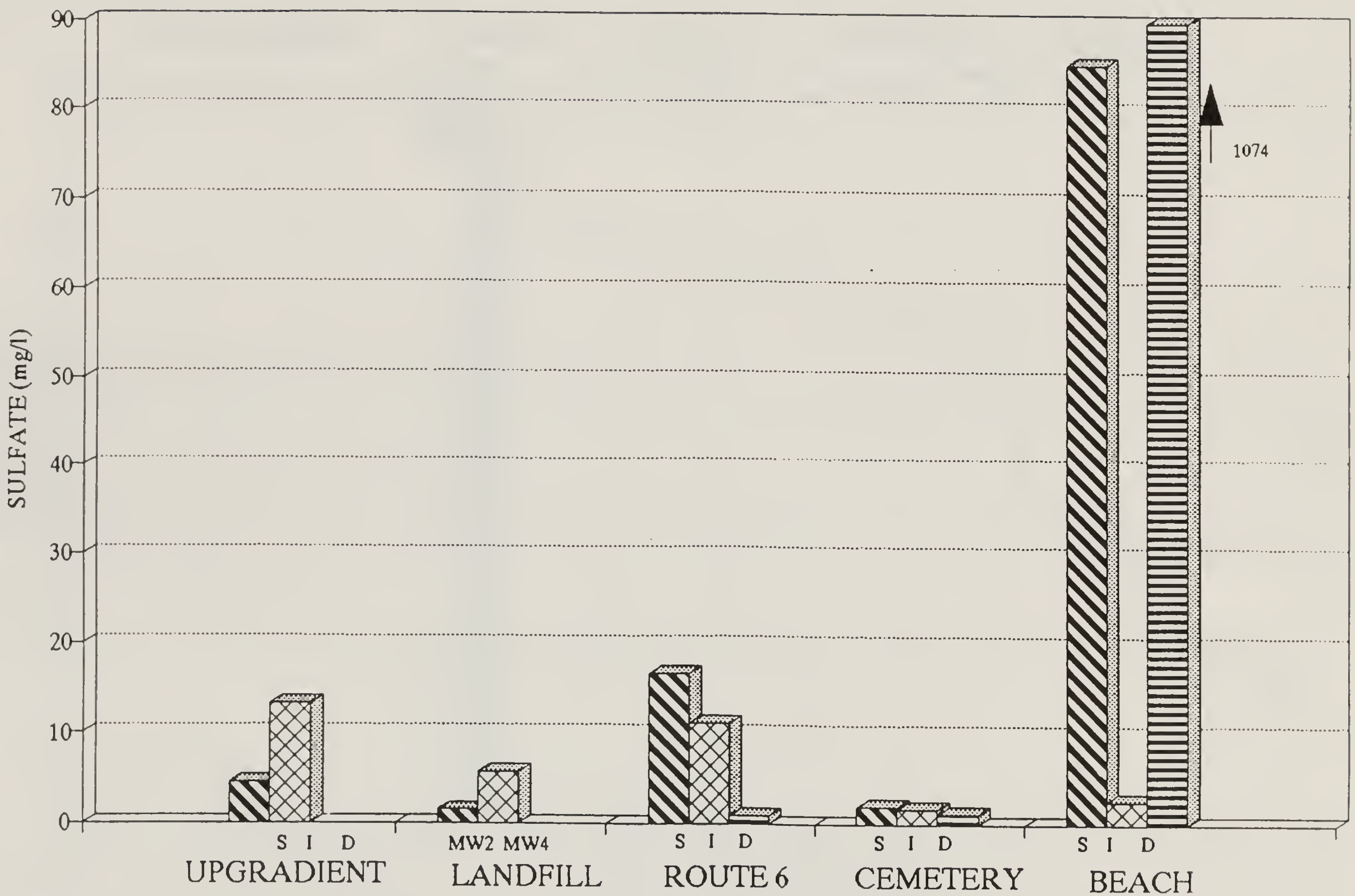


Fig. E-41. Sulfate (mg/L) concentrations - 8/91.

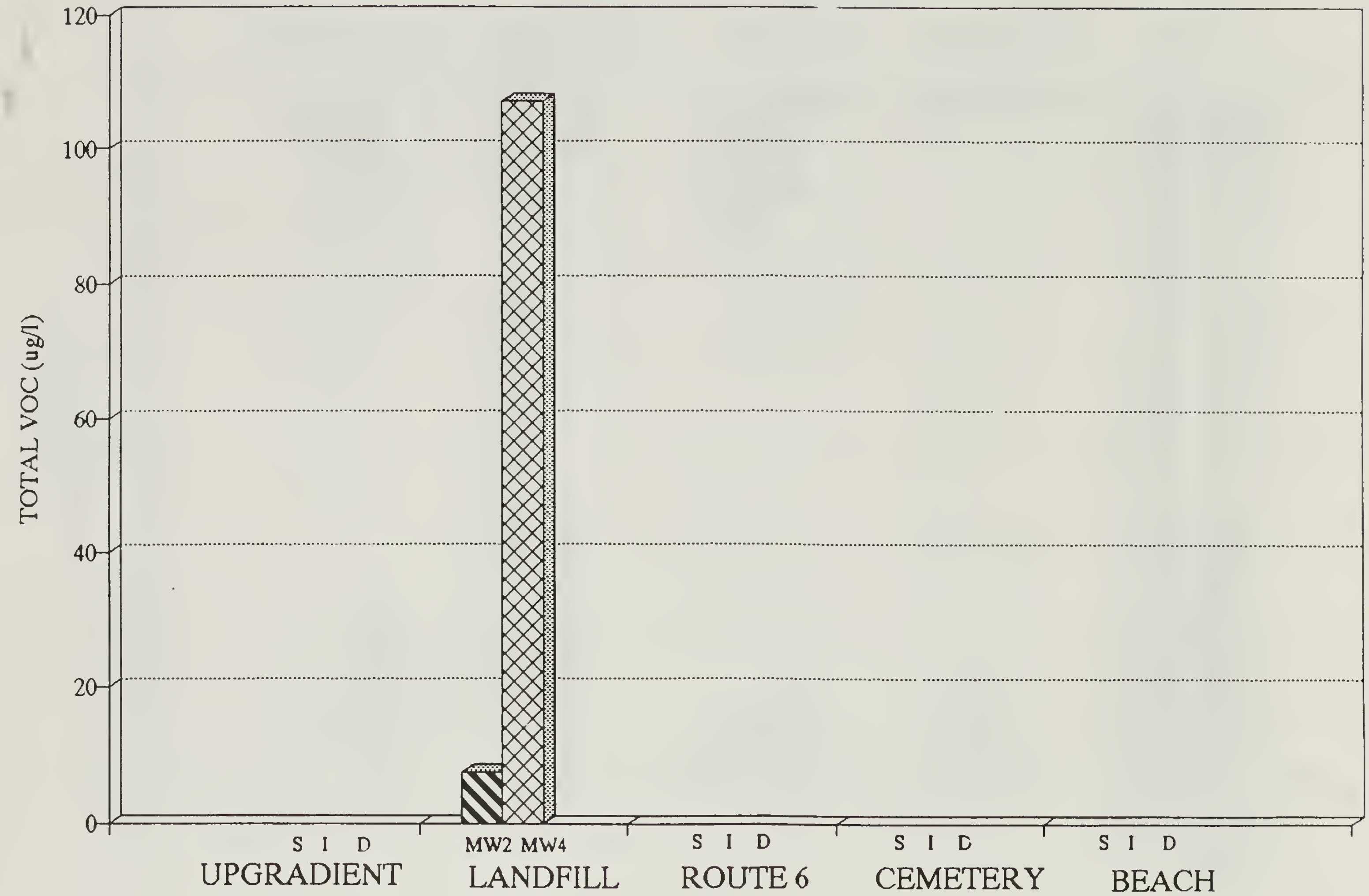


Fig. E-42. VOC (ug/L) concentrations - 8/91.

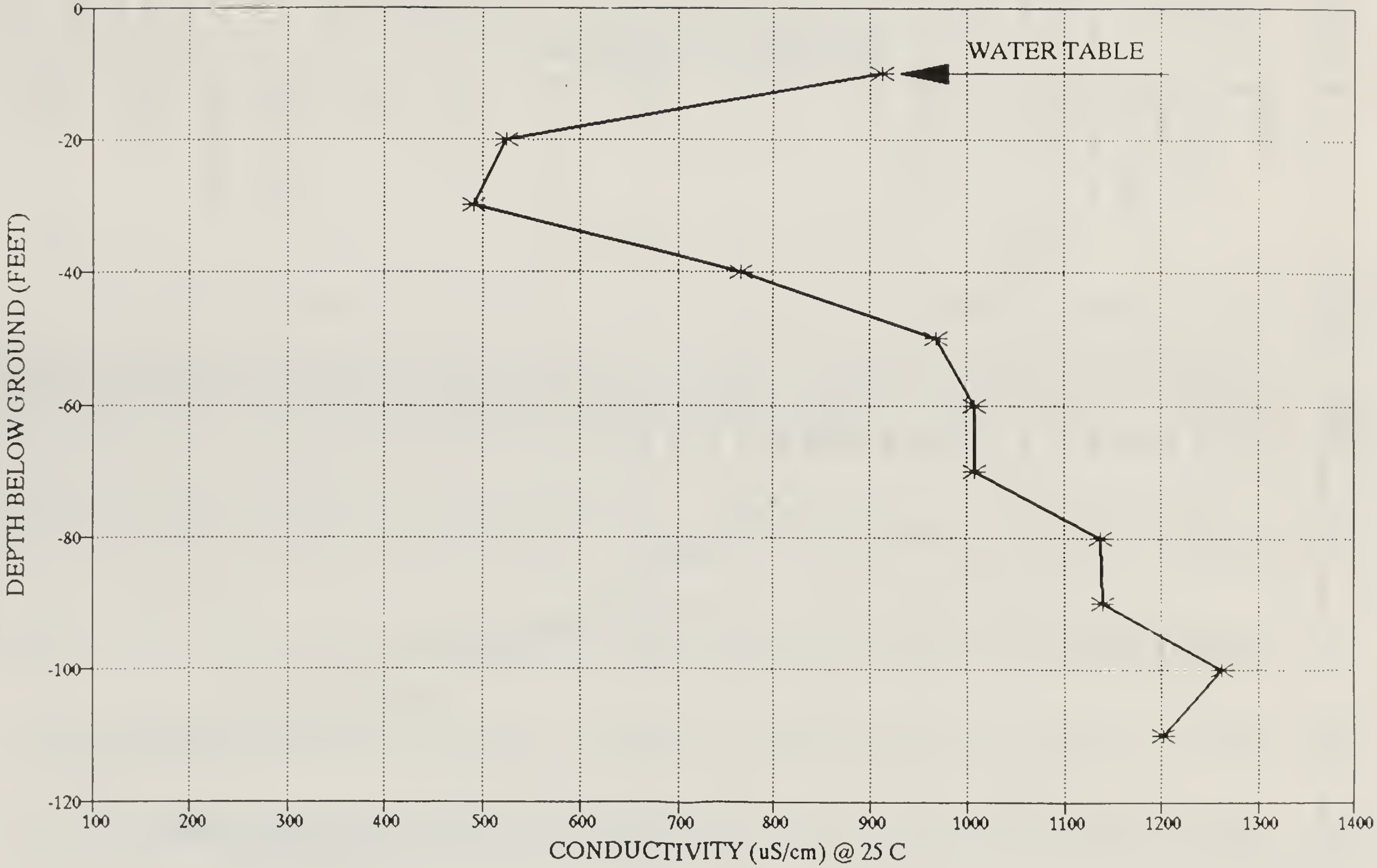


Fig. E-43. Electrical conductivity profile for MW15D - 2/5/92.

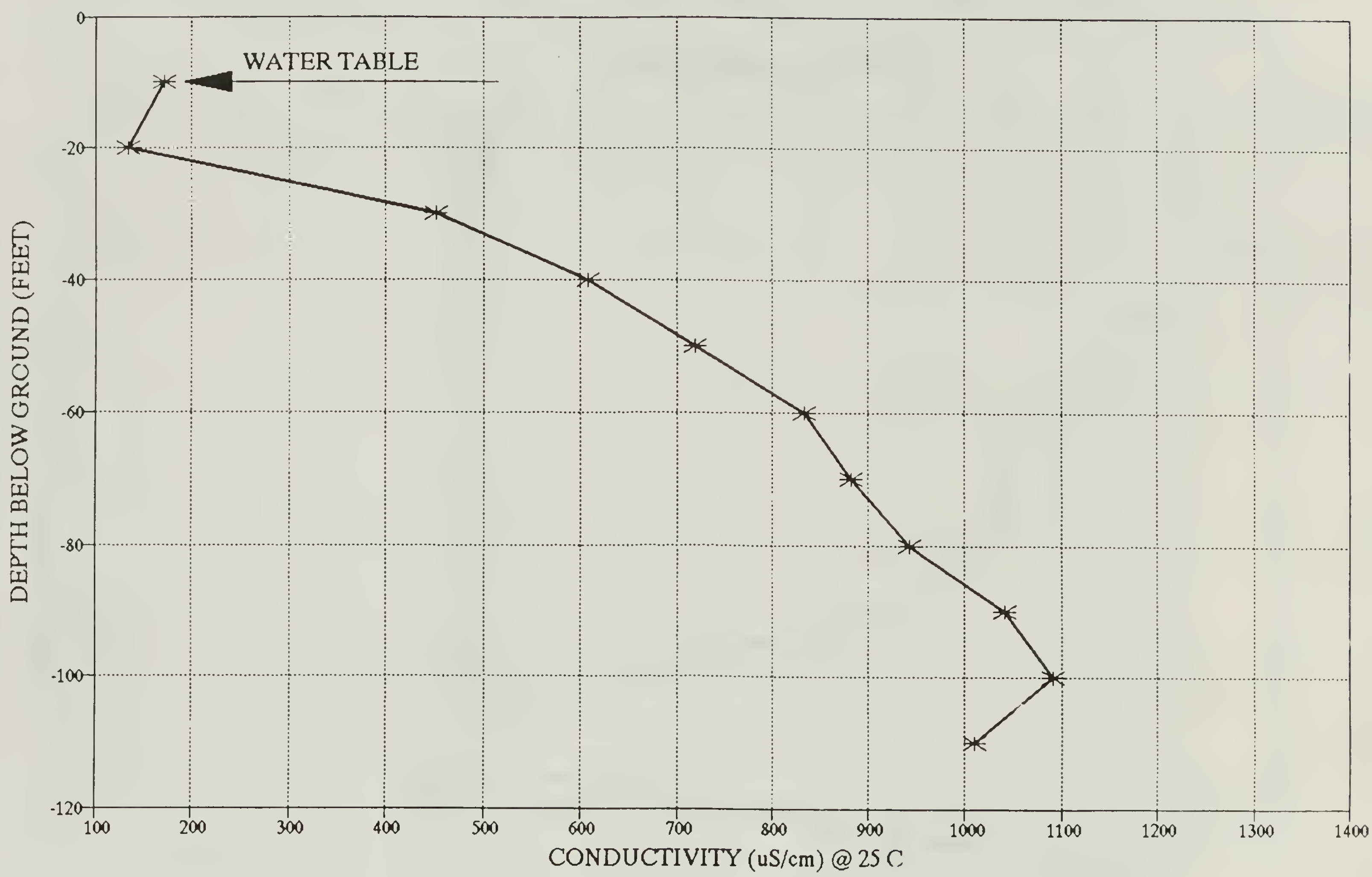


Fig. E-44. Electrical conductivity profile for MW15D - 7/24/92.

Table E-25. University of Rhode Island Metals Analysis

Station	T/D	Taken	Cr	Ni	Cu	Pb	Cd
Great pond-well	T	11/10/90	4.4	0.1	3.5	3.9	0.27
Station 1	T	11/10/90	1.1	1.2	4.8	18.6	0.17
Great pond-surface	T	11/10/90	0.6	0.7	2.3	11.9	0.09
Beech Forest-surface	T	11/10/90	3.0	3.7	8.9	78.7	0.64
Duck (16-C)-surface	T	11/11/90	2.1	2.6	6.4	31.6	0.42
Bennett-east-surface	T	11/11/90	0.6	0.8	2.0	9.0	0.09
Bennett (12-B)-surface	T	11/11/90	0.3	ND	3.1	3.7	0.07
Duck (16-B)-surface	T	11/11/90	0.4	0.1	1.9	4.7	0.05
Bennett-east-well	T	11/11/90	4	2.3	11.2	10.2	2.08
Bennett-west-surface	T	11/11/90	0.5	0.3	3.1	7.4	0.06
Clapps pond-surface	T	11/11/90	0.4	ND	1.4	4.3	0.05
Little Bennett-surface	T	11/11/90	0.3	ND	4.2	2	0.11
MW10-I	T	12/22/90	8.9	2.8	8.5	3.3	0.11
MW10-S	T	12/22/90	4.8	2.1	4.5	2.3	1.37
MW10-D	T	12/22/90	4.3	2.4	28.4	3.5	0.31
MW11-S	T	12/22/90	1	1.9	2	1.1	1.07
MW11-I	T	12/22/90	2.9	ND	1	0.6	0.04
MW12-S	T	12/22/90	8	2.8	14.9	29.8	2.16
MW12-D	T	12/22/90	0.8	ND	0.7	0.9	0.43
MW11-D	T	12/22/90	8.2	6.5	14.2	10.3	0.39
MW12-I	T	12/22/90	4.1	0.6	1	1.5	0.04
MW13-I	T	01/20/91	0.9	0.4	1.8	1.1	0.02
MW13-D	T	01/20/91	0.6	1.9	8.4	3.2	0.1
MW13-S	T	01/20/91	3.8	3.6	11	4.4	0.26
MW14-S	T	01/20/91	0.8	2.9	10.4	14.4	0.1
MW14-D	T	01/20/91	3.8	6.7	7.8	11	0.42
Blank-11:am	D	04/22/91	0.1	2.4	55.8	7.5	0.75
MW13-I	D	04/22/91	ND	0.4	3.9	1.5	0.26
Bennett-east-surface	T	04/22/91	0.2	2	2.6	2.8	0.15
MW13-D	D	04/22/91	0.2	2.5	12.2	1.1	0.58
Bennett-west-surface	T	04/22/91	0.5	2.8	11.9	8.3	1.27
MW11-D	D	04/22/91	ND	1.1	7.9	5	0.37
Blank2-2:30pm	D	04/22/91	ND	3.4	57.8	7.9	1.19
MW13-S	D	04/22/91	0.5	2.4	7.4	0.8	0.29
Station 7	T	04/22/91	ND	6.5	3.2	2.9	0.24
Little Bennett	T	04/23/91	0.4	41.8	7.6	7.1	0.3
Great pond	T	04/23/91	0.1	1.8	3.3	8.9	0.21

Table E-25. University of Rhode Island Metals Analysis

Station	T/D	Taken	Cr	Ni	Cu	Pb	Cd
MW4	D	04/23/91	0.9	2	3.4	0.6	0.13
MW5	D	04/23/91	0.4	1	1.1	0.6	0.22
Blank1-2:pm	D	04/23/91	ND	1.8	2.6	1	0.58
MW6	D	04/23/91	0.4	1.7	9.8	1.2	0.4
MW9	D	04/23/91	0.7	3	4.1	2.9	0.22
MW12-D	D	04/23/91	ND	1.6	4.1	1.6	0.35
Blank2	D	04/23/91	ND	3.1	2.8	1	0.49
MW3	D	04/23/91	0.4	7	1.3	1.3	0.17
MW2	T	01/27/91	2.6	2.4	3.5	3.6	0.33
MW4	T	01/27/91	3	4.5	14.6	4.5	0.17
MW8	T	01/27/91	2.2	1.6	7.9	2.3	0.25
MW1	T	01/27/91	30.5	22.2	27.4	0.9	0.05
Blank	T	01/27/91	0.5	1.4	8.4	0.9	0.11
MW9	T	01/27/91	2.3	3.5	7.2	18	0.27
MW6	T	01/27/91	3.6	1.3	2.6	0.8	0.01
MW7	T	01/27/91	3.4	44.6	6.8	3.7	1.34
MW5	T	01/27/91	1.3	1.4	1.2	0.2	0.02
Washdown well	D	09/02/91	1.8	6.8	4.8	2.1	0.17
MW13-S	D	09/02/91	0.2	0.6	6	6.2	0.38
MW13-D	D	09/02/91	0.6	2.2	6.2	0.6	0.4
MW14-I	D	09/02/91	0.1	0.5	3.1	0.1	0.03
MW13-D Rep	D	09/02/91	1.4	1.9	2.9	0.6	0.21
Duck (16-C) surface	D	08/27/91	0.7	0.9	0.7	0.2	0.1
MW3	D	09/02/91	0.7	5.7	12.3	4.5	15.66
MW13-I Rep	D	09/02/91	1.2	2.9	3.3	1.6	0.48
MW13-I	D	09/02/91	0.4	1.1	1.7	0.2	0.25
Blank	D	09/02/91	0.3	0.3	0.7	ND	0.13
MW14-S	D	09/02/91	0.4	1.6	3.7	1	0.22
MW12-S	D	08/27/91	0.7	4	14.4	3.9	14.97
MW1	D	09/02/91	1.2	2.6	9.7	3.7	0.67
Duck (16-C) surface	T	08/27/91	1.6	1.8	1.3	1.2	2.16
MW2	D	09/02/91	0.9	3.7	3	1.1	0.16
MW9	D	08/27/91	1.6	4.7	4.7	2.2	0.28
MW12-D	D	08/27/91	0.2	3.4	3.3	1.1	0.52
Blank	D	08/27/91	0.2	1	29.8	5	0.19
MW12-I	D	08/27/91	2.3	1.5	3.9	1.5	3.44
MW10-I	D	08/27/91	4.2	3.4	3.3	42.1	0.19

Table E-25. University of Rhode Island Metals Analysis

Station	T/D	Taken	Cr	Ni	Cu	Pb	Cd
MW11-I	D	08/27/91	1.6	1.6	1.4	1.3	0.65
Blank	D	08/26/91	0.2	0.5	29.5	6.5	0.21
MW11-S	D	08/27/91	0.6	3.2	6.5	2.7	5.1
Blank 2	D	08/27/91	0.4	2.1	29.9	4.7	0.38
Bennett-east-surface	T	08/26/91	0.7	7.9	8.1	17.2	0.65
Lil' Bennett-surface	D	08/26/91	0.4	4.4	13.1	8.9	1.34
MW11-D	D	08/27/91	0.1	0.7	3.2	1.3	1.07
MW8	D	08/27/91	1.4	3.5	3.6	7	2.19
MW4	D	08/26/91	2.1	8.6	5.4	1.7	0.48
Blank 2	D	08/26/91	ND	3	30.9	4	0.29
Station 7	D	08/26/91	0.1	3.7	5.3	3.3	0.47
MW5	D	08/26/91	1.2	0.6	0.8	1.4	0.29
MW6	D	08/26/91	1.4	6.1	1.7	1.2	4.05
Great-surface	D	08/26/91	0.4	2.7	5.1	4.4	0.43
Great-surface	T	08/26/91	0.4	8.2	3.2	4.5	0.44
MW10-D	D	08/26/91	0.7	2.5	1.4	1.3	0.59
Lil' Bennett	T	08/26/91	0.9	1.6	2.7	10.2	0.72
Station 7	T	08/26/91	0.4	1.9	1.8	3.9	0.23
MW10-S	D	08/26/91	0.9	5.6	3.2	1.8	0.66
MW14-D	D	09/02/91	0.1	0.5	1.7	ND	ND

Table E-26. Beachface Analysis - 5/28/92, Provincetown, MA.

Nutrient Analysis.

	Groundwater		Surface Water	
Distance feet	Nitrate-N mg/l	Ortho-P mg/l	Nitrate-N mg/l	Ortho-P mg/l
0	93.94	0.543		
175	0.401	0.038	0.709	0.145
375	0.426	0.008	0.047	0.191
1000	0.635	0.023		
1200	0.015	0.008		
1400	0.632	0.145	0.426	0.206
1500	2.228	0.053	0.992	0.008
1600	0.722	0.023		
1800	0.362	0.031		

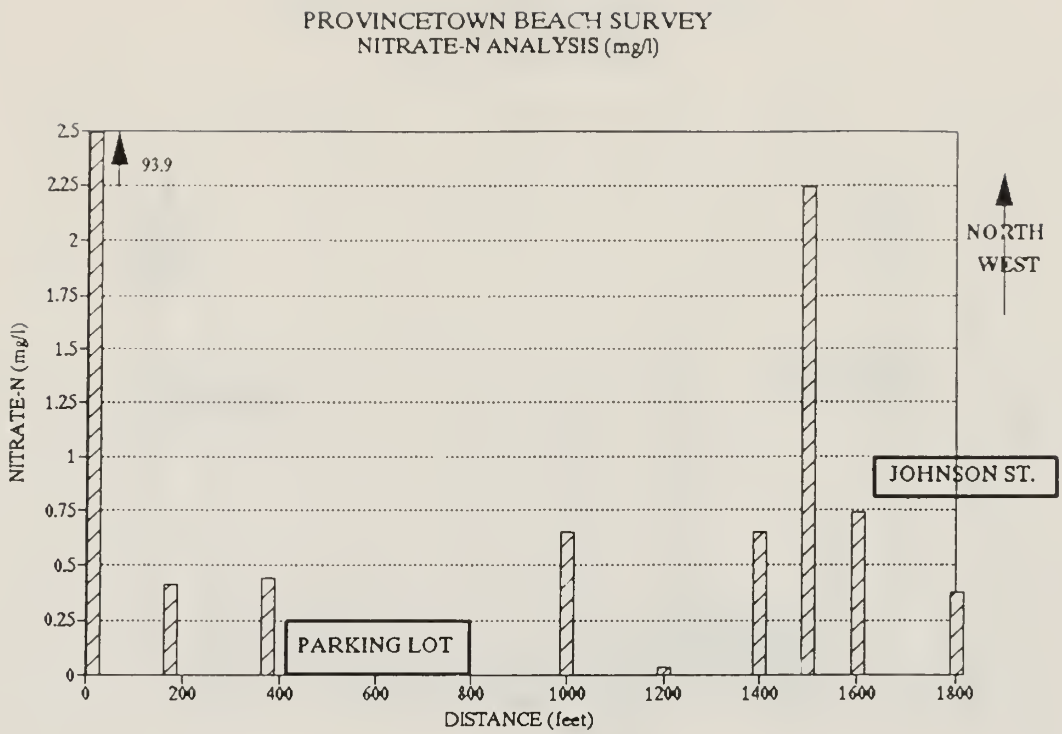
Metals Analysis:

Groundwater Samples

Distance feet	Cr ug/l	Ni ug/l	Cu ug/l	Pb ug/l	Cd ug/l	Salinity ppt
0	1.2	27.4	2.4	1.1	0.6	32
375	235.7	119.6	57.6	104.8	0.86	25
1000	485.2	212.4	98.3	107.4	1.04	30
1200	528.8	264.9	104.4	98.4	0.84	30
1400	107.2	43.1	129.5	88.3	0.45	25
1500	255.3	105.8	25.6	32.3	0.31	24
1600	168.5	71.6	29.6	87.4	0.91	30
1800	283.4	128.6	62.1	125.3	0.69	31

Seepage Water Samples

Distance feet	Cr ug/l	Ni ug/l	Cu ug/l	Pb ug/l	Cd ug/l
0					
175	1.8	8.6	54	29.3	0.14
375	1.5	0.5	7.1	3	0.16
1000					
1200					
1400	24.5	10.5	10.3	167.9	0.78
1500	1.9	1.6	8.2	1.4	0.11



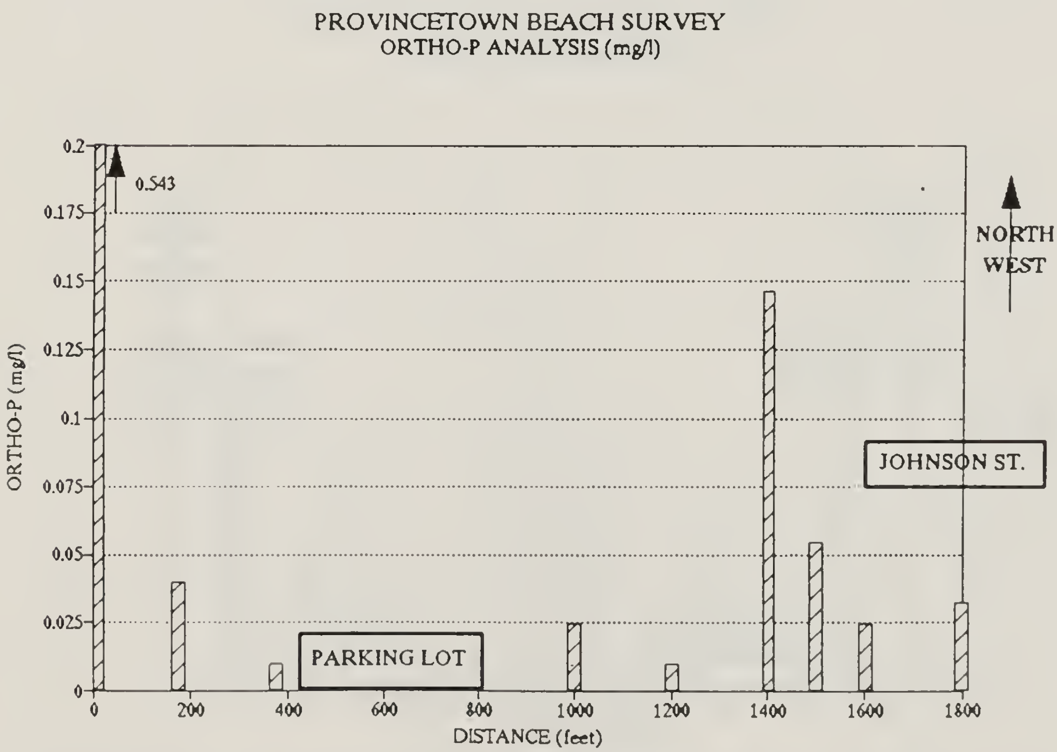
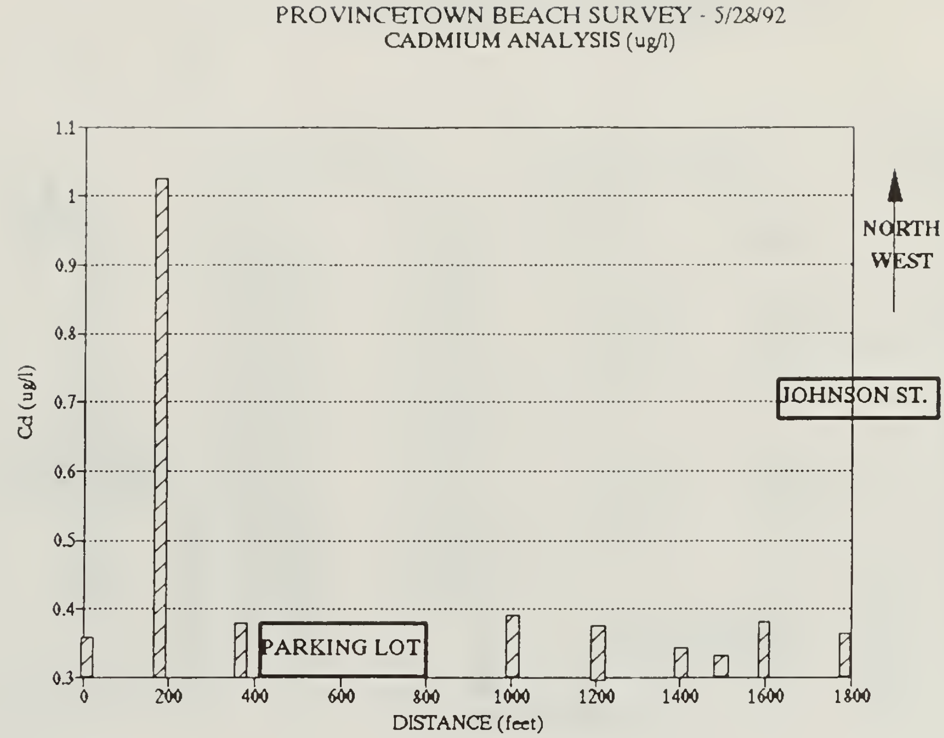


Fig. E-45. Nutrient concentrations along the beachface 5/28/92, Provincetown, MA.



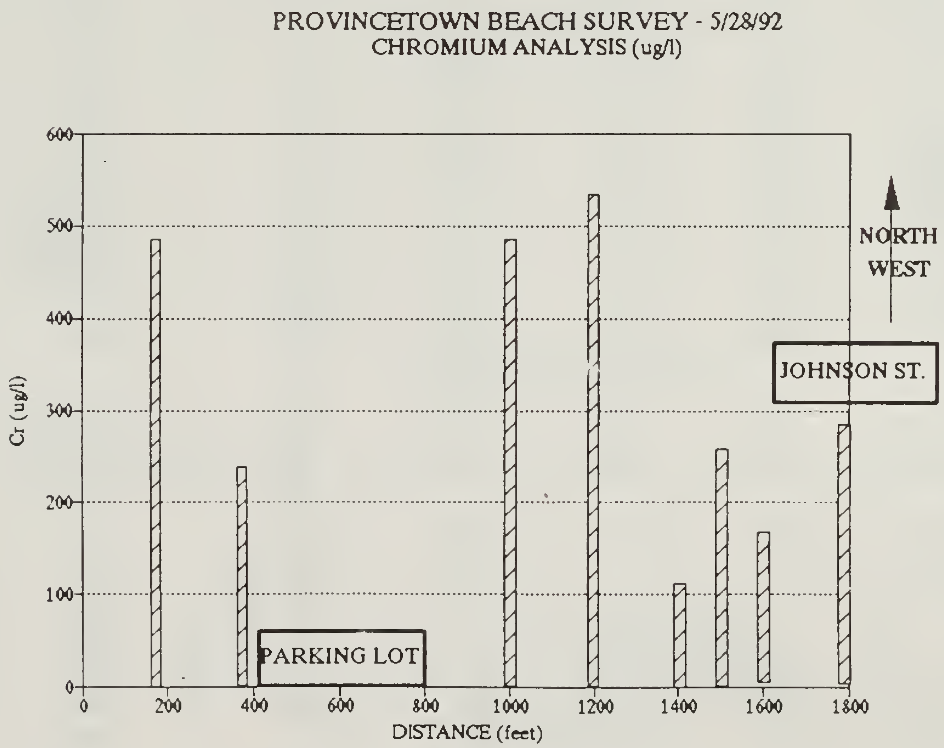
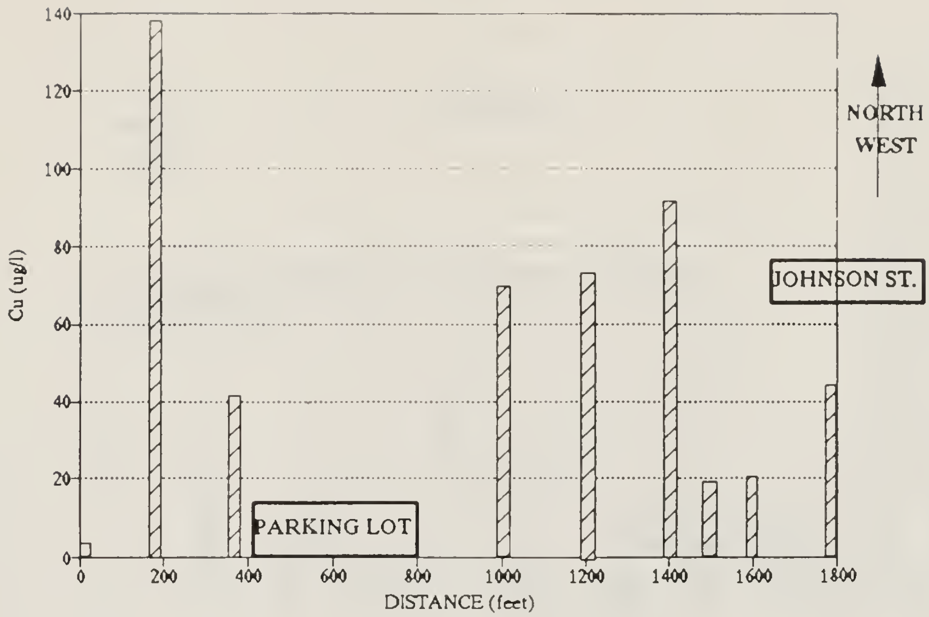


Fig. E-46. Metals concentrations along the beachface 5/28/92, Provincetown, MA.

PROVINCETOWN BEACH SURVEY - 5/28/92
COPPER ANALYSIS (ug/l)



PROVINCETOWN BEACH SURVEY - 5/28/92
LEAD ANALYSIS (ug/l)

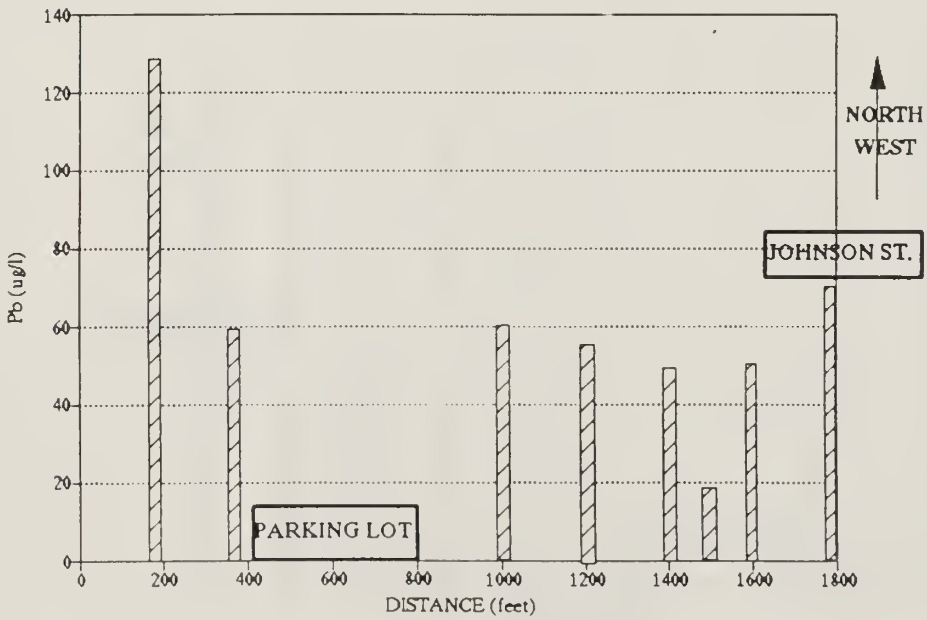
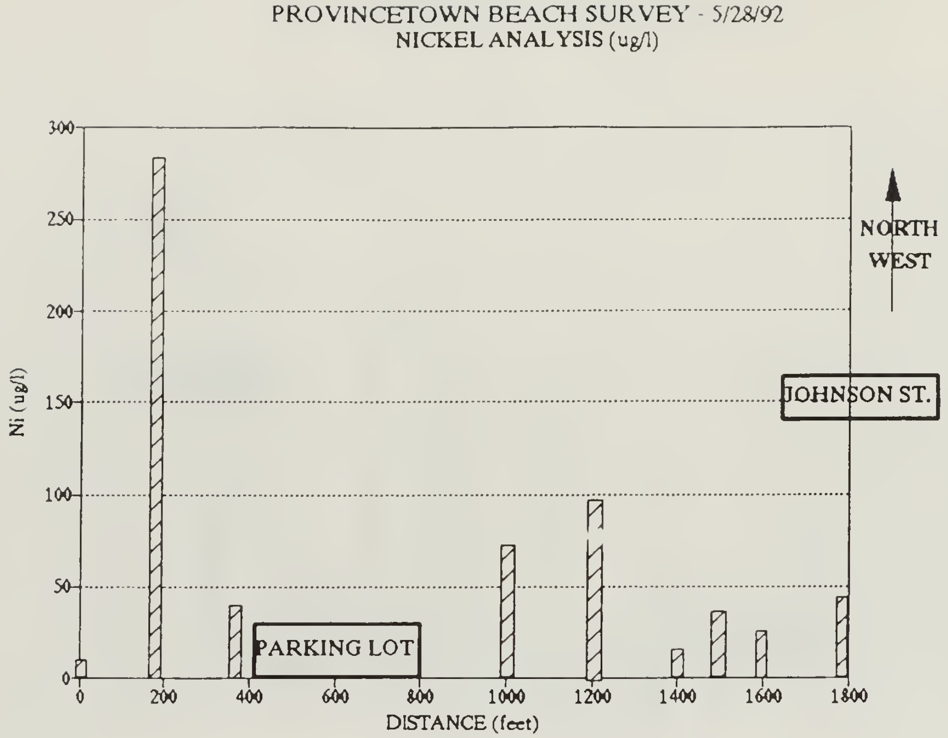


Fig. E-47. Metals concentrations along the beachface 5/28/92, Provincetown, MA.



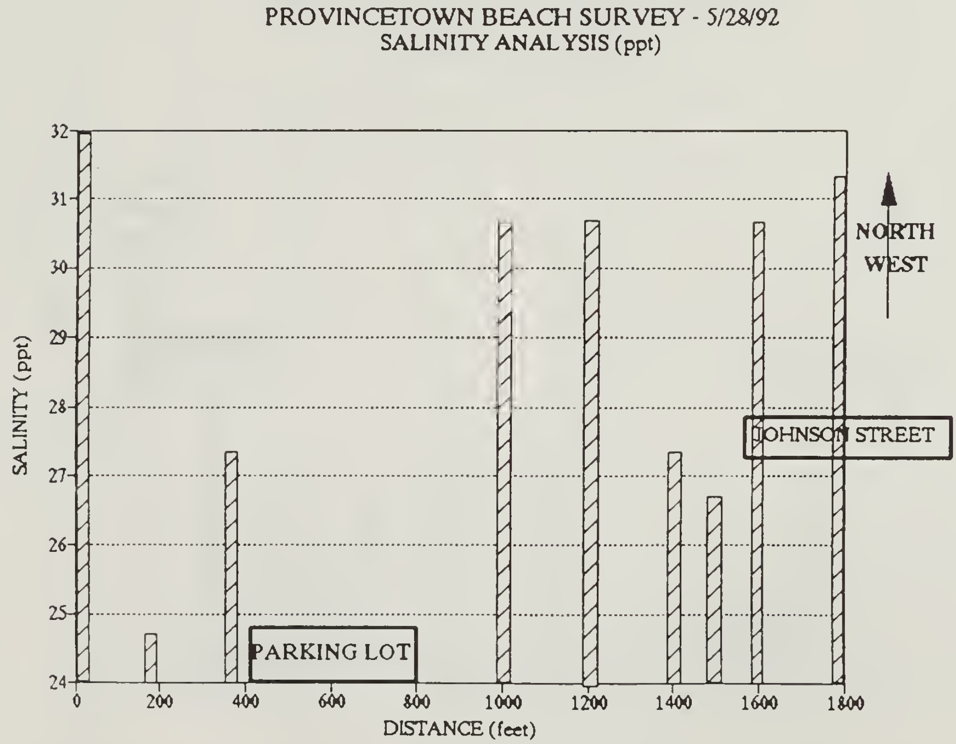


Fig. E-48. Nickel and salinity concentrations along the beachface - 5/28/92, Provincetown, MA.

APPENDIX F

BEACH DYNAMICS RESULTS

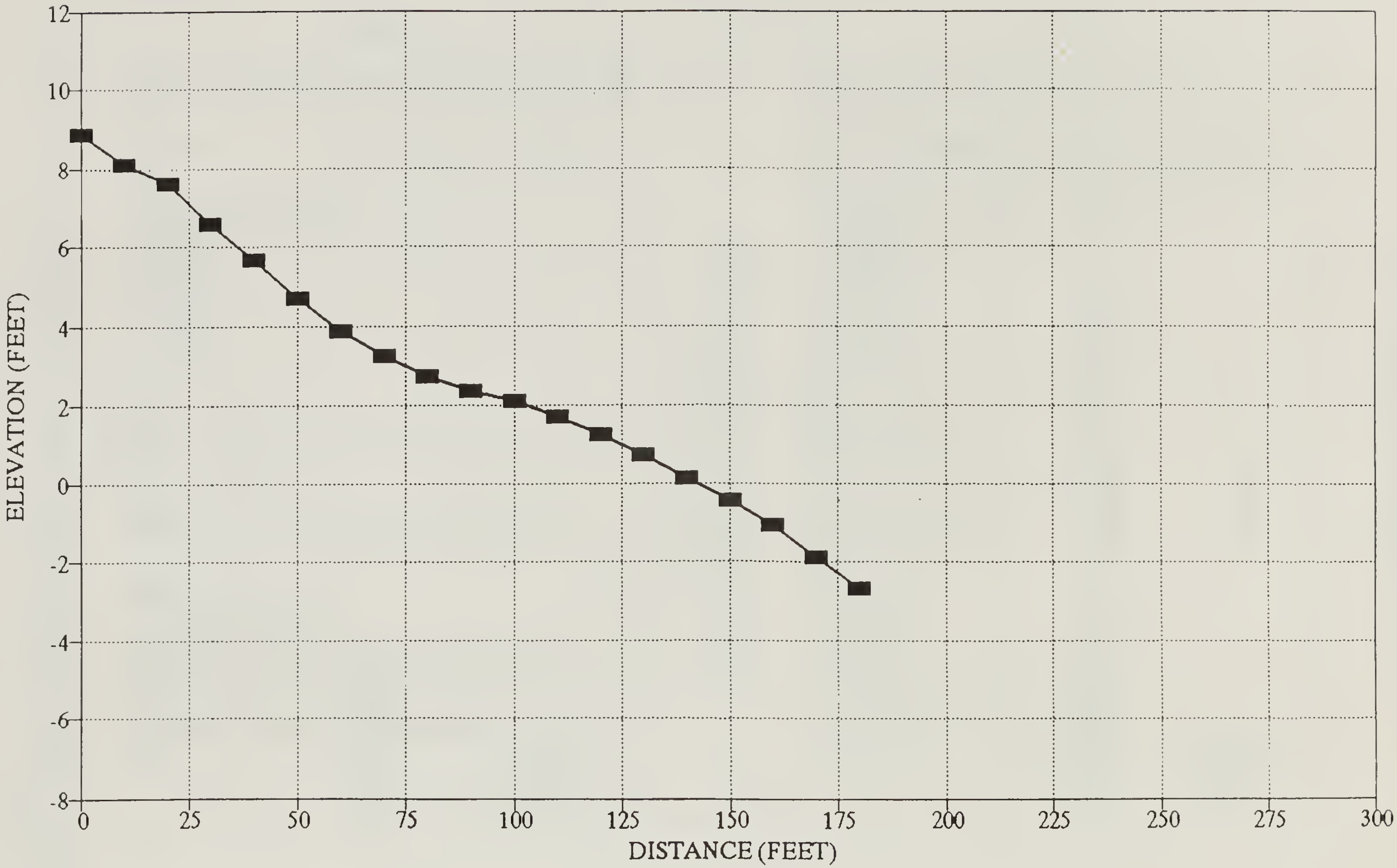


Fig. F-1. Provincetown beach profile - 3/28/91.

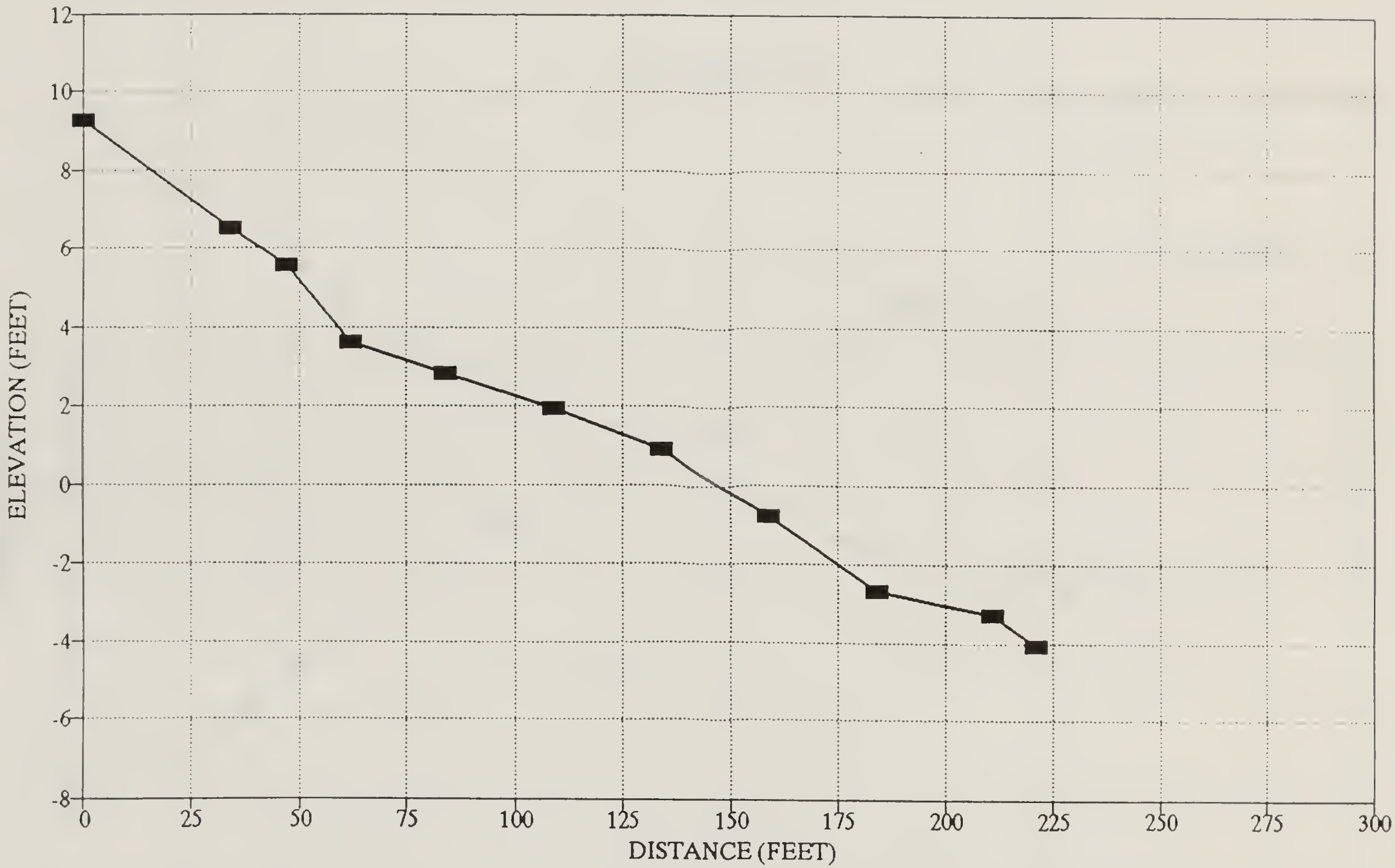


Fig. F-2. Provincetown beach profile - 7/19/91.

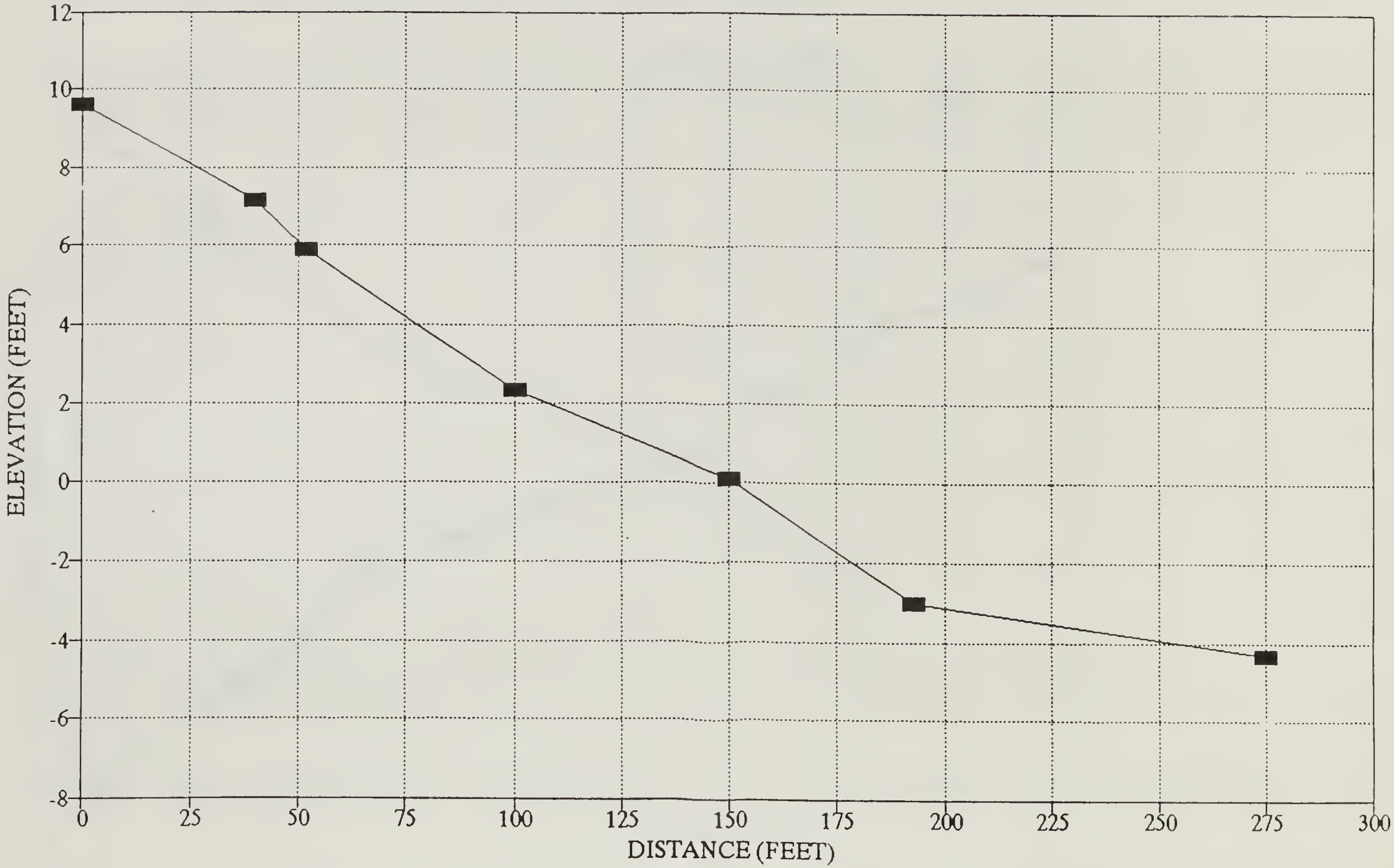


Fig. F-3. Provincetown beach profile - 10/10/91.

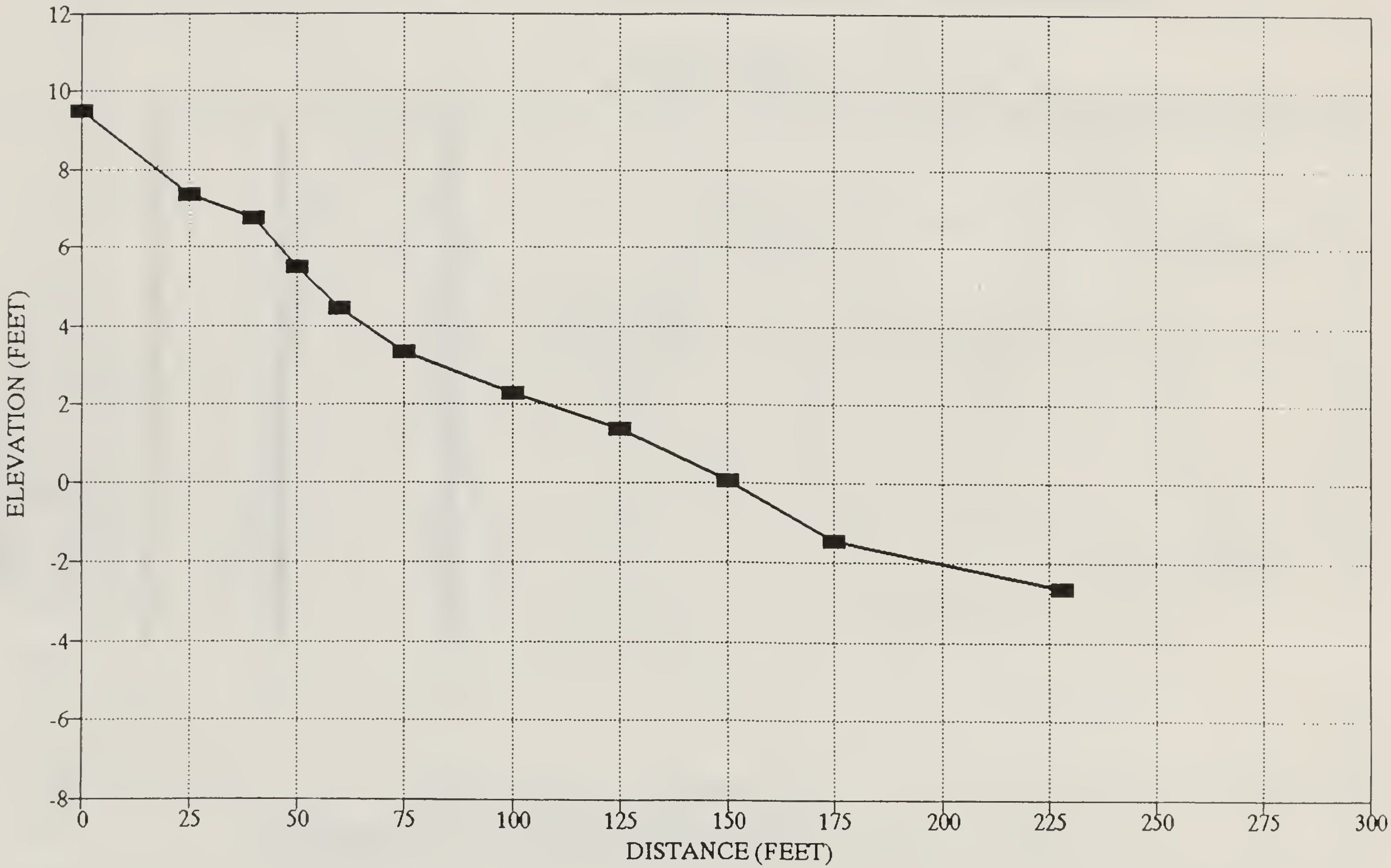


Fig. F-4. Provincetown beach profile - 11/15/91.

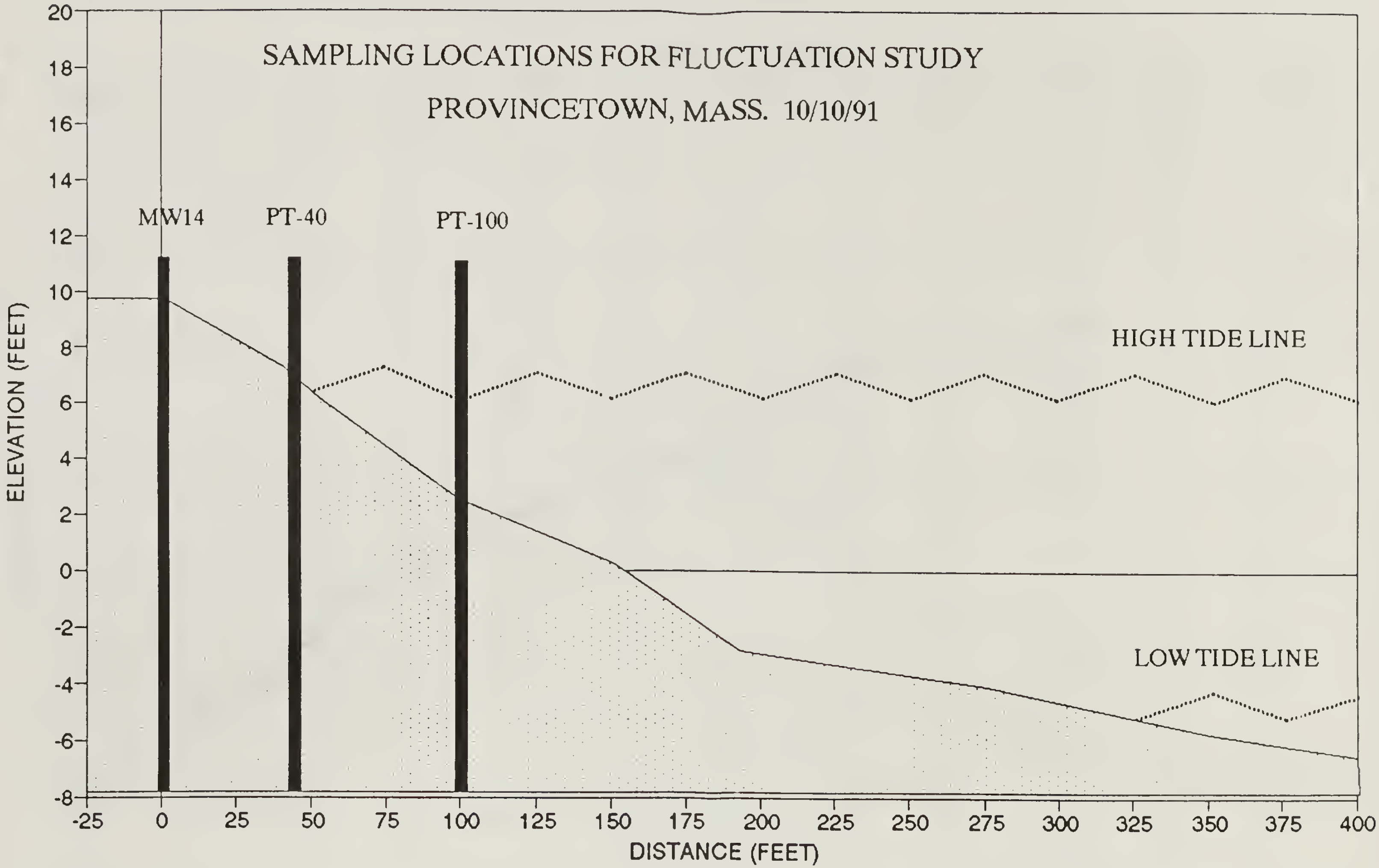


Fig. F-5. Sampling locations for fluctuation study, Provincetown, MA.

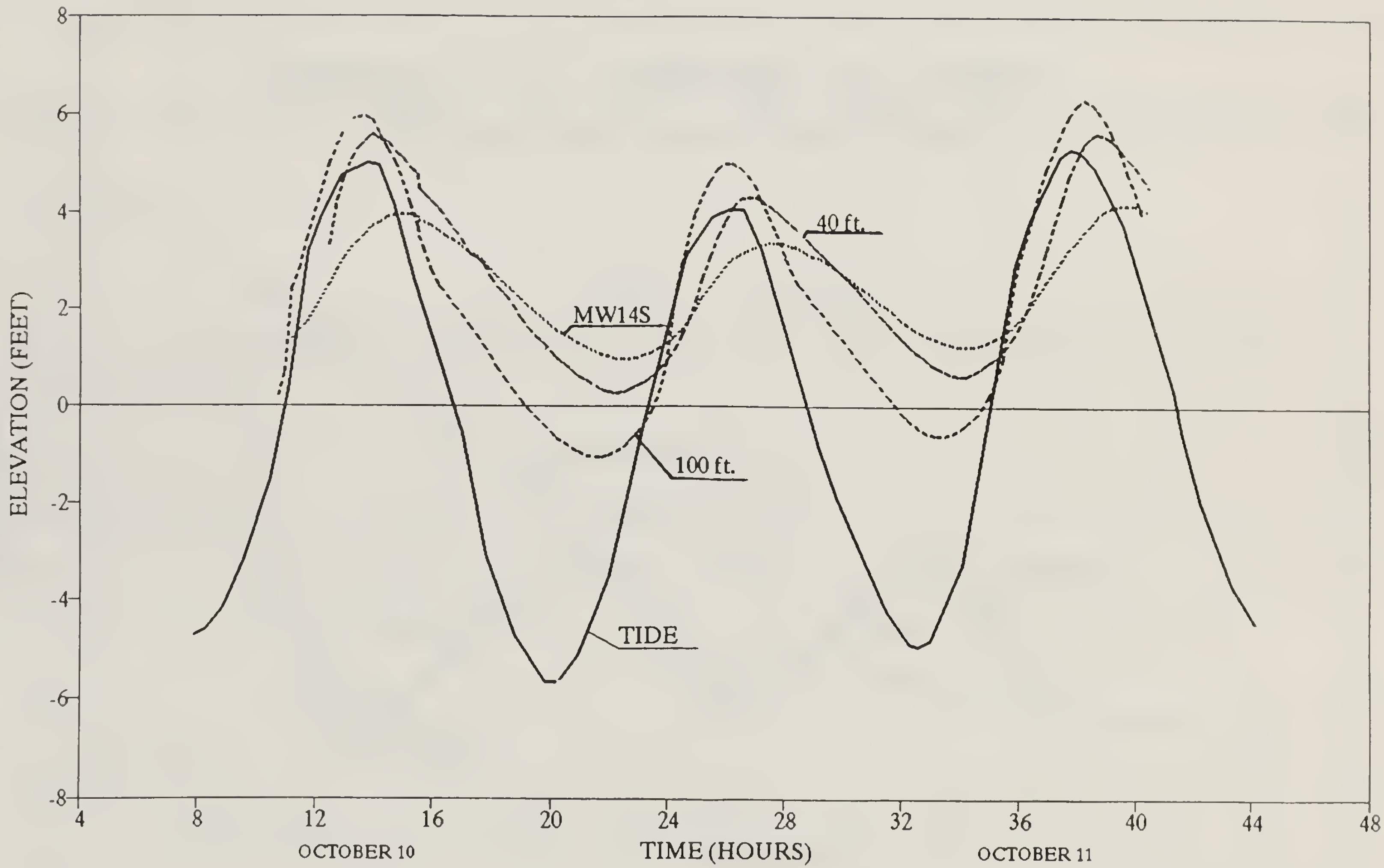


Fig. F-6. Tidal fluctuation with distance from MW14, Provincetown, MA. - 10/10/91.

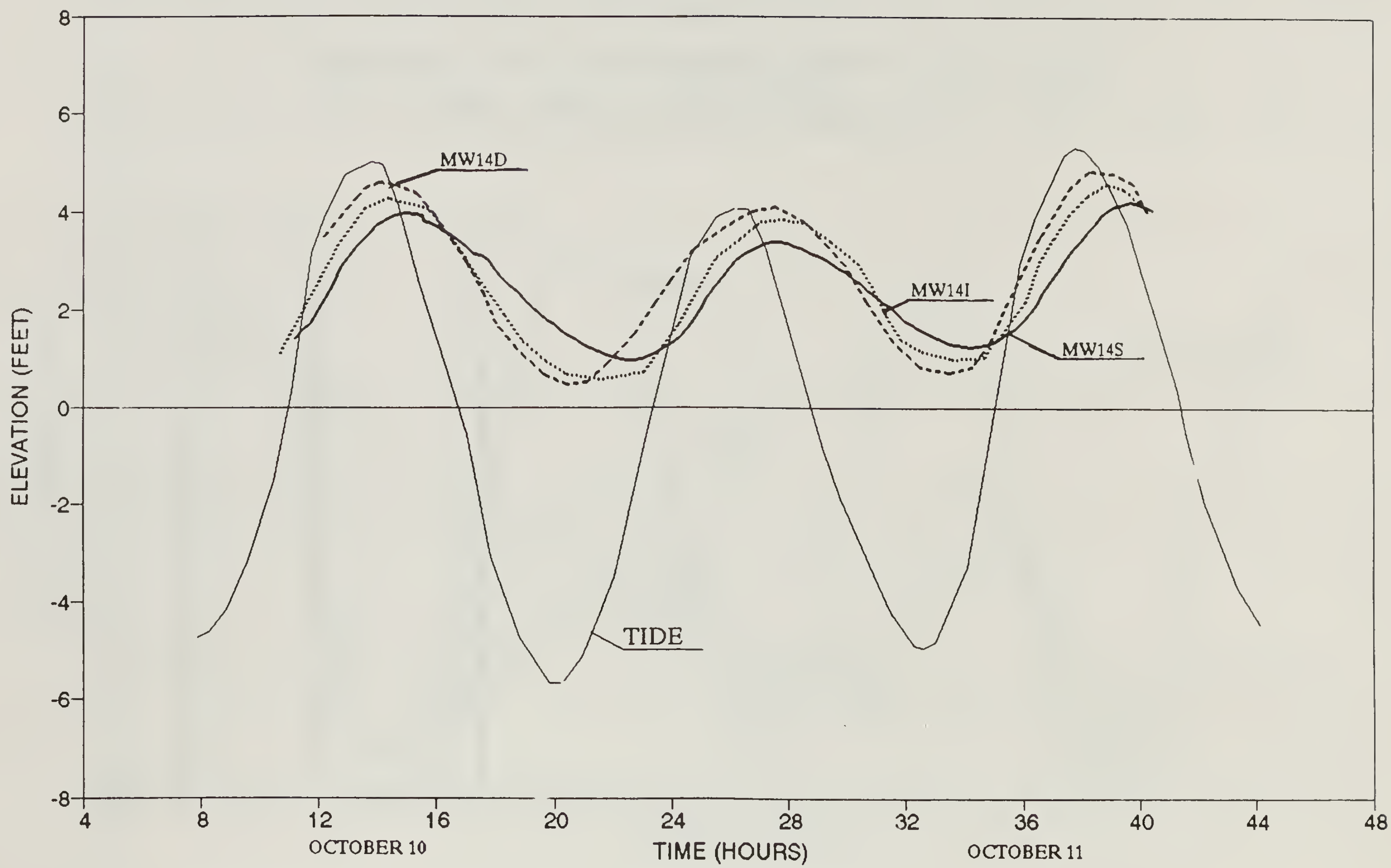


Fig. F-7. Tidal fluctuation with depth changes at MW14, Provincetown, MA.

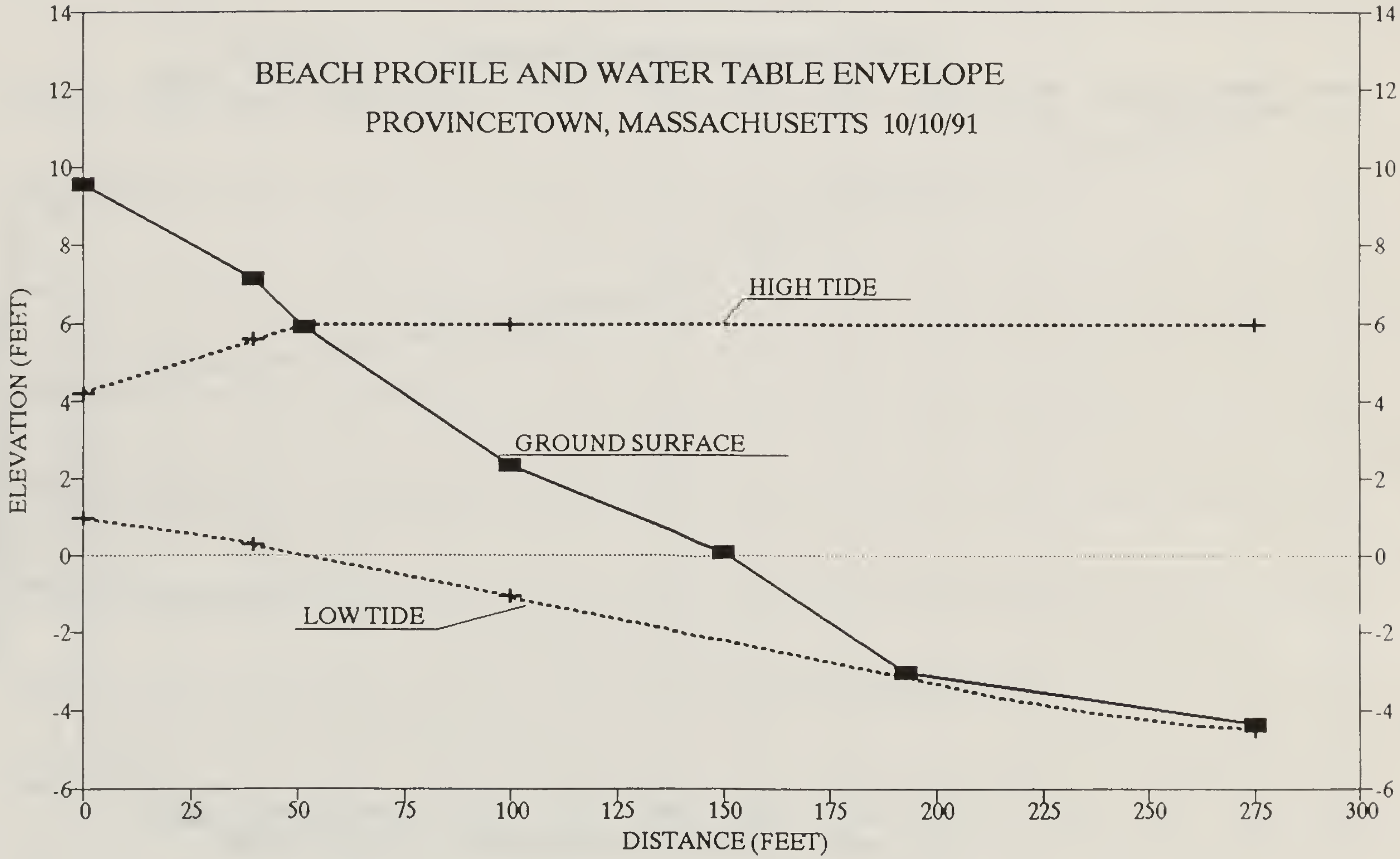


Fig. F-8. Beach profile and water table envelope, Provincetown, MA. - 10/10/91.

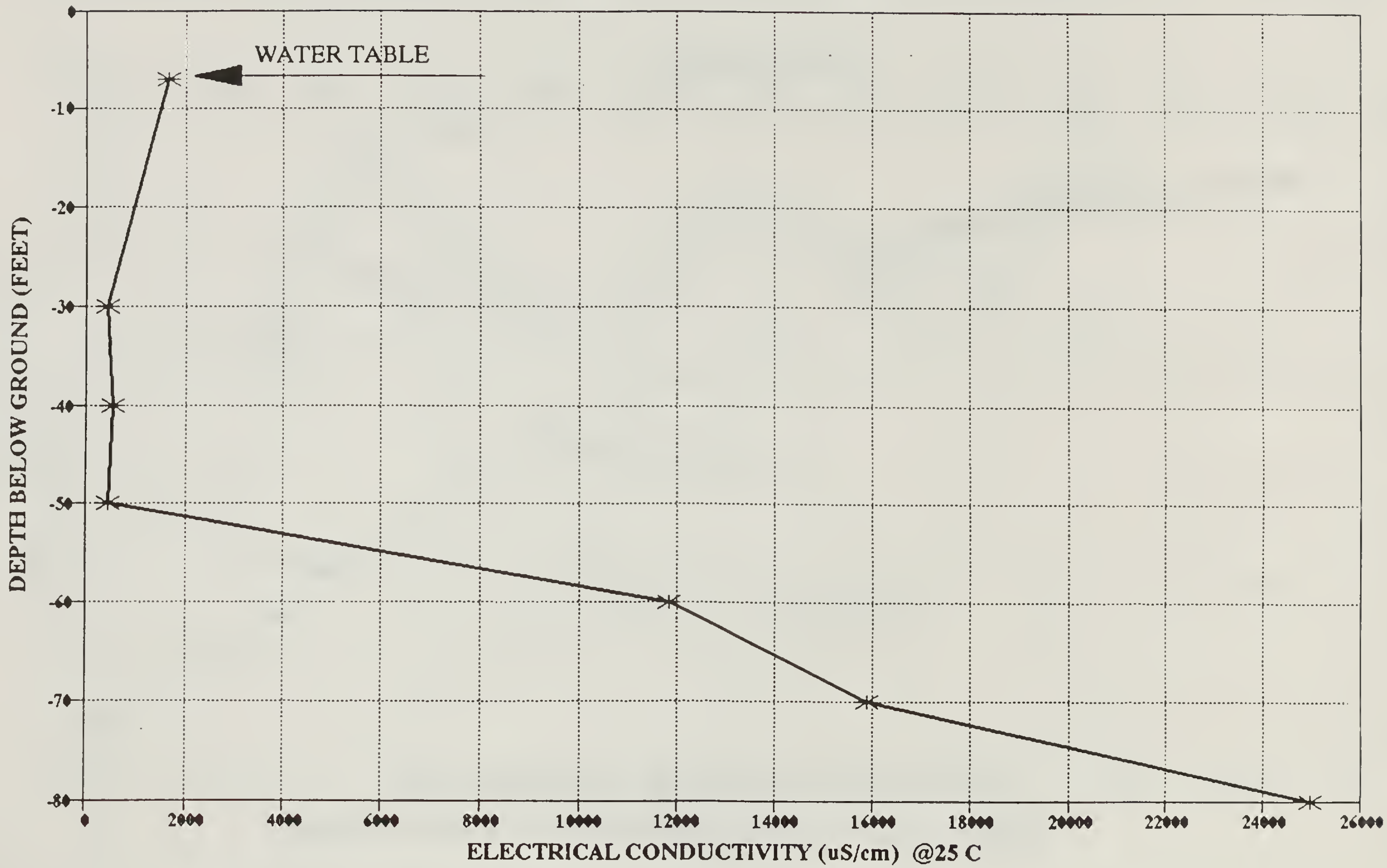


Fig. F-9. Electrical conductivity profile @ MW14D - 1/20/91.

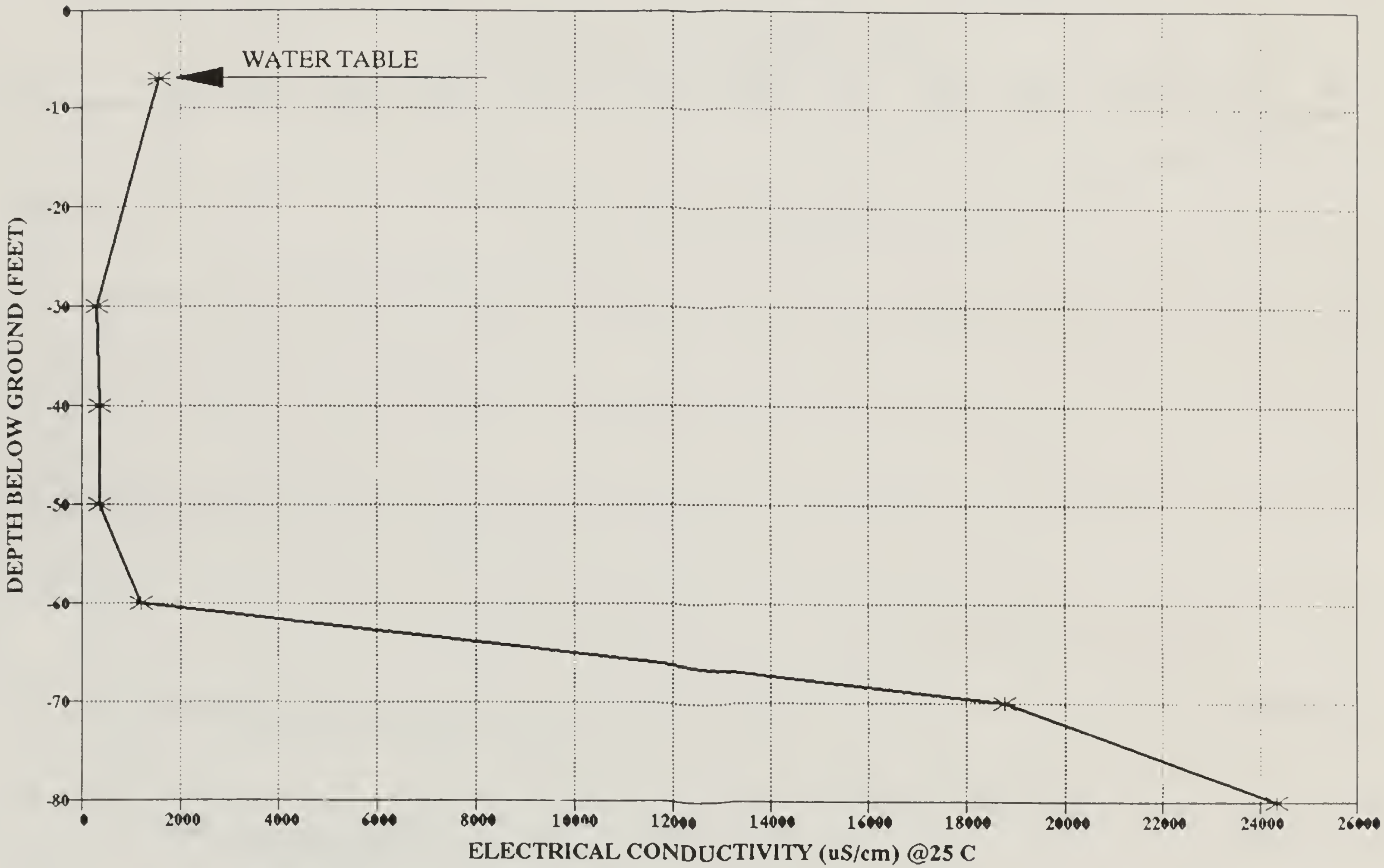


Fig. F-10. Electrical conductivity profile @ MW14D - 8/8/91.

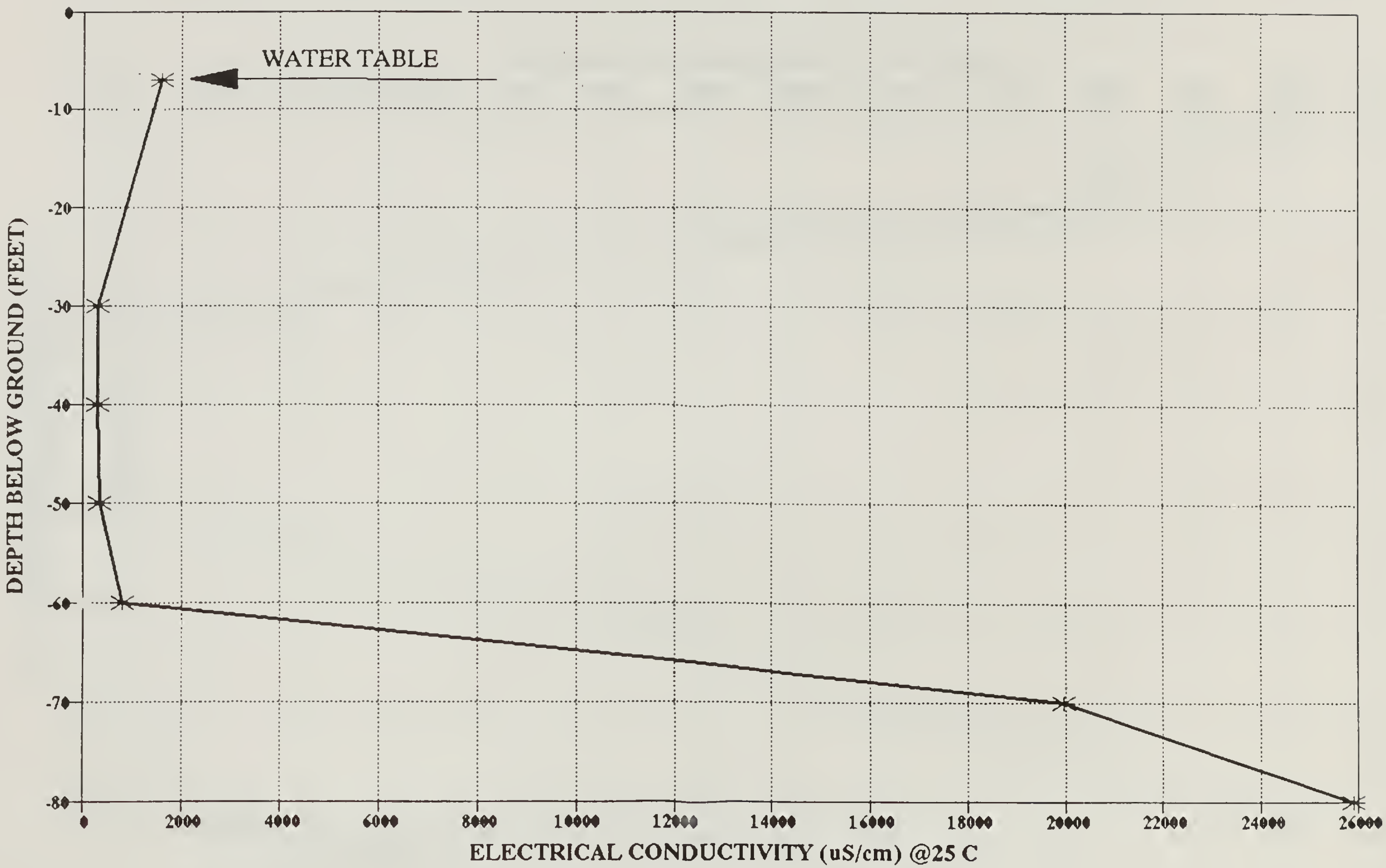


Fig. F-11. Electrical conductivity profile @ MW14D - 10/10/91.

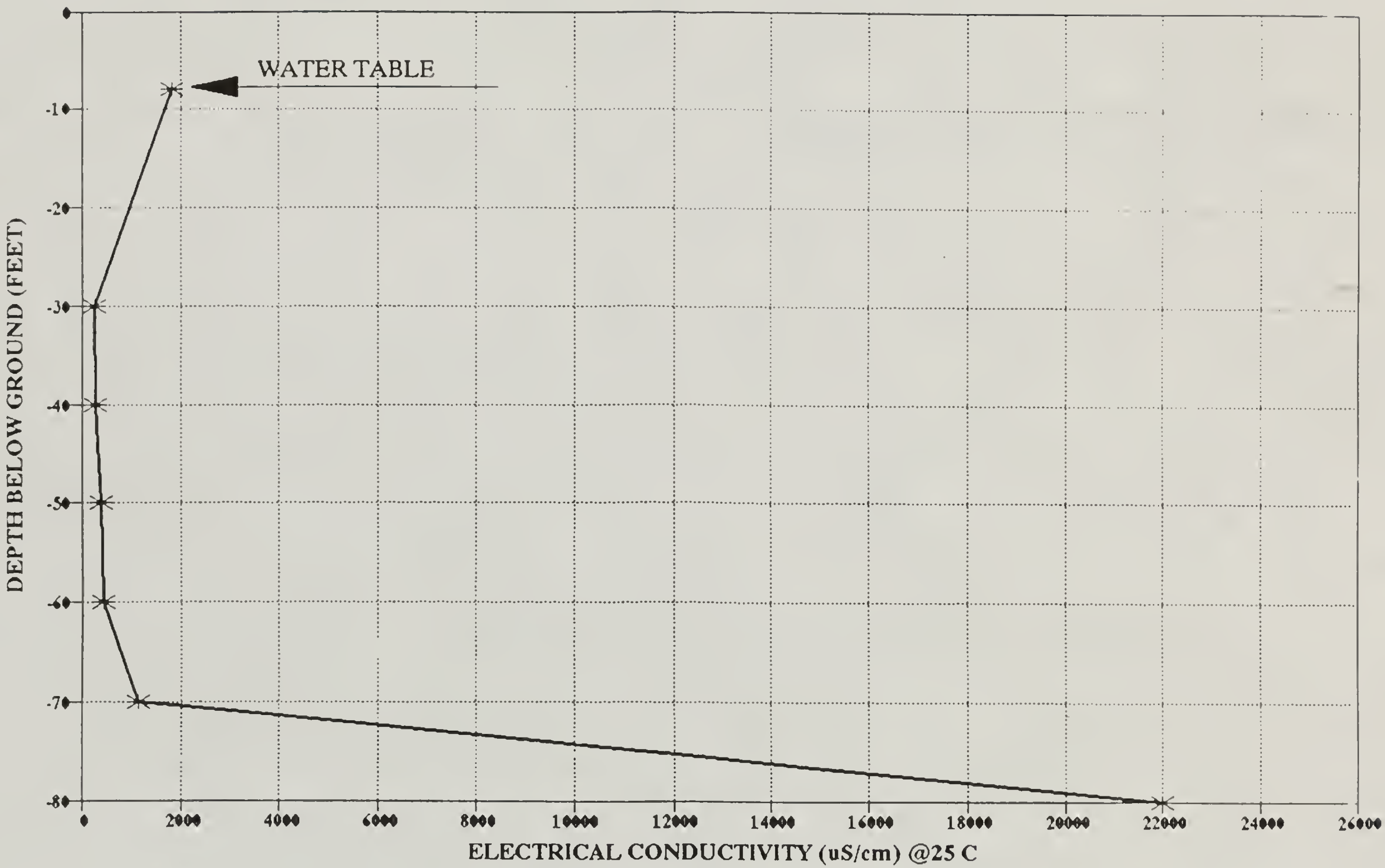


Fig. F-12. Electrical conductivity profile @ MW14D - 7/5/92.

NPS Reference No.
D-113

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people. The department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.