MASSACHUSETTS MILITARY RESERVATION SUPERFUND SITE
DID COSTS AND BENEFITS MATTER IN REMEDIATION DECISIONS?

by

CHRISTOPHE E. BÖSCH

Diploma (M.S.), Civil Engineering
Swiss Federal Institute of Technology, 1992

Diploma (M.S.), Economics
University of Lausanne, 1993

Submitted to the
Department of Civil and Environmental Engineering in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF ENGINEERING
in Civil and Environmental Engineering

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June, 1996

Signature of Author ....
Department of Civil and Environmental Engineering
May, 1996

Certified by ....
David H. Marks
James Mason Crafts Professor of Civil and Environmental Engineering
Thesis Supervisor

Accepted by ....
Joseph M. Sussman
Chairman, Departmental Committee on Graduate Studies

MASSACHUSETTS MILITARY RESERVATION SUPERFUND SITE
DID COSTS AND BENEFITS MATTER IN REMEDIATION DECISIONS?

by

CHRISTOPHE E. BÖSCH

Submitted to the Department of Civil and Environmental Engineering
On May 10, 1996
In Partial Fulfillment of the Requirements for the Degree of
Master of Engineering in Civil and Environmental Engineering

ABSTRACT

The Massachusetts Military Reservation (MMR) is a Superfund site located in Cape Cod, Massachusetts. Groundwater has been contaminated by years of military activity at the MMR. A number of plumes, or discrete zones of contamination, emanate from the reservation. A plan to control the sources and contain the leading edges of these plumes is currently under design. Remediation of the main portion of the plumes are not included within this plan. In light of the high costs (several hundreds of millions of dollars) and uncertainties relative to the technical feasibility of cleaning contaminated groundwater, questions have been raised about the benefit of the plume containment program. A benefit-cost analysis was completed to evaluate the decision to remediate at the MMR. Special emphasis was placed on the definition of a methodology to identify and evaluate benefits. The stated objectives of the program are the mitigation of public health and environmental hazards, and the preservation of valuable water resources. The analysis showed that benefits related to these objectives are expected to be small compared to the costs of the program. The study shed a new light on several hidden consequences of the contamination, notably risk perception due to unmitigated plumes and its socio-economic impact. In this respect, the remediation program may yield significant benefits, although one may question whether plume containment is the most cost-effective means to address these issues. It was determined that a more flexible and balanced approach could provide greater benefits to the affected communities by making a wider range of restoration options available. Accordingly, this thesis brings forward several options that may be considered instead of the plume containment alternative alone. Underlying the MMR case study is the question of whether and to what extent the benefit-cost criterion should play a role in Superfund. This issue, central to the ongoing reauthorization debate, is also discussed in this thesis.

This study was done in conjunction with the work of a project team formed in the framework of the Master of Engineering Program. The goal of the teamwork was to assess current and alternative remedial schemes for fuel contaminated groundwater at the Fuel Spill 12 at the MMR.

Thesis Supervisor: David H. Marks
Title: James Mason Crafts Professor of Civil and Environmental Engineering

Acknowledgments

I would like to express my thanks and gratitude to the many people who provided professional expertise, guidance, and encouragement as well as those who gave their personal support and friendship. In particular, I would like to thank:

- Professor David Marks, for having been a dedicated thesis and academic advisor. This year at MIT has been a great trip through the fascinating world of technology and science. I am especially grateful to Dave, for giving me the best directions, for advising me to make stops when I wanted to keep driving, and for taking the wheel when the ride was getting a little too bumpy. I realize now that one year was not enough, and that there are many more things to discover and learn, and I hope to continue my trip here for the next few years.
- Professor Lynn Gelhar for his encouragements and for making the whole Master of Engineering project an enjoyable learning experience.
- Shawn Morrissey for his useful comments and suggestions.
- Professors Richard Revesz and Robert Stavins at Harvard. The discussions in which I engaged with them have significantly increased my knowledge about economics and policy in Superfund.
- Mary Sanderson at the Environmental Protection Agency (Boston) and Leonard Pinaud at the Massachusetts Department of Environmental Protection (Lakeville). Open discussions with them provided me with a better understanding of the regulatory framework and the decision-making process surrounding the Massachusetts Military Reservation (MMR) Superfund Site.
- The following people at the MMR Installation Restoration Program, for their assistance and contributions to this thesis: Ed Pesce, Douglas Karson, and Robert Davis.
- The Water Districts Superintendents: Raymond Jack (Falmouth), Ralph Marks (Bourne), Robert Kreykenbohm (Sandwich), and David Rich (Mashpee). Interviews with them provided me with insight into the water supply issues of the Upper Cape Cod region.
- The following people at the Cape Cod Commission (Barnstable): Thomas Cambareri, Gabrielle Belfit and Marilyn Fifield. They enabled me to look for the bigger picture regarding environmental issues in the region.
- My teammates, Judy Gagnon, Holly Goo, Karen Jones, Vanessa Riva, and Mitsos Triantopoulos, for their contributions to the group project and the friendly environment which I enjoyed during our many hours spent together.
- The many outstanding faculty and graduate students I had the opportunity to interact with over the past nine months at MIT and Harvard, and from whom I learnt a great deal.
- Last but not least, my parents. Over the last 28 years I have had nothing but continued support from them.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Introduction

Under Superfund, the EPA is responsible for placing the most serious hazardous waste sites on the National Priorities List (NPL) through the Hazard Ranking System, for assessing the risks posed by the sites, and for selecting the most appropriate cleanup option for each site. By law, EPA is required to choose a cleanup strategy that protects the health of people living near each site regardless of cost. Superfund requires EPA to choose a cleanup strategy that is "cost-effective", but will also result in a "permanent and significant decrease" in the volume, toxicity, and mobility of contaminants. Therefore, EPA may consider most benefits, but the act is silent with regard to costs or economic impact analysis. As a result, costly remedial actions such as pumping and treating contaminated groundwater have been implemented and, although estimates vary widely, a recent study by the Congressional Budget Office places the total cleanup costs for current and future NPL sites in the $100 to $400 billion range. In light of the high costs and uncertainties relative to the technical feasibility of cleaning contaminated groundwater, questions have been raised about the benefit of the cleanup program (Resources for the Future, 1995). Do expected benefits favorably compare with costs resulting of the enforcement of stringent cleanup standards ? Surprisingly, and probably due to challenge represented by the estimation of benefits, little has been done to develop benefit-cost analysis tools that could help policy and decision-makers evaluating and prioritizing remedial actions.

This thesis addresses the following questions. Is it beneficial to society to enforce stringent cleanup goals at all costs? What are the resulting costs and benefits if the aquifer is allowed to clean itself through natural processes? How does it compare with remedial schemes? In order to address these questions, this thesis is comprised of the following chapters:

- Chapter 2 focuses on the definition of the evaluation process and determination of the parameters for the cost-effectiveness and benefit-cost analyses.
- In Chapter 3, the methodology is applied to the Massachusetts Military Reservation (MMR) Superfund Site. The decision to remediate is evaluated through a benefit-cost analysis in

order to determine if the proposed remediation scheme addresses damage mitigation in the most beneficial way.

- Chapter 4 uses the Fuel Spill no 12 at the MMR as a case study to assess various remediation techniques from an economic standpoint
- Finally, Chapter 5 reviews the current status of the debate regarding the introduction of benefit-cost analysis in Superfund

Due to the limited scope of this study and the uncertainties in the assumptions made, the results presented below should be considered with caution. Estimates are preliminary and are only intended to illustrate a methodology.

2. Economic analysis in remediation programs

2.1 Introduction

One of the indispensable tools used in remediation programs is environmental analysis which examines how actions affect the physical environment. Economic analysis provides a different perspective by analyzing the monetary effects of programs. Developing estimates of the costs and benefits of remediation programs (or obtaining a better understanding of the estimates of others) provides policy and decision makers with several advantages, namely efficient decision-making, efficient use of resources, priority setting, and, especially relevant in times of budget constraints, program justification.

2.2 Cost-effectiveness analysis

Cost-effectiveness analysis estimates the costs of alternative methods to achieve a given policy objective. Since the objective is taken as given, it is not necessary to compare it with other policy objectives. Thus, a crucial aspect of benefit-cost analysis, the need to measure the value of the benefits in monetary units, is avoided.

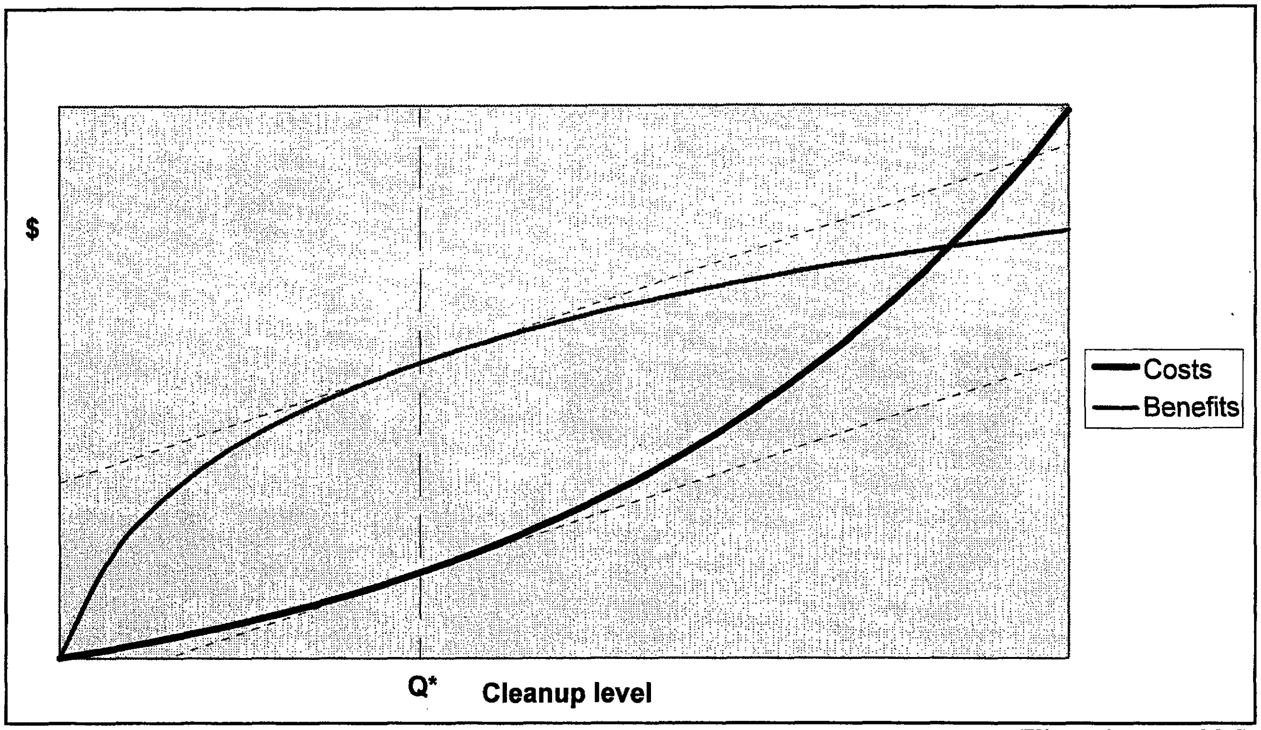
2.3 Benefit-cost analysis

A series of special techniques have been developed to value the benefits from environmental improvement or, conversely, to value the damage done by environmental degradation. Special techniques were necessary because most of the normal evaluation techniques which have been used over the years cannot be applied to environmental resources. While demand curves for normal commodities such as bread or automobiles can be estimated from readily available data, no such data exist for environmental resources which do not pass through markets. It is not possible to check your local grocery store for the current price of clean water. The special valuation techniques are now used in two related, yet different, contexts. On the one hand, they are used in ex post settings such as the groundwater contamination that occurred at the MMR. In this case the damage has already happened and the purpose of the valuation exercise is to establish the appropriate level of compensation. On the other hand, they are also used in ex ante settings, where the purpose of the valuation is to facilitate the process of deciding what good remedial or policy actions might be. Valuation has been used, for example, to rank the seriousness of environmental problems, to provide guidelines to environmental agencies as they decide how to focus their efforts. One of these techniques, cost-effectiveness analysis, has become the technique of choice for those who recognize the importance of economics for protecting the environment, but are skeptical of any efforts to monetize the value of environmental resources (Tietenberg, 1996).

The most ambitious of the techniques to value the benefits from environmental improvement is benefit-cost analysis. Though it makes the most precise statements about which policy choices are efficient, it also imposes the largest requirement for information in order to provide those statements. It is fairly easy for most people to accept the general premise that costs and benefits of actions should be weighed prior to deciding on a policy choice. The technique becomes more controversial, however, when specific numbers are attached to the anticipated benefits and costs and specific rules for translating these numbers into a decision are followed (Tietenberg, 1996).

Neither a benefit-cost ratio greater than 1.0 nor a positive net benefit ensures optimality. The net benefit is maximized when Q* is supplied. At this point the marginal benefit is equal to the marginal cost, so that total benefits exceed total costs by the largest possible amount (Figure 1).

Figure 1 - Costs versus benefits



(Tietenberg, 1996)

2.3.1 Methodology

Evaluations of the costs and benefits of remedial actions are based on the assumption that both the costs and benefits are measurable and can be compared to each other. In this regard it is essential to establish a balanced benefit-cost analysis that includes all of an action's associated costs and benefits. A benefit-cost analysis is typically comprised of the following steps:

- definition of the proposed remedial actions (objectives, alternatives, impacts)
- establishment of the baseline/do nothing alternative
- assessment of the costs of remedial actions
- identification and estimation of the types of benefits
- evaluation of costs and benefits

2.3.2 Identification of benefits

The critical aspect of the study is the identification and evaluation of benefits. There are essentially two types of benefits:

- commodity benefits accruing from the use of ground and surface water, for domestic, agricultural/fishing and industrial uses
- resource benefits :
  - *option values*, the benefit of being able to use the water at some time in the future
  - *bequest values*, the benefit of having a source of clean water for future generations)
  - *existence values*, the benefit of knowing the water is uncontaminated, even if there is no expectation that it will have to be used
  - *recreation value*, the use of streams and ponds for recreational purposes

Because markets generally do not exist for resource benefits, they are usually not priced. Instead, they are captured by what is called "consumer surplus".

In addition, distinction should be made between direct and indirect benefits (benefits passed on to others), and between primary and secondary benefits (e.g. benefits of remedial actions that spill over to the rest of the economy).
Estimating benefits is a particularly difficult task because some parameters, especially resources benefits, are untangible. However, they are no less important than commodity benefits. Because it is not always possible to measure benefits directly, a commonly used method is to estimate the program's costs, and then estimate the losses in well-being that are avoided by a remediation program relative to the do nothing alternative (baseline), e.g. costs of treatment, alternative water supplies, environmental damage.

There are basically four techniques used for estimating benefits to society:

- avoided cost method (costs due to the "do nothing" alternative as the benefits of the remediation program)

- health/ecological risk assessment (benefit to individuals and wildlife of avoiding increased illness and risk of cancer)
- contingent valuation method (survey method used to determine the willingness to pay for reaching a certain level of cleanup)
- hedonic pricing (relationship between property value and site contamination parameters such as water quality)

2.3.3 Estimation techniques

2.3.3.1 Avoided cost

This technique estimates the costs that would be incurred in the absence of a groundwater restoration program. Because a remediation program is design to detect, respond to, or treat contamination, it avoids these costs, which are treated as benefits of the program and are called avoided-cost benefits. The estimation of avoided-cost benefits has three components:

- *BC, the baseline costs:* the cost of damages incurred if a contamination event was not noticed, or if action was not taken (treatment, replacement and damage costs)
- *p, the probability of the program working*
- *PC, the direct and indirect program costs:* the costs to detect, respond, and comply with the program designed to address a contamination event

These three components are represented in the following simplified equation for calculating avoided-cost benefits:

$$(BC \times p) - PC = \text{Avoided-Cost Benefits}$$

Although estimating benefits using the avoided-cost method is fairly straightforward, it underestimate program benefits because it excludes the resource values associated with clean groundwater.

2.3.3.2 Risk valuation

An important an complex subset of avoided costs is the benefit of avoiding increased illness or risk of cancer by cleaning up contaminated groundwater. The basic method for calculating damages involves multiplying the number of health incidents by the total health-care costs applicable to that particular illness. For instance, if the health analysis estimates that exposure to contaminated groundwater causes 10 cancers per year, the total health-care cost damages can be calculated as follows (Table 1):

Table 1 - Example of risk valuation

	Number of cases	Costs/cancer ($)	Total Costs ($)
Cured cancers	6	100,000	600,000
Uncured cancers	4	2,000,000	8,000,000
Totals	10		8,600,000

<u>Assumptions:</u> cure rate is 60 %, medical-care costs for cancer $100,000, value of life $ 2 million Valuing life is extremely difficult. Figures ranging from $1 to $ 10 million have been cited in the literature; a value of about $2 million is typically used by insurance companies.

Estimating the value of non-fatal illnesses is much more difficult because these costs will vary considerably for different types of contaminant-induced illness and for different individuals. Because of the large number of assumptions involved in a health risk assessment, it is best to estimate a range of possible exposures. The range of values associated with health risks should then be applied to each possible level of exposure.

2.3.3.3 Contingent valuation method

Contingent Valuation is the officially approved method for valuing non-market goods by the U.S. Water Resources Council and for valuing natural resources under the Department of Interior's CERCLA regulations. The contingent valuation method (CVM) seeks to measure the economic nonuse value that individuals place on the environment by asking them how much they would pay to preserve a given natural resource from injury. In essence, it creates a hypothetical market (a sort of "what if" situation) and asks individuals to place a value on the good in this market. This willingness to pay (WTP) is obtained through in-person, telephone, or mail surveys. CVM assumes that the hypothetical market can be described in such a way that the respondents will react in the same way as they would in a real market. In this respect, questions have been raised about the accuracy of results in light of the many potential sources of bias pertaining to CVM surveys (where the sample WTP systematically diverge from the respondents "true" WTP) [5]. In addition, the values of environmental preservation are in large part noneconomic in character, based on society's objective to safeguard a common environmental heritage. Business, in particular, has attacked use of this new methodology as unreliable and unsound, although business traditionally has insisted that environmental law and policy be driven by economic analysis of the costs and benefits of environmental regulation. EPA's Office of Policy, Planning and Evaluation has recently completed a major study exploring the use of the contingent valuation method for valuing groundwater. This study determined that citizens will pay an average of $7 per person per month for non-use values of groundwater (EPA, 1993). An other survey determined that the mean willingness to pay for groundwater protection in Dover, New Hampshire, was $120 per year (EPA, 1990). To date, the most significant CVM case is the $900 million settlement of natural resources damages claims for the Exxon Valdez spill in Prince William Sound, Alaska.

2.3.3.4 Hedonic pricing

One way to determine the value of water when there is no real market is to look at the market for another good, such as housing values, whose price is affected by the quality of water. In this kind of indirect approach, the effect of different levels of water quality on housing prices can indicate the value placed on the quality of groundwater itself. Hedonic pricing is a method that uses property values to determine other values. For example, the difference in price between two "identical" houses located one mile and ten miles, respectively, from a plume of contaminated groundwater is a partial measure of the economic damage (or, conversely, an estimation of the benefits that would be yielded by a restoration program). Although academic researchers may be interested in applying this method to groundwater, several methodological questions need to be resolved to be sure that hedonic pricing correctly values groundwater cleanup efforts.

2.4 Economic analysis in Superfund

2.4.1 Introduction

Known popularly as the "Superfund Act", the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 created a $1.6 billion fund to be used over a five-year period to clean up existing toxic waste sites. The revenue was derived mainly from taxes on chemical industries. It offers compensation for the loss or destruction of natural resources controlled by the state or federal government, but it does not provide any compensation for injured individuals. A $9 billion reauthorization bill was passed in 1986 significantly increasing the amount of money dedicated to the clean up of these sites. The existence of Superfund allows the governments involved to respond quickly to incidents. They are not forced to wait until the outcome of court suits against those responsible to raise the money or to face the uncertainty associated with whether the suits would ultimately be successful. This formidable list of statutory and common-law remedies embodies a variety of approaches to the resolution of toxic substance problems. The question is whether or not these approaches are efficient or cost-effective.

2.4.2 Valuation of risk and benefit-cost analysis in Superfund

The high cost of cleanups has focused attention on the way in which EPA makes decisions about Superfund sites. One question that has been raised is whether the benefits of cleanup - which often accrue to a small population near the site - are worth the costs. This question is essentially a debate about the permanence of the cleanup. At most sites, imminent danger of contaminants usually can be removed at low cost. Contaminated soil can be fenced off or capped, and an alternative drinking water supply can be provided if groundwater is used for drinking. What raises the cost of cleanup is the decision to clean up the site for future generations: deciding, for instance, to pump and treat an aquifer for thirty years to contain a plume of pollution. To determine whether the benefits of long-term cleanup options are worth the cost is difficult. A question that has been raised regarding cleanups is what criteria EPA uses to select a cleanup strategy for a site (Resources for the Future, 1995).

Using analyses of a comprehensive database of 1991 Records of Decisions (RODs), the Harvard Center for Risk Analysis conducted a survey to document the official basis for cleanup decisions at Superfund sites. Major findings are presented below:

- public health is the primary rationale given for decisions to take remedial action at Superfund sites
- neither increasing nor decreasing the degree of conservatism alone is likely to profoundly influence decisions
- estimated human exposures from groundwater contamination often account for the maximum reported risks
- the estimated health risks at sites are not adjusted to reflect actions that have been taken or might be taken in the future to restrict human access to contaminated materials at the site or to contaminated water supplies
- remedial actions at sites are typically made without even rough information about the potential size of the exposed population, the number of expected excess cancers or the incidence of non-cancer health effects

The issue of the proper role of economic analysis in the Superfund program is an issue Congress is facing in the reauthorization of Superfund. It is an issue that is complicated by the tension between the more explicit, visible goal of protecting public health and the more understated, implicit objective of protecting groundwater resources. As the program is currently being implemented, risk assessment faces an increasingly minor role in remedial decisions. The cleanup goals are not set based on site-specific risk assessments and management considerations. For example, salient policy considerations (such as the size of the exposed population, the natural background levels of contaminants, and the costs of achieving various degrees of risk reduction) are not considered when cleanup goals are set at Superfund sites (Resources for the Future, 1995).

3. The Massachusetts Military Reservation Superfund Site

3.1 Introduction

The Massachusetts Military Reservation (MMR) is a Superfund site located in Cape Cod, Massachusetts. Groundwater has been contaminated by years of military activity at the MMR. A number of plumes, or discrete zones of contamination, emanate from the reservation. The contamination of groundwater by the plumes has affected the local water supplies, initiating the closure of municipal and private wells. The current action to remediate seven plumes on the reservation is deemed "interim"; only the source and leading edge of the plumes will be controlled. Remediation of the main portion of the plumes are not included within this plan. In light of the high costs ($250 million) and uncertainties relative to the technical feasibility of cleaning contaminated groundwater, questions have been raised about the benefit of the plume containment program. This chapter provides an assessment of the benefits that would be yielded by the proposed cleanup program. Special emphasis is placed on the investigation of water supply issues related to regional groundwater contamination. These issues include an assessment of the benefit of containing the plumes as opposed to the replacement of lost water supplies.

3.2 Study Area Characterization

This section provides background information on the Massachusetts Military Reservation (MMR). It covers physical and sociological features of the local region.

3.2.1 Physical characteristics

3.2.1.1 Location

The MMR is located in western Cape Cod, bordering the townships of Bourne, Falmouth, Mashpee, and Sandwich. The expanse of the MMR includes 22,000 acres located in Barnstable County (Figure 2).

3.2.1.2 Topography

The MMR is located on two distinct types of terrain on the Cape Cod Peninsula. The main Cantonment Area lies on a broad, southward-sloping glacial outwash plain. Elevation in the area ranges from 100 to 140 feet above sea level. To the north and west of the MMR, the terrain becomes hummocky with irregular hills and greater topographic relief, and lies in the southward extent of Wisconsin Age terminal moraines. The highest elevation is 306 feet (Stone & Webster, 1995). The entire site is dotted with numerous kettle holes and depressions forming ponds and lakes.

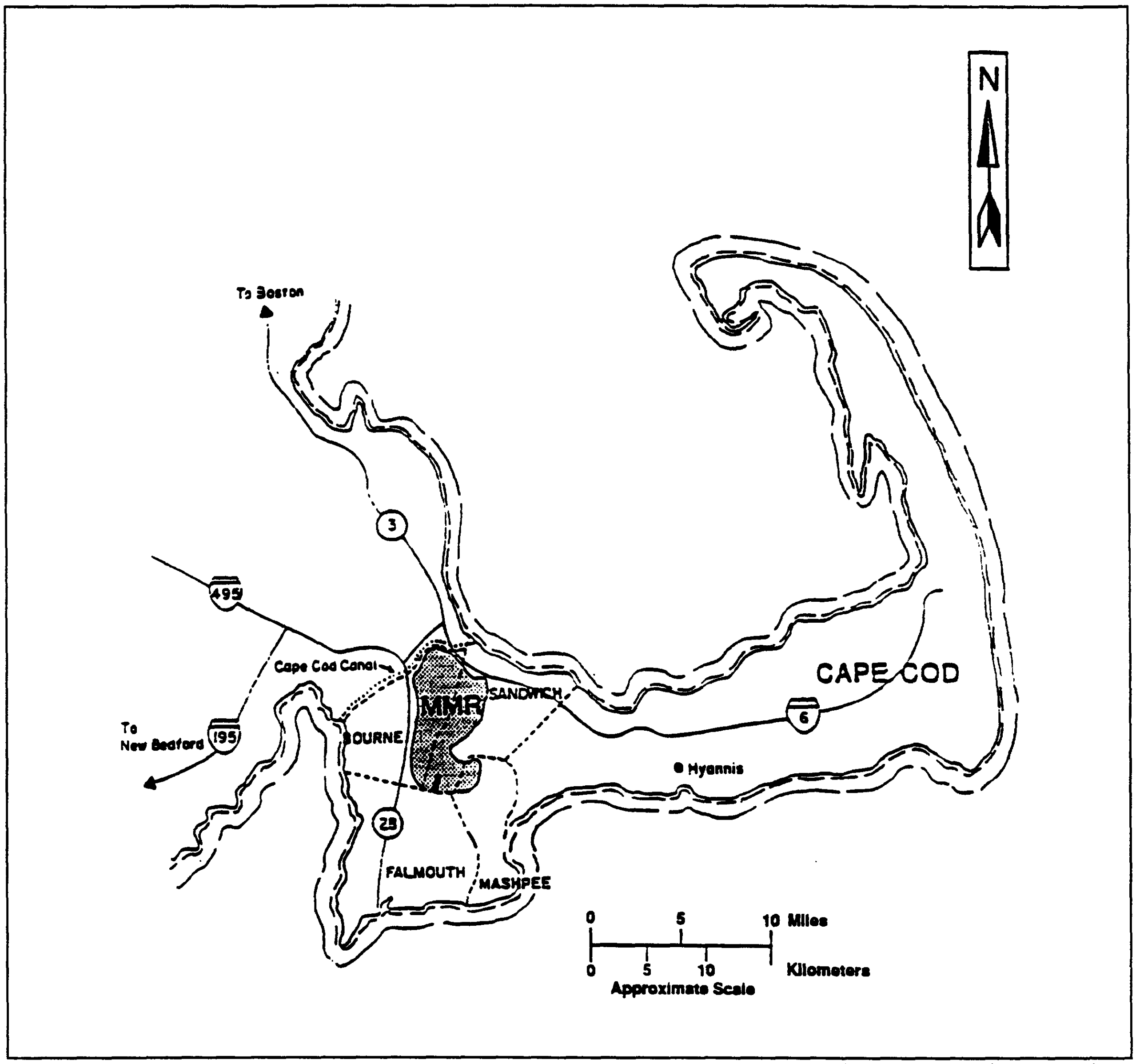
3.2.1.3 Geology and Hydrogeology

Geology

The area is categorized as a glacial outwash plain. Typically, the plain consists of highly permeable sand and gravel, as well as distinctly stratified layers of lower permeability silty sands and clays.

Hydrogeology

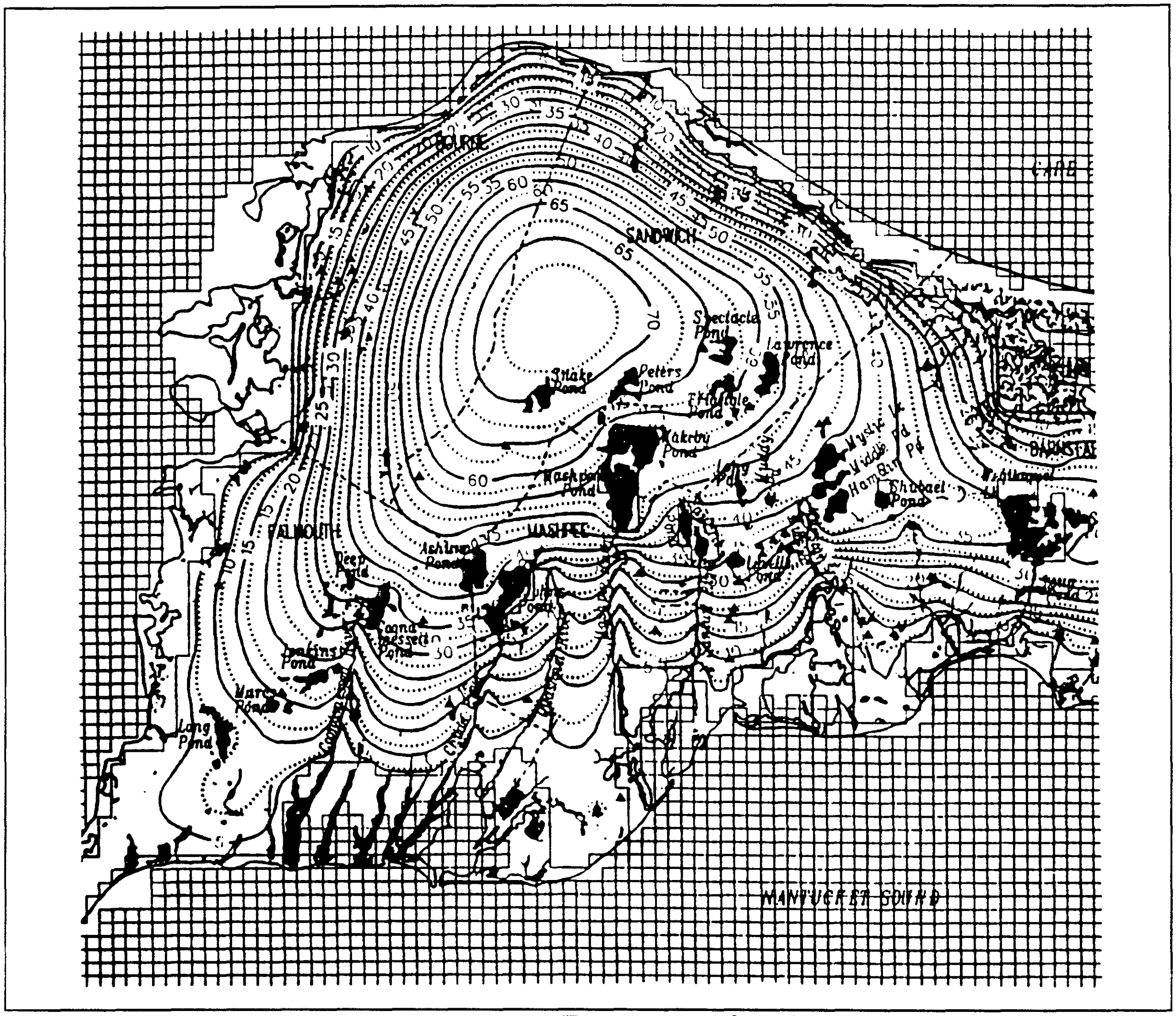
A single groundwater flow system underlies western Cape Cod, including the MMR. The aquifer system is described as unconfined and is recharged by infiltration from precipitation.



(Stone & Webster, 1995)

Figure 2 - Location of the MMR

Accordingly, the aquifer has been characterized by the US Environmental Protection Agency (EPA) as a sole-source aquifer. The high point of the water table is located beneath the northern portion of the MMR (Figure 3). Flow is generally radially outward from this mound. The ocean forms the lateral boundary of the aquifer on three sides.



(Department of Environmental Management, 1994)

Figure 3 - Hydrogeology of the MMR

3.2.1.4 Climate

Cape Cod has a temperate climate with precipitation distributed year round. The annual average precipitation is about 47 inches, and annual groundwater recharge is in the range of 0.67 to 0.91 inches/year (Department of Environmental Management, 1994). The highly permeable nature of the sands and gravels underlying the area allow for rapid infiltration of rainfall.

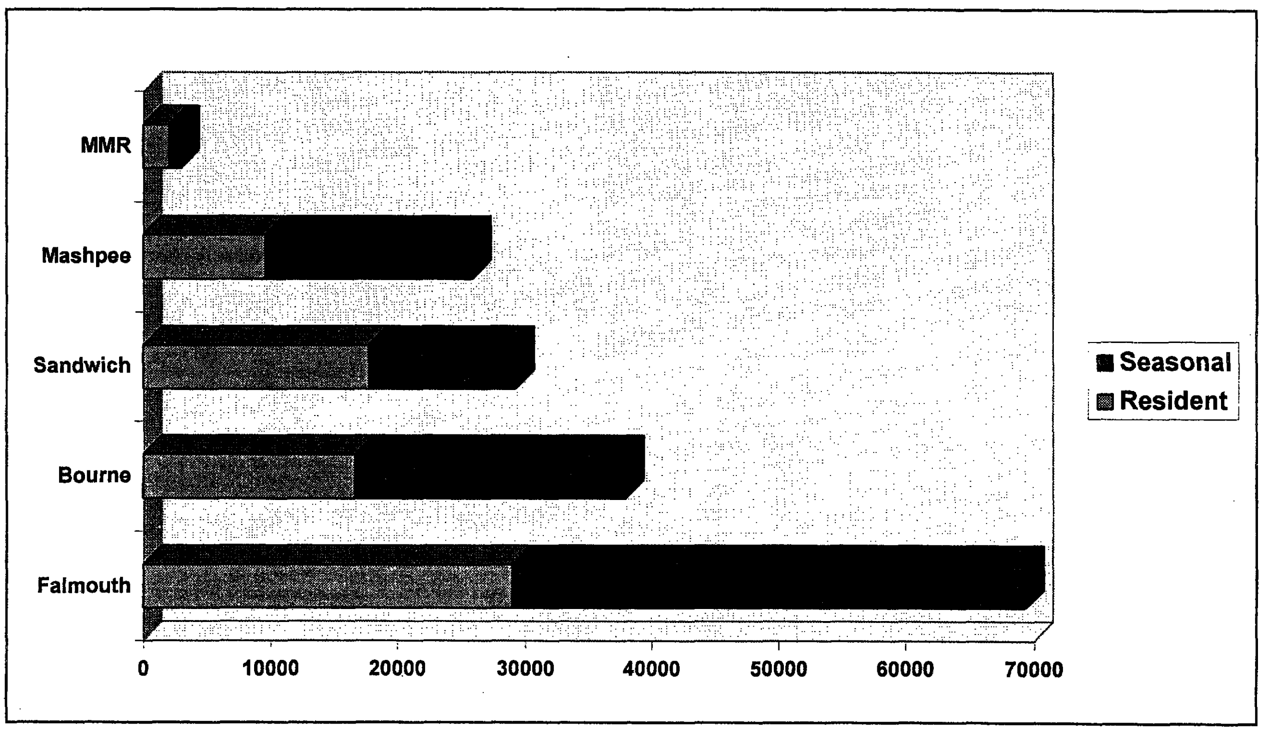
3.2.2 Socio-Economic Characteristics

The Upper Cape area comprises of the townships of Falmouth, Sandwich, Mashpee and Bourne. This section discusses demographics, water use and local economics pertaining to the MMR.

3.2.2.1 Demographics

The MMR has a year round population of approximately 2,000 people with an additional 800 nonresident employees. Both year round and seasonal residents live in the towns adjacent to the MMR - Falmouth, Mashpee, Sandwich, and Bourne. The population of these towns fluctuate significantly between winter (29,000) and summer (70,000) due to the influx of vacationers. (Figure 4).

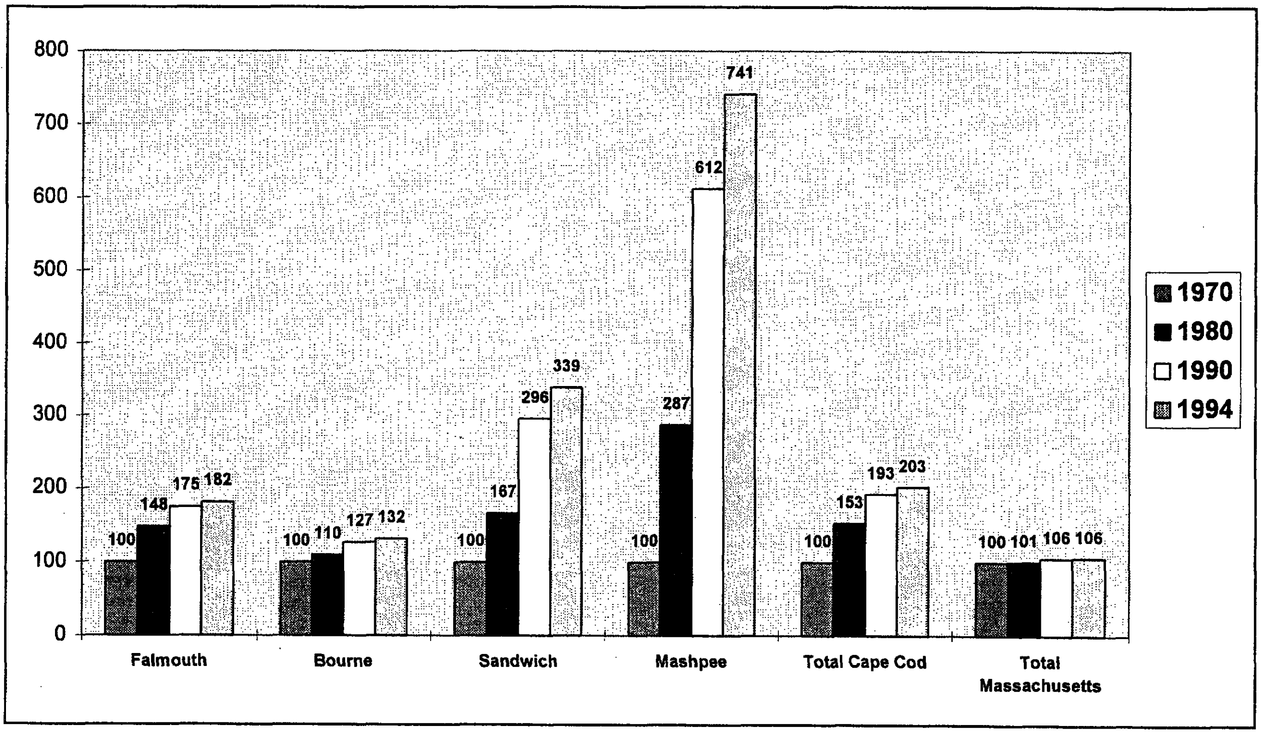
Figure 4 - Demographics of the Upper Cape Cod area



(Cape Cod Commission, 1996)

Between 1980 and 1990, the Upper Cape population grew 35%. However Mashpee registered a 113% increase. During the same period, population growth throughout Massachusetts amounted to only 5% (Cape Cod Commission, 1996) (Figure 5). Due to the fact that the Upper Cape is sparsely inhabited, the population directly affected by the plumes is relatively small - 4,000 (current situation) to 6,500 (no action alternative).

Figure 5 - Population growth of the Upper Cape Cod area (base = 100 in 1970)



(Cape Cod Commission, 1996)

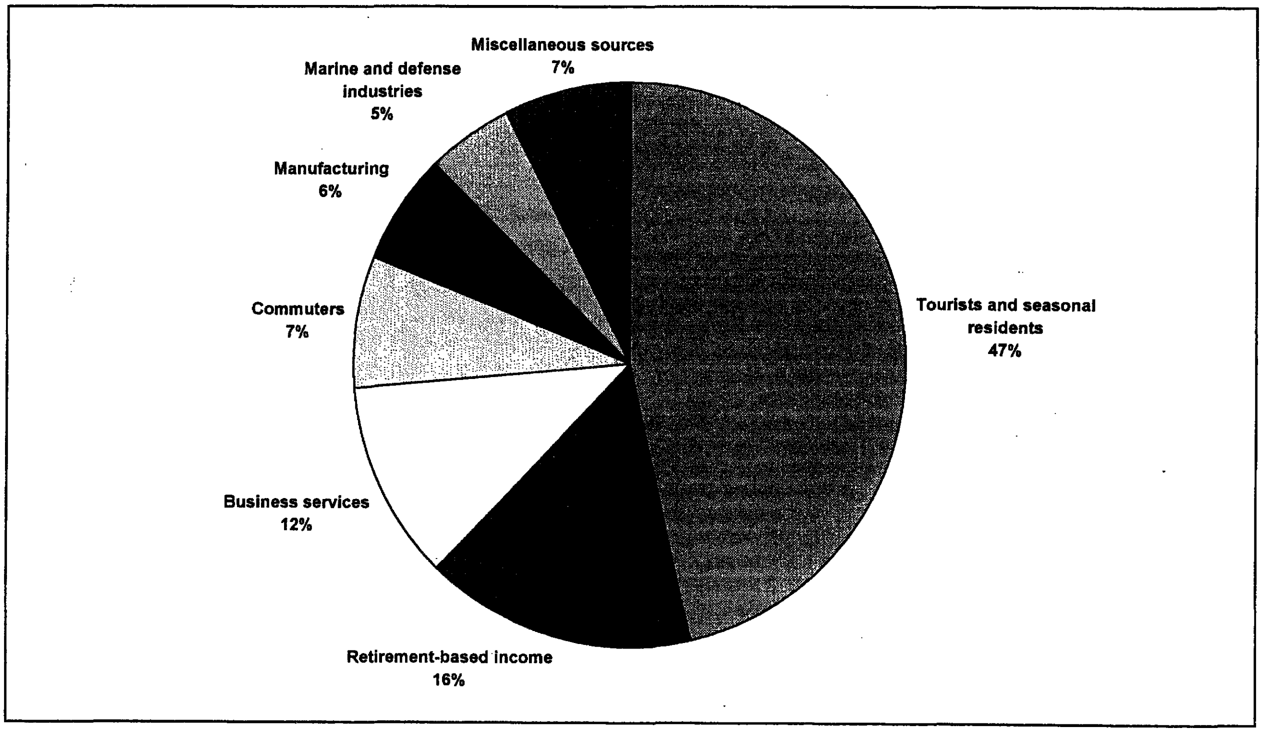
3.2.2.2 Water Use

Public water supply customers are the primary water users on Cape Cod, with a base off-season average demand of 8 million gallons per day (mgd) and 16 mgd in-season. In the Upper Cape, 80% of the population is on a central supply system; the remaining 20% of the population relies entirely on individual private wells. For further information regarding water resources, see section 3.3 (Department of Environmental Management, 1994).

3.2.2.3 Economy

The Upper Cape economy was valued at $600 million in 1992 (Figure 6); more than 60% was derived from tourists, seasonal residents, and retirement-based income. Hence, the economic base is believed to be highly sensitive to environmental contamination and associated perceived risk. The Upper Cape's overall valuation of real and personal property increased by 3 times in the past 10 years to $8 billion in 1994 (Cape Cod Commission, 1996).

Figure 6 - Upper Cape Economic Base (Total $600 million, 1992)



(Cape Cod Commission, 1996)

3.2.3 Ecosystems

The Massachusetts Division of Fisheries and Wildlife considers coastal plain ponds as unique, sensitive natural communities in the state. These ponds, found primarily in Cape Cod, occur in glacial kettles lacking surface water inlets. The specialized and rare ecosystem that develops on the shores of these ponds is highly sensitive to water level changes. (Department of Environmental Management, 1994)

3.2.4 History

3.2.4.1 Activity History

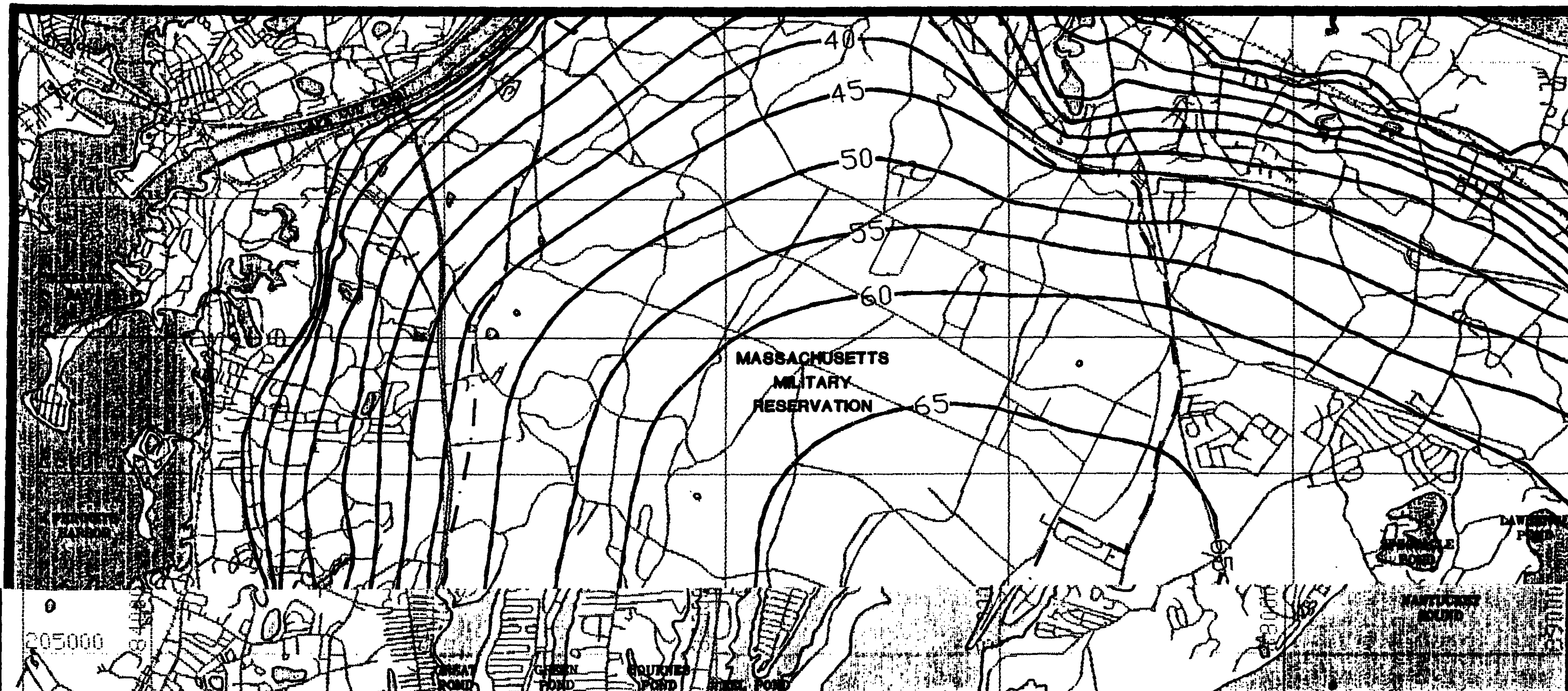
Operational units over the MMR's history include the U.S. Air Force, U.S. Navy, U.S. Army, U.S. Marine Corps, U.S. Air National Guard, U.S. Army National Guard, and U.S. Coast Guard. The MMR has housed and served the U.S. military forces since 1911. Within the reservation, military activities included troop training and development, ordinance development, vehicle operation and maintenance, fire fighting, and fuel storage and transport. The MMR was particularly active during World War II (1940-1946). Between 1955-1970, the MMR operated a number of surveillance missions and aircraft operations through the Air National Guard. Since 1970, the military activities have been scaled down (Advanced Sciences, Inc., 1993).

3.2.4.2 Regulatory History

On November 21, 1989, the MMR was listed on the National Priorities List as a Superfund site. As a result, the National Guard Bureau (NGB) and the U.S. Coast Guard entered into an Interagency Agreement (IAG) with the EPA in July 1991. As a result, the site investigations and remedial actions are subject to the requirements and regulations of the Comprehensive Environmental Response and Emergency and Liability Act (CERCLA). The Department of Defense (DOD) formulated and organized the Installation Restoration Program (IRP) to address investigations and remediation efforts as a result of hazardous waste sites at DOD facilities (Air National Guard, 1994). Through the Air Force Engineering Services Center, the NGB entered into an IAG with the U.S. Department of Energy (DOE). The NGB, with the support of DOE, analyzed the extent of contamination and potential site contamination at the MMR facility (Air National Guard, 1994).

3.2.4.3 Contamination History

Past releases of hazardous materials at the MMR have resulted in groundwater contamination in a number of areas. Documented sources of contamination include former motor pools, landfills, fire training areas and drainage structures such as dry wells. Nine major plumes of groundwater contamination (Figure 7) have been found to be migrating from these sources areas and have been defined during extensive groundwater investigations. Seven of the nine plumes have migrated beyond the MMR facility boundary. Extraction and treatment of groundwater have already been initiated for the purpose of containing one plume, the CS-4 plume, to manage the migration of contaminants and prevent further pollution of downgradient areas. The interim action planned by the IRP proposes to extend plume containment schemes to six other plumes (Stone & Webster, 1995).



LEGEND

- BASE BOUNDARY
- RIVER/POND/STREAM
- 5 LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL)
- COMPOSITE MCL EXCEEDANCE SOLVENT GROUNDWATER CONTAMINATION
- COMPOSITE MCL EXCEEDANCE FUEL GROUNDWATER CONTAMINATION
- COMPOSITE MCL EXCEEDANCE EDB CONTAMINATION
- WATER

NOTES:
1. GROUNDWATER ELEVATION INFORMATION IS BASED ON DATA COLLECTED IN NOVEMBER 1995 AND USGS WATER TABLE MAPS
2. PLUME PRESENTATIONS BASED ON COMBINATION OF DATA GAP AND REMEDIAL INVESTIGATION REPORTS
3. LOW LEVEL SPORADIC DETECTIONS OF EDB AT LOCATIONS OTHER THAN FS-12 ARE NOT SHOWN
4. PFSA PLUME DETERMINATION IS BASED ONLY ON RI DATA
5. CS-4 PLUME IS REPRESENTED AS A SUM OF THE VOCs PRESENT BASED ON 1989 DATA

N

0 5700

SCALE IN FEET

Figure 7 - Plume Area Map

Massachusetts Military Reservation
Cape Cod, Massachusetts

SOURCE: HAZWRAP, MODIFIED BY OPTECH 1996.

OPTECH
OPERATIONAL TECHNOLOGIES CORPORATION

MARCH 1996
OTIS\WTR-HYD

3.3 Water Supply Issues

The Plume Response Plan states that one of the major objectives of the remediation scheme is "to reduce the risks to human health associated with the potential consumption of water." In addition, various reports have quoted that the groundwater contamination may cause a potential shortage of water in the Upper Cape Water Districts (Falmouth, Bourne, Sandwich, Mashpee). The goal of this section is to assess the current and future water situation and determine if the proposed remediation program is effectively addressing water supply issues.

3.3.1 Current Water Situation In The Upper Cape Water Districts

3.3.1.1 Water Uses

Customers using the public water supply system are the primary water users on Upper Cape Cod, with an off-season average demand of 6.9 million gallons per day (mgd) and an in-season (June, July, August) average demand of 14.3 mgd. Depending on the water district, 50% (Mashpee, Bourne) to 90% (Falmouth) of the population is on a central water supply. The remainder is self-supplied, relying entirely on individual private wells. Groundwater is the source of all public water supplies, with the exception of the town of Falmouth which is partly supplied by a surface water source, Long Pond Reservoir. Estimated water needs by industrial and commercial users is 0.9 mgd. Registered cranberry growers on Upper Cape Cod use more than 5.4 mgd (Department of Environmental Management, 1994).

3.3.1.2 Water Resources

The maximum pumping capacity (or sustainable yield) for the four water districts was estimated at 40.4 mgd. The current in-season pumpage is 9.6 mgd, and is expected to rise to 14.5 mgd in 2020 (Department of Environmental Management, 1994). Assuming that 20% of the

Upper Cape water resources would be lost due to further migration of the plumes in the case of the do nothing alternative, the pumping capacity would be decreased to 32.3 mgd. In-season use in 2020 would then equal 45% of total water resources. According to these strict calculations, water shortages will not occur as a result of contamination from the MMR. However, other considerations such as land availability and the high cost of drilling new wells may make treating the water feasible and/or necessary.

3.3.1.3 Water Quality

To date, five public wells have been taken off line due to the contamination from the MMR plumes:

- Falmouth Water District: Ashumet Valley and Coonamessett Pond wells
- Bourne Water District: Wells # 2 and 5 (although they may be used on-season)
- Sandwich Water District: Weeks Pond well (for precautionary purposes only)

In addition to the threat posed by the MMR plumes, the aquifer is susceptible to contamination from septic wastes, municipal sewage systems, and fertilizer leachates. This is due to the highly permeable nature of Upper Cape Cod soils. In addition, data has shown that clean water at the well can be contaminated within the distribution system:

- anaerobic bacterial growth in stagnation areas, notably dead ends
- TCE contamination due to pipe lining (PVC). Falmouth reported TCE levels exceeding MCLs by a factor of eight (38 ppb vs. 5 ppb)
- chlorine residuals in the distribution system. This issue could be solved if water would be treated, allowing chlorination rates to be significantly reduced.

With the exception of Falmouth where water is chlorinated, the water in all districts is neither treated nor disinfected. Almost everywhere potassium hydroxide is used to reduce pH.

In Falmouth, it has been estimated that 60% of the water users have installed home treatment devices (Personal communication with Upper Cape Water District Superintendents).

3.3.1.4 Future Water Demand In The Upper Cape Water Districts

Due to population growth, average water needs are expected to grow from 7.5 mgd in 1995 to 11.5 mgd in 2020 (+ 1.7 % per year) (Department of Environmental Management, 1994). All water districts, except Falmouth, should be able to meet the demand until at least 2020, provided alternative water supplies are developed to substitute wells lost due to plume migration. This point will be discussed further in the next section.

3.3.2 Impact Of Do nothing Alternative On Water Supply

3.3.2.1 Alternative Water Supplies

In order to reduce human health risks to an acceptable level, public and private wells already contaminated or directly threatened by further plume migration should be replaced. The following alternatives could be considered:

- wellhead treatment
- drilling new wells in pristine water areas
- monitoring private wells and/or connecting self-supplied households to the municipal distribution system
- water conservation programs and incentives.

Selection of the first alternative would depend on public acceptance. From interviews conducted with the Water District Superintendents, people currently supplied from pristine water sources would be the least likely to accept treatment (e.g. Bourne), whereas Falmouth residents, whose water is already chlorinated, would probably accept this alternative provided adequate (see Appendix 7.5 for further details). The acceptance rate would certainly be greatly increased if this alternative was proposed by the local water districts and not the MMR, due to the history of poor relationships between the MMR and the surrounding towns (Personal Communication with Upper Cape Water District Superintendents).

Selection of the second alternative would depend on land availability. This is an important problem on the Cape due to extensive real estate developments and the economic inability of most towns to reserve land for water supplies.

BOURNE

In order to replace the public wells lost due to the LF-1 plume, the town of Bourne will drill a new well in the northwestern corner of the MMR and connect it to the main water carrier. Bourne is also considering the construction of transmission lines to put self-supplied properties on municipal water, notably in the Scraggy Neck residential area, should the LF-1 plume migrate further (Personal Communication with Ralph Marks).

FALMOUTH

The recent shutdown of the Coonamessett well (contaminated by CS-4 EDB plume) has put additional strain on the town's water supply. Falmouth is considering reopening it after the installation of a well head treatment plant. In the meantime, the town's water district will implement voluntary restriction programs in order to face the increased on-season demand. Further migration of the Ashumet Valley and CS-4 plume would not endanger additional public water supplies. Private wells are not likely to be contaminated because they are shallow. However, close monitoring would be required. Self-supplied households would be switched to municipal water if risk levels are exceeded. (Personal Communication with Raymond Jack)

SANDWICH

Although the Weeks Pond well has been taken off line for precautionary reasons, further migration of the FS-12 plume is not expected to contaminate the pond, nor any other public water supplies. If needed, private wells could be connected to public water systems in the threatened areas. (Personal Communication with Robert Kreykenbohm)

MASHPEE

There is no public supply well in the potential contamination path in Mashpee. However, close monitoring of private wells would be required. Self-supplied households should be switched to municipal water if risk levels are exceeded. (Personal Communication with David Rich)

3.3.2.2 Investments And Costs Required

Based on information provided by the Water District Superintendents, the following cost estimates have been obtained:

New 700 gpm well, including land purchase, drilling and equipment	$1.5-2.0 million
Well head treatment plant	$0.7 million
Transmission line (16 inch diameter) (per ft)	$250
Connecting Scraggy Neck residential area to public distribution system (100 properties)	$1.0 million

Therefore, in the case of the no-action alternative, the cost of replacing contaminated or threatened water supplies (and thus substantially reducing human health risks) would be approximately:

- $5 million for public wells substitution
- $10-15 million to put all concerned self-supplied properties on public water supply

The total cost of $15-20 million needs to be compared with the cost of remedial actions.

3.3.3 Impact On Water Supply After Remediation

3.3.3.1 Avoided Investments And Costs

Public Wells

Because all threatened public wells will be replaced (or equipped with well head treatment plants), even in the case of the remediation/plume containment alternative, the avoided costs will not be significant.

Private Wells

Plume containment will preserve pristine groundwater sources. Thus, investments related to the construction of transmission lines to replace potentially threatened private wells will be avoided. However, in the worst case scenario (maximum probable plume migration, all private wells contaminated), the avoided costs would amount to less than $10 million. This figure needs to be compared with the cost of remedial actions.

3.3.3.2 Feasibility Of Beneficial Use Of Treated Plume Water

Reuse of treated plume groundwater has been considered for potential beneficial reuse (drinking or irrigation water). Issues related to the public acceptance of this alternative are analyzed in Appendix 7.5. Based on three demand scenarios, extraction wells pumping rates and transmission lines investment costs, an assessment of the water reinjected/water extracted ratio and the water costs has been performed (Table 2) (Operational Technologies Corp., 1995)

Table 2 - An Assessment of Water Reinjection/Extraction Ratios and Water Costs

Scenario	Demand (mgd)	Reinjected (total pumping rate 16 mgd)	Reinjected (total pumping rate 27 mgd)	Water reuse cost ($/1000gal)	Current avg water price in 4 towns ($/1000gal)
1	0.95	94 %	96 %	1.79 - 3.84	2.07 - 2.45
2	3.90	76 %	86 %	0.19 - 0.41	? (private wells)
3	4.85	70 %	82 %		

Scenario 1: domestic reuse (drinking water)
Scenario 2: recreational/agricultural reuse (irrigation of cranberry bogs and golf courses)
Scenario 3: combination of scenarios 1 and 2

Based on this analysis, three comments can be made:

- For almost all scenarios, reinjection rates are higher than the rate commonly cited as the acceptable minimum (75%). However, further investigation would be needed to ensure that a partial reinjection will not jeopardize the aquifer water balance.
- Treated water costs include conveyance costs only. Treatment cost is not considered.
- The cost of treated groundwater should be compared to the marginal cost of developing additional water supplies (replacing the wells lost due to contamination).
- The cost of treated groundwater does not compare favorably with current water prices

The following conclusions can be made regarding water supply issues:

- Due to the abundance of water resources in the Upper Cape area, groundwater contamination is not expected to cause water shortages in the area for the next 25 years, and probably not beyond. The exception is the town of Falmouth where alternative water supplies such as treated groundwater are needed.
- One objective of the plume containment scheme is to protect the Upper Cape water resources. However, only a small fraction will be preserved by the proposed plan. In addition, the scheme does not address other constraints on future water supply expansion-the lack of access to land to drill new wells and other sources of contamination (agricultural and urban

leachates, especially from septic tanks). In this respect, there is a clear need to protect groundwater resources by establishing zones of groundwater protection, and land acquisition near wellfields.

- Beneficial reuse of treated water is not attractive from an economic standpoint

3.4 Economic analysis

This section only addresses benefit-cost analysis. No cost-effectiveness has been performed. Hence, it has been assumed that the remediation scheme proposed by the IRP was cost-effective and could be included as such in the baseline. However, this assumption is questionable because alternative innovative remediation technologies may be more cost-effective than the pump and treat system selected by the IRP.

3.4.1.1 Baseline Definition And Remedial Actions Considered

The no action alternative was established as the baseline. The remediation alternatives considered were:

- no action with water supply replacement (both contaminated and threatened public and private wells)

  Estimated cost: $15 million

- plume containment (seven plumes as proposed by the IRP)

  Estimated cost: $250 million (net present worth of capital, operation and maintenance expenses) (Rolbein, 1995). The $100 million spent to date are not taken into account.

  Costs and benefits were assumed to accrue over the period 1995-2020 (25 years), and the discount rate was set at 5%.

3.4.1.2 Identification And Estimation Of The Types Of Benefits

This section presents findings about the different types of benefits: commodity/resource, direct/indirect, and primary/secondary.

3.4.1.3 Primary benefits

Water Supply

As shown in Section 3.3, avoided costs (compared to no action alternative) due to the plume containment alternative would be $10 million.

Health Risks

The risk valuation method has been selected to assess the health costs to society. Using a conservative scenario, it was assumed the population supplied from public or private wells that are already or potentially contaminated by the plume would be exposed for 25 years to the risk level defined as "probable" in the MMR Risk Assessment studies. In other words, the population would use water contaminated to the average levels found in the plume. Even in the case of this conservative scenario, the number of additional cancers developed in the entire area over 25 years would amount to 15, over 80% due to EDB present in the FS-12 plume (See Figure 8).

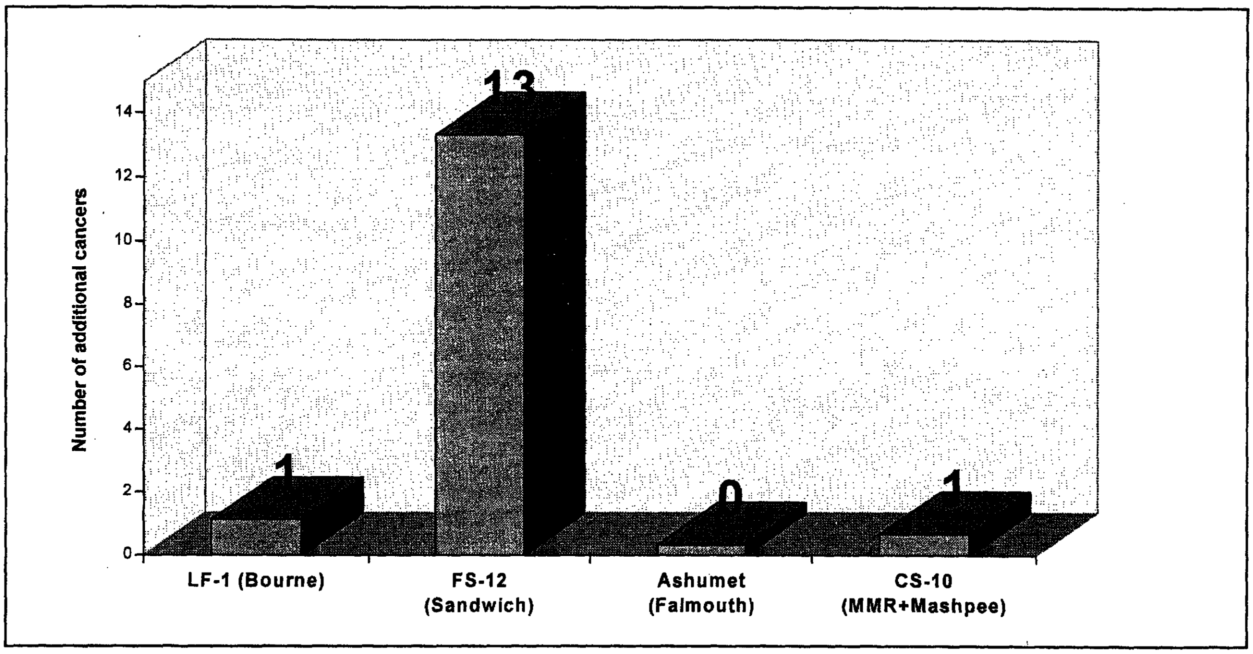
Table 3 - No Action Alternative - Human Health Risks

	Incremental risk*	Exposed population**	Number of additional cancers
LF-1 (Bourne)	0.000151	2542	1
FS-12 (Sandwich)	0.05	2372	13
Ashumet (Falmouth)	0.00003	1216	0
CS-10 (MMR+Mashpee)	0.000129	3978	1

* (Stone & Webster, 1995)

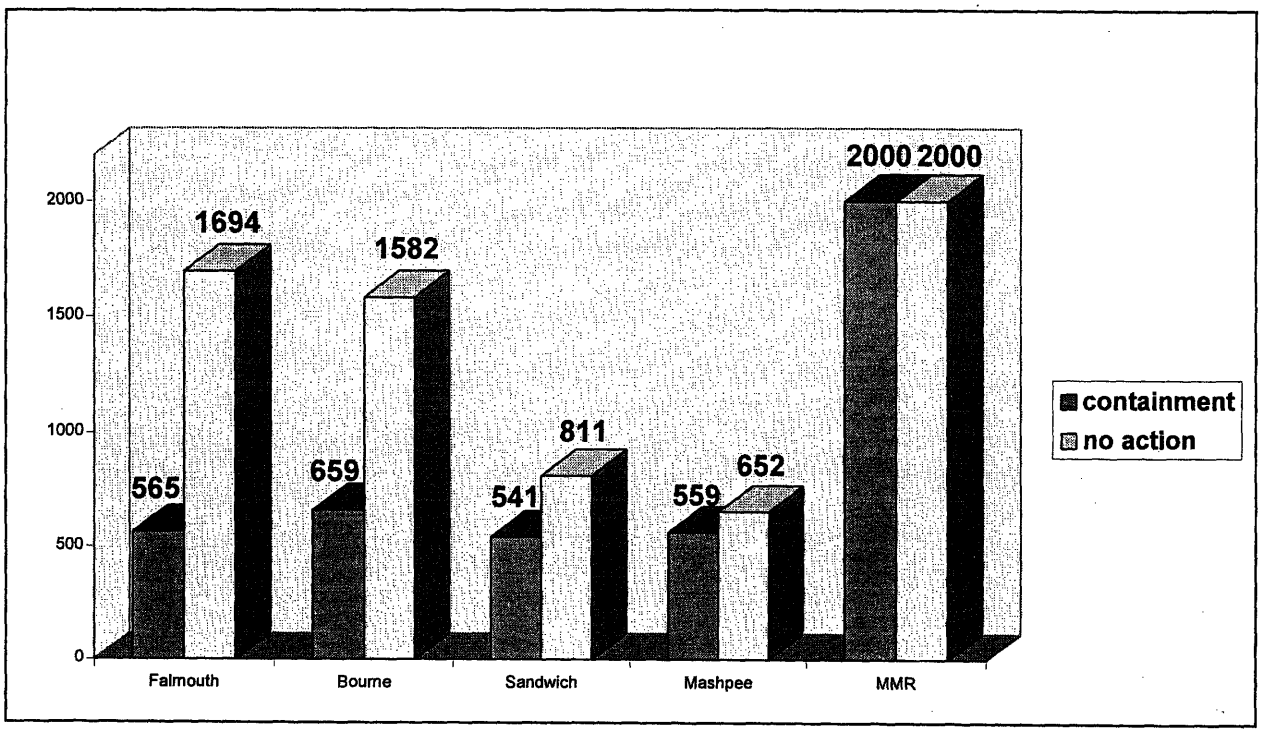
** Exposed population over 25 years, calculated from (Cape Cod Commission, 1996).

Figure 8 - No Action Alternative- Number of Additional Cancers Developed Over the Next 25 Years



Assumptions: *Probable risk. Public and private wells contaminated to plume concentration levels, exposed population supplied from contaminated wells*

Figure 9 - Exposed population to contaminated groundwater consumption



Assuming a cured rate of 60 %, treatment costs of $100,000, and a value of $2 million per life lost, the resulting cost to society would be $13 million. The number of cancers is surprisingly low, even in this worst case scenario: the exposed population is small, (approximately 5000 residents) (Figure 9).

Health risks could be essentially eliminated if the contaminated water supplies would be replaced as shown in section 3.3. Therefore, avoided costs due to water supply substitution would amount to $13 million. Additional benefits generated by the plume containment alternative would not be significant.

Ecological Risk

Valuation of ecological impacts is difficult because of the absence of quantitative studies. Contamination pathways have been analyzed only qualitatively. In addition, ecological risk was based on current plume concentrations; hence attenuation processes were neglected and figures are likely to be overstated. Concerns have also been raised about the impact on the ponds' water levels due to the pump and treat system. The planned extraction rates (27 mgd) may have a significant impact on the overall aquifer balance. As mentioned in section 2.1.1, the specialized and rare ecosystem that develops on the shores of these ponds is highly sensitive to water level changes. The containment plan itself has significant ecological risks that need to be weighed against the risks of taking no action. Because of the many unknown variables associated with the long-term operation of the containment system, it will be assumed that its ecological risks equal the risks associated with the do nothing alternative. Therefore, ecological risks have been removed from the benefit-cost comparison.

Property Value

In towns, cities, and neighborhoods nationwide, scientific and statistical studies have documented that proximity to hazardous waste sites decreases property value. This negative impact of "perceived risk" has been shown in real estate markets around the MMR. Figures ranging from 5 to 15% in value reduction (real estate professionals). In this study, it has been conservatively assumed that all properties located less than a mile from an existing or future plume would experience a decrease of 10% in their value. Valuation techniques such as hedonic pricing would provide more accurate results. These results are shown in Table 4 and Figure 10.

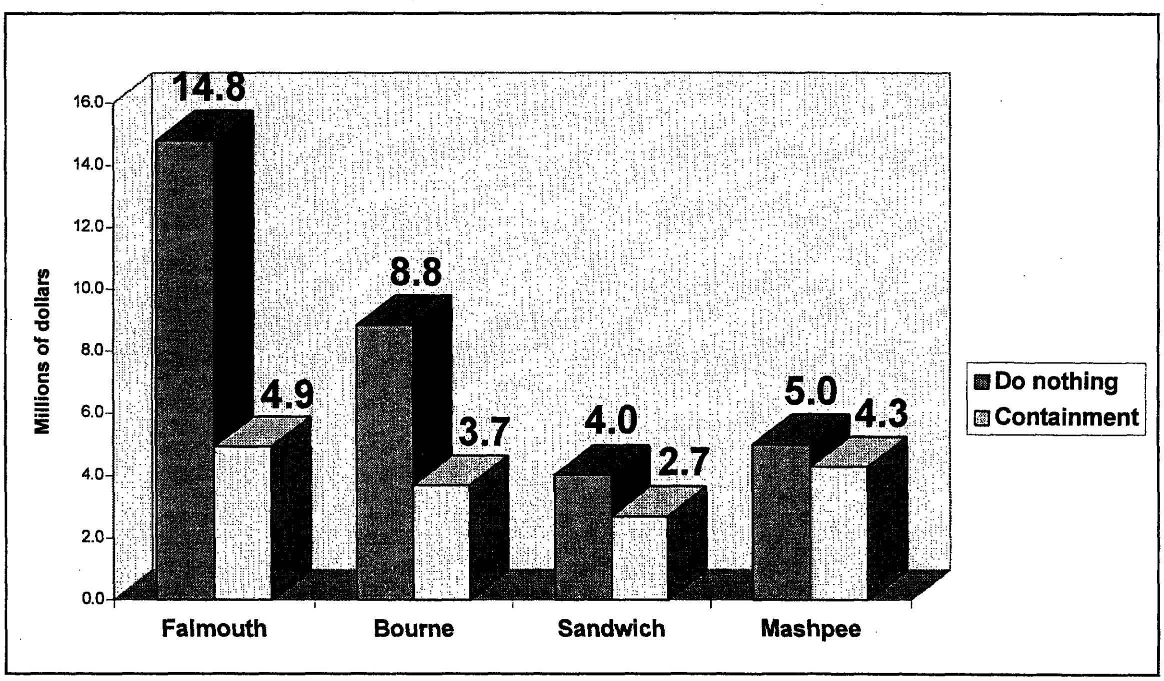
Table 4 - Calculation of property value losses

	Number of properties affected*		Average property value ($)**	Total loss ($ million)	
	Do nothing	Containment			
Falmouth	900	300	164411	14.8	4.9
Bourne	600	250	147338	8.8	3.7
Sandwich	300	200	134077	4.0	2.7
Mashpee	350	300	143002	5.0	4.3
TOTAL	2150	1050		32.7	15.6

* Calculated from (Cape Cod Commission, 1996)

** (Cape Cod Commission, 1996)

Figure 10 - Loss on Property Values Due to MMR Contamination ($ million)

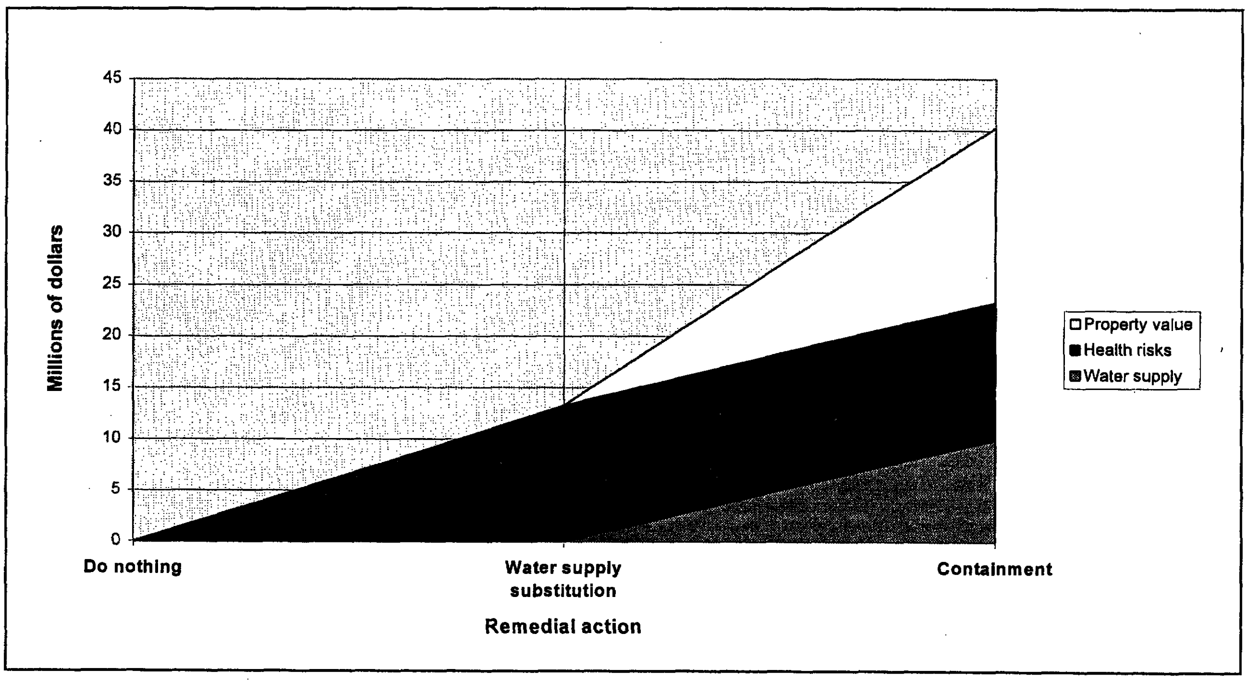


<u>Assumption:</u> 10% reduction in the value of all property located less than a mile from a plume

In the case of the plume containment alternative, the total loss in all four towns would be $16 million (properties already affected by the plumes). In case of the no action alternative, this figure would rise to $33 million due to the potential expansion of the contaminated area. Therefore, the avoided cost due to plume containment would be $17 million. However, one may question whether the containment plan will raise property values back to previous levels.

All primary benefits identified are summarized in Figure 11. If only primary benefits are considered, the total of $40 million would not justify the expenses incurred in the case of the plume containment alternative.

Figure 11 - Primary Benefits Accruing Over 1995-2020 ($ million, cumulative)



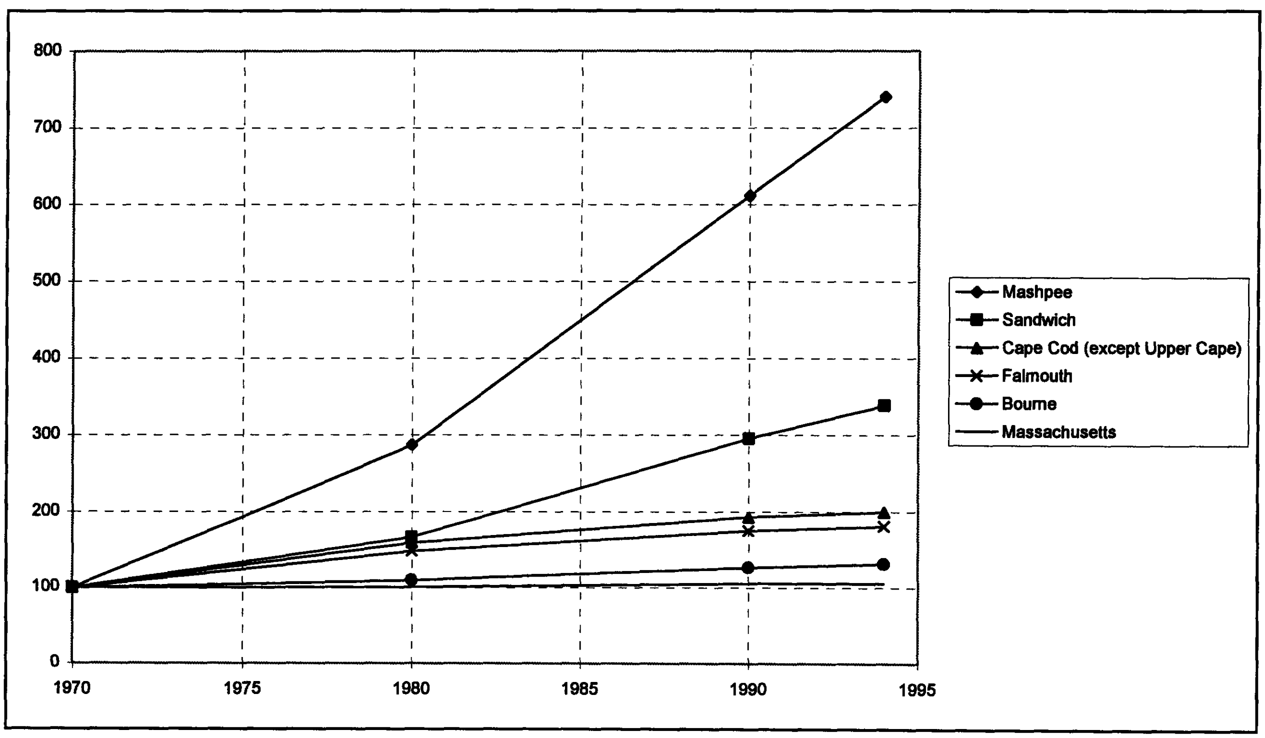
3.4.1.4 Secondary benefits

Economy

The psychological impact of the MMR groundwater contamination on the local economy and tourism is difficult to quantify and measure. Nonetheless, it is important to consider it in evaluating any remediation alternative. In 1994, the economy base was estimated at $610 million for the Upper Cape area (Cape Cod Commission, 1996). More than 80% of the economic base can be considered highly sensitive to perceived risk of groundwater contamination (tourism, retirement-based income, business, commuters).(see Figure 6, Section 3.2.2.3).

There is evidence of a marked slowdown of the population growth in the townships of Bourne and Falmouth, the most affected by the MMR contamination. Sandwich and Mashpee, the least impacted towns, show a constant growth. Although other factors may be determinant, such as availability and price of land and real estate, it is interesting to note that there is a correlation between the population growth and the contamination (Figure 12).

Figure 12 - Comparison of population growth in the Upper Cape townships - 1970 = base 100



(Cape Cod Commission, 1996)

In the absence of any study documenting the impact of the MMR contamination on the local economy, an analysis was conducted to determine the sensitivity of the economic base to the variation in growth rate. As opposed to the no-action alternative, the assumption that, any level of remediation would provide a strong positive signal to the local economy because public confidence would be restored. If there were no contamination problems, the Upper Cape economy is assumed to grow at a constant yearly rate of 3% over the period 1995-2020. An examination of the impact on the economic base of any decrease in the growth rate be due to the perceived risk (e.g. smaller number of tourists than expected) follows.

Table 5 - Impact of Perceived Risk on Economic Base

Yearly Growth	3.0 %	2.9 %	2.8 %	2.7 %	2.6 %	2.5 %
Economic base decrease ($ million)*	0	-119	-236	-351	-463	-572

* net present value (I = 5 %, n = 25 years)

Assuming that the growth rate would decrease from 3.0 to 2.8% as a result of the no action alternative, the cost to the local economy over 25 years (in net present value terms) could be as high as $236 million. This would justify the proposed cleanup actions. This rationale implies that cleanup operations would give the necessary positive signal to the local economy. However, one may question whether plume containment would be the most cost-effective means to restore public confidence and reduce the perceived risk. In addition, questions have been raised whether continued growth is a desirable objective for the Upper Cape area.

Resource Benefits

Resource benefits (or non-use values) consist of option values (benefit of being able to use the water at some time in the future), bequest values (benefit of having a source of clean water for future generations), existence values (benefit of knowing that the water is uncontaminated, even if there is no expectation that it will have to be used), and recreation values. An EPA study determined that citizens will pay an average of $7 per person per month for non-use values of groundwater (see section 3.2). When added over the Upper Cape towns over 25 years, assuming that future Cape Cod residents would demonstrate the same willingness to pay, the resource benefits would amount to $150 million. However, this value is likely to be overestimated because the plume containment would preserve only a very limited fraction of the Upper Cape's water resources. A contingent valuation survey should be conducted to determine resources benefits with greater accuracy.

3.4.1.5 Costs versus benefits

Benefits and costs can be compared to obtain the net benefit (see Table 6):

Table 6 - Discounted Costs and Benefits for the Period 1995-2020

I = 5%, n=25 years	No Action (baseline)	Water Supplies Replacement	Plume Containment
COSTS	0	10	250
BENEFITS			
Water Supply	0	0	10
Health Risks	0	13	13
Property Value	0	0	0 to 17
Economic Base	0	0	0 to 250 ?
Non-Use Values	0	0	0 to 150 ?
NET BENEFIT	0	3	-227 to 190 ?

The following comments can be made:

A) The water supply replacement alternative yields positive net benefits. However, this option does not answer equity issues. While net benefits are positive for society as a whole, they are negative for the Upper Cape area. This is due to the fact that economic and non-use negative impacts are not alleviated. Hence, a transfer of financial resources to the Upper Cape area should be considered. This transfer could take the form of a compensation package valued according to the economic cost of environmental damage. Among the possible uses of the compensation package, the following alternatives may be suggested:

- direct compensation paid to residents affected by the pollution
- creation of an investment fund for beneficial use by future generations
- purchase of land (e.g. MMR) for effective protection of groundwater resources
- elimination of septic tanks and other current pollution sources to protect groundwater

B) The remediation alternative would yield positive net benefits only if negative impacts on economic base and non-use values would exceed $210 million. Further investigations would be required to confirm this figure. In addition, even if analyses demonstrate that this remediation alternative would yield positive net benefits, the optimal cleanup level may not be attained. Alternative technologies, cleanup goals or compensation options (such as those cited above) may prove more efficient.

4. The Fuel Spill 12 - A Case Study

4.1 Introduction

Fuel Spill 12 (FS-12) is one of the plumes emanating from the MMR. It is located in the northeast section of the reservation. This plume is the result of a leak in a pipeline which carried JP-4 fuel to the MMR. It is estimated that 70,000 gallons was spilled. Two contaminants within the fuel which pose health hazards are EDB, a fuel additive, and benzene, a fuel component. These contaminants are known carcinogens. Currently, the FS-12 source is being controlled through air sparging and soil vapor extraction. However, the remainder of the plume continues to migrate off base. The nearby Snake Pond, which is used for recreational purposes, is potentially in the pathway of the plume. However, predictions say the plume will not affect the pond.

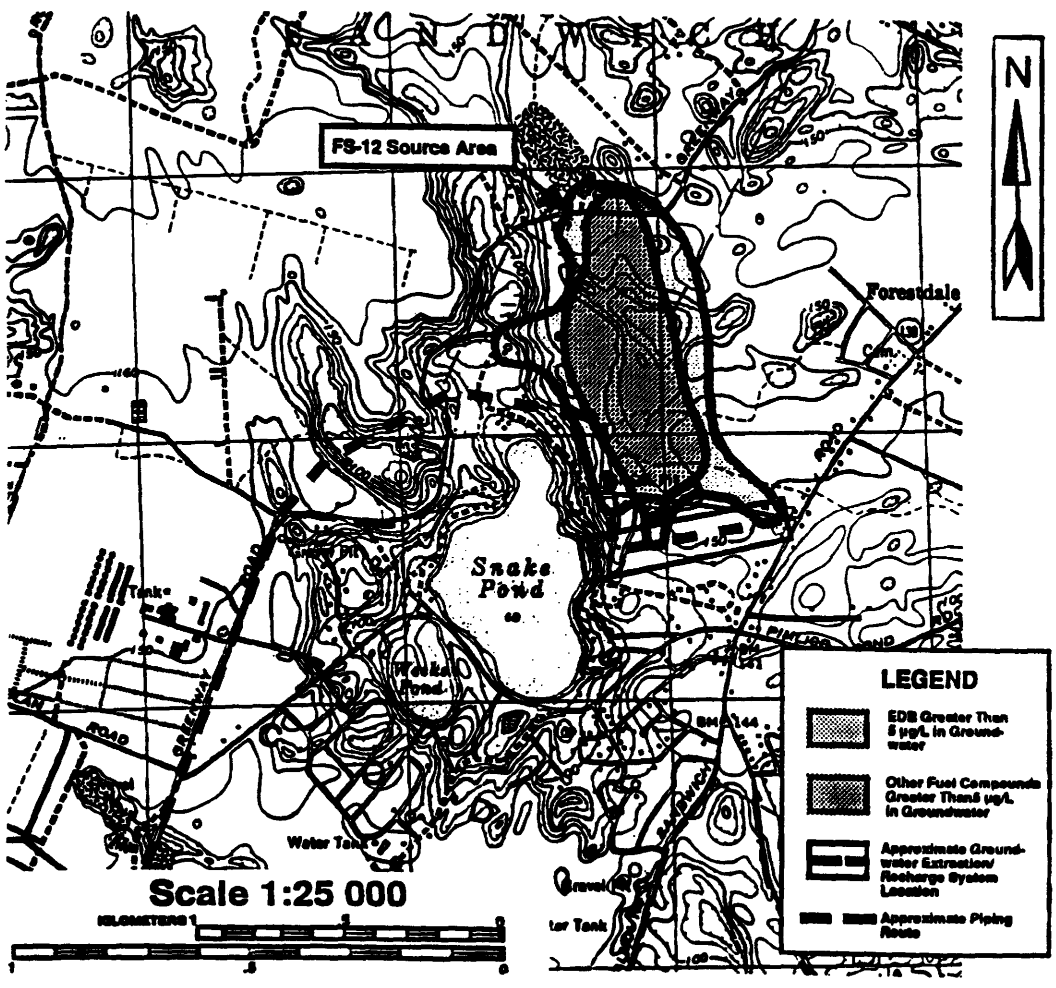
This chapter provides a detailed study of the FS-12 case. Several options are assessed, from both technical and economic standpoints. Alternatives are then compared, using cost-effectiveness and benefit-cost analysis. Special emphasis is placed on the assessment of the do nothing alternative as a baseline for comparison.

4.2 Site characterization

This section provides background information on Fuel Spill 12 (FS-12). It covers physical and sociological features of the region.

4.2.1 Physical Site Data

The FS-12 area is located within the Mashpee pitted plain, with a substrata consisting of outwash sands and gravels. The subsurface contains discontinuous lenses of low and high permeability that extend down to 130 feet below the water table. On average, the unconfined Cape Cod aquifer lies 90 feet below ground level on average. It surfaces at Snake Pond which is located south-southwest of the source. Horizontal groundwater velocities in the area average 0.15 feet/day. This velocity is less than characteristic rates for other plumes on the MMR. This area is located near the crest of the water table mound where the hydraulic gradient is small. Horizontal hydraulic conductivities range from 150 to 400 feet/day.



(Stone & Webster, 1995)

Figure 13 - FS-12 Area Map

The topography consists of low relief and rolling hills. Elevations range from approximately 200 feet mean sea level (MSL) to 50 feet MSL. Generally, the north-northwestern portion is characterized by higher relief. Topographical elevation decreases in a southeastern direction. Several water bodies are present in the area surrounding the zone of contamination.

The case study site area, FS-12, is sparsely populated, although a summer camp is located off-base directly south of the source. Most of the contamination flows beneath Camp Good News, as can be seen on Figure 13.

4.2.1.1 Geology of FS-12

FS-12 is located within the Mashpee pitted plain. The Mashpee pitted plain is characterized by coarse grained materials, mostly sands and gravels. The sand and gravel grains become finer with depth. Throughout the entire depth of the outwash there exists discontinuous lenses of fine sands, clays and silts left from ice and glacial sediments. The sand and gravel materials are underlain by the bedrock. In the FS-12 area, the bedrock elevation ranges between 82 to 328 feet below MSL. Observations suggest the existence of fine sands and clay deposits at depths of 130 to 215 feet below MSL (Advanced Sciences, Inc., 1993). It is possible that these sediments are part of a continuous layer of finer materials within the sandy aquifer. However, there is not enough data to verify the existence of a continuous layer of finer sediments (HydroGeoLogic, Inc., 1994).

4.2.1.2 Hydrology

FS-12 is located above the Cape Cod aquifer. The aquifer is unconfined and its water table is located on average 80 feet below ground surface. The water table intersects the ground surface creating the following ponds in the area: Snake Pond, Peter's Pond, Mashpee Pond, and Wakeby pond. The groundwater flows in the south-southeastern direction. From the Feasibility Study (Advanced Sciences, Inc., 1993), it was determined that the horizontal hydraulic gradient varies between 0.0003 and 0.00067. The aquifer test indicates the horizontal conductivity to vary between 236.75 and 368.21 feet/day (HydroGeoLogic, Inc., 1994). From the aquifer test other properties were found as shown by Table 7:

Table 7- Aquifer properties

Kr horizontal conductivity (ft/day)	Kz / Kr vertical/horizontal conductivity ratio	Ss Specific Storage	Sy Specific Yield
236.75 - 368.21	0.05 - 0.55	0.000001 - 0.00058	0.008 - 0.184

(HydroGeoLogic, Inc., 1994)

The runoff from the site can be assumed to be insignificant due to the high permeability of the soils. The only significant form of recharge to the aquifer is rainfall which averages approximately 23 inches/year (Masterson and Barlow, 1994).

4.2.2 Site History

The current FS-12 contamination area is the result of an extended leak in a fuel line discovered in 1972. The location of the leak is at the intersection of Greenway Road and the western entrance to the L-firing range. The pipeline was constructed in the early 1960's. Its main purpose was to transport aviation fuel from Cape Cod Canal to the Air National Guard flight line area. Both aviation gasoline and JP-4 jet fuel were carried in the pipeline. In order to stop the leak, it underwent repairs in 1972. Part of the repairs included the use of contaminated soil as backfill for the excavation. Thus, even after the 1972 repairs, JP-4 fuel entered the subsurface soil and groundwater. The line was later closed in 1973. The IRP has estimated a spill volume of approximately 70,000 gallons, which currently contaminates 11 acres of soil. The plume originating from the FS-12 source area extends 5400 feet in length south-southeast from the spill; 1,100 feet wide; 50 feet thick; and moves 0.75 to 1.35 feet/day.

4.2.3 Extent of Contamination

As estimated from evaluations of organic soil vapor concentrations, benzene and ethylene dibromide (EDB) are the primary contaminants of concern at FS-12. (Figure 13) maps out the extent of soil contamination from an areal view. EDB, a significant organic contaminant at this site, is not a component of jet fuel and was added to the aviation gas as a lead gas scavenger. It is present throughout the dissolved plume, though the free product does not constitute a continual source, as with benzene. When contaminants are not absorbed by soil particles or dissolved into the groundwater, they remain in the free phase form, also known as free product. Being less dense than water, the free product tends to float on top of the groundwater. The free product 'source' of the plume covers five acres ranging in thickness up to 0.7 feet. Near the spill, higher concentrations of benzene and EDB were measured at 1600 ppb and 600 ppb, respectively. The plume extends in an elliptical shape, approximately 5000 feet downgradient (Advanced Sciences, Inc., 1993).

During the remedial investigation of FS-12, it was determined that EDB and benzene posed the largest threat to human health. Their distributions are similar, with the EDB plume located at a slightly deeper depth in the aquifer than the benzene plume (HAZWRAP, 1994). The plumes are depicted in more detail in Appendix 7.1. Risk values were determined for the contaminants of concern based on groundwater exposure and future land use. Most probable carcinogenic risks far exceeded the EPA's upper limit for cleanup guidelines. Therefore, cleanup processes were promptly initiated. (Advanced Sciences, Inc., 1993)

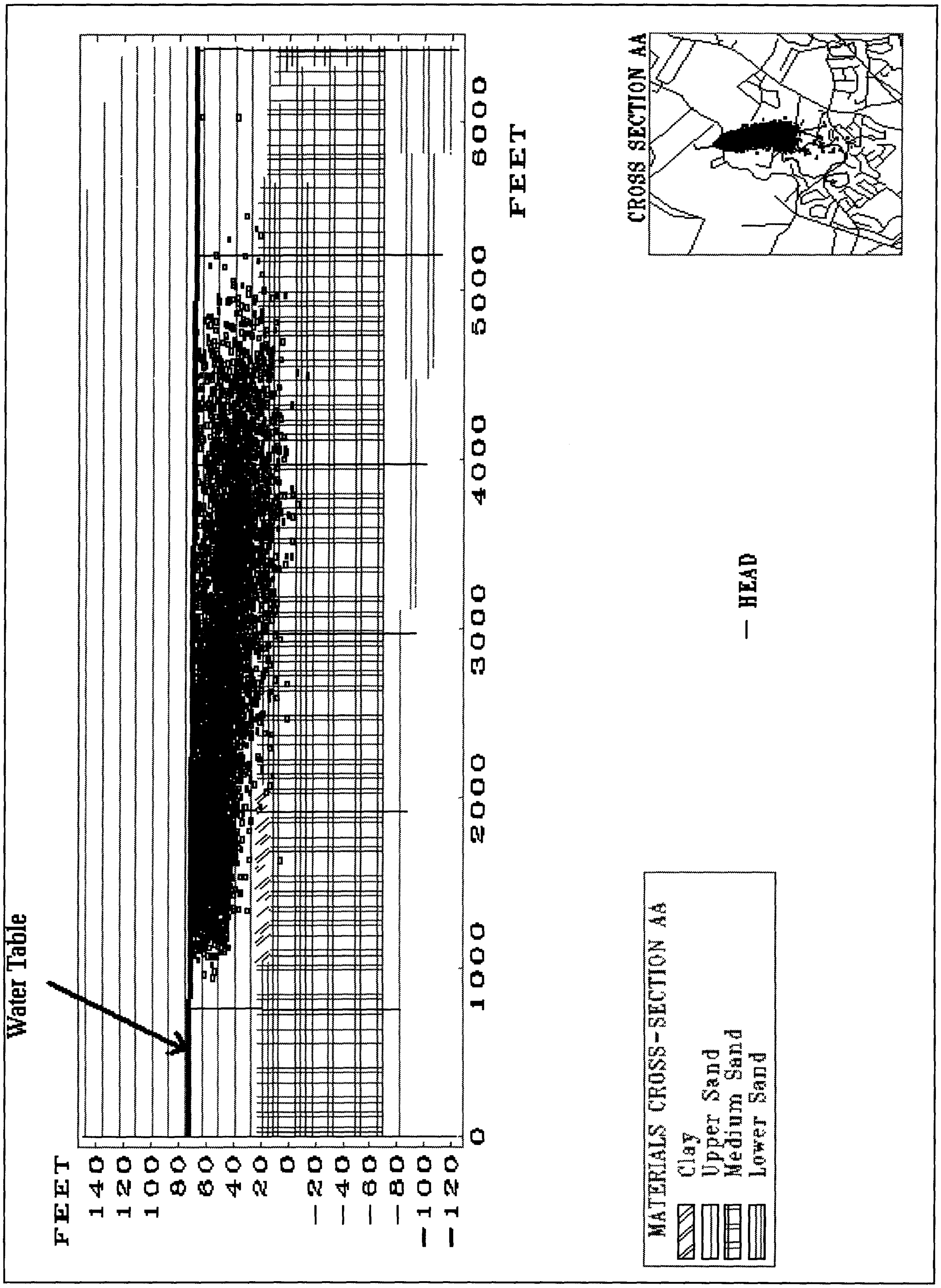


Figure 14 - FS-12 Plume Cross-section

4.2.4 Current Situation

After surveying applicable treatment schemes, the IRP selected a combined Air Sparging/Soil Vapor Extraction system to control the source and a well fence to contain the plume movement. The air sparging pilot study was deemed a success for two reasons: (1) the pressure differentials were conclusive enough to predict an adequate extraction well radius of influence and (2) field measurements are indicative of productive vapor extraction in the outwash sands and gravel (HAZWRAP, 1994). A more detailed description can be found in source control, Appendix 7.2.

Consequently, an air sparging/soil vapor extraction system was designed and quickly implemented to control the source area at FS-12. The air stripping action of the sparging will transfer contamination from the aqueous phase into the vapor phase and carry it to the unsaturated zone. There it can be captured by the soil vapor extraction wells, and treated with catalytic oxidation and activated carbon in a vapor control unit. The combined system has been running since November 1995, though the first 100 days utilized only the vapor extraction wells. At the March 1996 FS-12 Sandwich Subcommittee Meeting, Ed Pesce of the IRP reported that clean-up of the source area is expected to take two years (HAZWRAP, 1994).

The Plume Containment committee meets regularly, and is involved in design analysis for site remediation. Preliminary designs indicate proposed locations for the five pump and treat wells that will capture and extract a total of 300-330 gallons/minute of contaminated groundwater. This will be treated and reinjected nearby. With an estimated start-up in September 1996, this process is not a final solution, but meets the immediate goals of the MMR in "source control and plume containment." The MMR is not currently planning to reuse any of the treated water, which means that 100% of it will be reinjected. Public perception of water reuse issues indicate a current unwillingness to drink any treated water. (Installation Restoration Program, July 1995). More details pertaining to ongoing FS-12 issues are presented in the Appendices.

4.3 Proposed actions

4.3.1 No Action Alternative

The no-action alternative relies solely on natural attenuation to degrade contamination in the groundwater. This section describes the many natural processes that are involved with natural attenuation: biodegradation, volatilization, and adhesion. Calculations of expected costs are also included. Given this background, the application of the no action alternative to the FS-12 plume is discussed.

4.3.1.1 Background Information

The National Contingency Plan states that it is appropriate to evaluate a limited number of alternatives for interim remedial actions rather than the full range of alternatives typically assessed for final remedial actions. Accordingly, two remedial alternatives were developed and evaluated in the Plume Response Plan: No-Action and Plume Containment. The no-action alternative provides a baseline for comparison for other alternatives. This alternative relies on natural attenuation to treat contaminated groundwater. The Record of Decision states that this alternative is not acceptable because it does not reduce risk and would not meet the following response objectives (Stone & Webster, 1995):

- reduce risks to human health associated with the potential future consumption and direct contact with groundwater and surface waters
- protect uncontaminated groundwater and surface waters for future use by minimizing migration of contaminants
- reduce potential ecological risks to surface waters and sensitive coastal waters through the implementation of the containment system
- reduce time required for aquifer restoration

4.3.1.2 Process Description

Natural attenuation is not in itself a groundwater containment or a treatment technology. This approach relies on natural subsurface processes such as dilution, volatilization, biodegradation, abiotic oxidation, and adsorption to reduce contaminant concentrations to acceptable levels. Application of natural attenuation involves evaluation of site characterization data, modeling of fate and transport processes based on that data, continual field monitoring to provide evidence showing that degradation of contaminants is occurring naturally at an acceptable rate (USEPA, 1993). Processes involved with natural attenuation are described below.

Dispersion and Dilution

The mechanical mixing of flowing water with contaminants is called dispersion. The most important effect of dispersion is to spread the contaminant mass beyond the region it would otherwise occupy. Dilution is the result of the mechanical dispersion spreading the mass of contaminants over a larger volume and mixing with clear water. This results in a reduction in contaminant concentration.

Volatilization

Volatilization is the conversion of volatile chemical constituents in groundwater to vapor, which is ultimately transferred to the atmosphere. Natural volatilization is likely to occur in shallow unconfined aquifers. Volatilization rates in surface waters is expected to be much higher. Field studies have shown half-lives ranging from 5 hours for benzene to 6 hours for EDB for evaporation from a river of 1 meter depth with wind speed of 3 meter/second and water current of 1 meter/second (MacKay et al., 1992). These values are of particular interest to determine the impacts of potential plume discharge into streams and ponds.

Sorption

Retardation processes consist of sorption of organic substances. Sorption can contribute to the attenuation of the concentration of contaminants because it reduces the rate of movement of contaminants as compared to the average flow rate of groundwater.

Biodegradation

BTEX compounds are known to biodegrade easily in groundwater. Biodegradation processes are studied in detail in a later section.

4.3.1.3 Application at FS-12

The IRP gave little consideration for the no-action alternative for natural restoration and impacts on environment and human health. For example, the following questions have not been addressed :

- What is the probability of future consumption of contaminated groundwater?
- What are the future risks associated with direct contact with contaminated groundwater? Exposure scenarios are based on current concentrations in the plume. However natural attenuation may decrease significantly concentrations and future risk may be overstated.
- Are water shortages so likely that significant expenses to reduce the time required for aquifer restoration would be justified?

The long range model depicts key facts about the FS-12 plume (Figure 15)

- The natural groundwater flow is simulated using a finite element model. The movement of contaminants is tracked on a local scale. The effects on Snake Pond, a water body close to the source of the plume, are also assessed. The model shows that the contamination effects on Snake Pond are negligible under a worst case scenario simulation (see Appendix 7.1 for details)

- The plume will discharge into Mashpee Pond in approximately 35 years assuming a groundwater flowrate of 0.5 feet/day (see Appendix 7.1 for details)

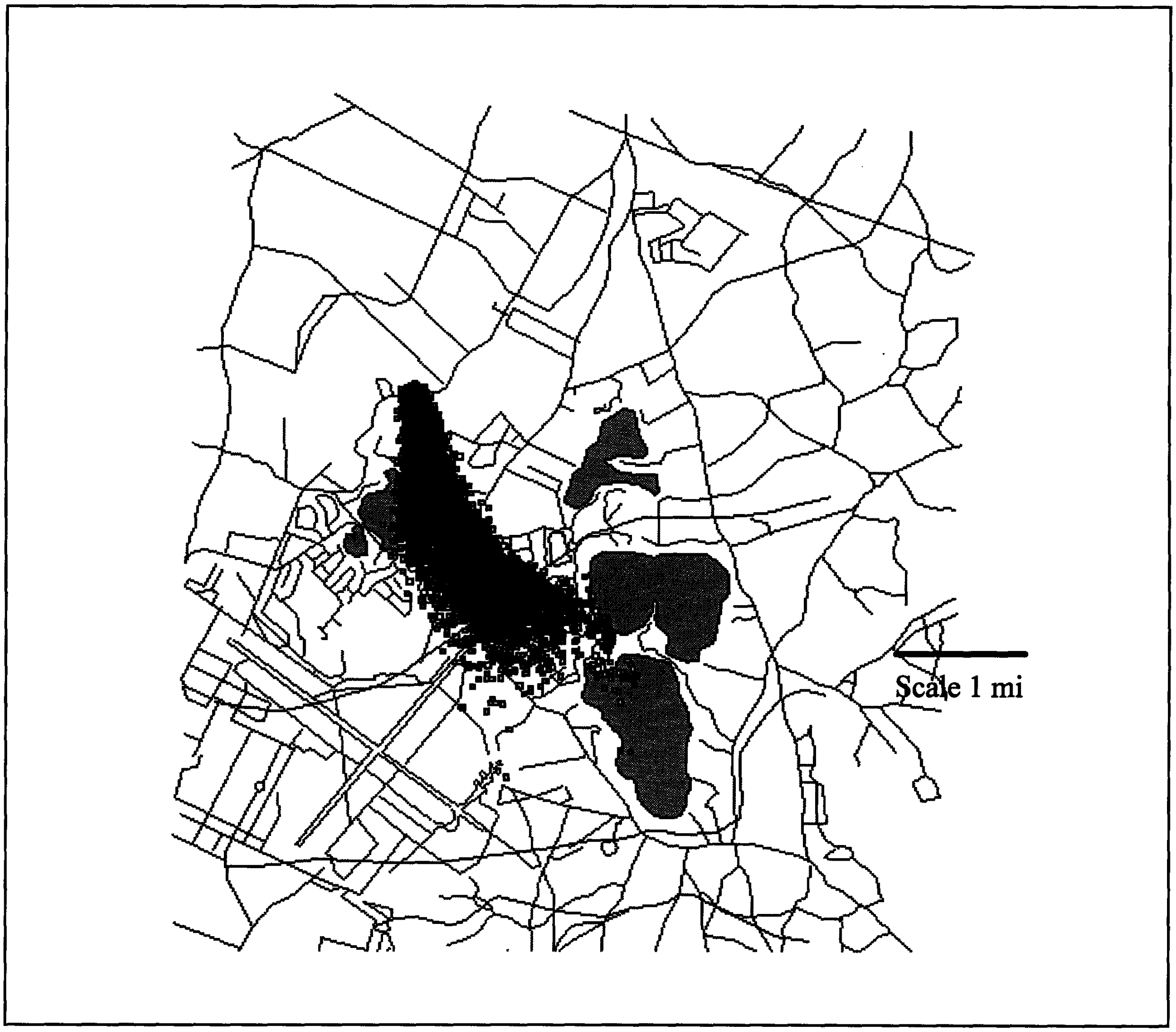


Figure 15 - Long-Term Contaminant Transport

Based on the simulations described above, two exposure pathways have been identified:

- plume discharge in Mashpee Pond

- consumption of water from contaminated public and private wells

The following will examine the natural attenuation processes and exposure risks of plume migration. Potential impacts of plume discharge in Mashpee Pond are also discussed.

Table 8- Contaminants of Concerns: Comparison of Average and Maximum Concentrations in the FS-12 Plume Against Established MCLs

Contaminant of Concern	Average Concentration (µg/L)	Maximum Concentration (µg/L)	MCL (µg/L)
Benzene	65.1	1550	5
Toluene	4.7	10	1000
Ethylbenzene	12.8	203	700
Xylenes	13.7	195	10000
EDB	21.4	578	0.05

(Operational Technologies Corp., 1995)

It has been estimated that 70,000 gallons of JP-4 fuel were released before the leak was repaired.

The contaminants of concern in the FS-12 plume are benzene and EDB (Table 8). Benzene is expected to undergo aerobic biodegradation. This conclusion is supported by both the presence of shorter chain hydrocarbons and low levels of dissolved oxygen within the plume. However, low dissolved oxygen concentration in the areas of highest benzene concentrations suggest contaminant levels have overcome the capacity of the biological system. Studies have shown that benzene will migrate by advective transport until areas with sufficient dissolved oxygen levels are encountered. At that location, biological activity can reach equilibrium with the rate and concentrations at which benzene migrates further in the aquifer (Cambareri et al., 1992). EDB has been shown to undergo both aerobic and anaerobic degradation processes in laboratory and field studies. However, relatively low concentrations of EDB overcome the capacity of the biological system. Degradation rates are not expected to match the rate of groundwater flow. Therefore, the EDB plume will continue to migrate. Table 8 compares the average and maximum concentration levels with the MCLs (Operational Technologies Corp., 1996).

Assuming first order decay, and biodegradation rates observed in the environment (MacKay et al., 1992), the time required for complete dissolution of contaminants to MCLs was calculated as 4.5 years for EDB and 8.3 years for benzene (Table 9). According to these biodegradation rates, the maximum additional extension of the plume exceeding MCL limits is 1000 feet downstream of the current plume toe. Therefore, Mashpee Pond would not be threatened by excessive MCLs.

Table 9 - Biodegradation Rates and Time to Reach MCLs

Contaminant of concern	Half-life (days)		Years to reach MCLs			
			Average initial concentration		Maximum initial concentration	
	Minimum	Maximum	Min 1/2 life	Max 1/2 life	Min 1/2 life	**Max 1/2 life**
Benzene	30	365	0.30	3.70	0.68	8.28
Toluene	10	110	0.00	0.00	0.00	0.00
Ethylbenzene	6	28	0.00	0.00	0.00	0.00
Xylenes	14	105	0.00	0.00	0.00	0.00
1,2-Dibromoethane EDB	20	120	0.48	2.87	0.74	4.44

However, studies have shown that the rate and extent of biodegradation are strongly influenced by the type and quantity of electron acceptors present in the aquifer. Once the available oxygen, nitrate, and sulfate are consumed, biodegradation is limited and is controlled by mixing aerobic biodegradation at the plume fringes (Borden et al., 1995). Therefore, a combination of natural attenuation with source control; such as free product recovery or air sparging, would significantly enhance biodegradation and the biodegradation rates could be met with greater confidence.

These results suggest that risks posed to the environment due to plume discharge in surface waters may be much less than those stated by the MMR Installation Restoration Program. Their risk assessment study assumes potential concentration levels in the environment would equal the current ones found in the plume, thereby neglecting attenuation processes such as biodegradation. This leads to overly conservative results. However, current concentrations of contaminants do pose a threat to private wells, at least until attenuation processes have decreased contaminants levels below the MCLs.

4.3.1.4 Plume monitoring: investments and costs

The no-action alternative would include semi-annual sampling of groundwater monitoring wells and a review of the site every five years. The operations and maintenance costs would amount to $ 48,300 per year. The net present value for an estimated time of operation of 20 years would be $ 602,000 (Operational Technologies, 1994).

4.3.2 Water supply replacement

This alternative could be considered as a means to reduce human health risks to an acceptable level. This alternative would involve the closure of all public and private wells potentially threatened by the plume, and the extension of the municipal water system to supply affected customers. Based on data provided by the Sandwich Water District, this would require hookups for about 150 properties currently self-supplied. The only public well supplying the area, the Weeks Pond well, is not believed to be threatened by the FS-12 plume. In addition, this well could accommodate additional withdrawals. Assuming a cost of $5000 to $10000 per hookup, total cost of water supply replacement would amount to approximately $1 million.

4.3.3 Remediation alternatives

Several remediation alternatives have been proposed. They include:

- *Source control such as air sparging and product recovery (see Appendix 7.2 for full details):*

- Air sparging & soil vapor extraction are currently being implemented at FS-12 to control the source of contamination. The estimated time to remediate the source is two years, though modeling results from this study indicate that a much longer remediation time will be necessary to attain MCLs. This estimation was attained through the use of a spreadsheet model that calculates relative volatilization rates for each chemical constituent of JP-4 fuel. This study estimates a remediation time of more than 9 years to reach MCLs of 5 ppb in the groundwater near the source--over four times higher than the MMR's estimate. Both estimates rely primarily on the 'liquid to vapor phase' mass transfer mechanism.

- *Plume containment alternatives such as pump and treat (see Appendix 7.3) and reactive wall (see Appendix 7.4):*
- An extraction well "fence" is currently being designed to contain the leading edge of the FS-12 plume. A fence is a row of pumping wells designed to capture the plume as it migrates downgradient. Using the finite element model for this case study, a fence was designed. The design calls for 11 pumps operating at 800 gallons per minute (gpm) to capture the plume.
- The permeable reactive wall is assessed for its potential application at the FS-12 site. As the contaminated groundwater passes through the wall, the reactive media degrades the contaminants. After passage through the wall, clean water exits from the other side. Although the wall can degrade EDB, it cannot readily degrade benzene. Based on field observations, the plume is too deep within the ground for the wall to be implemented.

Assuming a MCL cleanup goal, the costs associated with each alternative would be:

- $2 million for air sparging (see Appendix 7.2)

- $12 million for the pump and treat alternative (Operational Technologies, 1994)

- the reactive wall technology is not economically feasible in the case of FS-12 due to the excessive depth of the plume. However there is evidence that this technology could be attractive from an economic standpoint when compared to conventional technologies.

According to Air Force numbers, reactive wall technology should reduce remediation costs by about 50% for chlorinated solvents (Civil Engineering Review, May 1996).

Probabilities of failure were not taken into account. It is unsure whether innovative technologies such as air sparging or reactive wall would imply a higher risk of failure than the pump and treat alternative. However, questions have been raised about the ability of the air sparging scheme to reach MCLs levels (see Appendix 7.2).

4.4 Economic analysis

This section provides a synthesis of the findings presented in section 4.3 from an economic perspective. The different remediation technologies are analyzed in terms of cost-effectiveness. Finally, using the methodology developed in Section 2, several remediation alternatives are assessed in terms of costs and benefits.

4.4.1 Cost-Effectiveness Analysis

The goal of the cost-effectiveness analysis is to determine which treatment alternative meets the a set cleanup goal (i.e. contamination level decreased to MCLs) at the least cost. Three technologies have been considered in the present analysis: pump and treat, air sparging, and reactive wall. In addition, the natural attenuation alternative is used as a baseline (Table 10).

Table 10 - Discounted Costs for the Period 1995-2020 (Interest Rate = 5 %)

	Natural Attenuation	Natural Attenuation and Water Supply Replacement	Pump and Treat	Product Recovery and Air Sparging	Reactive Wall
Costs	0.6	1.6	12.0	2.0 +	na
Time to Reach MCLs (years)	> 10	> 10	15	**	na
Plume migration	yes	yes	no	yes (limited)	no
Human health risks	not acceptable	acceptable	acceptable	acceptable?	acceptable

** Air Sparging will not reach MCLs within the planned operation time (2 years) (see Appendix B)

If the goal of the MMR program is to reach MCLs and preserve pristine groundwater from contamination, the air sparging option would be the most cost-effective. However, due to the uncertainties related to the ability of this technology to reach MCLs, the pump and treat alternative may be more attractive. Natural attenuation combined with water supply replacement would be the most cost-effective alternative if further migration of the plume is not a determinant factor at FS-12.

4.4.2 Benefit-cost Analysis

The benefit-cost analysis answers the following question: how do incurred costs to reach cleanup levels compare with benefits?

4.4.2.1 Primary Benefits

Water Resources

As shown in Section 4.3, avoided costs (compared to no action alternative) due to the plume containment alternative would be $1 million.

Human Health Risks

Using a conservative scenario, it was assumed the population supplied from public or private wells that are already or potentially contaminated by the plume would be exposed for 25 years to the risk level defined as "probable" in the MMR Risk Assessment studies. In other words, the population would use a water contaminated to the average levels found in the plume. In the case of this conservative scenario, the number of additional cancers developed in the FS-12 area over 25 years would amount to 13 (Table 11). Resulting costs to society would amount to $11 million.

Table 11 - No Action Alternative - Human Health Risks

	Incremental risk	Exposed population	Number of additional cancers
FS-12 (Sandwich)	0.05	2372	13

<u>*Assumptions:*</u> *Probable risk. Public and private wells contaminated to plume concentration levels, exposed population supplied from contaminated wells*

Ecological Risk

Section 3.2.1.3 suggests that impacts on the environment would be negligible. However, further investigation would be required to confirm this statement.

Property Value

Assuming that all properties located less than a mile from an existing or future plume would experience a decrease of 10% in their value, the loss would amount to $4 million in the case of the do nothing alternative, and $2.7 million if the plume is contained (Table 12). Therefore, the plume containment would yield a benefit of $1.3 million.

Table 12 - Calculation of property value losses

	Number of properties affected		Average property value ($)	Total loss ($ million)	
	Do nothing	Containment		Do nothing	Containment
Sandwich	300	200	134077	4.0	2.7

<u>*Assumption:*</u> *10% reduction in the value of all property located less than a mile from a plume*

4.4.2.2 Secondary Benefits

Economy

The perceived risk due to unmitigated contamination could lead to a reduction of the growth rate in the area surrounding FS-12. Considering the high potential for development of the area, the impact may be significant, although difficult to presently quantify.

Resource Benefits

Due to the fact that significant amounts of pristine groundwater could be contaminated in the case of the do nothing alternative, resource benefits associated with remediation, notably containment alternatives, could be important. Based on the assumptions made in Section 3.3, resource benefits could amount to $10 million over the next 25 years.

4.4.2.3 Costs versus Benefits

The high cancer risk and the uncertainties associated with the do nothing alternative would call for the implementation of remediation measures. Depending on the value placed on the groundwater potentially contaminated by further plume migration, plume containment alternatives may be more beneficial than source control alternatives.

Table 13 - Discounted costs and benefits for the period 1995-2020 (I = 5 %)

	no action (baseline)	Natural attenuation and water supply replacement	Remediation (cleanup level: MCLs)
COSTS	0	1	12
BENEFITS			
Water supply	0	0	1
Health risks	0	11	11
Property value	0	0	2
Economic base	0	0	0 to 20
Non-use values	0	0	0 to 10
NET BENEFIT	0	10	2 to 32

5. The benefit-cost debate and the future of Superfund

5.1 Integrating benefit-cost analysis in environmental regulation

The growing impact of regulations on the economy has led both Congress and the administration to search for new ways of reforming regulation. One of the central issues in the debate is the use of benefit-cost analysis in environmental, health and safety regulation. In an effort to develop a consensus view on this controversial subject, a meeting of many of the leading economists in the field was organized in September 1995. The following highlights the set of consensus principles that emerged from that meeting (Arrow et al., 1996):

- A benefit-cost analysis is a useful way of organizing a comparison of the favorable and unfavorable effects of proposed policies.

- Economic analysis can be useful in designing regulatory strategies that achieve a desired goal at the lowest possible cost.

- Congress should not preclude decisionmakers from considering the economic costs and benefits of different policies in the development of regulations. At the very least, agencies should be encouraged to use economic analysis to help set regulatory priorities.

- Benefit-cost analysis should be required for all major regulatory decisions

- Agencies should not be bound by a strict benefit-cost test, but should be required to consider available benefit-cost analyses

- Benefits and costs of proposed policies should be quantified wherever possible. Best estimates should be presented along with a description of the uncertainties.

- Not all impacts of a decision can be quantified or expressed in dollar terms. Care should be taken to assure that quantitative factors do not dominate important qualitative factors in decisionmaking

5.2 Current Status of Superfund Reauthorization

Federal agency officials, including White House staff, have agreed, in principle, to elevate the role of cost in Superfund cleanups. According to administration sources, the Department of Energy, as well as the Defense Department, face staggering cleanup costs and stand to realize massive savings from benefit-cost decisionmaking in cleanups. The White House, in a move that marks the shift in the administration's position, will support the passage of controversial legislation to require the application of a risk assessment and benefit-cost tests to cleanups only if it is enacted as part of congressional efforts to reauthorize Superfund (Environmental Policy Alert, May 1995). Because of the controversy surrounding Superfund reauthorization, no major decision is expected before the 1996 Presidential elections. However, CERCLA funding is likely to be significantly scaled down in the future. In addition, the transfer of responsibilities from the Federal government to the States, as proposed by the Republican Party, could lead to more site-specific cleanup goals. Agency heads may be required to consider economic analysis to justify the reasons for remediations decisions in the event that the expected costs of a cleanup program far exceed the expected benefits. Therefore, benefit-cost analysis may well play a more significant role in the choice of target cleanup levels.

6. Conclusions and recommendations

6.1 Benefit-cost Analysis - Fuel Spill 12 at the MMR

Natural restoration of the FS-12 site could be an attractive clean-up strategy given the high costs associated with active remediation of contaminants. Provided conditions are favorable, the dissolved plumes of benzene and ethylene dibromide are expected to degrade rapidly. Concentration levels below the maximum contaminant levels (MCLs) could be attained before the plume discharges into nearby surface waters. However, there is a lack of information needed to quantitatively assess the consequences of this strategy.

The high cancer risk and the uncertainties associated with the do nothing alternative would call for the implementation of cleanup measures. This statement is reinforced by the results of the analysis which show that net benefits would be positive. Depending on the value placed on the groundwater contaminated by further plume migration, source control alternatives may be more beneficial than plume containment alternatives.

6.2 Benefit-cost Analysis - Massachusetts Military Reservation Superfund Site

One of the greatest myths about the current operation of the MMR Superfund program is that remediation is justified by the need to protect people's health from consumption of contaminated groundwater. If this was the primary rationale for action, there are many feasible options short of treating contaminated groundwater, such as providing alternative water supplies or capping landfills, that could protect public health. One should question the appropriateness of a $250 million cleanup program in light of the fact that the same public health objectives could be met by replacing the contaminated water supplies, at an additional cost of only $10 million.

The review of costs and benefits also disproves the following myths:

- *The plume containment plan will reduce ecological risks.*

  The containment plan itself has significant ecological risks that need to be weighed against the risks of taking no action. In addition, further investigation is required to assess the acceptability of risks resulting of contaminant discharge into surface water bodies.

- *The plume containment plan will protect property value.*

  In the worst case scenario, the total devaluation of property would amount to less than $20 million. This does not justify the $250 million containment costs. Other alternatives such as financial compensation schemes should be investigated.

- *The plume containment scheme will preserve valuable water resources.*

  One of the hidden yet worthy objectives of the program is to protect the quality of the Upper Cape's groundwater for future, yet unspecified uses by humans and nonhuman species. However, the water resource benefits associated with preservation of groundwater for future generations are expected to be small. Only a minor fraction of the Upper Cape water resources will be preserved. The review of the water supply issues highlighted the need for the establishment of a comprehensive plan to protect the Upper Cape water resources. The current focus on the plume containment overshadows other issues pertaining to water resources such as development and other sources of contamination.

Based on the above analysis, the proposed plume containment plan is not justified. However, the hidden objectives of the plume containment scheme appear to be driven by psychological, economic, and political motivations. Tourism and retirement-based income are the main contributors to the Upper Cape's economy. Perception of risk due to unmitigated plumes could significantly impede the Cape's growth, and result in lost revenues amounting to several hundreds of millions of dollars. Thus, assuming growth is a desirable goal, the $250 million investment could be justified. However one may question whether plume containment would be the most cost-effective means to restore public confidence and reduce the perceived risk.

The above results suggest that a new approach, more balanced and flexible, should be considered for the MMR. This approach would imply less expense by making a wider range of restoration options available, from which the most cost-effective could be picked.

6.3 Benefit-cost analysis - Superfund

Benefit-cost analysis can play a very important role in Superfund. It can help illustrate the tradeoffs that are inherent in remediation decisions as well as make those tradeoffs more transparent. For instance, assessing the remediation decisions at the MMR through a benefit-cost analysis shed light on hidden consequences such as ecological impacts and effects on the local economy. However, the analysis emphasized that not all benefits or costs can be easily quantified, much less translated into dollar terms. There are especially severe difficulties in developing appropriate measures of damages. One measure of damages is the cost of restoring the injured resource. There is controversy as to whether restoration requires physical and biological replication of the injured resource, which could be tremendously costly, or may include acquisition of other resources providing comparable services to the public, such as land purchase to protect groundwater resources and ecosystems for future generations. Nevertheless, even qualitative descriptions of the pros and cons associated with a remediation decision can be helpful. Benefit-cost analysis should be used to help decisionmakers reach a decision. If properly done, it can be a very helpful tool but neither necessary nor sufficient for designing policies and setting priorities. There is evidence that EPA, currently barred from considering costs explicitly in Superfund, does so implicitly. Removing such prohibitions could help promote more efficient and effective remediation decisions, and thus make better use of society's resources. Current planning in Superfund places insufficient emphasis on the likely benefits and costs of cleanup programs and excessive emphasis on politics and deadlines. Congress should consider changing that emphasis by explicitly asking EPA to consider costs and benefits in Superfund..

7. Appendices - Group Project Results

7.1 Modeling of the Plume

A finite element model was used to simulate the natural flow of the groundwater. The primary application of the model was to track the contaminants from their source. The potential contamination of Snake Pond, a surface water body southwest of the pipe leak, was assessed using this model.

7.1.1 Model Description and Development

First developed in 1982 by Camp, Dresser & McKee, the DYN system programs were used to model the FS-12 plume. DYNFLOW solves the governing groundwater flow equation by finite element analysis. DYNFLOW is capable of simulating flow under natural equilibrium conditions, as well as transient conditions induced by pumping. DYNFLOW bases its solution on an elemental grid. The nodes of the model form a three dimensional, trapezoidal element. The head and velocity vectors are calculated for each element in a time step process. Using the results from DYNFLOW, the plume migration was determined using DYNTRACK. DYNTRACK can simulate tracking for a simple single particle. In addition, it can simulate particle tracking for three dimensional, conservative, and first order decay contaminants. DYNTRACK can also account for the absorption and dispersion of contaminants. (Camp, Dresser & McKee, 1992). The first step in the model building process is to create a conceptual model. In order to determine the appropriate location and extent of the elemental grid, the following were analyzed: (1) topographical and geological maps (U.S.G.S., 1974; LeBlanc et al., 1986; Savoie, 1995), and (2) data from the FS-12 Remedial Investigation and Feasibility Study Reports (Advanced Science, Inc., 1993). The grid used for the model covered a much larger area than the actual contamination (Figure 16 and Figure 17) to appropriately represent and model the local stratigraphy and hydrogeology. The grid was approximately triangular in shape and was defined by three sides. The elements of the grid were made smaller and denser in locations of greatest interest. These regions correspond to the plume, Snake Pond, and the proposed pumping fence location.

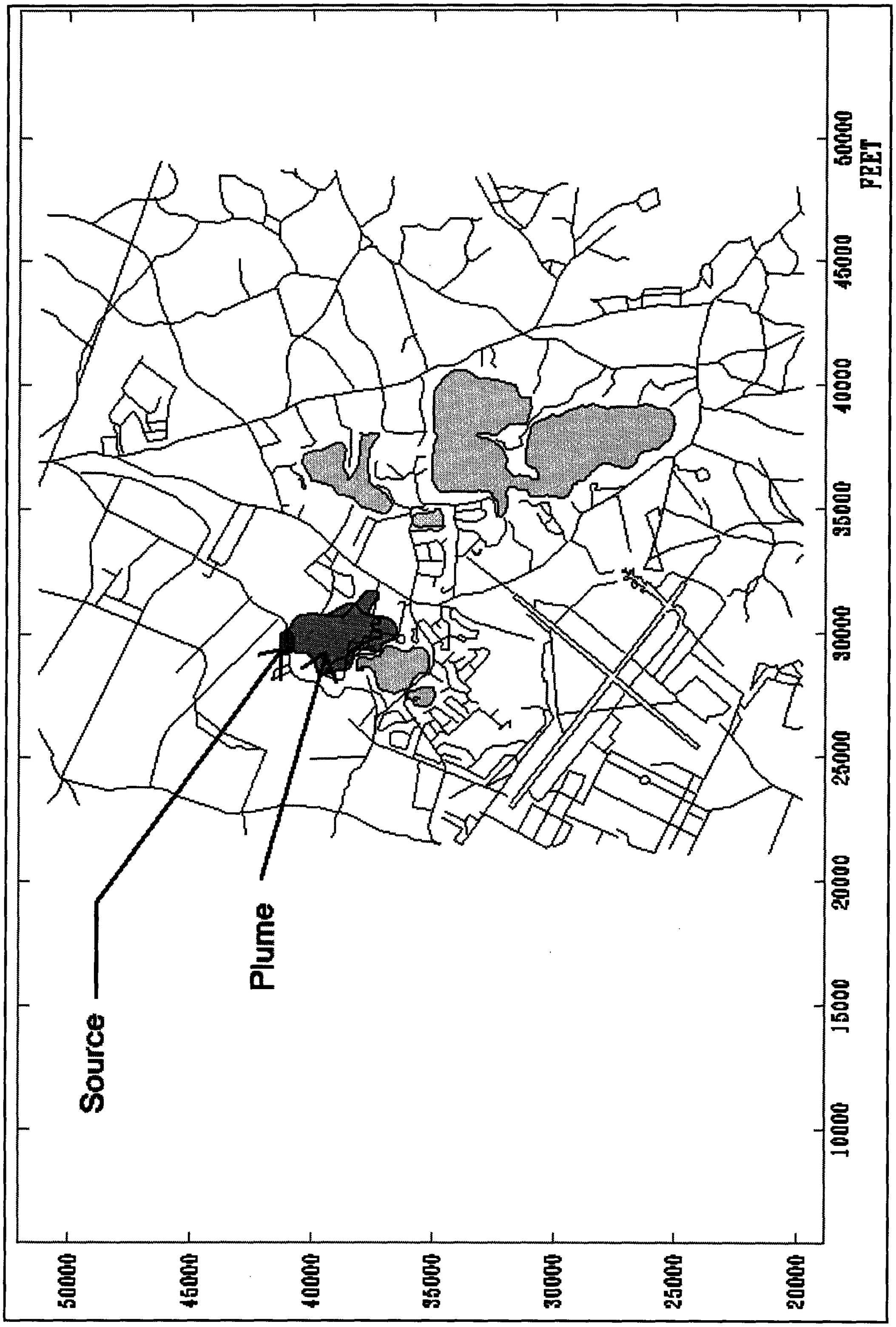


Figure 16- Area Map: Plume Location and Extent of Contamination

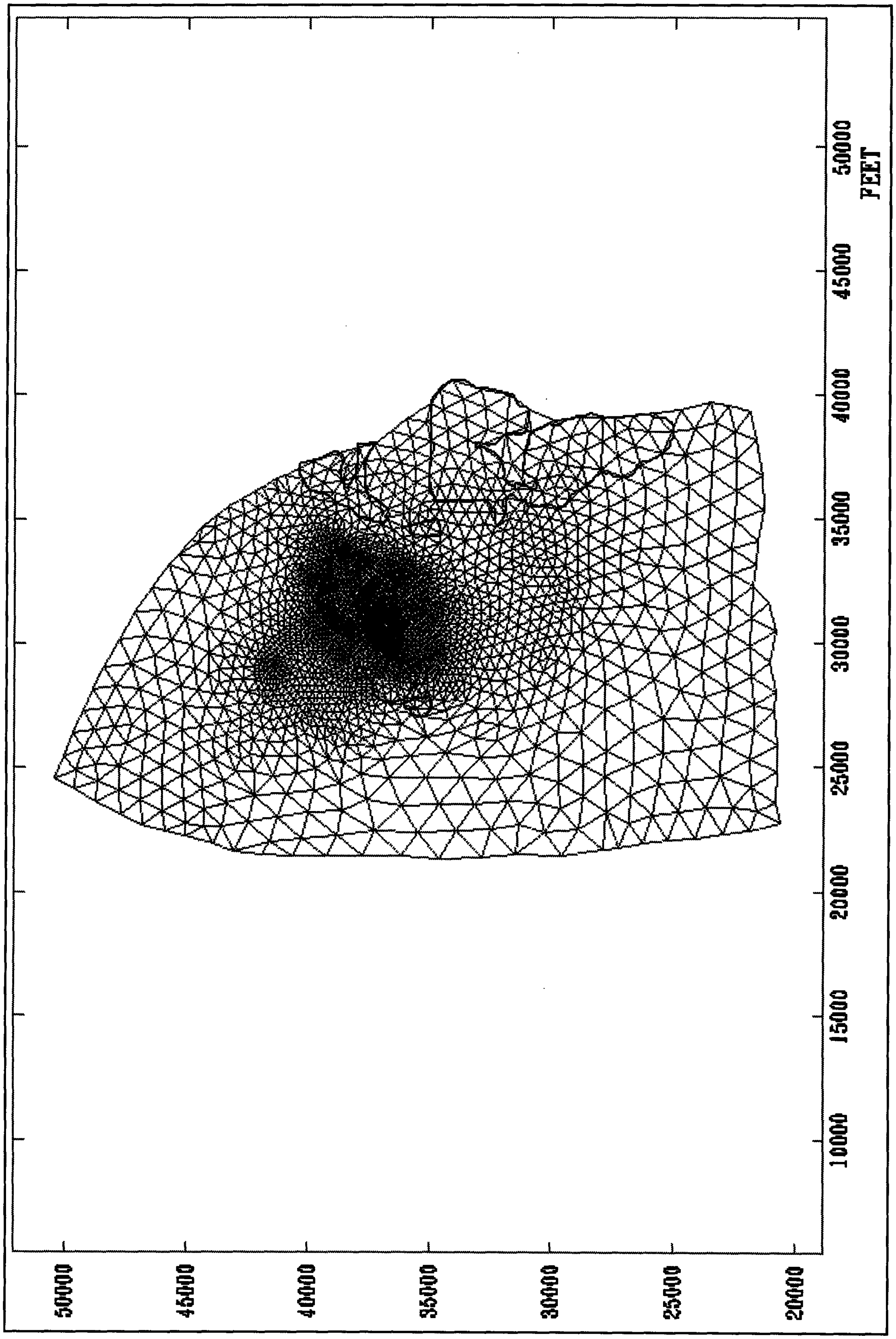


Figure 17- Grid Area

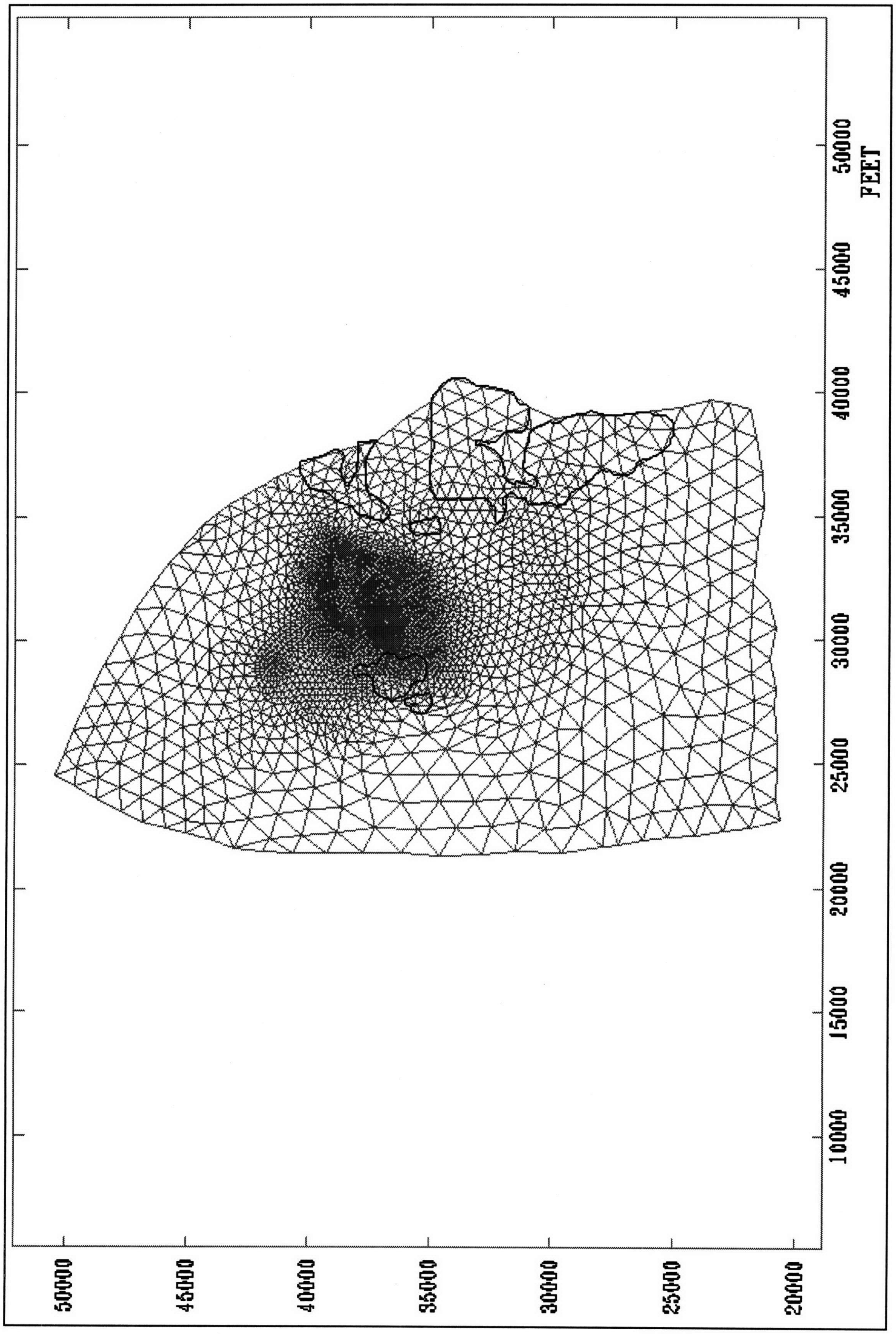


Figure 17- Grid Area

The left and upper right borders of the grid area were modeled as no-flow boundaries. The lower part of the right border, which included Peter's, Wakeby, and Mashpee Ponds, was set at a fixed-head value equal to the water elevations of the ponds. For the bottom perimeter, fixed-head values between 40 ft and 45 ft MSL were specified for each of the nodes.

For the grid area, the bottom of the aquifer was bounded by bedrock from an elevation of approximately 82 to 330 feet below MSL (Oldale, 1969). The ground surface, whose highest point was about 200 feet MSL and the lowest 50 feet MSL, was defined by the topography of the local area (USGS, 1974). In the vertical direction, the model was subdivided into layers, defined between two levels, to represent the different types of soil materials and characteristics. According to the geology, the aquifer was divided into three major layers: upper sand, medium sand, and lower finer sand (Figure 18).

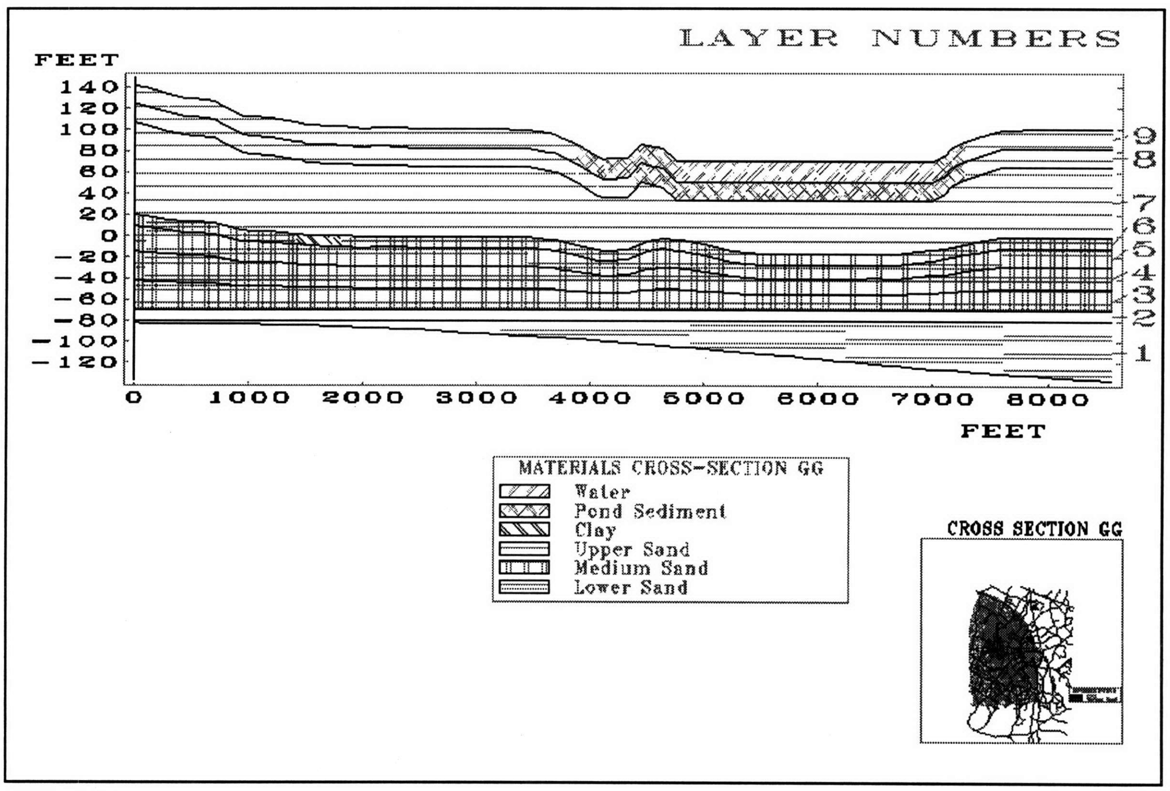


Figure 18 - Cross-Section Showing Layers and Materials

7.1.2 Assessment Of Model Results

7.1.2.1 Natural Groundwater Flow

The natural flow of the system was reproduced with the DYNFLOW model. In order to assess the validity of the results, the computed hydraulic head values were compared to the observed head values of Savoie (1995). The two sets of hydraulic head values demonstrated satisfactory matches. The mean difference in hydraulic head values was 0.348 feet with a standard deviation of 1.687 feet. Furthermore, the equipotential lines resulting from the model (Figure 19) were close to the equipotentials of the same study. (Savoie, 1995) The flow pattern has a general north-south direction with a slight tilt to the east.

7.1.2.2 Contaminant Tracking

Since the fuel released from the pipe contains many compounds, the tracking was limited to one contaminant. Benzene was selected because it is highly toxic and soluble in water, exhibiting lower retardation and higher transport velocities than the other contaminants.

The source of the contamination is a pancake-shaped volume of free product which was modeled as a fixed concentration source. The concentration was set equal to the solubility of benzene. The particle path was modeled with the DYNTRACK model and the resulting plume is shown in Figure 20. A cross-section parallel to the plume is also shown (Figure 21).

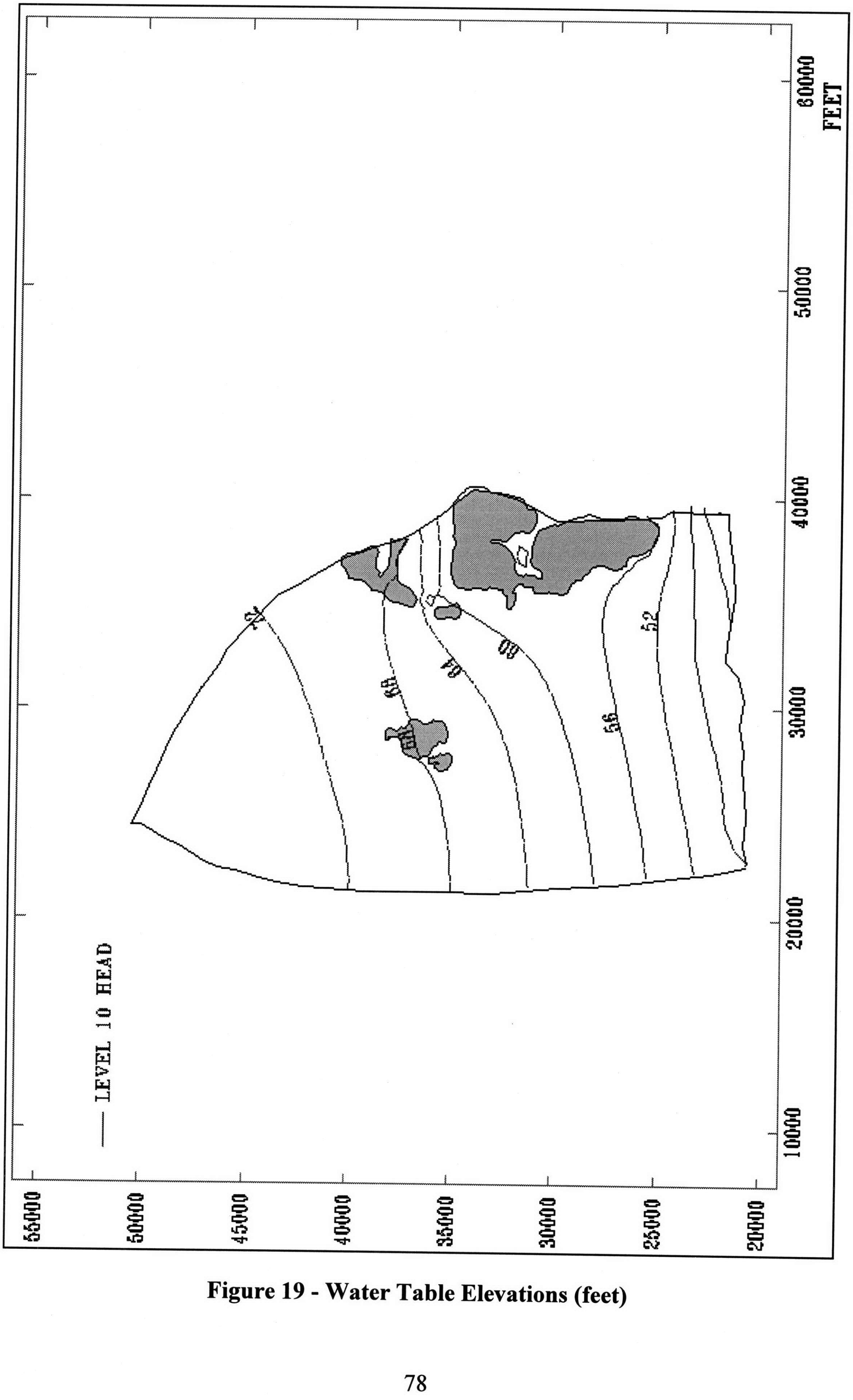


Figure 19 - Water Table Elevations (feet)

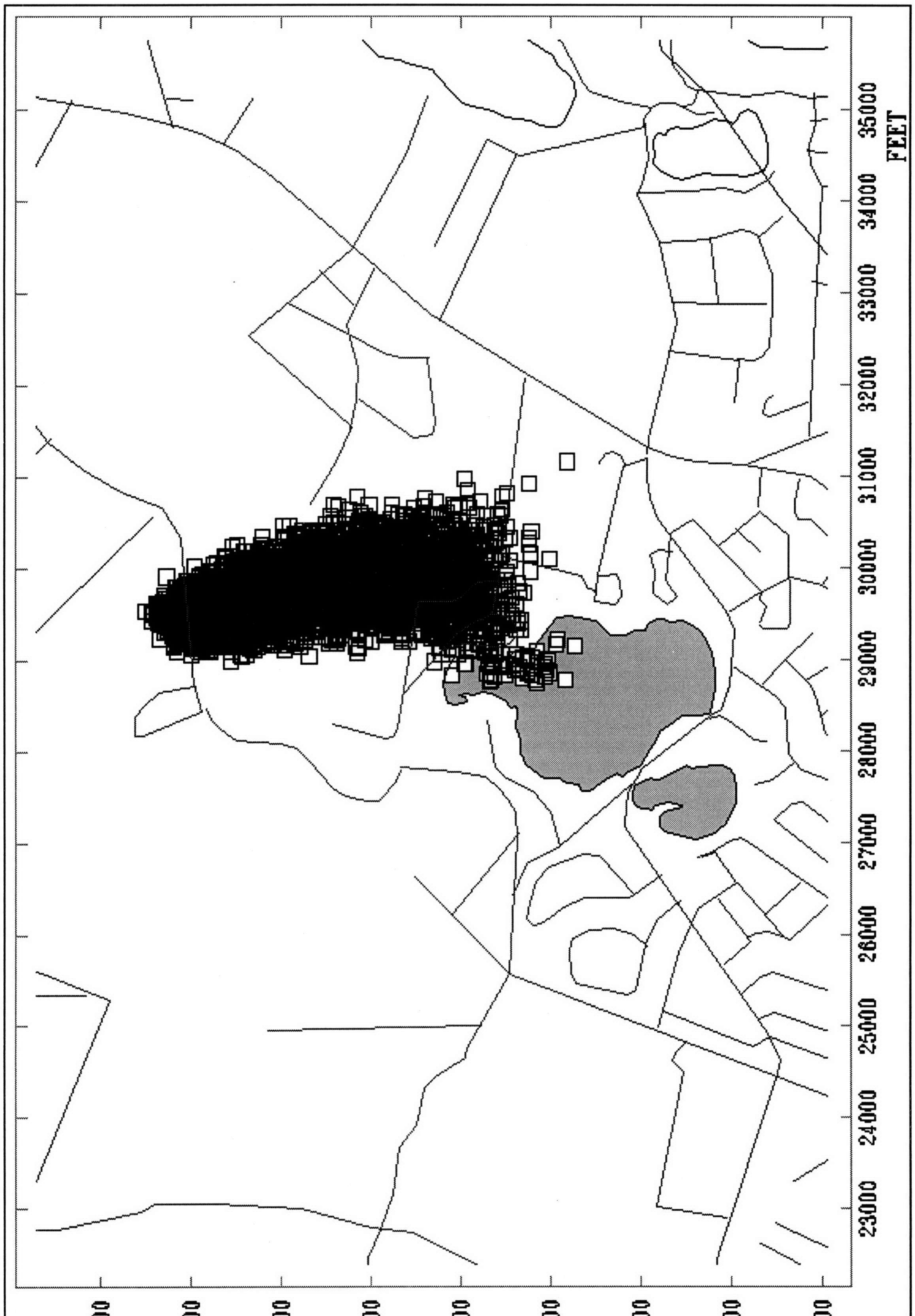


Figure 20 - Simulated Benzene Particles

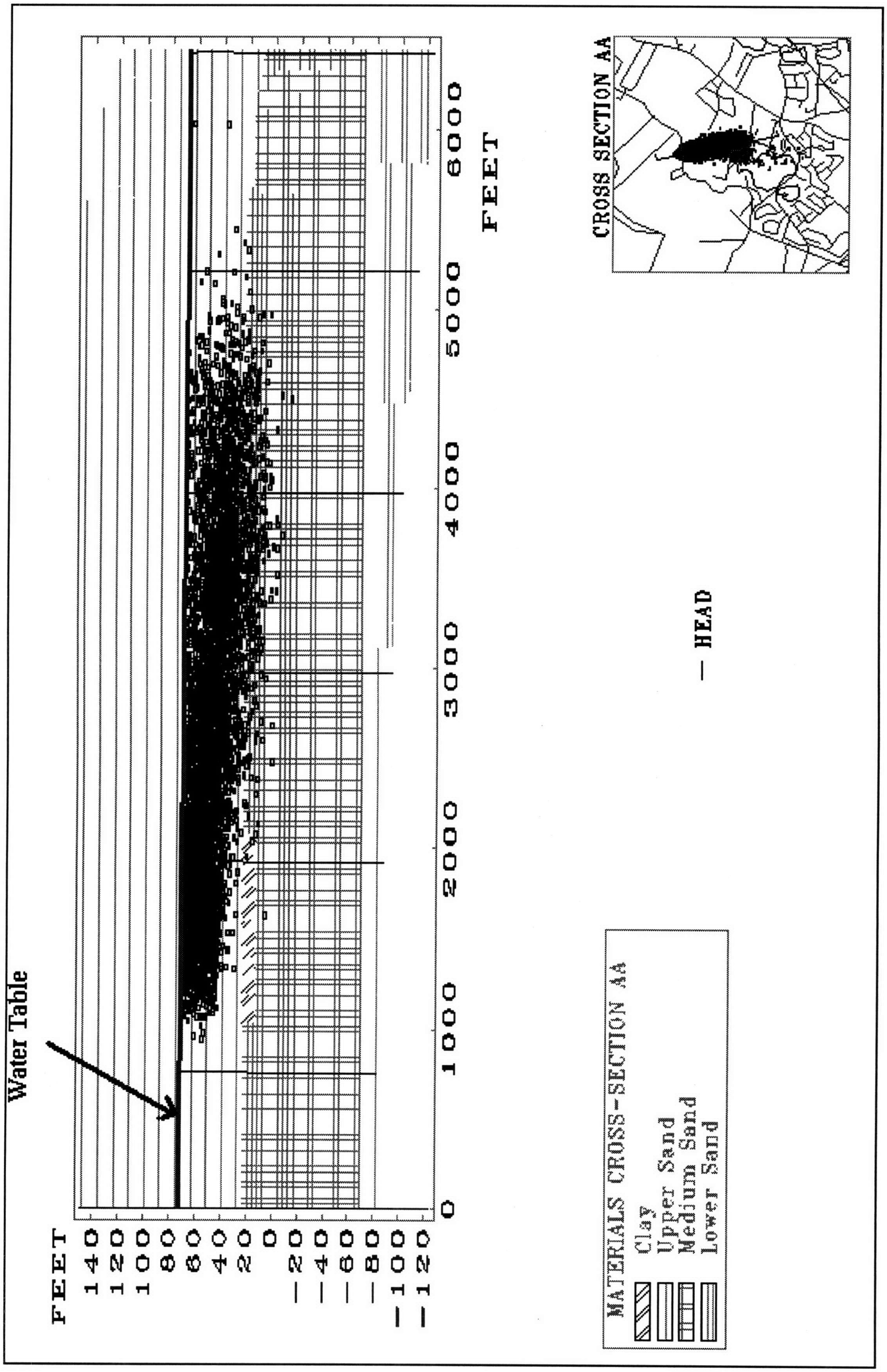


Figure 21 - Cross-Section Across Plume

The position of the modeled plume is approximately 20 feet higher than the measured concentrations of benzene. The discrepancy is attributed to the uncertainty regarding the location of the groundwater divide. It is suspected that the actual position of the divide is closer to the source than the distance input into the model; due to the sparseness in the head observations in the divide area, this cannot be confirmed at this time. Closer proximity to the divide would result in more pronounced vertical movement of the plume. Since the modeled plume is closer to the ground surface, it is also closer to the pond. Therefore, the results of this simulation will represent a highly conservative model. If the resulting benzene concentration in the pond is insignificant, despite the proximity of the modeled plume to the pond, Snake Pond will be safe in reality.

7.1.3 Surface Water Impacts

Despite the inconsistencies of the plume position, valid predictions can be made concerning the safety of Snake Pond. Since the placement of the modeled plume is higher than actual measurements show, it can be considered a 'worst-case scenario.' A cross-section of Snake Pond (Figure 22) shows very few particles being released in the pond even with this conservative model. The resulting concentration was less than 0.5 mg/L, well below EPA standards. Therefore, it is safe to say that the pond is not in danger of contamination from FS-12.

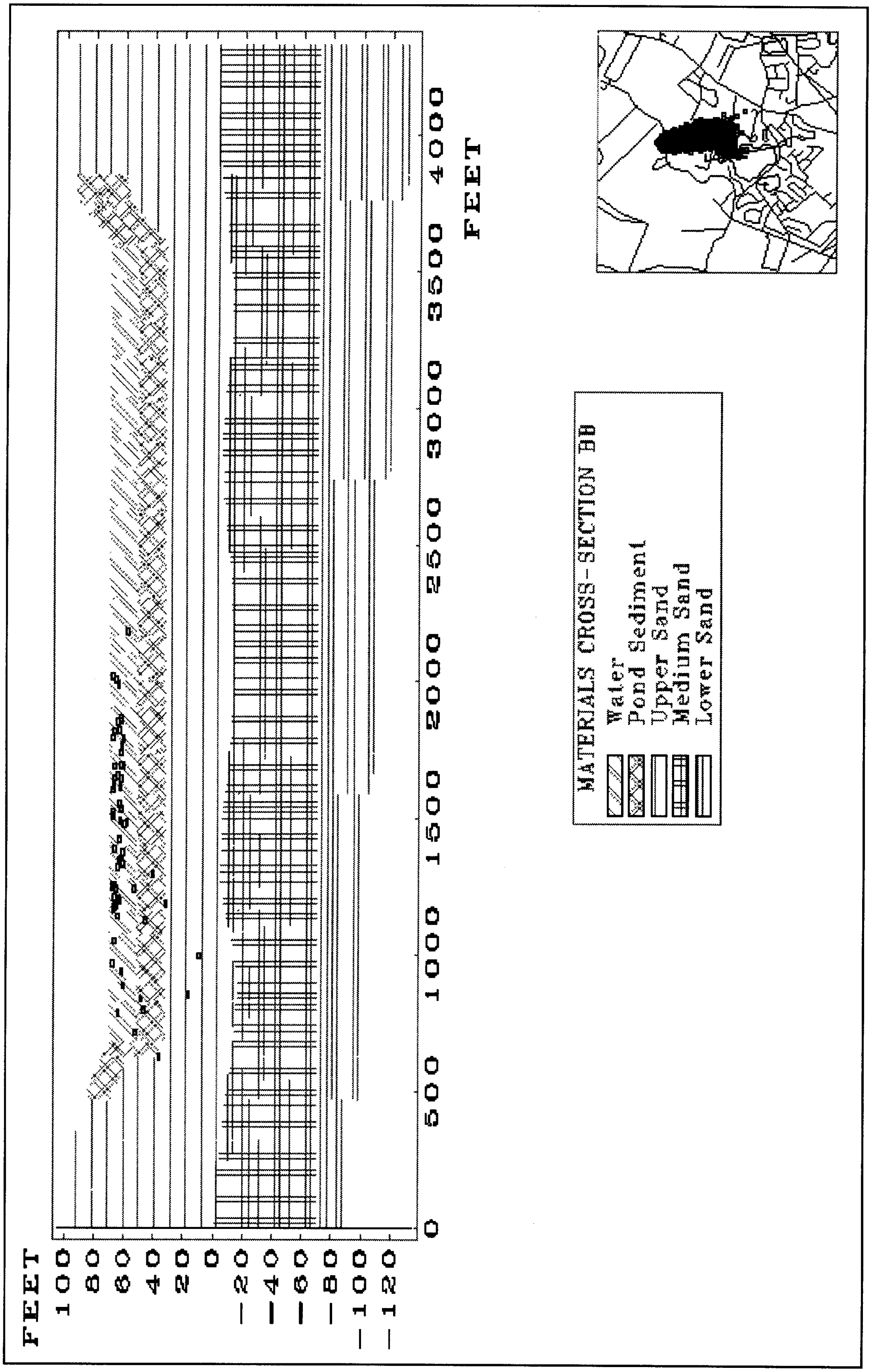


Figure 22 - Cross-Section Across Snake Pond Showing Particles

7.2 Source Control - Air Sparging

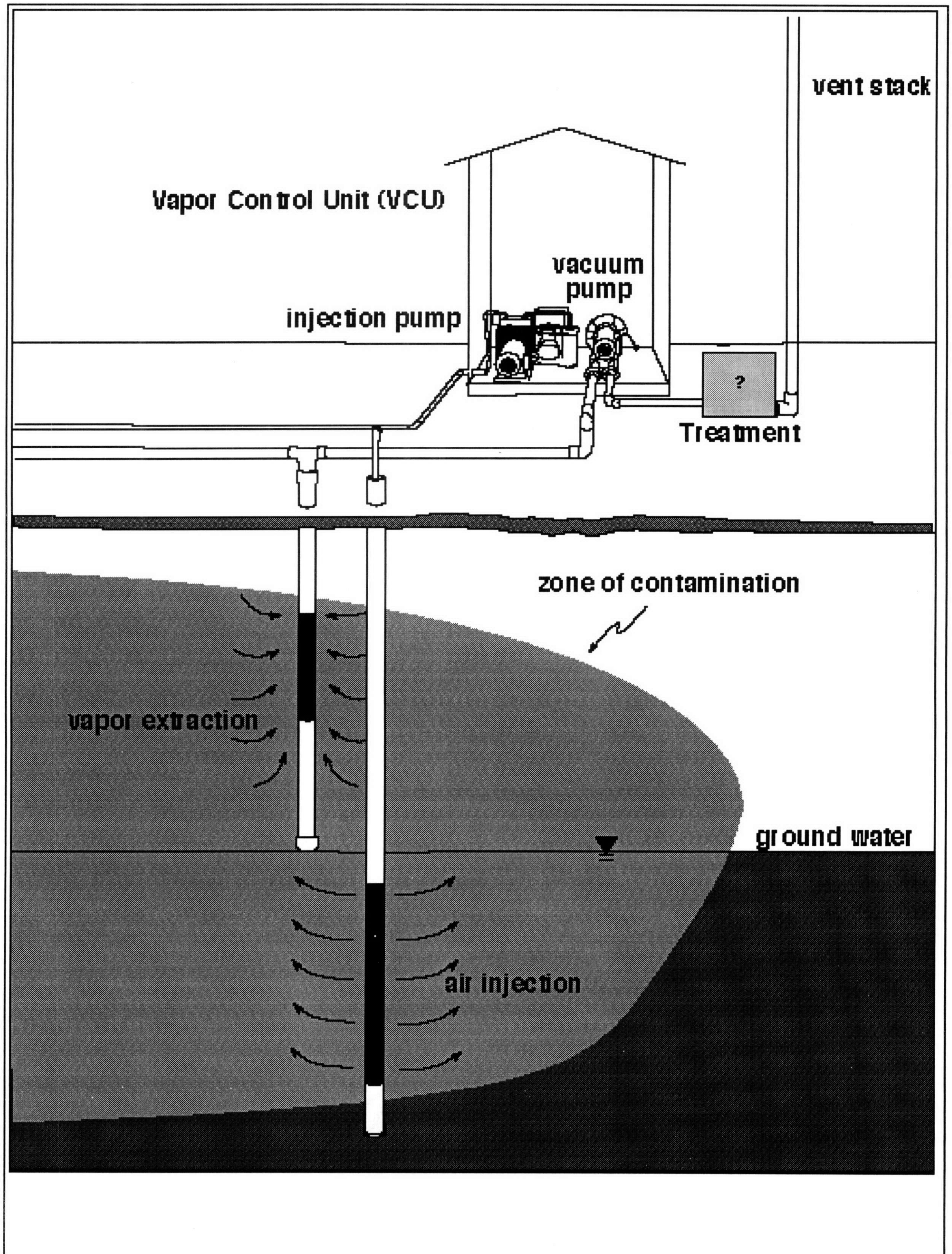
The purpose for this study is to evaluate air sparging as an appropriate choice for source control at FS-12. It includes a basic description of the system processes, as well as primary mechanisms for contaminant removal. The main goal is to determine a new time estimate for source remediation.

7.2.1 Background Information

Air sparging is predominantly used to treat soil and groundwater that is contaminated with volatile organic compounds (VOCs) or petroleum hydrocarbons. The technique involves air injection into water saturated zones. Through a combination of volatilization and biodegradation organic contaminants are removed. Air sparging has a broad appeal due to its relatively simple implementation and modest capital costs which compare favorably with other remediation treatments. Several field-scale applications indicate air sparging's effectiveness in remediating groundwaters contaminated with dissolved VOCs at a faster rate and 50% lower cost than pump and treat. (Chao, 1995). As an *in situ* process, it meets an important provision of the Superfund amendments that calls for minimal exposure to the public and nearby environment. Sparging does not require groundwater extraction and treatment, is operationally low maintenance, and can be adapted to serve a variety of special situations.

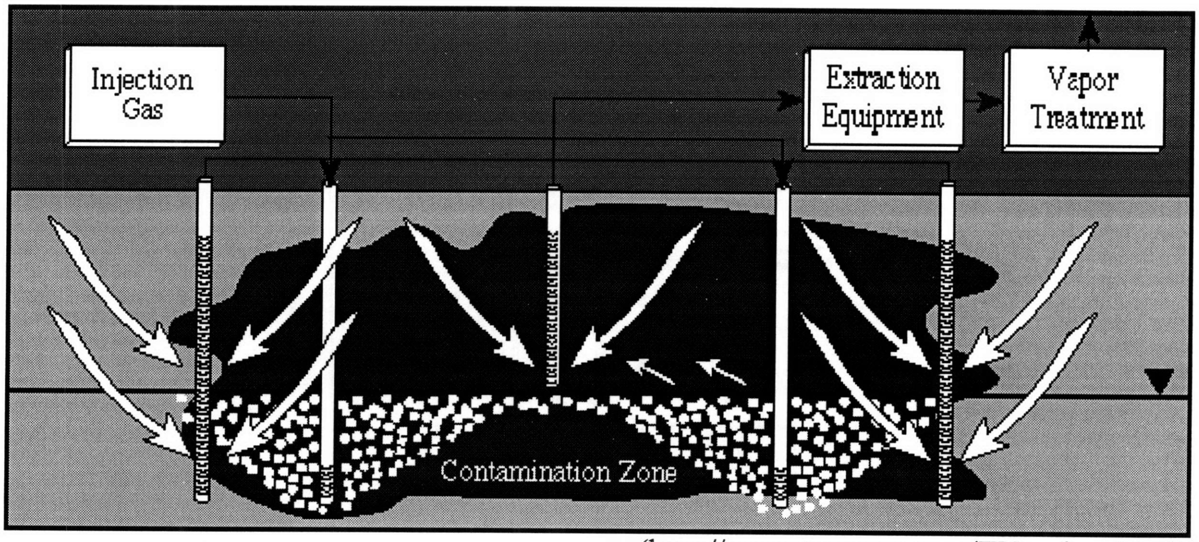
7.2.2 Process Description

Air sparging involves the injection of a hydrocarbon free gaseous medium (typically air), under pressure, into the saturated soil zone (see Figure 23). Air traverses upward through the saturated zone as it mixes with dissolved and adsorbed phase contaminants. In the vadose zone contaminated air is extracted and pumped to on-site vapor treatment units. Ideally, the vacuum extraction rates are three to four times greater than the sparge rate. This ensures the capture and treatment of all escaping contaminant vapors.



(http://www.aristotle.com/Sparging/TechResponses/whatis/ResponseMeny.html)

Figure 23 - Combined Air Sparging/Vacuum Extraction Diagram



(http://www.terravac.com/TVtoolsas.html)

Figure 24 - Air Sparging (Sparge VAC)

7.2.3 Primary Mechanisms and Design Parameters

The key mechanisms incorporated in this technology are volatilization, biodegradation, and mass transfer. Contaminants are transferred, or redistributed, to the advective vapor phase through an established contaminant gradient between the solid/liquid and gas phases. Here, oxygen is exchanged into the aqueous phase. VOC transport into the sparging air results from diffusion/dispersion and air-induced circulation of the water in the vicinity of the sparging well (Wilson, 1994). Percent removal efficiencies of VOC's are proportional to the injected air flowrate and Henry's law constant. "Henry's law constant is a partition coefficient defined as the ratio of a chemical's concentration in air to its concentration water at equilibrium." (Hemond, 1992) To achieve effective stripping via sparge wells, contaminants must have a Henry's constant greater than 0.01, a vapor pressure greater than 0.1 mm Hg, and a soil/water partition coefficient less than 1000 (In Situ Aeration, 1995).

Bioremediation provides a second simultaneous pathway for removal (destruction) of the VOCs. Although "bioventing" is frequently discussed as a separate technology, both evaporation and bioremediation will occur whenever there is air movement through soil (Mohr and Merz, 1995).

For air sparging to be effective, air must be able to flow freely through the aquifer. Thus, air sparging is most widely applicable within sandy soils. A hydraulic conductivity of 0.001 centimeter/second is necessary to maintain sufficient subsurface air flow, since horizontal impermeable zones can trap air and push contamination downward or laterally.

The air sparging 'radius of influence' can be defined in the field through a process of dissolved oxygen measurements, pressure changes, groundwater mounding, or tracer gases. It is important to determine this parameter to evaluate the probable effectiveness of the air sparging technology. Radius of influence is defined as the distance from an air sparging well where air flow can be detected or where the effects of air contact, groundwater mixing, or groundwater oxygenation are detectable (Marley, 1995). The influential radius is rarely radially symmetric. An EPA survey of 21 sites using *in situ* air sparging reports influence ranging from five to 177 feet, though typically less than 25 feet. These distances are directly affected by factors such as soil type, well depth, and injection pressure and flow rate (Loden, 1992).

7.2.4 System Limitations

As with all remedial technologies, air sparging has its limitations. In an operating air sparging/soil vapor extraction system, it is essential to keep the rate of extraction higher than the inflow sparging rate, thus maintaining a favorable gradient of vapor travel. Regardless of flow rate, off-gas concentrations are shown to exhibit an initial sharp decrease followed by proportionally smaller changes in contaminant concentrations with time, a characteristic often attributed to diffusion limitation.

As described previously, the air injected below the water table displaces water as it makes its way up towards the surface and actively strips VOCs from portions of the porous medium. Laboratory evidence indicates that the injected air may flow preferentially through a system of discrete air channels (Ji, 1994). Discrete air flow patterns may lower the effectiveness of treating an entire contamination zone and restrict the distribution of dissolved oxygen to zones near the discrete air-filled channels (Baker, 1995). It can also lead to the risks of lateral mobilization and off-site migration of VOCs. Initial field testing and experiments are usually necessary prior to the implementation of this technology; though they are basically run by trial and error, the potential benefits to be gained demand such an effort (Baker, 1995).

7.2.5 Applications at FS-12

The system installed at the FS-12 plume for source control covers five acres and includes 21 sparge wells below the water table and 22 extraction wells in the unsaturated, vadose zone. The radii of influence used in the design are larger than average but still feasible for sandy soil type aquifers with high conductivity and very deep water tables. The design influence for the sparge wells, as determined by the pilot study, is taken to be 75 feet, and for the soil vapor extraction (SVE) wells is 90 feet. The system incorporates an overlapping design to augment complete source area remediation and capture of the volatilized contaminants (HAZWRAP, 1994). The SVE system began running in October, 1995, and continued for approximately 100 days before air sparging began. This staggered start-up also helped to deter any VOC's from escaping into the atmosphere.

The remediation time for source clean-up at FS-12 was estimated based on the computer program, "Venting", along with outputs from a numerical air sparging model to predict groundwater clean-up rates (HAZWRAP, 1994). The IRP has allotted two years for sparging in order to volatilize enough fuel components to keep the remaining residuals below MCLs. It is important to note that volatilization is the only mechanism taken into account in this approximation. A complete cost estimate for the design, implementation, operation and maintenance of this system comes to almost 2 million dollars (Davis, 1995).

7.2.6 Alternative Remediation Rate Model

A significant step in the critical analysis of this treatment alternative was to recalculate remediation times for site cleanup. Due to the initial urgency of process design and construction, many explicit, and sometimes implicit, assumptions were used to determine initial remediation rates. The current model takes the existence of pure phase free product to be the limiting factor for complete hydrocarbon volatilization. The new time calculation acknowledges the individual respective rates of volatilization for each VOC component in JP-4 jet fuel. Using mole fraction calculations and corresponding partial vapor pressures, this process accounts for the fact that some components of fuel will volatilize more quickly than others. By assuming a state of equilibrium within each sparged volume of air, a new fuel volume can be calculated. This leads to iterative chemical concentrations and adjusted pressures within the sparged air.

As a source control treatment alternative, air sparging is an optimal choice for the site conditions at FS-12. The sandy soil and the contaminant's volatility present a cost-effective and efficient opportunity for air sparging/soil vapor extraction system remediation.

7.2.7 Time For Contamination To Reach MCLs

Based on the spreadsheet model, the mole fraction of benzene in the fuel would need to be reduced to 1.33×10^{-6} in order for an equivalent groundwater near the source to measure below the MCL of 5 ppb. Sparging would have to continue for longer than 9 years to reach these levels. It is important to note that this model takes only removal by volatilization into account. Although the transfer of VOCs into the vapor phase is the dominant process, other mechanisms that contribute to decreasing organic concentrations in the aquifer include biodegradation, dispersion, sorption, and dilution. In addition, the groundwater concentrations measured here are assumed to be directly adjacent to the free product pancake before any dispersion or dilution occurs. Another way to analyze these results is at the conclusion of the previous remedial estimation time of two years. After two years of simulated sparging and vapor extraction, the mole fractions of fuel components were transformed into water concentrations. The corresponding volumes of clean groundwater needed to dilute each liter of fuel-contaminated water near the source to 5 ppb were calculated to be 285 liter/1 liter of contaminated water.

Air sparging may not be as effective if there are significant amounts of less-volatile compounds present in the plume. The less volatile component curves exhibit lower rates of volatilization. Correspondingly, they are present in much lower incidental concentrations, and are more subject to the bioremediation mechanism of removal. Since the BTEX component concentrations are the primary regulated and measured contaminants at the FS-12 site, they are the basis for comparison of the model outputs.

7.3 Plume Containment - Pump and Treat

7.3.1 Pump and Treat - Extraction Well Fence

The following provides the necessary background, design, and application of a pump and treat system for the containment of the FS-12 plume. The design provides a extraction well fence that controls additional migration and spreading of the current contamination. The well fence is not intended to remediate or eliminate the entire plume, but it ensures that the dissolved contaminants do not spread further. In addition, the water contained by the extraction fence will be removed and treated by activated carbon filtration.

7.3.2 Background Information

Pump and Treat is one of the oldest techniques for the remediation and containment of groundwater contamination. Although it has been replaced and surpassed in certain instances by other more efficient remedial technologies, it is still widely used for remediation of contaminated groundwater. Pump and treat consists of pumping contaminated water from the aquifer and treating the water to remove the contaminants. The "clean" water can then be either re-injected into the aquifer by injection wells, or retained for other uses. Optimal field conditions for the application of pump and treat at a contaminated site are highly conductive aquifer material and coarse grained and sandy soil in the saturated zone. It is possible to use pump and treat in less conductive materials; however, the required increase in pumping rates would necessarily increase costs of operation. (Domenico and Schwartz, 1990; Member Agencies of the Federal Remediation Technologies Roundtable, 1995).

7.3.3 Process Description

The location and pumping rate of the wells depends on the position, depth and extent of the plume. Usually wells are drilled surrounding the contaminated area, down-gradient of the direction of flow. The screening interval is typically positioned at a depth equal to that of the plume. The length of the actual screen is proportional to both the vertical extent of the contamination and to the applied pumping rate. There is a trade off between the number of wells and the pumping rate required to successfully contain the plume. To determine the most efficient design, capture curves are used. These define the volume of water of the aquifer that is being captured by a particular system of pumping wells. Therefore, the total area of influence of the extraction fence will be proportional to the total number of wells and their respective flowrate. The treatment of contaminated water by granular activated carbon is a very common process of water purification. The water extracted by the well fence is passed through tanks containing granular activated carbon on which the contaminants are sorbed (Domenico and Schwartz, 1990; Member Agencies of the Federal Remediation Technologies Roundtable, 1995).

7.3.4 Implementation and Design

The first step in the design of a well extraction system is to determine the location and extent of the plume. The well fence should be approximately located at the toe of the plume just down-gradient in the direction of flow. Various layouts for the well fence can be produced. For each layout, several systems can be designed with different numbers of wells and different pumping rates. To actually test and analyze the results of the various designs, the groundwater finite element model was utilized (see Section 7.1). To determine its position in space and time, the volume of contaminated groundwater was represented by visible particles. The particles represent the groundwater as it flows through the aquifer. They can be positioned and started at a particular cross section of the contaminated plume. Their flow path can be analyzed in time by selecting the desired time step for the model's simulation. When the model containing the extraction well fence is simulated it is possible to determine whether the flow volume of the plume, as represented by the particles, is captured by the wells. The particles can be analyzed in three dimensions to ensure that the entire plume is captured. In addition, particles surrounding the actual contamination were also included to ensure that clean water was not being unnecessarily captured by the well fence. Each pumping well was defined in the model by a nodal point with the same coordinates to which the proper outflow was assigned. The model was then simulated under transient conditions to analyze the flow and determine if the extraction well fence actually captures the plume. The capture curves were then determined by analyzing which and how many of the flow particles are being captured by the wells in the simulated model. The analysis of different systems of wells was based on an optimization method. Several solutions were tested with different numbers of wells and different flow rates. The various solutions were then plotted on graphs displaying the interdependence of number of wells, required pumping rate, and depth of the screening intervals.

7.3.5 Application at FS-12

The most efficient system for the well extraction fence consisted of 11 wells pumping at a total rate of 800 gpm. The well fence layout and location is shown in Figure 25. Figure 26 and Figure 27 summarize the results of the simulations of contained particles in plan view and vertical cross section, respectively. As shown, the capture intervals was between 40 feet mean sea level (MSL) and 70 feet below MSL, corresponding roughly to the lowest portion of the contaminated water volume. The optimal vertical placement of the well screening placed at this lower position because the higher soil layers are more conductive than the lower soil layers. The pumping rate of nine of the wells was assigned a flow rate of 70.5 gpm per well. The two wells next to Snake Pond were assigned higher flow rates of 83 gpm per well in order to capture the plume.

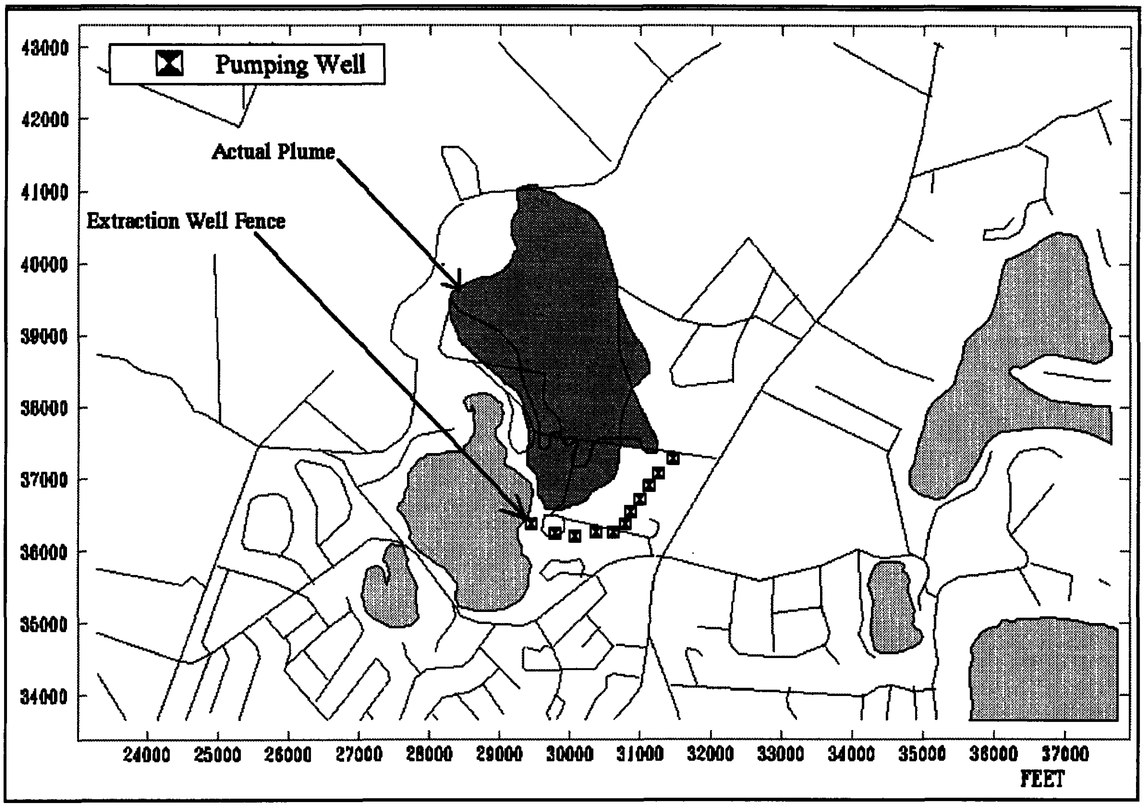


Figure 25 - Extraction Well Fence and Observed Plume Location

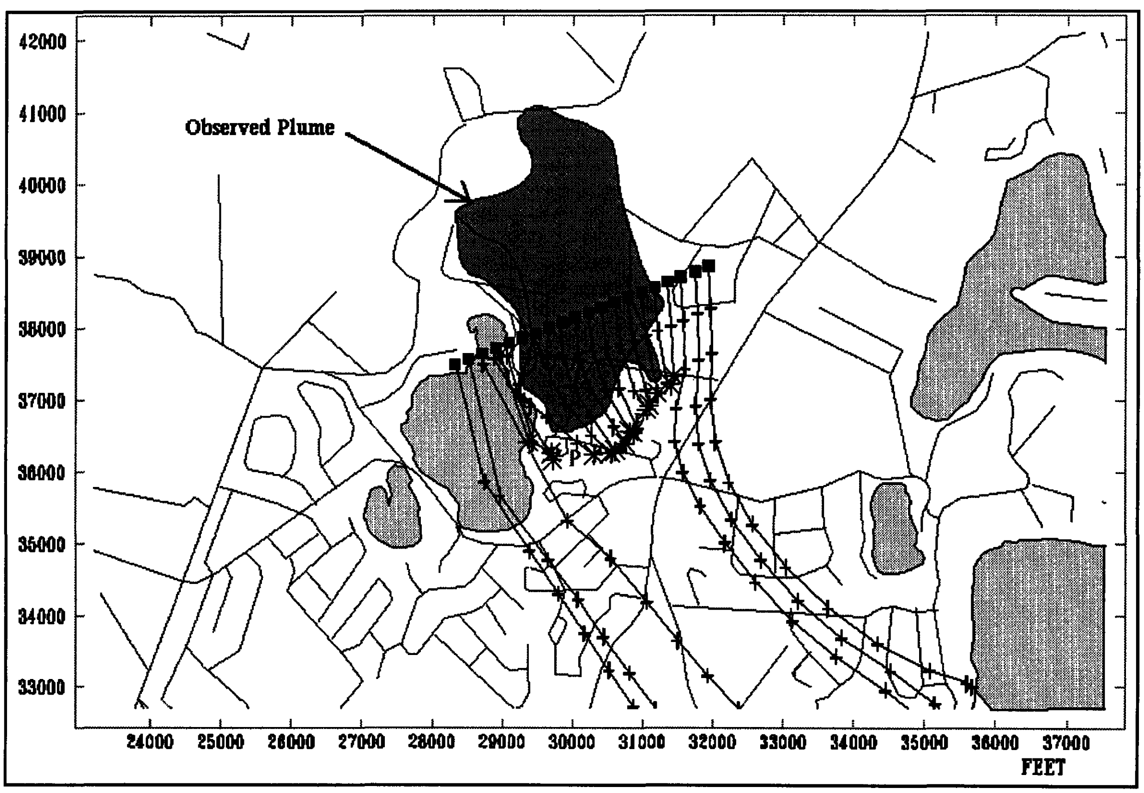


Figure 26 - Plan View of Particle Capture by Extraction Well Fence

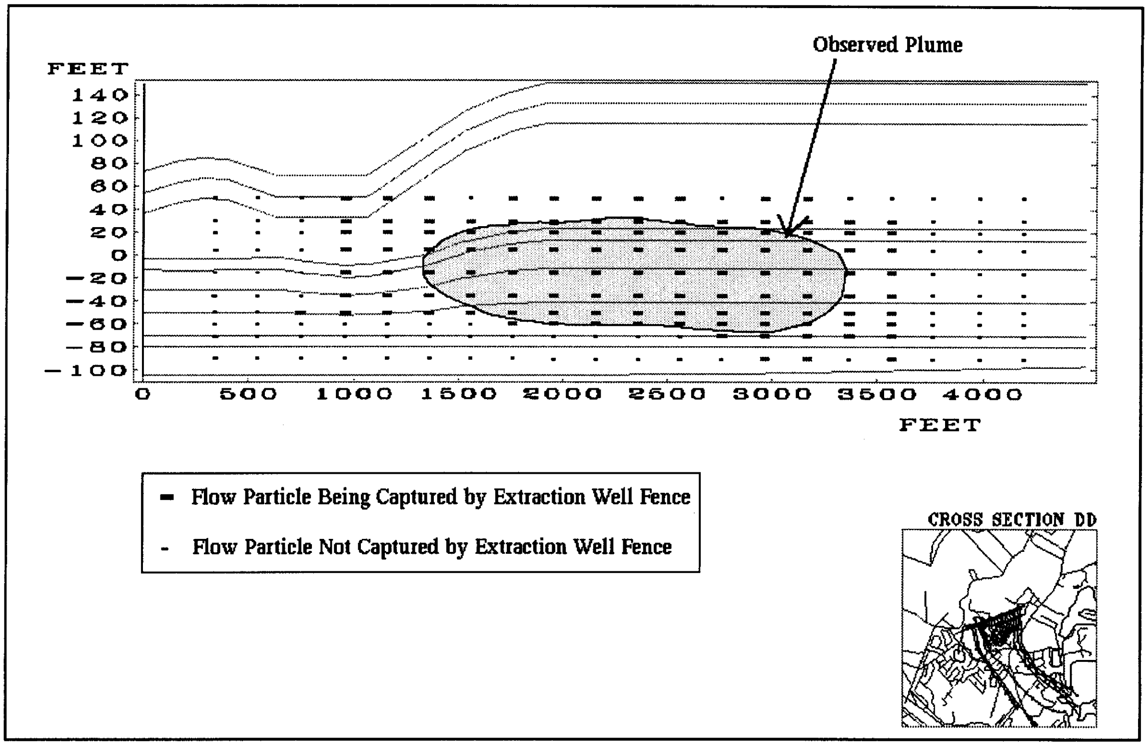


Figure 27 - Cross Section of Particles Captured by the Extraction Well Fence

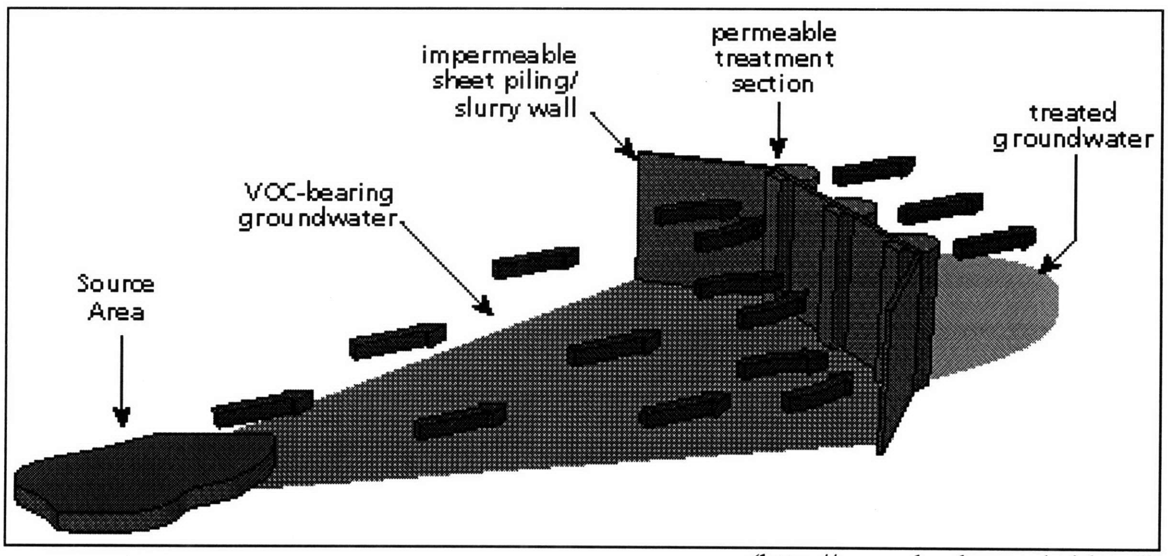
7.4 Plume Containment - Reactive Wall

This section will provide a brief summary of the technical workings of the reactive wall as it applies to the degradation of halogenated organic compounds. Discussion of the advantages and disadvantages of implementing this system over more conventional methods will follow. Finally, this section will conclude with a short evaluation of the potential for application of the technology to the FS-12 site.

7.4.1 Background Information

The permeable reactive wall, a promising innovative technology, provides a remedial alternative to common groundwater contamination cleanup efforts. Developed by Dr. Robert

Gillham of the University of Waterloo (CANADA), this technology provides flexibility in its implementation and application to treating groundwater contamination. The reactive media acts on the plume as the groundwater flow carries the contaminated water through the wall (see Figure 16). The wall can be applied to enhance biodegradation, reduce harmful contaminants, or precipitate out metals in groundwater. Its versatility extends to its implementation as either an *in situ* or *ex situ* treatment. Specifically for the purposes of this group project, its degradation capability has been expanded to a number of halogenated organic contaminants, including tetrachloroethene (PCE) and trichloroethene (TCE), through a reductive dehalogenation using zero valent iron. But of more importance to the FS-12 plume, this technology has readily degraded ethyl dibromide, a contaminant of concern at this site.



(http://www.beak.com/eti.html)

Figure 28 - Permeable Reactive Wall Used in Conjunction with Funneling Barriers

7.4.2 Process Description

The chemical pathways involved with the degradation of these halogenated organic contaminants by the zero valent iron is still unclear. Gillham and O'Hannesin (1992) have concluded that the reaction is abiotic (independent of biological breakdown) and involves reductive dehalogenation of the contaminant. Gillham and O'Hannesin (1994) believe that there are two reductive reaction series that could be occurring in the wall--one that requires the hydrolysis of water and one that does not. Current thinking is that the series of reactions does not in fact, require hydrolysis to occur, resulting a single step reaction process (Gillham and O'Hannesin, 1994).

In terms of the rate of reaction, studies have found that this reaction exhibits a first order rate constant (Helland et al., 1995). However, a number of factors could influence the speed of degradation of the halogenated organic contaminants. In field tests, lower groundwater and field temperatures have been noted to decrease reaction rates. With decreasing temperatures, the impact on reaction rates are greater for more chlorinated and halogenated contaminants (Personal Communication with John Vogan). pH, on the other hand, has not exhibited a direct affect on the reaction rate (Personal Communication with John Vogan). However, studies have noted that pH levels above 9.5 may cause an indirect decrease in reaction rate due to precipitation resulting in coating of the reactive surface or clogging of the pore spaces in the wall (Gillham et al., 1993). As for degradation of VOCs, this technology appears rather "robust" in that "stabilizing agents commonly added to industrial solvents or by inorganic groundwater chemistry" do not affect the reaction rate (Vogan et al., 1995).

7.4.3 Implementation and Design

Designing an effective wall requires careful consideration of a number of factors. These include the hydrogeologic characteristics of the site and plume, contaminant levels in the groundwater, and MCL goal following treatment. These factors affect the selection of the implementation site, the ratio of iron to sand in the reactive media, and the width and thickness of the wall.

A key concern for implementing this technology is selecting a site through which the entire plume will pass through for treatment. This relies on a clear model and understanding of the site characteristics and plume movement--information not always readily available. Site selection also requires finding an implementation point that is not too deep to insert the wall and funneling barriers. Funneling barriers, walls of low conductivity (ex: slurry walls, sheet pilings), are sometimes constructed to direct flow to minimize the required width of the reactive wall.

The width of the wall is also a concern in the design process. To compete with conventional methods, such as pump-and-treat, the design must be effective and efficient. Iron filings and implementation costs can be cost prohibitive at times. Iron filings cost at a minimum of $400 per ton (Personal Communication with John Vogan). But, new findings show that this concern may become inconsequential, as recycling of iron wastes from foundry and mining operation can be used with minimal effect on the reaction rate. Implementation costs are dependent on the equipment and method chosen, the depth required for entrance, and the geological characteristics of the site. The reaction process itself, in the case of PCE and TCE, has produced low levels of toxic chlorinated products such as dichloroethene and vinyl chloride. Thus, an appropriate residence time is required within the wall to ensure complete degradation. This requires an appropriate thickness of the wall.

The relative thickness of the wall can be balanced by the ratio of the reactive zero valent iron to sand. The percentages can range depending on the contaminant levels and the MCL allowed following treatment. As a design rule of thumb, if the levels of contaminants are at the parts per million level, 100% zero valent iron is used for the reactive media. For lower levels of halogenated organic compounds, a balance must be struck between reactive surface area of the iron and the sand and the hydraulic conductivity of the wall. (Personal Communication with John Vogan)

In selecting a remedial technology, the site manager desires an effective and efficient solution to the groundwater contamination at the site. The reactive wall technology requires a high initial capital investment, but minimal operation and maintenance cost as a result of its passive nature. In comparison to the conventional method of pump-and-treat, the wall provides a more cost effective treatment. Furthermore, the reduction reaction series of the wall (given a sufficient residence time) degrades the contaminant rather than transfers the contaminant to a different media; such as activated carbon. There is uncertainty over the duration that the zero valent iron is able to sustain effectiveness. Gillham predicts that the iron will be effective for at least ten years (Personal Communication with Robert Gillham). However in comparison to pump-and-treat, this technology is not anymore time efficient in its required cleanup time, since it relies on the groundwater flow to bring the contaminated water to the wall.

As the capabilities of the wall develop, its versatility can be applied during the design of a system. As varying elements are used for degradation and precipitation of contaminants, as well as enhancement of biodegradation, a system of walls, placed in series can degrade a range of contaminants. The reactive walls can also be part of a treatment train--one in a series of technologies used together to remediate arrange of contaminants in groundwater. When complemented with funneling barriers, walls can also be implemented in parallel such that a larger plume width can be efficiently treated. This system configuration is popularly named the "funnel-and-gate."

7.4.4 Application at FS-12

The two contaminants of concern at the FS-12 site are benzene and EDB. EnviroMetal Technologies, Inc. have found the reactive wall to successfully degrade EDB. Thus far, Gillham found that the zero valent iron is not able to degrade BTEX, which includes benzene, without significant changes, such as metal enhancement of the iron (Personal Communication with Robert Gillham). However, the plumes of these contaminants plunge to a depth over 100 ft near the source area. Application of this technology to FS-12 is possible, if the plume resurfaces near the shore of a surface water body. Using the model formulated in section 7.1, the plume does not enter Snake Pond. Thus, application of this technology is not possible at the FS-12 site.

7.5 Public Perception of Drinking Treated Groundwater from MMR

Under the MMR's Installation Restoration Program (IRP), a design is currently underway to contain the leading edges of the plumes emanating from the base. The proposed plan includes extraction of contaminated groundwater, treatment to remove contaminants to MCLs regulated by law, and subsequent subsurface discharge of the water. This program is funded by the Department of Defense (DOD) within its Defense Environmental Restoration Account (DERA). The DOD requires all programs funded by this account to assess other beneficial reuse options besides subsurface discharge for the extracted water. (Operational Technologies Corp., 1995) Beneficial reuse options include surface discharge to ponds, irrigation and agricultural use, and municipal use as a potable water source.

To fulfill this requirement, the Senior Management Board (SMB), the tasking body of the IRP, requested their design consultant, Operational Technologies, to review the beneficial reuse options according to effectiveness, feasibility, and cost. In addition, the SMB also requested that the Long Range Water Supply Process Action Team (LRWS PAT) and the Program Implementation Team (Team 2) conduct discussions concerning reuse options and present their opinions to the SMB. These two teams are comprised of the Water District Superintendents from the four towns surrounding the MMR (Falmouth, Bourne, Sandwich, and Mashpee), local residents, representatives from local groups, and the Cape Cod Commission.

It is this second task which is the focus of this study. The recommendation made by the teams to the SMB included 100% reinjection of the treated water to the aquifer. The main reason behind this recommendation was the lack of public acceptance to drinking treated groundwater. Little of the conversation focused on the other two beneficial reuse options, recharge to ponds and irrigation. The focus of this study was to more clearly define the reasons behind this public sentiment by conducting interviews with the members of the teams. This issue could become a very important one for the surrounding water districts of Falmouth, Bourne, Sandwich, and Mashpee as more of their water supplies are affected by the contamination emanating from the base. The LRWS PAT, made up of the four water district superintendents, is tasked with ensuring that those four water districts have sufficient supplies to meet demands until the year 2020. Currently, they are predicting a shortfall, most drastically in Falmouth and Bourne. (LRWS PAT, 1994) Falmouth has lost several of its wells to contamination, the Ashumet Valley well in 1979 and the Coonamessett well in February 1996; and Bourne has lost Wells #2 & #5. With the potential for additional well contamination the towns have begun to search for new sites on which to drill wells. The issue becomes complicated as new sources of water become more difficult to establish due to lack of land availability and well construction and land costs. Thus, the use of treated water may need to be considered by these water districts, whether it is treatment of the water from their own contaminated wells, or treated water from the MMR. Consequently, this study assessed the reasons behind the lack of public acceptance of drinking treated groundwater from the MMR by conducting interviews with the members of the LRWS PAT and Team 2 Committees.

Interviews

The interviews were informally conducted in person or by telephone. Each individual was asked the following question: What are the main reasons behind this lack of public acceptance to drinking treated groundwater from the MMR? The following four reasons were the most prevalent:

- *The perception that Cape Cod water is "pristine".*

  This belief in the pristineness of their water supply is evidenced in their absence of water treatment. Bourne, Sandwich, and Mashpee only control the pH of the water; they do not even disinfect the water through chlorination. The communities also believe that their water contains zero levels of contaminants. This belief is actually incorrect. For example, although the water being pumped from the aquifer might be "clean", the pipes of the distribution system are leaching PCE, TCE, and other chemicals into their water at detectable levels below the MCLs (Personal Communications with Raymond Jack and Ralph Marks). Lastly, this belief is upheld in their perception that the water which would be available from the MMR would be treated, previously contaminated water. In a community which believes treatment and contamination are unacceptable, it would be difficult to convince them to drink treated water from the MMR.

- *The MMR cannot guarantee the water will reach non-detect (ND) levels of contaminants.*

  Connected with their idea that their current water is pristine, the communities would accept nothing less than ND levels of contaminants in the water. The MMR, with its planned treatment facility, can technologically reach these levels. However, under its agreement with the DOD it cannot legally guarantee these levels. Therefore, the community sees this water as "cleaner, polluted water" (Public Meeting Participant).

- *There exists an adversarial relationship between the MMR and the surrounding communities.*

  The local residents have little faith in the MMR's convictions. They have been waiting for 17 years for a solution to emerge . . . and they are still waiting (Personal Communication with Raymond Jack).

- *The public would prefer that the water district managers continue to search for new locations to drill water supply wells as long as this option remains viable.*

  Bourne is currently searching for new well sites on MMR property.

As evidenced by these interviews, the lack of public acceptance is multi-faceted. There are technological, political, and social aspects which combine to create these public perceptions.

Outlook to the Future

As part of the final recommendation the teams made to the SMB, they suggested that if water reuse is considered in the future, public education programs would need to be implemented in order to increase the public acceptance of drinking treated groundwater. Currently, the only water district manager who was and still is willing to use treated water from contaminated sources is Raymond Jack of Falmouth. In his interview, he pointed out that Falmouth is already using treated water from a local surface water body, Long Pond. This water, although not from a contaminated site, is treated with chlorine for disinfection purposes. In the future, as demand continues to grow over supply; land and well costs increase; and availability of land for new wells decreases, using treated water may become an option. Falmouth would be most receptive to the idea. Therefore, assessing the reasons behind the public's perception of the idea is a very important one in order to design appropriate educational programs for the future.

References

Advanced Sciences, Inc. *Remedial Investigation Report, Remedial Investigation/Feasibility Study, FS-12 Study Area*. Installation Restoration Program, Massachusetts Military Reservation. Prepared for HAZWRAP, Oak Ridge, Tennessee. December 1993.

Air National Guard. *Field Sampling and Analysis Plan for Groundwater Monitoring Program.* Massachusetts Military Reservation. June 1994.

Arrow, K. J., M. L. Cropper, G. C. Eads, R. W. Hahn, L. B. Lave, R. G. Noll, P. R. Portney, M. Russell, R. Schmalensee, V. K. Smith, R. N. Stavins. Benefit-Cost Analysis in Environmental, Health, and Safety Regulation, A Statement of Principles. AEI, 1996

Baker, Ralph S., et al. *Evidence of Preferential Vapor Flow During In Situ Air Sparging*. In Situ Aeration: Air Sparging, Bioventing, and Related Remediation Processes. Columbus: Battelle Memorial Institute, 1995. pp. 63-73.

Borden, Robert C., et al. "Geochemical Indicators of Intrinsic Bioremediation." *Groundwater*, Vol. 33, No. 2, 1995.

Cambareri, T. C., et al. "Benzene Transport Through a Mature Hydrocarbon Plume in a Sand and Gravel Aquifer." *Focus Conference on Eastern Regional Groundwater Issues*, Newton, MA. 1992.

Camp, Dresser & McKee, Inc. *Dynflow, A 3-Dimensional Finite Element Groundwater Flow Model, Description and User's Manual, Version 3.0*. 1984.

Camp, Dresser & McKee, Inc. *Dynsystem, Groundwater Flow And Transport Modeling System, Reference Guide*. 1992.

Camp, Dresser & McKee, Inc. *Dyntrack, A 3-Dimensional Transport Model for Groundwater Studies, Description and User's Manual, Version 1.0*. 1984.

Cape Cod Commission. *Cape Trends, Demographic and Economic Characteristics and Trends*. Barnstable County, 3rd edition. 1996.

Chao, Keh-Ping and Say Kee Ong. *Air Sparging: Effects of VOCs and Soil Properties on VOC Volatilization*. In Situ Aeration: Air Sparging, Bioventing, and Related Remediation Processes. Columbus: Battelle Memorial Institute, 1995. pp. 103-110.

Clayton, Wilson S., et al. *Air Sparging and Bioremediation: The Case for In Situ Mixing*. In Situ Aeration: Air Sparging, Bioventing, and Related Remediation Processes. Columbus: Battelle Memorial Institute, 1995. pp. 75-85.

Davis, Robert. " Correspondence." Cost Estimate for Furnishment, Installation, and Operation of a Combined Air Sparging/Soil Vapor Extraction System. Installation Restoration Program. 1995.

Department of Environmental Management, Massachusetts Executive Office of Environmental Affairs. *Water Resources of Cape Cod.* October 1994.

Domenico, P. A. and F. W. Schwartz. *Physical and Chemical Hydrogeology.* John Wiley & Sons, Inc., New York. 1990.

Dupont, Dr. R. Ryan. "Fundamentals of Bioventing Applied to Fuel Contaminated Sites." *Environmental Progress,* Vol. 2, No. 1, 1993. pp. 45-52.

Frank, U. and N. Barkley. "Remediation of Low Permeability Subsurface Formations By Fracturing Enhancement of Soil Vapor Extraction," *Journal of Hazardous Materials,* Vol. 40, 1995. pp. 191-201.

Freeze, R. A. and J. A. Cherry. Groundwater. Prentice Hall, Inc., New Jersey, 1979.

Gagnon, Judy. *The Public Perception of Drinking Treated Groundwater from the Masachusetts Military Reservation, Cape Cod, Massachusetts.* M.Eng. Thesis. Massachusetts Institute of Technology, 1996.

Gelhar, L. W., C. Welty, and K. R. Rehfeldt. "A Critical Review of Data on Field-Scale Dispersion in Aquifers." *Water Resources Research,* Vol. 28, No. 7, July 1992. pp. 1955-1974.

Gillham et al. "Metal Enhanced Abiotic Degradation of Halogenated Aliphatics: Laboratory Tests and Field Trials." *1993 HazMat Central Conference.* Chicago: March 9-11, 1993.

Gillham, Robert and Stephanie O'Hannesin. "Enhanced Degradation of Halogenated Aliphatic by Zero-Valent Iron." *Groundwater,* Vol. 32, November/December 1994. pp. 958-967.

Gillham, Robert and Stephanie O'Hannesin. "Metal-Catalyzed Abiotic Degradation of Halogenated Organic Compounds." *1992 IAH/AIH Conference: Modern Trends in Hydrogeology.* Ontario: May 11-13, 1992. pp. 94-103.

Goo, Holly. *Barriers to Demonstrating and Implementing Innovative Technologies at Hazardous Waste Sites: A Case Study of the Permeable Reactive Wall at the Massachusetts Military Reservation.* M.Eng. Thesis. Massachusetts Institute of Technology, 1996.

Hazardous Waste Remedial Action Program. *Final Design Package for the FS-12 Product Recovery System.* Massachusetts Military Reservation. Prepared for the National Guard Bureau. July 1994.

Helland et al. "Reductive Dechlorination of Carbon Tetrachloride with Elemental Iron." *Journal of Hazardous Materials,* Vol. 41, 1995. pp. 205-216.

http://www.terravac.com/TVtoolsas.html. "Air Sparging (Sparge Vac)." Terra Vac.

Hutchings, T. *Application of Modeling Techniques to Test Hypotheses Concerning the Migration of Aviation Gasoline from a Surface Spill.* M.S. Thesis, Dept. Of Civil and Environmental Engineering, Massachusetts Institute of Technology, 1995.

HydroGeoLogic, Inc. *Aquifer Test Analysis, Massachusetts Military Reservation, Cape Cod, Massachusetts*. Hazardous Waste Remedial Action Program, Oak Ridge, Tennessee. June 1994.

Installation Restoration Program. *Group Meeting Minutes - Long Range Water Supply/Team 2*. Massachusetts Military Reservation. July 13 & 18, 1995.

Ji, Wei. *Air Sparging: Experimental and Theoretical Analysis of Flow and Numerical Modeling of Mass Transfer* Ph. D. Thesis, The University of Connecticut, 1994.

LeBlanc, D. R., J. H. Guswa, M. H. Frimpter, and M. H. Londquist. *Ground-Water Resources of Cape Cod, Massachusetts*. Department of the Interior, U.S. Geological Survey Hydrologic Investigations, Atlas HA-692 (sheet 3 of 4), 1986.

Loden, Mary E. *A Technology Assessment of Soil Vapor Extraction and Air Sparging.* EPA/600/R-92/173. September, 1992.

Long Range Water Supply Process Action Team. *Draft Long Range Water Supply Strategy*. 1994.

MacKay, D., W. Y. Shiu, and K. C. Ma. *Illustrated Handbook of Physical/Chemical Properties and Environmental Fate for Organic Chemicals, Vol. I, Monoaromatic Hydrocarbons, Chlorobenzenes and PCB's*. Lewis Publishers, 1992.

Marley, Michael C., et al. "Air Sparging Technology: A Practice Update." In Situ Aeration: Air Sparging, Bioventing, and Related Remediation Processes. Columbus: Battelle Memorial Institute, 1995. pp. 21-37.

Masterson, John P. and Paul M. Barlow. *Effects of Simulated Ground-Water Pumping and Recharge on Ground-Water Flow in Cape Cod, Martha's Vineyard, and Nantucket Island Basins, Massachusetts*. U.S. Geological Survey, Open-File Report 94-316, 1994.

McCaulou, Douglas R., et al. "Evaluation of Vertical Circulation Wells For Enhanced Bioremediation." In Situ Aeration: Air Sparging, Bioventing, and Related Remediation Processes. Columbus: Battelle Memorial Institute, 1995. pp. 495-501.

Member Agencies of the Federal Remediation Technologies Roundtable. *Remediation Case Studies: Groundwater Treatment*. EPA-542-R-95-003, March 1995.

Mohr, Donald H. and Paul H. Merz. "Application of a 2D Air Flow Model to Soil Vapor Extraction and Bioventing Case Studies." *Groundwater.* Vol. 33, No. 34, 1995. pp. 33-444.

Oldale, R. N. *Seismic Investigations on Cape Cod, Martha's Vineyard, and Nantucket, Massachusetts, and a Topographic Map of the Basement Surface from Cape Cod Bay to the Islands*. U.S. Geological Survey Prof. Paper 650-B, B122-B127, 1969.

Operational Technologies Corporation. *Technical Memorandum for Beneficial Use of Treated Groundwater.* Massachusetts Military Reservation, Air National Guard, July 1995.

Operational Technologies Corporation. *Plume Containment Design Analysis Plan, Evaluation of Alternatives*. Massachusetts Military Reservation, Air National Guard, 1996.

Pankhow, James F., et al. "Air Sparging in Gate Wells in Cutoff Walls and Trenches for Control of Plumes of Volatile Organic Compounds." *Ground Water*, Vol. 31, No. 4, 1993. pp. 654-662.

Personal Communication with Robert Gillham. University of Waterloo. April 1996.

Personal Communication with Robert Kreykenbohm. Sandwich Water District Superintendent. March 1996.

Personal Communication with Thomas Cambareri. Water Resources Program Manager, Cape Cod Commission. March 1996.

Personal Communication with Raymond Jack. Falmouth Water District Superintendent. March 1996.

Personal Communication with Ralph Marks. Bourne Water District Superintendent. March 1996.

Personal Communication with John Vogan. EnviroMetal Technologies, Inc. March 1996.

Public Meeting Participant. Falmouth Town Meeting. February 1996.

Resources for the Future. Analyzing Superfund, Economics, Science and Law. Washington DC, 1995.

Riva, Vanessa. *Groundwater Modeling to Predict Plume Migration and to Design a Well Fence for a Fuel Spill at the Massachusetts Military Reservation.* M.Eng Thesis. Massachusetts Institute of Technology, 1996.

Rolbein, Seth. The Enemy Within. The Struggle to Clean Up Cape Cod's Military Superfund Site. Association for the Preservation of Cape Cod, 1995

Savoie, J. *Altitude and Configuration of the Water Table, Western Cape Cod Aquifer, Massachusetts, March 1993*. U.S. Department of the Interior, U.S. Geological Survey, Open-File Report 94-462, 1995.

Schwarzenbach, R. P., P. M. Gschwend, and D. M. Imboden. Environmental Organic Chemistry. John Wiley & Sons, New York, 1993.

Stone & Webster Environmental Technology & Services. *Final Record of Decision for Interim Action - Containment of Seven Groundwater Plumes*. 1995.

Styliannou, Chrystalla and Bruce A. DeVantier. "Relative Air Permeability as Function of Saturation in Soil Venting." *Journal of Environmental Engineering*, Vol. 121, No. 4, 1995. pp. 337-346.

Tietenberg Thomas. Environmental and Natural Resource Economics. Harper Collins, 1996.

Triantopoulos, Dimitris. *Modeling of a Jet Fuel Spill in the Groundwater at the Massachusetts Military Reservation*. M.Eng. Thesis. Massachusetts Institute of Technology, 1996.

U.S. Environmental Protection Agency. *A Guide for Cost-Effectiveness and Benefit-cost Analysis of State and Local Groundwater Protection Programs*. Office of Water, Doc. No. 813-R-93-001, 1993.

U.S. Environmental Protection Agency. *Methods for Measuring Non-Use Values: A Contingent Valuation Study of Groundwater Cleanup*. 1993.

U. S. Geological Survey, Department of the Interior. *Cotuit Quadrangle, Massachusetts, N4132.5-W7022.5/7.5*. 1974.

U.S. Environmental Protection Agency. *Superfund Innovative Technology Evaluation Program: Technology Profiles*. 7th Edition, EPA/540/R-94/526, Office of Research and Development. Cincinnati (Ohio), November 1994.

Westinghouse Savannah River Company. *VOCs in Non-Arid Soils Technology Summary: Air Sparging/Vapor Extraction via Horizontal Wells*. Internet: 'VOCNA_TOC.html'. Sect.3.1, p. 1.

Wilson, David J., et al. "Groundwater Cleanup by In-Situ Sparging. VIII. Effect of Air Channeling on Dissolved Volatile Organic Compounds Removal Efficiency." *Separation Science and Technology*, Vol. 29, No. 18, 1994. pp. 2387-2418.