Barriers to Demonstrating and Implementing Innovative Technologies at Hazardous Waste Sites: Case Study of the Permeable Reactive Wall at the Massachusetts Military Reservation

by

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ABSTRACT

The complexity of Superfund sites continues to challenge the technological methods designed to remove contamination and restore the land for future use. Many conventional technologies applied to these hazardous waste sites are neither time-efficient nor cost-effective. Thus, various sources continue to develop innovative technologies to address this need for more effective and efficient mechanisms.

While this need is recognized by both the public and private sectors, innovative technologies have not been widely developed and implemented. This study examines the technical workings of one innovative technology, the permeable reactive wall. These walls can be employed to provide nutrients to enhance biodegradation, reduce contaminants to non-toxic forms, and precipitate contaminants out of the groundwater. Permeable reactive walls can be applied either in situ or ex situ. For the purposes of this study, the use of zero-valent iron in the walls was examined for its degradation of halogenated aliphatic contaminants, namely chlorinated volatile organic compounds.

A case study of the transfer history of the wall at a Superfund site, the Massachusetts Military Reservation (MMR), was examined. To bring the technology from the University of Waterloo to the MMR has taken approximately six years thus far. Over this period of time, feasibility studies were conducted to select a site for implementation. The time consuming process is attributed to negotiation and bureaucratic loops.

Expanding the scope of the case study to the entire United States, an examination of the current innovation environment for technology developers in the field of hazardous waste technologies was conducted. An evaluation of the current environment for barriers and obstacles to development and implementation of these innovative technologies follows. The thesis concludes with recommendations for increased communication, funding, and flexibility to improve the environment for increased innovation.

Thesis Supervisor: Professor David H. Marks
Title: Professor of Civil and Environmental Engineering
Acknowledgments

I would first like to thank my family for the love and support I have received throughout my life. Without the numerous sacrifices you have made for me over the years, I would not be what I am today.

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This thesis is a partial fulfillment of a class in the Master of Engineering Program in Environmental Engineering in the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology. This research contributed to a group project which analyzed water supply issues and technology options to remediate at a fuel spill site at the Massachusetts Military Reservation. The other members of this group are Christophe Bosch, Judy Gagnon, Karen Jones, Vanessa Riva, and Mitsos Triantopoulos. The group project was a compilation of each group member’s individual thesis. The results of this group project are presented in full in Appendix A.
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1.0 INTRODUCTION

Over 1300 Superfund sites are currently listed on the National Priorities List (NPL). This number does not include those federal hazardous waste sites not listed on the NPL, as well as those state hazardous waste sites requiring remediation. The number of sites continues to increase rather than decrease as sites are identified and evaluated.

Further complicating the remediation of hazardous waste sites are the increased complexity of the hazardous wastes themselves. The number of sites and the complexity of the wastes currently require the investment of billions of dollars. Current remediation alternatives typically require decades of operation to bring a site within compliance standards. One can conclude that conventional methods are not providing the desired results in a time-efficient and cost-effective manner.

The need for innovative technologies is recognized among all parties associated with hazardous waste site remediation--regulatory agencies, legislative bodies, impacted communities, industries, and technological developers. An innovative technology is a remediation technology or method for which there is incomplete data. An existing technology or method may also be considered innovative if applied in a new manner.

An awareness of the limitations of conventional methods is driving a number of changes to encourage the development of new technologies. This includes appropriations and allowances in legislation for implementing innovative technologies. Federal agencies; namely the U.S. Environmental Protection Agency (USEPA), the Department of Defense (DOD), and Department
of Energy (DOE); are implementing programs which support the research, development and
demonstration of innovative technologies.

Despite these efforts, the demonstration and validation of innovative technologies have
been limited. The costs of development and demonstrations can be prohibitive. Implementation
of these unproven technologies are often halted by regulatory bodies or the local communities.
Thus, many factors are involved with the slow development and acceptance of innovative
technologies.

This paper will evaluate the technical workings of the permeable and its application at the
Massachusetts Military Reservation given its local conditions. Further, this research will show
that aspects of current programs are working toward greater technological innovations. Despite
these programs, the whole process in general needs improvement.

1.1 SCOPE

This thesis examines one innovative technology and its implementation at a Superfund
site—the permeable reactive wall at the Massachusetts Military Reservation (MMR). Section 2
provides background on the hydrogeologic features and history of the MMR. Section 3
examines the technical workings of the reactive wall, as well as the advantages and
disadvantages of its use in comparison to other technologies. This will be followed by a
summary of the technology transfer history from the University of Waterloo (CANADA) to the
MMR in Section 4. Section 5 presents an examination of the current innovation environment
including a look at legislative and programmatic support. Section 5 also discusses the barriers
facing developers as they continue to research new ways to remediate hazardous waste sites.
Section 6 provides suggested changes to this program. In closing, Section 7 summarizes the finding of this research.
2.0 CASE STUDY OF MMR: SITE CHARACTERIZATION AND HISTORY

This section provides background information on the Massachusetts Military Reservation (MMR). It covers physical and sociological features of the local region. This information was extracted from the group project contained in Appendix A.

2.1 PHYSICAL CHARACTERISTICS

2.1.1 Situation

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 1).

2.1.2 Topography and Geology

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.
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.

Figure 1 - Location of the MMR
(Stone & Webster, 1995)
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. Accordingly, the aquifer has been characterised 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 2). Flow is generally radially outward from this mound. The ocean forms the lateral boundary of the aquifer on three sides.

Figure 2 - Hydrogeology of the MMR

(Department of Environmental Management, 1994)
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.

2.1.5 Ecosystems

The Massachusetts Division of Fisheries and Wildlife considers coastal plain ponds as one of the most unique and 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).

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.

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.
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). 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, see paragraph 3.4.2.2)).

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).

2.2.3 Economy

The Upper Cape economy was valued at $600 million in 1992; more than 60% was derived from tourists, seasonal residents, and retirement-based income (see section 3.4.2.2). 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).

2.3 HISTORY

2.3.1 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).

2.3.2 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).

2.3.3 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 3) 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)
Figure 3 - Plume Area Map

Massachusetts Military Reservation
Cape Cod, Massachusetts

Source: HAZWRAP, Modified by OPTECH 1996.
3.0 PERMEABLE REACTIVE WALL

The reactive wall is a promising innovative technology used to remediate groundwater by expediting the degradation of contaminants to harmless products. These versatile walls can be employed to provide nutrients to enhance biodegradation, reduce contaminants to non-toxic forms, and precipitate contaminants out of the groundwater (USEPA (1995)). Permeable reactive walls can be applied either in situ or ex situ (USEPA (1995)). Whether the technology is implemented in situ or ex situ to remove chlorinated volatile organic compounds (VOCs) from the groundwater and whether it is or is not operated in conjunction with funneling barriers, the reducing reactions which destroy the chlorinated organic contaminants using zero-valent iron are still the same.

Research continues to evaluate and expand on the application of the reactive wall capabilities. Some are examining the potentials of other metals for enhancing degradation of groundwater contaminants, while others are studying various configurations of the reactive wall for more effective uses.

3.1 HISTORY OF ZERO-VALENT METALS FOR DEGRADATION

The history of using zero-valent metals to degrade organic contaminants dates back to as early as 1972 when Sweeny and Fischer studied and patented the use of granular zinc to enhance the degradation of pesticides (Gillham and O'Hannesin (1994), 958). This concept of using zero-valent iron for enhanced degradation was later patented twice by Sweeny in 1973 and 1983 (Gillham and O'Hannesin (1994), 958). Internationally, Senzaki and Kumagai of Japan also completed studies considering the application of zero-valent iron to enhance degradation of
tetrachloroethene (PCE) and trichloroethylene (TCE) in wastewater between 1988 and 1991 (Gillham and O'Hannesin (1994), 959). In 1990, the use of zero-valent metals for the remediation of groundwater was developed by Dr. Robert Gillham of the University of Waterloo and commercialized by the same university through EnviroMetal Technologies, Inc. (Vogan et al., 800).

In the past two years, over 35 feasibility studies have been initiated many of which have lead to field scale and full scale implementation (EnviroMetal Technologies Inc., 1). The reactive wall passively reduces common groundwater contaminants; such as TCE and PCE, into harmless products thereby destroying their toxic capabilities. Current studies are also looking to apply reactive iron to remove other groundwater contaminants. The reactive wall can be used alone or in conjunction with funneling barriers which direct the plume towards the wall. When the funnel-like barriers and the reactive wall are used together, this technology is dubbed the "funnel-and-gate."

For the purposes of this thesis, the focus will be on the processes and limitations associated with the destruction of aliphatic chlorinated contaminants by an in situ permeable reactive wall consisting of zero-valent iron. For additional information about the ex situ application of zero-valent iron to treat chlorinated solvents, see Tillman (1996).

3.2 TECHNICAL WORKING OF THE REACTIVE WALL

Demonstrations continue to validate the capabilities of the reactive wall. Despite increasing interest and implementation of this technology, understanding of the degradation
processes within the wall is still unclear. Researchers continue to study the reaction process and factors which impact the reaction rate of the zero-valent iron.

3.2.1 Chemical Pathways

Researchers of this technology have found successful results using iron for reducing chlorinated solvents, common groundwater contaminants to many Superfund sites (Gillham and O'Hannesin (1993), 3). These dissolved halogenated organic contaminants include PCE, TCE, vinyl chloride (VC), and trichloroethane (TCA).

Despite various studies of the process, researchers are still uncertain as to the exact chemical reducing step or steps. Gillham and O'Hannesin have concluded that the reaction is abiotic, independent of biological breakdown (Gillham and O'Hannesin (1992), 15). When degrading the chlorinated VOCs, the non-toxic end products are ethene, ethane, methane, and chloride ions (http://www.beak.com/eti.html). This discussion looks at two proposed reactive pathways in particular. Further research to clarify the reduction of chemical solvents continues.

3.2.1.1 Multi-Step Reaction Process

The first theory on the reductive dehalogenation of chlorinated VOCs is a multi-step process detailed below.
This series of reactions assumes that water, a chlorinated organic compound \((X-Cl)\), and zero-valence iron are present. During this series of reactions, iron is oxidized from \(Fe^0\) to \(Fe^{+2}\) and water undergoes hydrolysis. While these two reactions have been shown to be separate, it is uncertain whether the hydrolysis of water is necessary for the dechlorination of the organic compounds. (Gillham and O'Hannesin (1994), 965)

### 3.2.1.2 One-Step Reaction Process

The next theory on the reduction of these solvents is a one-step reductive dechlorination, which is as follows:

\[
Fe + X-Cl + H_2O \rightarrow Fe^{+2} + OH^- + X-H + Cl^- 
\]

(Gillham and O'Hannesin (1994), 965).

Using the same notation as the theory above, this reaction process assumes hydrolysis of water is not a key reaction to the dechlorination of the halogenated organic compounds (Gillham and O'Hannesin (1994), 965).
3.2.1.3 Current Thinking

Though a clear determination between these reaction pathways is lacking, certain facts suggest that the single step reduction is likely. During laboratory experiments, Gillham and O'Hannesin have detected no other dechlorination products besides those "less chlorinated forms of the parent compound," leading to the conclusion that the degradation is reductive dehalogenation of Fe0 (Gillham and O'Hannesin (1994), 966). In addition, small amounts of chlorinated products suggest the necessity for a transfer of electrons through a precipitous reaction resulting from direct contact between the X-Cl compound and the iron. The concept of transferring electrons by direct contact is further supported through other studies reflecting a "mass transfer limitation" in the reaction rate resulting from the ratio of surface area to volume. This mass transfer limitation will be discussed in the following section. Table 1 summarizes the reaction rates of different compounds successfully degraded by the reactive wall. (Gillham and O'Hannesin (1994), 966).

3.2.2 Reaction Rate

While this reaction is thermodynamically favorable, a number of studies have examined limiting factors in the rates of reduction of halogenated organic compounds by iron (Helland et al., 212). pH levels are an important consideration, as are temperature levels. Other considerations include dissolved oxygen levels and oxygen levels. Lab results have shown that
Table 1: Half Lives of Compounds Degraded with Pure and Commercial Grade Zero-Valent Iron (normalized to 1 m² iron surface per mL of solution)

<table>
<thead>
<tr>
<th>Organic Compound</th>
<th>Pure Iron $t_{1/2}$ (hour)</th>
<th>Commercial Iron $t_{1/2}$ (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Methanes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.020, 0.003, 0.023</td>
<td>0.31-0.85</td>
</tr>
<tr>
<td>Chloroform</td>
<td>1.49, 0.73</td>
<td>4.8</td>
</tr>
<tr>
<td>Bromoform</td>
<td>0.041</td>
<td></td>
</tr>
<tr>
<td><strong>Ethanes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hexachloroethane</td>
<td>0.013</td>
<td></td>
</tr>
<tr>
<td>1,1,2,2-Tetrachloroethane</td>
<td>0.053</td>
<td></td>
</tr>
<tr>
<td>1,1,1,2-Tetrachloroethane</td>
<td>0.049</td>
<td></td>
</tr>
<tr>
<td>1,1,1-Trichloroethane</td>
<td>0.065, 1.4</td>
<td>1.7-4.1</td>
</tr>
<tr>
<td><strong>Ethenes</strong></td>
<td></td>
<td></td>
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<tr>
<td>Tetrachloroethene</td>
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<td>2.1-10.8, 3.2</td>
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<td>Trichloroethene</td>
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<td>1,1-Dichloroethene</td>
<td>5.5, 2.8</td>
<td>37.4, 15.2</td>
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<td>trans 1,2-Dichloroethene</td>
<td>6.4</td>
<td>4.9, 6.9, 7.6</td>
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<tr>
<td>cis 1,2-Dichloroethene</td>
<td>19.7</td>
<td>10.8-33.9, 47.6</td>
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<tr>
<td>Vinyl Chloride</td>
<td>12.6</td>
<td>10.8-12.3, 4.7</td>
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<tr>
<td><strong>Other</strong></td>
<td></td>
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</tr>
<tr>
<td>1,1,2-Trichlorotrifluoroethane (Freon 113)</td>
<td>1.02</td>
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<td>1,3-Dichloropropene</td>
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<td>1,2-Dibromo-3-chloropropane</td>
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<td>0.72</td>
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<td>1,2-Dibromoethane (Ethyl Dibromide)</td>
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<td>1.5-6.5</td>
</tr>
<tr>
<td>n-Nitrosodimethylamine (NDMA)</td>
<td>1.83</td>
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<tr>
<td>Nitrobenzene</td>
<td>0.008</td>
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<tr>
<td><strong>No Apparent Degradation</strong></td>
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<tr>
<td>Dichloromethane</td>
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<td></td>
</tr>
<tr>
<td>Chloromethane</td>
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</tbody>
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(Gillham (1996), 257)
zero-valent iron is particularly effective in the degradation of the halogenated organic
compounds (Gillham and O'Hannesin (1993), 3). It has been noted that the degradation of
VOCs by zero-valent iron is unaffected "by stabilizing agents commonly added to industrial
grade solvents or by inorganic groundwater chemistry." (Vogan et al., 800)

Dechlorination of TCE appears to follow first order kinetics (Helland et al., 211).
Analyzing results from 6 field tests of varying site conditions, studies have found that the TCE
degradation rate is between 0.3 and 0.6 hours, consistent with laboratory findings of Gillham and
O'Hannesin (1994) (Vogan et al., 800). The ranges in the actual rate of dechlorination are a
result of a number of factors.

Dissolved oxygen (DO) has been noted to significantly reduce the dechlorination rate of
TCE as a result of competition between TCE and DO for Fe0. Helland et al. also propose that
oxygen will also inhibit the rate of binding to the iron surface and decrease the reactive surface
(Helland et al., 212).

Gillham et al. found pH has no effect on reaction rates until levels approach 9.5; above
which the rate noticeably decreases (5). As a greater percentage of iron is used in the reactive
media, pH levels increase in the water (Gillham et al, 5). While tests using higher percentages of
iron in the reactive media initially exhibit a high degradation rate, the rates significantly drop as
the pH increases in the water (Gillham et al., 5). Similar to the effects of high levels of iron on
pH, there is also a simultaneous increase in pH as DO levels decrease (Helland et al., 212).
However once DO is depleted, pH stabilizes (Helland et al., 212).

The effects of high pH levels include precipitation of minerals present in the
groundwater. Precipitation can decrease the reaction rate as a result of coating of the reactive
surface or clogging of the pore spaces of the reactive media (Gillham et al., 5). The half lives of the degradation of VOCs are significantly decreased using 100% iron versus 50% iron in the reactive media (Vogan et al., 801). Percentages of iron and effects on pH levels must also be balanced during the design process.

As expected, the half lives of VOCs depends on the reactive surface area (Vogan et al., 801). Matheson and Tratnyek found that the first order rate constant increases linearly with the iron surface area (Scherer and Tratnyek (1995), 805). In further study, Scherer and Tratnyek found that using a wide range of Fe\(^0\) surface areas results in an observed hyperbolic relationship (Scherer and Tratnyek (1995), 805). This relationship suggests that a shift in the rate limiting step occurs between the amount of available surface area and the reactive rate associated with reductive dehalogenation (Scherer and Tratnyek (1995), 805).

Gillham and O'Hannesin (1994) observed that for TCE the optimal ratio of surface area of iron to solution volume is 0.078 m\(^2\)/ml. At values greater than 0.078 m\(^2\)/ml, the half life relates inversely proportionally to the ratio of surface area to solution volume as a result of the longer time required for the solute to contact an iron surface. Meanwhile ratios less than 0.078 m\(^2\)/ml, the half life is limited by the reaction rate. (Gillham and O'Hannesin (1994), 962)

Given a porosity of 0.40 and a given maximum allowable contaminant level of 5 ppb, the required thickness of a reactive wall with a surface area has been calculated below for varying contaminant levels of PCE and flow rates in Table 2. PCE was selected because of its common presence at Superfund sites. The half life of PCE in the reactive media (100% commercial grade iron) is between 2.1 and 10.8 hours (Gillham (1996), 257). For the purposes of the calculations...
below, the average of this range was used, 6.45 hours. It was assumed that PCE will degrade to harmless products in the time required rather than to its less chlorinated toxic forms.

**Table 2: Calculations of the Required Thickness of a Reactive Wall of 1 m\(^2\) Unit Area of Varying Contaminant Levels and Flow Rates**

<table>
<thead>
<tr>
<th>Contaminant Level = 10 ppb</th>
<th>Flow Rate (meters/day)</th>
<th>Time Required in Wall (hours)</th>
<th>Required Thickness (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.030</td>
<td>6.45</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td>0.152</td>
<td>6.45</td>
<td>0.102</td>
</tr>
<tr>
<td></td>
<td>0.304</td>
<td>6.45</td>
<td>0.205</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contaminant Level = 100 ppb</th>
<th>Flow Rate (meters/day)</th>
<th>Time Required in Wall (hours)</th>
<th>Required Thickness (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.030</td>
<td>27.87</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>0.152</td>
<td>27.87</td>
<td>0.440</td>
</tr>
<tr>
<td></td>
<td>0.304</td>
<td>27.87</td>
<td>0.884</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contaminant Level = 1 ppm = 1000 ppb</th>
<th>Flow Rate (meters/day)</th>
<th>Time Required in Wall (hours)</th>
<th>Required Thickness (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.030</td>
<td>49.29</td>
<td>0.155</td>
</tr>
<tr>
<td></td>
<td>0.152</td>
<td>49.29</td>
<td>0.780</td>
</tr>
<tr>
<td></td>
<td>0.304</td>
<td>49.29</td>
<td>1.56</td>
</tr>
</tbody>
</table>

The above calculations use the half-life of PCE normalized to 1 m\(^2\) surface area per mL of solution. However, Gillham (1996) calculated the actual surface area to volume ratio as 6 m\(^2\)/mL. Since the degradation rate is directly proportional to the surface area to volume ratio, there is a safety factor of six contained in these calculations.
As seen in Table 2, for given values for PCE, a number of factors impact the required
time in the wall, thereby influencing the design thickness of the wall. These include the flow
rate, initial concentration levels, and maximum allowable concentration levels. See Appendix C
for further details on these calculations.

3.3 OPERATING CONDITIONS AND SITE IMPLEMENTATION

The number of full scale and field scale *in situ* permeable reactive walls continue to
increase in the United States. Field applications of this technology are occurring at both public
and private facilities. Installation of a reactive wall requires a careful design process to ensure an
effective performance. The conditions and considerations involved with implementing this
technology are summarized in the sections to follow. (Gillham (1996), 264-270)

3.3.1 Complementing the Reactive Wall with Funneling Barriers

To minimize construction costs, funneling barriers can be used to intercept the plume and
minimize the width of the reactive wall. Funneling barriers are vertical cutoff barriers or low
conductivity walls installed to direct or "funnel" the plume towards the reactive wall. Hence, the
configuration name "funnel-and-gate" when the reactive wall is used in conjunction with
funneling barriers. (Smyth et al., 38)

When selecting from the variety of barrier types available; such as slurry walls or sheet
pilings, a number of factors should be considered. As in any design, effectiveness and economic
considerations are key. Site conditions and construction feasibility of the funneling walls are
also of concern. Given a site’s hydrogeology, attention to the expected hydraulic performance of the wall including durability, quality insurance and control must be taken into consideration. The material of the funnel must not negatively impact the performance of the reactive wall. (Smyth et al., 40)

3.3.2 Design Considerations

To effectively implement the reactive wall, a number of factors must be considered during the design phase. These factors include hydrogeologic characteristics of the plume site, as well as data on the plume itself. Another consideration is the desired concentration levels upon exiting the wall.

3.3.2.1 Site Selection

Selecting the site of implementation can be a difficult process. The wall needs to be installed in the pathway of the plume, such that the entire plume passes through the wall. If the plume is located in the upper region of the aquifer, the wall can be installed such that it penetrates only the upper portion of the aquifer (See Appendix D for diagrams). The alignment of the wall in relation to the direction of groundwater flow must also take into consideration the seasonal. The width of the reactive wall system is influenced by these factors. (Smyth et al., 39-41)
3.3.2.2 Wall Design

Many details are involved with designing the wall portion. The residence time must be appropriate to degrade the contaminants to harmless products. In addition, the wall must be both wide and thick enough to treat the entire plume. Thus, iron percentages in the reactive wall media are key to ensuring the effectiveness of the wall.

When applying this technology on chlorinated VOCs, a small percentage of chlorinated parent compounds; such as PCE and TCE, degrades to harmful chlorinated products like DCE and VC (Gillham and O'Hannesin (1994), 965) (See Appendix B for additional information about the dechlorination process of PCE.). Thus, an appropriate residence time within the wall must be calculated to ensure the removal of the contaminants and its toxic products during the design process (Gillham and O'Hannesin (1994), 965). The residence time is dependent on the influent concentration, the effluent concentration and the reaction rate (Smyth et al., 41). The residence time is also dependent on the goal concentration level to be reached and the flowrate of the contaminated water (Gillham and O'Hannesin (1994), 966). Thus, the knowledge of the hydrologic characteristics of the region and the reactive wall is critical to designing an effective remediation system (Smyth et al., 41).

The relative thickness of the wall can be balanced by the ratio of the reactive zero-valent iron to sand/gravel contained in the wall. The percentages can range depending on the initial contaminant levels and the maximum allowable contaminant levels 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)

To ensure flow through the reactive media, the hydraulic conductivity must be greater than that of the local region. While design criteria must include a higher conductivity for the wall, an appropriate surface area must also be available for the contaminants to react with. Thus, a balance must be made during the design process. (Smyth et al., 41)

3.3.2.3 System Configuration

Balancing the hydrogeologic behavior of the region and the wall and selecting the installation site, designers must carefully consider the configuration and components of the system. Some suggested configurations apply multiple walls in series where each wall degrades a different contaminant. This is sometimes referred to as a “treatment train.” If a funnel-and-gate system is used, the angles of implementation of the funneling barriers can significantly impact the optimization of the system. Variations on the funnel-and-gate system include a multiple gate system to span a large plume. The chosen configuration and its components, whether it is solely a reactive wall or a funnel-and-gate system or otherwise, must accommodate a full capture and treatment of the plume. See Appendix D for diagrams of these various system configurations. (Smyth et al., 41)
3.4 CURRENT TREATMENT METHOD VERSUS REACTIVE WALL

This section compares the reactive wall to the current conventional treatment method, namely pump and treat. With limitations on pump and treat, alternatives, such as the reactive wall, provide a more effective and efficient treatment method for contaminated groundwater (Gillham and O'Hannesin (1992), 94). Despite the wall's capabilities, there are significant disadvantages to implementing this system.

3.4.1. Pump and Treat versus Reactive Wall

Pump and treat technology is the conventional solution to contaminated groundwater. In fact, over 90 percent of the sites with contaminated groundwater are treated through this methodology. However, this technology has not been proven to be highly efficient. Over 75 percent of the U.S. hazardous waste sites the limiting factor to "satisfactory remediation" is the restoration of groundwater quality. (http://clean.rti.org/clnup21.htm)

The limitations of this current solution are numerous. Pump and treat is neither time efficient nor cost effective, in that large amounts of water are extracted while only a minimal amount of contamination is removed (Bouwer et al., 841). Thus, pump and treat must be operated for a long period of time- ranging from decades to centuries for full remediation (Starr and Cherry, 465; http://clean.rti.org/clnup21.htm). This leads to high operating and maintenance costs resulting from its requirement for a continuous source of energy for continual pumping (Starr and Cherry, 465). Following treatment by this method, the disposal of these treated waters and contaminated activated carbon requires additional technical considerations which must comply with EPA regulations (Starr and Cherry, 467).
3.4.2 Advantages of the Reactive Wall

Implementing the reactive wall provides flexibility and effectiveness in remediation of contaminated groundwater. This technology can destroy contaminants, such as halogenated organic compounds, through reductive dehalogenation rather than transfer them to another media (Gillham and O'Hannesin (1992), 99). The reductive dehalogenation process appears to be thermodynamically favorable to total decomposition in a range of groundwater conditions (McCollough et al, 1159).

In initial laboratory experiments, lab quality iron was used. But in the vast quantities needed to remediate a plume, purchasing lab quality iron can be cost-prohibitive. A low costing granular iron used in many successful laboratory experiments is commercially available--produced from a "waste product from machining and foundry operations, and after processing, [and]... marketed as an additive to improve the wear characteristics of concrete." (Gillham and O'Hannesin (1994), 964) This granular iron has not significantly decreased reaction rates (See Table 1). The cost of this iron is at least $400/ton of iron (Personal Communication with John Vogan). One kilogram of iron can dechlorinate 0.5 million liters of water at an initial concentration of 1 mg/l. However, the rate of corrosion of the iron by water is much faster than that of dechlorination. Thus, the containment unit of the reactive media, either in situ or ex situ, must be built to prevent the corrosion of iron for many years; construction of such units is conceivable. (Gillham and O'Hannesin (1994), 964)

Following an initial capital investment in the acquisition and implementation of reactive media and containment unit(s), operation and maintenance costs for an in situ application are
minimal because the wall relies on the natural groundwater flow for operation (Starr and Cherry, 467). In addition, experiments have shown the reactive media requires minimal maintenance (Starr and Cherry, 467). Researchers predict the reactive media will not require maintenance for decades (Smyth et al., 42). If precipitation on the reactive surface significantly reduces the wall's effectiveness, contractors need only remove a few centimeters of the reactive surface to restore full capabilities (Personal Communication with Robert Gillham). By relying on an in situ technology, there is no need to consider the disposal of treated water and the environmental regulations associated with its disposal (Starr and Cherry, 467).

In the future, as the development of this technology continues, reactive walls can be implemented in parallel or in series to treat varying types of contaminants (Newell et al., 23; Smyth et al, 39). When used with funneling barriers, reactive walls can be entered in parallel to span the width of the plume to ensure capture of the contaminated water while minimizing the amounts of the reactive media. Meanwhile a series of walls, each destroying a different type of contaminant, can systematically be employed to destroy a range of contaminants (Smyth et al., 39).

3.4.3 Disadvantages of the Reactive Wall

While there are many strengths to this passive technology, the reactive wall has a number of concerns associated with it. Similar to the pump and treat technology, remediation of groundwater by means of the reactive wall is a slow process requiring an extensive period of time because of it relies on the groundwater's flowrate to bring the contaminants to the wall. In the case of degrading chlorinated solvents, the intermediate bi-products; such as DCE, VC,
chloroform, are produced in small quantities. These products are sometimes more hazardous than the original contaminant (Gillham and O'Hannesin (1992), 97; McCollough et al., 1159).

Furthermore, the implementation and construction of this technology can be limiting. While there are minimal operating and maintenance costs, a significant initial capital costs is required during installation. For practical construction of the reactive wall, the site is dependent on depth to the plume, as well as the width of the plume (Starr and Cherry, 465). Both of these concerns limit the cost effectiveness of implementing this technology. The direction of groundwater flow and size of the capture zone varies make designing an effective wall tricky (Starr and Cherry, 467). Upon completion of construction, the removal of the reactive media is difficult to impossible; the cost of replacing may be prohibitive as well (Gillham (1992), 7).
4.0 TRANSFER HISTORY AND IMPLEMENTATION OF THE REACTIVE WALL AT THE MMR

Since the beginning of the remediation and containment efforts in October 1992, the reactive wall is the first innovative technology to be implemented at the MMR (Personal Communication with Edward Pesce). This section will examine the process that brought the permeable reactive wall to the MMR and the current status of this technology transfer.

4.1 INITIAL CONTACT

In 1990, the MMR was first notified about the reactive wall technology by the National Guard Bureau Headquarters located in Washington, D.C. (Personal Communication with Edward Pesce). The NGB Headquarters contacted Mr. Edward Pesce, Environmental Engineer from the MMR's Installation Restoration Program (IRP), about the technology for its strong potential for effective implementation and remediation of the MMR given the hydrogeological characteristics of the military reservation (Personal Communication with Edward Pesce). The IRP handles the remediation of DOD contaminated facilities, similar to USEPA oversees the cleanup of non-military hazardous waste sites.

NGB Headquarters provided Mr. Pesce with a contact, Dr. Robert Gillham of the University of Waterloo Institute for Groundwater Research. From there, Mr. Pesce communicated with Dr. Gillham to discuss the technology, its results, and its potential for remediation the MMR. Following lengthy communication, the IRP issued a Statement of Work (SOW) outlining the required testing and support needed from contractors. Leading up to the
SOW, the IRP initiated public education about the reactive wall. The University of Waterloo was later awarded the contract (Personal Communication with Edward Pesce).

### 4.2 TESTING AND IMPLEMENTATION AT THE MMR

The IRP office outlined the demonstration of this technology as a series of tasks in the SOW—Task 1A and Task 1B (Public Private Partnership Meeting- March 28, 1995). Below is the outline of the responsibilities associated with each task (Public Private Partnership Meeting- March 28, 1995).

<table>
<thead>
<tr>
<th>Task</th>
<th>Responsibilities</th>
</tr>
</thead>
</table>
| Task 1A | • Evaluate existing data  
          • Select target location for the funnel-and-gate field test  
          • Conduct pile drivability test |
| Task 1B | • Conduct laboratory column treatability testing  
          • Design a "prototype" of the reactive wall system using laboratory results |

(Public Private Partnership Meeting- March 28, 1995)

Both tasks were awarded to the University of Waterloo (Personal Communication with Edward Pesce). The specifics and known results of these tasks are discussed further in the sections to follow. Public education and involvement is discussed in a later section.
4.2.1 Task 1A

The responsibilities under Task 1A include data evaluation to actual field testing. The specifics involved with this task are detailed below.

_Evaluate Existing Data_  

This responsibility was two-fold in that it involved both review and analysis of available hydrogeologic and geochemical information. Based on a review of the existing data, the University of Waterloo was to recommend additional sampling and testing required to assess the "feasibility of treating the contaminant plume." (Revised Statement of Work- April 25, 1994)

_Selecting Test Site_  

Upon evaluation of the various plume characteristics, the selection of sites were limited. As a result of University of Waterloo's evaluation, plumes Storm Drainage-5 (SD-5), Landfill-1 (LF-1), Chemical Spill-4 (CS-4) and Chemical Spill-10 (CS-10) warranted consideration (Public-Private Partnership-March 28, 1995). In comparison to the Ashumet plume, these plumes have higher concentrations of contaminants and dive deeper in the aquifer. This allowed data to be collected on the implementation constraints of the funnel-and-gate system. (Public-Private Partnership-March 28, 1995)

Upon initial evaluation, the University of Waterloo staff selected CS-10 for the field test site assuming installation was feasible at this plume. Selection of the area around Monitoring Well 30 (MW-30) included measurements of TCE ranging 22 to 670 µg/l, with a maximum measured level of 3200 µg/l in the MW-30 at 150 feet below ground (90 feet below the water
table). According to the data analysis by the University of Waterloo, further testing and investigation to determine the extent of this "high concentration zone" was necessary (Public-Private Partnership-March 28, 1995).

*Determining Pile Drivability (Optional Task #1)*

Assuming a successful pile drivability test, this task involved designing a field test "prototype" consisting of a 50 foot reactive wall, also known as the "gate" of the funnel-and-gate system. The design of the gate consists of a three foot diameter section of pipe filled with sand and iron filings. In conjunction with the gate, the funneling walls will ensure that this technology spans a portion of the width of the plume. (Revised Statement of Work- April 25, 1994)

Since this is an innovative technology, the implementation constraints are still being determined. The steel pilings, which would serve as funnels to the reactive wall, are limited by their drivability due to the soil grain distribution, relative density of the pile, presence of gravel or cobble lenses etc., and the thickness of the unsaturated zone (Public-Private Partnership-March 28, 1995). Through this testing, University of Waterloo was to determine pile section thickness, hammer size, and required "driving enhancement techniques" for implementing the piles (Revised Statement of Work- April 25, 1994).

The pile drivability test was conducted downgradient of MW-30 between Connery Avenue and Gaffney Road using two types of steel sheet piles, Canadian Rolling Mills XZ 95 and Hoesch H 175 (Public-Private Partnership-March 28, 1995). XZ 95 is a lighter, less robust sealable sheet metal than the H 175 piles (Draft Report on a Pile Drivability Test, 2). H 175 piles
would be tried if the XZ 95 piles met refusal due to outwash sediments or damage experienced before reaching the water table (Draft Report on a Pile Drivability Test, 2). The piles were driven in with a vibratory hammer (Draft Report on a Pile Drivability Test, 4). The results of the test will be discussed as part of the current status section.

4.2.2 Task 1B

Task 1B involved laboratory treatability tests using groundwater samples gathered from the selected site (Revised Statement of Work- April 25, 1994). These tests include evaluation of the degradation rates of contaminants through bench tests. In addition, task responsibilities involved a design of a full scale "prototype" based on the laboratory tests (Public-Private Partnership-March 28, 1995).

Laboratory Testing

Groundwater samples were to be collected from the monitoring wells at the MW-30 implementation site. Examinations of the samples included measurements of the ranges of BTEX, VOCs, and phosphorous. Additional testing involved determinations of degradation rates of contaminants with varying flowrates and ratios between sand and iron in the reactive media. This information helps determine whether the technology can be effectively employed at the actual site. (Revised Statement of Work- April 25, 1994)
"Prototype" Design (Optional Task #2)

Using the available data and the laboratory results, the contractor would complete a design for a full-scale funnel-and-gate system. Considerations for full design includes results from the 50 ft. reactive wall field test and pile drivability test. (Revised Statement of Work- April 25, 1994)

4.3 PUBLIC EDUCATION AND INVOLVEMENT

As a component of task responsibilities, the contractor would be required to participate in various public meetings. This includes participation in the public-private partnership kickoff meeting, as well as in the funnel-and-gate project status meetings. In addition, the contractor must participate in a minimum of six Technical Environmental Affairs Committee (TEAC) meetings to present the status and results in a public forum. Participation in meetings can range from public presentations to written responses and answering questions. (Revised Statement of Work- April 25, 1994)

Informing the public at TEAC meetings is a significant priority to the MMR’s IRP and therefore, the contractor. In three consecutive TEAC meetings (49th-51st TEAC) over a period of about four months, updates and information about the reactive wall and its implementation were shared with the public by members of the IRP. These meetings, in addition to those held at later dates, provided the public with the following facts:

- the reactive wall is an innovative technology with "great expectations of success" and additional information will be available in Summer 1995 (49th TEAC)
- the wall will consist of a fifty foot (ft) long pipe three feet in diameter filled with iron filings and funneling barriers (49th TEAC)
• the reactive wall project was awarded to the University of Waterloo Institute for Groundwater Research (49th TEAC, 50th TEAC)
• the project just completed renegotiation and awaiting the approval of the Canada Commercial Corporation (50th TEAC)
• installation of the 50 ft reactive wall should begin in August 1994 (50th TEAC)
• kickoff meeting for the project and planned date for implementation is March/April 1995 (51st TEAC)
• delays of the implementation occurred due to the paperwork involved with renegotiation of project and approval required from the Canada Commercial Corporation, as well as difficulty with the acquisition of a sole source contract from the USEPA (51st TEAC)
• the design is for a 50 ft bench scale prototype with no plans to implement the final task of the SOW--a full-scale reactive wall (51st TEAC)
• laboratory bench scale treatability studies were completed in preparation for the pile drivability test at CS-10 (54th TEAC)
• USEPA Public-Private Partnership is being used to help validate the project (54th TEAC)
• announcement of FTA-1 and CS-10 as the two potential sites for the wall (57th TEAC)
• the pile drivability test was only successful to 80 ft in depth (57th TEAC)
• additional geotechnical testing is scheduled for the week of October 7, 1995 (57th TEAC)
• the second pile drivability test planned for November 1995 (57th TEAC)

At these TEAC meetings, the public took the opportunity to ask their questions which were as follows:

• Has the technology been tested elsewhere? (49th TEAC)
• How long would it take to get results? (49th TEAC)
• How long will it take for the reactive wall to cleanup the contaminants? (49th TEAC)
• Why is there a continual delay in the process and testing dates? (51st TEAC 54th TEAC)
• Has the design and contractor been chosen yet for the project? (51st TEAC)
• Why was the pile drivability test only successful to eighty feet? Was this due to equipment failure? (57th TEAC)

These questions were answered by the presenters at the respective TEAC meetings.

4.4 CURRENT STATUS

The current plans regarding the implementation of the reactive wall at the MMR are still not finalized. The results from the pile drivability test have been drafted and discussed below.
In addition, recent decisions regarding final site selections and design specifications are also summarized.

4.4.1 Results of the Pile Drivability Test

The drivability test was conducted May 22-25, 1995 on the CS-10 plume downgradient of the MW-30. Both sheet pile types, Canadian Metal Rolling Mills XZ 95 and the Hoesch H 175 were driven using the conventional driving mechanism, the ICE 815 vibratory hammer. The lighter, less robust XZ 95 met refusal in the range of 30-55 ft, as well as exhibited damage during hard driving. One XZ 95 pile was successfully driven 80 ft in depth before meeting refusal. The test was determined unsuccessful as a result of the great depth of the unsaturated zone (approximately 69 ft at this site) and variable stratification within the unsaturated zone. Some key factors also involved with the unsuccessful driving of both pile types are the compaction of soils at the site due to vibration and bowing of the pile and the side friction due to the soil along the length of the pile and friction in the pile joint. (Draft Report on a Pile Drivability Test, 1-6)

4.4.2 Recent Decisions Regarding the Demonstration

Based on the results of the pile drivability test, plans for a second driving attempt were scheduled for November 1995. However, this test was postponed. During a meeting in March 1996, Mr. Pesce met with Dr. Gillham to discuss a new demonstration site for the technology and a second pile drivability test. As a result of this meeting, two key decisions were made: selection
of a final implementation site and judgment not to conduct a second pile drivability test (Personal Communication with Edward Pesce).

Based on the most recent hydrogeologic data and monitoring information, Mr. Pesce and Dr. Gillham have decided the demonstration would be entered in the vicinity of the CS-10 source area during Summer 1996 (Personal Communication with Edward Pesce). The implemented configuration would be similar to a funnel-and-gate system. However, an innovative technology will be selected as a new funneling mechanism for the reactive wall.

The decision to use a new funneling or "delivery" system was based on two reasons. First, as seen in the pile drivability test, plume depths are too deep and thus not suitable for sheet piles as a funneling mechanism. While the funnel-and-gate system is still fairly young in its development, full scale implementations at other sites in the United States has provided significant amounts of data. Thus, the need for further validation of the funnel-and-gate configuration is no longer required. In addition, implementation of an innovative delivery system provides another opportunity for the MMR to be the first again in implementing of an innovative technology worldwide. As a result of this decision to use a new delivery mechanism with the reactive wall, the judgment was made that a second drivability test would not be necessary since sheet piles were no longer an option (Personal Communication with Edward Pesce).

4.5 EVALUATION OF THE CASE STUDY

The implementation of the reactive wall has yet to occur at the MMR. As seen here, the technology transfer of an innovative technology from a developer to a site is often a slow
process. The design of innovative technologies typically requires one to three years, resulting in few contracts and implementations and even fewer completed installations (USEPA (1994), 6).

In the early stages, specifics of the contract, which included formulating a reasonable list of tasks, required a significant amount of time. However, even after formulating the detailed SOW, a number of delays have affected the implementation of the technology--some were bureaucratic, while others were inherent uncertainties associated with the geology and hydrology of the site.

Bringing the technology from Canada, where the technology is patented by the University of Waterloo and Dr. Robert Gillham and commercialized through EnviroMetal Technologies, Inc., resulted in an assortment of delays. A small time sink was the delay in paperwork due to renegotiation of the project and signature approval from the Canada Commercial Corporation. A significant delay in the technology transfer was the contracting constraint by the USEPA on a sole source procurement. The reactive wall is solely commercialized through EnviroMetal Technologies, Inc., thus making this technology sole source procurement. In order to contract such a technology, a slow process was undertaken to justify the selection of the technology. (Personal Communication with Robert Gillham)

An innovative technology requires attention to details--especially if the data is to be used to validate a technology; such as the funnel-and-gate system. Thus, both technical and administrative details become especially time-consuming when the two parties are separated by a great distance and both are exceedingly busy with additional projects.

Bureaucratic delays may also come in the form of additional interest in the demonstration. This technology demonstration is under the Public Private Partnership program
under the USEPA and administered by Clean Sites, Inc. For additional information on this program, see section 5.1.6.1. By involving Clean Sites, Inc., engineers must work with an additional level of management. This can require an extra effort to handle additional levels of communication and increased paperwork.

Despite this additional level of management, MMR and the entire hazardous waste industry will benefit from demonstration. Clean Sites, Inc. handles administrative details; industry provides their expertise; MMR gains free advice; USEPA gains a validation opportunity for a technology (Personal Communication with Edward Pesce).

Another significant delay is public distrust or protest. However, this was and still is not the case for the MMR. The public continues to be very supportive of this initiative to implement an innovative measure (Personal Communication with Douglas Karson).

Some delays were beyond the capabilities of the IRP and the University of Waterloo. As in all Superfund sites, site characterization is never complete—typically limited by technology capabilities and financial constraints. As each site is unique, determining how the equipment will interact with the local media and if the material can be applied at the site is typically unknown. At the MMR, while there was general knowledge of the site and its hydrogeological characteristics, the piles were not able to withstand the driving into the glacial till with the selected pile thickness and types.

The result of these delays is that three full-scale demonstrations have been implemented in the United States in 1995 with plans for more in 1996 (EnviroMetal Technologies, Inc.). The reactive wall gains validation each time the reactive wall is selected as an appropriate remediation technology for an EPA Record of Decision (ROD). One of the most recent ROD
decisions is applying the wall to treat a plume originating from a landfill in Somersworth, New Hampshire (Scales (1996)). As a result of these full-scale applications and the collected data, the funnel-and-gate system planned for the MMR is not considered as "innovative" as it was in 1990. Thus, current plans are to use the reactive wall in a more "innovative" configuration with an untried delivery system to the wall. This keeps attention and excitement focused on the cleanup at the MMR, and the local IRP office can maintain claims to being the first to implement this innovative system (Personal Communication with Edward Pesce).
5.0 ASSESSMENT OF OBSTACLES LIMITING THE DEMONSTRATION AND IMPLEMENTATION OF INNOVATIVE ENVIRONMENTAL REMEDIAL TECHNOLOGIES IN THE UNITED STATES

Over 1300 hazardous waste sites are currently listed on the United States Environmental Protection Agency's (USEPA) National Priorities List (NPL), in addition to thousands of federal and state sites not listed on the NPL. Remediation efforts can take place voluntarily, through legislation, and other means. But nonetheless, individual sites can take as long as "13 years and cost an average $20 to $30 million." (Hoffman, 1) While new hazardous waste is generated daily, old hazardous waste sites still require remediation despite the available remediation technology. Thus, a call for more efficient and effective innovative technologies and methods has arisen.

An innovative technology is "a treatment technology [or approach] for which cost or performance information is incomplete, thus hindering routine use at hazardous waste sites." (Dean, 1) An innovative technology can also be a conventional technology applied in a new way (Bellandi, xxiv). While the U.S. is noted for its creativity, its ingenuity in the area of remediation of hazardous sites has not developed.

This research examines the current innovation environment for hazardous waste technology that is shaped by federal and state regulations and authorities, industry, local communities, and independent associations. Based on this background, an assessment of the obstacles facing the development and demonstration of these innovations will be addressed. Finally, the study will conclude suggested changes in policy and process to support and expedite these implementation and validation of these technologies.
5.1 CURRENT INNOVATION ENVIRONMENT

Today's remediation efforts typically include conventional technologies--those that are fully proven and routinely applied both privately and commercially. These technologies include pump-and-treat for groundwater and incineration for soils (NATO/CCMS, 587). Despite the development of innovative solutions, sites continue to implement the conventional technologies. For example, over 90 percent of the sites selected pump-and-treat to remediate contaminated groundwater (http://clean.rti.org/clnup21.htm).

This section examines the environment innovators must work in as they develop new or improved mechanisms for remediation. The forces that shape this environment are federal regulations, federal agencies, industry, interested parties, and the public. A summary of these different factors is provided.

5.1.1 Pertinent Regulations

One of the foremost influences on technological innovation is the federal legislation passed by Congress, in particular Resource Conservation and Recovery Act (RCRA) including its 1984 Amendments, Comprehensive Environmental Response and Liability Act (CERCLA) of 1980 including its 1986 Amendments, Federal Technology Transfer Act (FTTA), Clean Air Act (CAA), and Clean Water Act (CWA). Through these Acts, each federal statute will be summarized as they apply to technology and its implementation at contaminated sites.
5.1.1.1 Resource Conservation and Recovery Act (RCRA)

RCRA regulates the cleanup of active regulated facilities. One of the main features of this legislation is the "cradle to grave" management of hazardous wastes from the generator to transport to treatment to storage and disposal. In 1984, its Hazardous and Solid Waste Amendments established the land ban provision, which restricts land disposal of certain hazardous wastes unless specific USEPA cleanup standards are met. This forces application of processes and technologies that fix the problems rather than covers the symptoms. (Hoffman, 4-5)

5.1.1.2 Comprehensive Environmental Response and Liability Act (CERCLA)

CERCLA is often referred to as the Superfund legislation. This legislation covers the remediation of inactive and abandoned hazardous waste sites. The National Priorities List (NPL) continues to grow as sites are identified and evaluated by the Hazardous Ranking System. (Hoffman, 7)

In 1986, the Superfund Amendments and Reauthorization Act (SARA) of 1986 passed, establishing the renewal of funding through a tax on crude oil and chemical feedstocks. One of the key aspects of the SARA amendments is the required development and application of permanent solutions that "significantly reduce the waste volume, toxicity, or mobility and that encourage alternatives to land disposal." (Hoffman, 7) However, this did not immediately spur the development of innovative technologies. Instead solidification and stabilization technologies were employed; such as incineration. SARA also implemented mandatory deadlines for
remediation, increased enforcement of standards and deadlines, and developed greater public and state involvement. (Hoffman, 7)

5.1.1.3 Federal Technology Transfer Act (FTTA)

Passage of the FTTA founded the cooperative research and development agreements (CRADAs) which establish a joint innovation process among federal laboratories, industry, and academia under the supervision of USEPA Office of Research and Development. Innovation of environmental technologies requires a range of expertise. Thus, the twelve interdisciplinary USEPA research laboratories and non-USEPA researchers join together to formulate a better understanding and an effective solution to complicated environmental topics, such as hazardous waste remediation. (http://www.epa.gov:80/cgi-bin/wais...ed=innovative&byte_count=2437#head)

5.1.2 Federal Programs and Services

In addition to federal regulations, many programs exist to protect, regulate, and restore the environment of the United States. The Clinton Administration formulated the Environmental Technology Initiative (ETI), a strategy to support the development and validation of U.S. environmental technology industry. In addition, offices and programs were formulated by federal agencies to support and promote the development and demonstration of remediation technologies. The USEPA, the Department of Defense (DOD), and the Department of Energy (DOE) are the leading federal agencies supporting the innovation of environmental remediation
technologies. In the sections below, some of the most prominent federal programs are discussed. See Appendix E for specific data on funding available through various federal programs which support the development and demonstration of innovative technologies.

5.1.2.1 Clinton Administration—Environmental Technology Initiative

On February 17, 1993, President Clinton announced his Environmental Technology Initiative (ETI). This plan recognizes economic development and environmental protection are linked. The ETI believes technological and industrial innovation is key to the economic, environmental, and social welfare of the United States and its citizens. Through the ETI, additional plans include analyzing USEPA statutes and regulations, as well as permit and enforcement programs, to better support environmental programs. (Preuss, 28)

5.1.2.2 U. S. Environmental Protection Agency

The USEPA provides a multitude of services and databases to technology user and technology developer communities. Databases; such as the Vendor Information System for Innovative Treatment Technologies (VISITT) and Alternative Treatment Technology Information Center (ATTIC), offers a common forum to publicize varying alternative treatments available for remediation plans. The EPA also administers a number of programs which support the development and demonstration of innovative technologies; such as the Superfund Innovative Technology Evaluation (SITE) program and the Cooperative Research and Development Agreements (CRADAs).
Vendor Information System for Innovative Treatment Technologies (VISITT)

To promote the development of innovative remediation technologies, this database system provides an avenue for vendors to publicize technologies available to remediate hazardous waste. The intended audience is the remediation community which includes USEPA officials, technology users, and technology developers. This database is provided for free, requiring no additional software or training.

While the service is provided through the USEPA, information in VISITT is supplied by the vendors. To enter information, vendors complete a questionnaire which the USEPA reviews for clarity and completeness, but not for accuracy. Thus, the data provided in this database are solely vendors' claims. By Summer 1995, this database contained 231 technologies at various scales of implementation (bench, field, full-scale) provided by 141 vendors (http://www.epa.gov:80/cgi-bin/wais...ed=innovative&byte_count=3867#head).

Alternative Treatment Technologies Information Center (ATTIC)

ATTIC provides comprehensive information and data on alternative treatment technologies for hazardous waste. This system is a free public access bulletin board consisting of a number of databases. A central component of this information system is the Treatment Technology Database. It contains abstracts and summaries of technical documents including treatability studies and Superfund Innovative Technology Evaluation (SITE) documents. The database is easily accessed and able to be downloaded. (USEPA (1995/1996), 279).
Clean-Up Information Bulletin Board System (CLU-IN BBS)

This on-line electronic bulletin board originated under the Office of Solid Waste and Emergency Response to encourage communication between parties involved with hazardous waste remediation and corrective actions. Beyond communications among various groups, full text of documents and databases of information on treatment technologies. CLU-IN also provides updates from the Federal Register, Commerce Business Daily, as well as hazardous waste hotlines (USEPA (1995/1996), 281).

5.1.2.3 Additional USEPA Programs

Other programs; such as the Superfund Innovative Technology Evaluation (SITE) program, support demonstration and evaluation of these innovative alternatives. Enrollment in this program is one of many initiatives developed to support technological innovation in remediation of contamination sites.

Superfund Innovative Technology Evaluation (SITE)

With the authorization granted through the SARA Amendments of 1986, the EPA established the SITE program "to accelerate the development, demonstration, and use of treatment technologies and demonstrate and evaluate new innovative measurement and monitoring technologies." (NATO/CCMS, 586). This program partners public agencies with private industries, sharing the costs and monetary risks between the USEPA and the technology developer. The USEPA assumes the cost of evaluation (i.e. collection and analysis of samples) and the preparation of the final report, while the developer pays the cost of the design and
demonstration of the technology. The gathered information is then distributed to regional USEPA staff and other interested parties, who might use this information to select technologies for other sites. (Lindsey and Kelly, 24)

Other aspects of this program support evaluations of emerging technologies, technologies not ready for full scale implementation, through bench scale and pilot scale tests. This program also promotes technology transfer and dissemination of cost performance information to parties involved with hazardous waste site remediation. In addition, the SITE program encourages commercialization through partnering with industry, academia, non-profit organizations, and other federal agencies to develop reliable cost and performance data. (Lindsey and Kelly, 25-26)

Cooperative Research and Development Agreements (CRADAs)

The Federal Technology Transfer Act responded to the need to remove barriers between public and private entities--allowing partnerships to form to develop and commercialize innovative environmental technologies. CRADAs have been established between federal laboratories, industry, and academia. These partnerships are particularly beneficial for the exchange of ideas and information--"essential for the development of commercially competitive technologies." (Preuss, 28) In return for federal support during the development and commercialization phases, the government retains the rights of the patent of the new technology. At the same time, the firm gains exclusive right to the technology for seventeen years. During the seventeen year period, the company gives the government a portion of the profits each time the technology is implemented (Hoffman, 43).
Since 1989, the USEPA has entered into 59 CRADAs and negotiated 13 patent licensing agreements with the private sector for commercializing environmental technologies. One of the most publicized CRADAs is the Lasagna Project, an innovative technology to treat dense contaminated soil, developed under the joint expertise of the USEPA, Monsanto, DuPont and General Electric. (Preuss, 28)

5.1.3 Department of Defense (DOD)

In the past decade, the U.S. military services were one of the significant contributors to the contamination of the environment. Artillery tests, chemical disposal, and underground storage tanks are just the start of the many means that the military has devastated their properties and surrounding areas. Presently, the military is slowly assuming responsibility for past actions and remediating these sites.

5.1.3.1 Advanced Applied Technology Demonstration Facility (AATDF)

To accelerate the technology development which may expedite the remediation efforts at their numerous hazardous waste facilities, DOD awarded a $19.3 million grant to the University Consortium of Environmental Research Centers to design, manage and operate the DOD’s AATDF. This Consortium is led by Dr. Herb Ward of the Energy and Environmental Systems Institute at Rice University. Support is provided by five leading consulting firms who are currently seeking proposals from various sources wishing to demonstrate their emerging technologies. (Rice University, 1)
The AATDF provides a program which tests environmental technologies at different phases of development. A demonstration site will be selected from existing DOD facilities as the Experimental Controlled Release Site (ECRS), where emerging technologies can undergo field testing and verification under controlled conditions. ECRS will allow careful monitoring of performance data at all stages of development, particularly in the early stages. (Rice University, 1)

Another program available through the AATDF is the DOD Technology Development and Demonstration Program (D₄T) for more mature technologies. D₄T will permit developers to complete field tests and demonstrations—allowing for the collection of detailed performance, cost, and implementation data. These demonstrations and tests will be performed at DOD facilities and Consortium research sites. This program is modelled similar to the USEPA’s SITE program. (Rice University, 2)

5.1.3.2 Strategic Environmental Research and Development Program (SERDP)

Current estimates show over 17,000 current and former defense facilities require cleanup at the cost of over $200 billion (http://prop.wes.army.mil/sердп/ overview/summary.html). The SERDP program serves as the DOD's primary environmental technology research and development program. Established by Congress in Public Law 101-510, this DOD-lead initiative joins with the efforts of DOE and the USEPA. With its multi-agency components, one of the goals of SERDP is to minimize duplication of research and maximize communication on environmental-related research, developments, and demonstrations. SERDP also supports both government and non-government entities with analytical assistance to address national and
international environmental problems. An additional goal is to support programs which look to research, develop, and demonstrate remediation technologies which "facilitate environmental compliance, remediation, and restoration activities" (http://prop.wes.army.mil/serdp/overview/summary.html).

Established in 1990, SERDP is organized in six major "thrust areas"—Cleanup, Compliance, Conservation, Pollution Prevention, Global Environmental Change, and Energy Conservation/Renewable Resources in efforts to develop transition technologies for the purposes of environmental conservation and restoration. Of particular interest to those remediating hazardous waste sites is the Cleanup thrust area. The principal focus of the SERDP strategy for 1997 for this thrust area is to be more cost effective, particularly in terms of cleanup/remediation technologies, monitoring and characterization techniques and methods, and assessment techniques. In fact, estimates for this thrust area from the FY97 SERDP budget is 32%, the largest allocation of the six thrust areas. Based on past experience has shown them that the return on investment on these new technologies range from a factor of 10 to 1000. Another goal which complements technology research and development is to facilitate the transfer of these technologies to field demonstrations. One form of support is the DOD/National Environmental Technology Demonstration Test Sites. (http://prop.wes.army.mil/serdp/overview/summary.html)
National Environmental Technology Demonstration Test Sites (NETDP)

This program is a continuation of a FY93 SERDP funded project, the National Department of Defense Environmental Technology Demonstration Program. NETDP provides a comprehensive technology demonstration and evaluation transfer program. This program seeks to join the efforts of the DOD and USEPA, as well as those of the Western Governors’ Association, AATDF, USEPA Public Private Partnerships, Federal Remedial Technologies Roundtable, and many more. The objectives of this program are the following:

- “query regulators, users, and the public to ascertain what information is needed from a demonstration, and what presentation format is preferred in order for their acceptance of new technology;
- standardize the data collection and analysis to the extent possible across the agencies based on findings from the first objective;
- develop test locations for the demonstration and evaluation of innovative technologies under comparable and well characterized hydrogeologic and climatic conditions;
- involve regulators, users, and the public throughout the course of technology demonstrations;
- provide test beds for supporting environmental research;
- support the widespread dissemination of technical evaluations, performance or guide specifications, and economic data.”

(http://clean.rti.org/clnp3k.htm)

5.1.4 Department of Energy (DOE)

The DOE faces the largest environmental cleanup of all government agencies. The goal of the DOE’s Environmental Restoration Program is to remediate all contaminated DOE and legislatively authorized sites within the next 30 years. As a result of this goal, the DOE has a key interest in developing and supporting the development of effective remediation technologies. Therefore, the DOE created the Office of Technology Development to identify technologies at
various stages of the research, development, and demonstration process. In addition, this office will demonstrate, test and evaluate those technologies which may aid the DOE with accelerated and improved methods to meet its goals. (FRTR, x)

5.1.5 Industry

A range of industries are seeking to reduce their production of hazardous waste through voluntary programs initiated through various entities. Recently, the USEPA has established voluntary pollution prevention (P2) programs which include the "array of partnership programs ... collectively refer[red] to as Partners for the Environment."

(http://es.inel.gov/partners/index.html) One of these voluntary programs is the 33/50 Program, where in industries reduced their release of 17 "high priority" contaminants listed on the Toxic Release Inventory by 33% by 1992 and 50% by 1995

(http://es.inel.gov/partners/3350/3350.html). Under the P2 Research Branch where a portion of current projects support the 33/50 Program, Waste Reduction Innovative Technology Evaluations (WRITE) has been organized whose final objective is "to provide information that can assist companies adopting technology for reducing these substances on a voluntary basis."

(http://es.inel.gov/3350/p2projs.html) Through WRITE and other such programs, the USEPA and industry acknowledges the need for innovation in the production process (i.e. recycling, storage, disposal) and in the remediation technologies. A noticeable change in the national strategy is visible joint industry and government programs whereby voluntary programs are producing positive results in a time-efficient and cost-effective manner.

(http://es.inel.gov/3350/p2projs.html)
In terms of industry taking the lead in innovation or responsibility for managing it waste, some organizations have taken the lead. The Chemical Manufacturers Association (CMA) has organized Responsible Care, where member companies publicly commit to continual improvement of responsible industry management of chemicals and implement the "6 Codes of Management Practice" (http://es.inel.gov/program/regional/trade/cma-rprt.html).

While industries may have made these P2 commitments, their goals do not explicitly include promotion of research and development of innovative technologies to handle hazardous wastes. However, there is a slow, but positive movement by industry to participate in joint programs to promote environmental protection and restoration, which include development of innovative remediation technologies. One such program to be discussed in the next section is the Public Private Partnerships.

5.1.6 Associations

Associations are studying the barriers to developing environmental technologies and implementing process changes to remove these obstacles. The goals of these associations may vary. Some desire to improve pollution controls and remediate environmental contamination sites, while others want to promote economic development in their area.

5.1.6.1 Clean Sites, Inc.

Clean Sites, Inc. is a not-for-profit organization who helps negotiate Superfund cleanups under current law. To promote more time-efficient and cost-effective cleanups, this organization
documents cost and performance data gathered from demonstrations of innovative technologies.

In fact, the establishment of Clean Sites, Inc. resulted from an analysis of why the technology user community was not applying innovative technologies to hazardous waste site cleanups. This study found that new technologies were not applied because they lacked cost and performance data that the older conventional technologies had. (Personal Communication with Gene Peters)

Currently, Clean Sites administers the Public Private Partnerships through a cooperative agreement with the USEPA, industry, and federal facilities. These partnerships provide added value to a technology demonstration in number of ways. Using the Clean Sites staff, additional expertise and support in data generation is provided. This Public-Private Partnership brings together parties-industry, regulatory, and government-who share common hazardous waste problems and need to find a more effective remedial schemes. Thus, the primary focus of these partnerships is the generation, evaluation, and documentation of the results of the demonstrations.

5.1.6.2 Western Governors’ Association (WGA)

This association was created in 1984 as an independent, nonpartisan organization consisting of eighteen Governors from eighteen western states, two Pacific-flag territories, and one commonwealth. Through this Association, “the Western Governors’ identify and address key policy and governance issues in natural resources, the environment, human services, economic development, international relations and public management.” (WGA, 2) The WGA has six main objectives:
1. Develop and Communicate Regional Policy
2. Serve as a Leadership Forum
3. Build Regional Capacity
4. Conduct Research and Disseminate Findings
5. Form Coalitions and Partnerships to Advance Regional Interests
6. Build Public Understanding and Support for Regional Issues and Positions

(WGA, 2).

One focus area is “continuing their leadership in meeting the current and future hazardous waste
management needs of the West.” (WGA, 10) The focus is provided through four areas: direct
financial assistance, technical assistance, preparation of a regional capacity assurance plan
(CAP), and preparation of regional studies to assist western states meet their capacity needs.
The CAP prepared for 1993-1994 was submitted to the USEPA to continue Superfund funding in
this region. (WGA, 10)

**The Committee to Develop On-Site Innovative Technology (DOIT Committee)**

The WGA created the DOIT Committee in December 1992 to expedite the cleanup of
hazardous waste sites and support the development of improved technologies. This committee
serves as an advisory board to the federal government. Its members include Western governors;
representatives from DOD, DOE, and Department of the Interior; and the Administrator of the
USEPA. The current focus of a three year study is to identify barriers to innovative technologies
and to test new approaches to expedite the development, demonstration, evaluation and
commercialization of technologies. Other focuses are to recommend and identify sites for
demonstrations to apply these new technologies at. These approaches apply to stakeholder involvement, regulatory review and technology demonstrations. (WGA, 6-7)

5.2 OBSTACLES TO INNOVATION

Despite support though regulations and programs, many innovative technologies fail to reach the demonstration and commercialization phases. There are a number of barriers in the current innovation environment. Some are due to regulations, while others result from the risk averse nature of the environmental technology industry. This section examines these obstacles which many ascribe to the limited developments in the field of innovative environmental technologies.

5.2.1 Government

Congress legislates statutes as the need arises in the United States. In response to environmental disasters in the 1970s, such as Love Canal, Congress drafted many Acts, including the CAA and CWA, to address the need to protect the environment and its natural resources.

To respond to this call for environmental protection and remediation, policy makers can implement a range of options to ensure adequate measures are taken. These include imposing command and control regulations. Command and control regulations include those that set a level of source reduction, as well as those that "command " a standard based on the capabilities of current technologies.
Examples of technology-based standards can be seen in many environmental acts including the CAA, CWA, and RCRA in various forms; such as Best Achievable Control Technology and Best Demonstrated Available Technology. Many of the technology-based standards result in end of pipe solutions. However, this type of solution fixes the symptoms, but not the problem itself. Technology forcing is a means of driving the goals behind these environmental policies. Driving the development of innovative technologies for hazardous waste remediation is the need for more efficient cleaner, potentially cheaper processes so that economic development and environmental protection can coexist.

5.2.2 United States Environmental Protection Agency

As Congress continues to amend existing legislation and pass new statutes, they delegate more responsibilities to the USEPA. Each act has its own nuances and requirements that the USEPA must adhere to. At the same time the USEPA must ensure its actions achieve the congressional intent of the legislation.

5.2.2.1 Institutional Barriers

- Limited Resources

One barrier, not confined to the development of new innovative technologies, is the limited manpower and resources of the USEPA. There is a high employee turnover contributes to the lack of "institutional memory" that might encourage a longer term view of innovative
technology evaluation and selection.” (Federal, 6) These problems also hold for state environmental agencies.

- **Requirements of Record of Decisions (RODs)**

  The requirements of RODs is another obstacle to the implementation and commercialization of innovative technologies. The ROD provides the proposed plan for remediation at each site. This must bear the scrutiny of the public, regulators, engineers, and the court. In CERCLA Section 121, the prescribed "remedial action must comply with all applicable or relevant and appropriate Federal and State requirements (ARARs), be cost effective, and utilize permanent solutions and alternative treatment technologies to the maximum extent possible." (Hoffman, 38) Most importantly, the technology chosen must work. This requirement biases the selection of technologies against innovative technologies because of their incomplete performance data. If the innovative technology does not work, there is a fear that the cleanup process may become further complicated. Incurring additional costs to implement another technology and cleanup the remains from the failed technology only adds to the risk adverse nature of the ROD and implementation process. (Hoffman, 38)

### 5.2.2.2 Programmatic Obstacles

- **Complying with All Guidelines in Acts**

  The USEPA is mandated by Congress to meet the established guidelines in the environmental acts. As Congress promulgates additional legislation, the USEPA's programs must be developed and adhere to these new guidelines. New command and control regulations
and specific treatment standards can further complicate the formulation of an appropriate ROD. (Hoffman, 38)

One example of additional guidelines which compounds to the complexity of the mandates is the "land ban" provision of the RCRA Hazardous and Solid Waste Amendments of 1984. The provision states that hazardous waste is banned from land disposal unless the waste meets the cleanup standards set by the USEPA. A common situation at hazardous waste sites is the excavation of contaminated soils. The ROD must address the remediation of the soil to be in compliance with the land ban provision. Some innovative technologies may not be an appropriate or feasible solution, while other innovative technologies may. One type of innovative technologies, *in situ* technologies, are ideal to address contaminated soils. These technologies do not require excavation of the soil and therefore, avoid the need to comply with land ban provisions. But, *in situ* technologies have not been verified and demonstrated adequately for the USEPA to feel at ease implementing them. (Hoffman, 38-39)

- **Difficulties with Procedures Regarding Contractors and Innovative Technologies**

  The USEPA has a number of procedural rules for hiring contractors and acquiring innovative technologies. In the Federal Acquisition Regulations, one such provision prohibits the same contractor to both formulate the design plans and implement the construction for the same job (Hoffman, 39). In addition, a contractor may not want to complete a treatability study during a remedial investigation/feasibility study since this will negate his/her opportunity to implement the cleanup plans (Dean, 13). In addition, the USEPA prohibits contractors from working for both the Agency and the Potentially Responsible Parties (PRP) on the same job site.
This causes extreme difficulties since the USEPA often enters into cooperative agreements with the PRP to share the work. Procedural difficulties also arise when only one contractor has the skill and equipment to perform a particular task. (Hoffman, 39-40)

As for the procurement of innovative technologies, the Agency has a contracting policy on sole source procurement of technologies. Many innovative technologies today are currently patented and commercialized through one company. If a site would like to implement a sole source technology, a slow and uncertain process must be undertaken for approval. If only one contractor is able to complete the cleanup procedures, the USEPA must justify this restriction on the normal open bidding process. (Hoffman, 40)

- **Inconsistencies Among Regional USEPA Offices and State Agencies**

  Developers find federal and state agencies lack predictability with regard to their standard setting and permitting requirements. These variations in requirements create a uncertain environment for developers and potential investors because a successful demonstration in one state or under one particular regulatory program may not be accepted by another state or program. (Note: Each demonstration of a technology, successful or otherwise, is a costly and time consuming undertaking.) This may be due in part from a lack of a nationwide certification program. Investors do not want to invest in a product that captures only a portion of the market. (Federal, 5)
• Lack of Standardized Data Collection

As demonstrations are performed, significant data is being collected on innovative technologies. However, standardized cost and performance data is lacking. Thus, regulatory agencies and technology users are wary of the collected data. (Federal, 5)

• Lack of Incentives and Flexibility in Permits

Many environmental statutes encourage and approve the use of innovative technologies (RCRA Research, Development, and Demonstration Permits and the CERCLA 121(e) approval process). Despite these established incentives, some feel innovative technologies have not been encouraged. Other concerns are the lack of flexibility and incentives for permit writers to allow for provisions for innovative technologies in permits and enforcement agreements. (Federal, 5)

5.2.3 Remediation Technology Developer

Today, developers originate from a range of places—large corporations, small businesses, academia, and elsewhere. But, each developer faces many of the same risks and concerns in developing innovative remediation technologies. This section discusses these risks not related directly to federal and state programs and legislation.

5.2.3.1 Liability

As with any technology, innovative or not, there is always a factor of liability involved. The potential of an accident release or failure of a system opens the developer and contractor to a
range of liability cases. Persons affected by hazardous waste can seek relief through the court system under common law. Common law allows remedy through four actions: trespass, negligence, nuisance, and strict liability. For a quick summary of common law as it applies to hazardous waste sites, see Hoffman pages 29-30. (Hoffman, 29)

In many ways the liability issues that face the hazardous waste technology sector are different than those in other industries. One such difference is "the long term, latent aspect of the injuries"; such as cancer. This leaves the contractor open to liability for a long time after the completion of a job. Even if the injury is detected early, the extent of injury and the requisite award size is vague and entirely up to the court's discretion. Hoffman describes this as "leav[ing] contractors open to unlimited liabilities." (Hoffman 30)

In addition, this liability can extend beyond the contractor who completes the work. It is not uncommon that courts find a corporation and its members-directors, employees, shareholders, and officers- directly liable for injuries. (Hoffman, 31)

5.2.3.2 Funding

Funding is also a large barrier to the development, demonstration, and commercialization of innovative technologies (Federal, 6). Technology development is a capital intensive activity. High costs of equipment and requisite research and development must be assumed during innovation. The difficulty with commercialization and long period to market entry also add to the risky nature of this industry (Hoffman, 31). "Time periods for industry and regulatory acceptance of the new technology can be as long as four years. Then time periods between the issuance of an ROD (and signing of a cleanup contract) and the actual remediation completion
 Many developers find the cost of meeting bureaucratic requirements and obtaining a permit extremely costly and time consuming (Federal, 6). The period requiring demonstration and verification period typically becomes the most time-consuming step before market entry (Hoffman, 32). This usually requires developers to assume financial loans from lending institutions at various interest rates. (Hoffman, 32)

In addition, as discussed in the previous section, developers must be prepared to assume liability costs in the future in the case that the system fails or injuries result. The financial risk associated with these liabilities can easily bankrupt a small business or at least seriously set back a large company. Thus, entry into this market requires serious consideration (Hoffman, 31)

5.2.3.3 The Market

The market is impacted by a range of factors. These include the ever-changing environmental legislation and standards and range in sizes of firms.

- Environmental Legislation and Standards

As stated earlier, there is a need for innovative technologies in the field of hazardous waste remediation. This need and market exists as a result of federal and state regulations, industry and the public. However, the regulations governing this market are ever changing on the federal level (Hoffman, 33). At the same time, varying standards among states also complicate the market.

There are currently no standardized performance standards and permitting procedures. Thus, technology developers and investors are concerned with this fragmented market. One
technology may be accepted in one state or through one regulatory program, but not in another (Federal, 5). In addition, as regulations and technologies change, companies may become liable for what they thought they had cleaned up. These complications and concerns cause investors to be wary since the market is ever changing and fragmented (Hoffman, 33).

"For example, if a firm invested heavily in perfecting cap and containment technologies in the early 1980s, the SARA amendments effectively eliminated that company's market segment. If a company invested heavily in the incineration technologies in the last 1980s, it is probably watching its market segment dry up as the siting of commercial incinerator facilities becomes increasingly impossible." (Hoffman, 32)

- **Small Businesses v. Large Firms**

  The environmental technology industry consists of firms, ranging from small to large. In order to enter this market, small businesses must form a subcontractor relationship with a larger contracting firm. These larger companies dominate the industry, forcing small businesses to rely on them for an opportunity to enter the market. Without this tie to a large firm, the small developer is left with limited opportunities. (Hoffman, 33)

**5.2.4 Supporting Institutions**

As with any innovation, developers and contractors wish to obtain insurance, bonding, and financing. However, those involved with the hazardous waste industry have difficulty procuring these or must obtain them at an additional cost. This section will discuss these difficulties in obtaining insurance, bonding, and financing.
5.2.4.1 Insurance

Insurance companies today are wary of involving themselves with the pollution industry. Environmental claims do not require proof of cause and effect relationships. In fact, the courts have shifted the burden of proof to the contractor to disprove his/her responsibility for third party injuries. Furthermore, there is no set limit on the amounts that plaintiffs can sue for. Insurance companies today can become liable for pollution claims under CERCLA. (Hoffman, 35)

If an insurance company does decide to provide insurance to those in the environmental industry, a contractor typically must purchase multiple types of insurance. Like all businesses, hazardous waste contractors purchase Commercial General Liability Insurance for litigation coverage. Of particular interest to those involved with the hazardous waste industry are exclusions that specifically exclude “claims arising out of pollution, claims arising from operations at a hazardous waste site, . . . , claims that arise out of injuries to the insured’s employees, and claims that arise out of a professional error, act, or omission.” (Hoffman, 34) To cover these gaps, hazardous waste contractors must purchase additional insurance coverage. Contractors Pollution Liability is purchased by contractors to cover the exclusion of pollution claims in General Liability. Architects and Engineers Errors and Omissions (E&O) policy covers the exclusions of design errors and omissions in the General Liability. For a hazardous waste contractors, the E&O policy must be amended by the Specialty Environmental Engineers Errors and Omission Policy. Some insurance agencies are introducing a Specialty Policy which combines pollution coverage with Professional Liability or General Liability. (Hoffman, 34)
A current trend in insurance policies is that they are written as “claims made” policies. “Claims made” policies cover claims which are made during the term of the policy. This does not protect contractors following the completion of a job.

Other contractors are addressing their need for adequate insurance policies personally through a captive insurance company. These insurance companies are “a self insurance association with other contractors or simply a financial trust fund.” (Hoffman, 35) It is also not uncommon for contractors to form a separate subsidiary for its hazardous waste operations. (Hoffman, 35)

5.2.4.2 Bonding
Bonding companies which supply sureties to contractors are also wary about involving themselves with hazardous waste contractors. Like insurance agencies, bonding institution fear being held liable for late claims beyond the terms of the contract. Today, many only get involved if there is a “hold harmless” clause in the contract that releases the bond company from any work beyond the scope of the contract. (Hoffman, 36)

5.2.4.3 Funding
While the environmental market is growing, investors hesitate to support those companies which perform research and development in hazardous waste. Many large investors fear future liability for damages and injuries suffered as a result of implementation of the new technology or process.
Lending institutions are also wary of lending money to those companies involved with hazardous waste cleanups for fear of liability and potential costs to the institution. If the firm is sued for damages, the firm could go bankrupt and the institution would not recoup the loan. Furthermore, if the firm goes under and the lending institution assumes management of the site, the bank may become held liable as a PRP by the court. Sometime the cost of the cleanup exceeds the value of the property. (Hoffman, 37-38)

As mentioned earlier, clear performance standards and permitting requirements are currently lacking. Furthermore, there is an uncertainty that a successful technology demonstrations in one state or through a specific federal program will be accepted in another state or program. This limits the selection of available technologies to those technology users who might consider using innovative technologies. As a result of the varying state standards among states, a fragmented market exists. This discourages investors from supporting such technologies, because the return on investment is restricted because it only captures a portion of the available market. (Federal, 5)

5.2.4.4 Demonstration Programs and Technology Centers

Many hazardous waste sites are being transformed to technology demonstration sites and environmental technology centers, as seen in the case of the DOD’s AATDF program. Each year the numbers transformed for this use continue to increase. Despite the increased facilities, the technologies are not being demonstrated and validated at a noticeable accelerated rate.
5.2.5 Public Trust

In general, there is public mistrust in remediation technologies, regulatory agencies, technology developers and users. This typically hinders the permitting process and reinforces the risk averse nature of the regulatory members. The main opportunity for public participation is during the permitting process. Therefore, concerns are voiced at this point which slows and sometimes stops the permitting process of technologies. Furthermore, the public views innovative technologies as an untested, inferior solution to remediation because the performance data is incomplete.
6.0 CONCLUSIONS: SUGGESTED POLICY AND PROCESS CHANGES

In the last decade, support has grown for the development and implementation of innovative hazardous waste technology. In response, encouraging legislation and development and demonstration programs have evolved. The General Accounting Office found that innovative technologies were used in 20% of the Superfund cleanups in 1994 in comparison to just 6% in 1986 (Renner, 71A). However, the overall process still requires improvements.

6.1 POSITIVE MOVEMENTS IN THE CURRENT ENVIRONMENT

Despite the numerous reports which indicate various obstacles to innovation, there are a number of encouraging measures already in existence which improve the current environment. This section will highlight these measures.

6.1.1 Reduction in Adversarial Roles

Clinton’s ETI to develop technologies for the good of the U.S. economy and environment unites the government, industry, and the American population under one vision. The adversarial roles between the government (including the USEPA) and industry have diminished as a result of joint programs. The SITE program and the CRADA agreements have the USEPA working together with industry and other federal agencies in cooperative effort. Such programs as the Public-Private Partnership are an efficient mechanism for research efforts to be streamlined across the United States. This improved communication and coordination in research and
funding can only accelerate these efforts to improve current technologies and develop new
innovative solutions to the hazardous waste problems.

6.1.2 Encouragement Through Legislation

In the past decade, environmental legislation has made strides to encourage the
innovation of new remediation technologies through technology forcing mechanisms. For
instance, the "land ban" provision in the recent reauthorization of RCRA has definitely moved
towards fixing the problems rather than covering the symptoms through technology-based
standards. Congress should avoid standards based on performance capabilities of existing
technologies. At the same time, the SARA amendments of 1986 spurred the creation of the SITE
program by the USEPA. These provide minimal incentive for federal agencies and industries to
develop and implement new technologies to remediate hazardous wastes. SARA has also led to
the implementation of permanant solutions over containment options.

6.2 SUGGESTIONS FOR CHANGE

While there is definite movement towards technology innovation, additional initiatives
must be assumed to expedite the development and demonstration process. Some require changes
in legislation and its interpretation, while others call for additional programs and support.
6.2.1 Increased Funding and Support

Development, demonstration, and commercialization of innovative technologies is capital intensive. The development of a technology can be stifled without adequate funding from federal monies, lending institutions, or investors. The process of accessing funding and support is time consuming as a result of application processes and proposal evaluations.

Dr. Robert Gillham, developer of an innovative technology called the permeable reactive wall, believes one barriers to innovation is quick access to funds. For example, he has two technologies under the SITE program. However, he finds the support from the USEPA is minimal because the USEPA only covers the monitoring costs and data reporting during a demonstration. However, there are larger costs incurred as a result of acquisition of materials and equipment, construction, and implementation. (Personal Communication with Robert Gillham)

Gillham suggests that if a significant investment is made early on (enough to complete initial tests), a number of unsuccessful technologies can be weeded out before a large investment is made in the technology. This saves the government, developers, and investors both time and money. (Personal Communication with Robert Gillham)

However, federal budgets must allow for this funding. In 1995, Clinton’s ETI suffered a significant set back when the House of Representatives denied the administration’s request for $127 million for this initiative (The U.S. Senate approved a mere $20 million for the program.) (Shannon, 496A). As with all federal initiatives the politics of the federal budgets is key.

During the federal budgeting and review sessions, the USEPA must stress its need for these
monies. This includes highlighting the significance and achievements of particular programs supporting environmental technologies.

6.2.2 Expedite the Entire Process

Even if a developer is able to access the necessary funding for his/her technology, the time before a return on investment is lengthy. This slow return may impact a developer's access to additional investors and loans. The long duration of the research to commercialization process can be a discouraging prospect for most developers.

The most time consuming process step in the process is usually the demonstration and validation phase of the process (Hoffinan, 32). Programs; such as the AATDF program of controlled field tests, should be expanded to expedite this process. Demonstration sites and technology centers; such as those planned through the AATDF program, continue to be established each year. However, these sites and centers have not greatly increased the verification and implementation program thus far. These demonstration programs and technology centers need to be managed differently such that more technologies are verified and made available to the regulators and technology users.

6.2.3 Standardization

Standardization is lacking throughout all efforts of technology development. In particular, the system currently lacks a nationwide verification process and cost and performance reporting procedure.
The lack of a standardized data reporting procedures limits the implementation of innovative technologies. Regulators and technology users wary of the available performance and cost data without standardized formats. Standardized cost and performance guidelines will instill confidence through an unbiased program.

Investors are also wary of committing funds for environmental technology development. Technologies successfully demonstrated in one state or through one program are not necessarily accepted in another state or another program. As mentioned in the earlier section, this lack of nationwide acceptance creates a fragmented market for the technologies. Thus, a standardized verification program is needed. Not only will this provide confidence to regulators and technology users, but investors will be more willing to invest in this market that is no longer fragmented. Perhaps a national controlled release site, such as Canadian Forces Base Borden, would aid in establishing a national verification program.

6.2.4 Flexibility in Permits

Some technology users avoid innovative technologies, fearful of not meeting the requirements of their permits. Innovation waivers could stimulate innovation by allowing noncompliance with existing legislation and standards while developing and implementing a new technology. Another mechanism that may improve the innovation environment is regulatory acceptance of a “fail-soft” strategy (Ashford, 283). This is where the regulatory agency is forgiving of failed implementation of an innovative technology “where a firm made an imperfect effort but a good faith effort.” (Ashford, 283) This decreases the innovator’s fear of penalty from the regulatory agencies as a result of a failed technology innovation. (Ashford, 283)
Another variation on this idea would be to provide limited permit variances which grant technology users leeway for compliance for a designated period of time. However, variances tend to be subject to the interpretation of the permit writers. If the USEPA provides guidelines, perhaps a more standardized implementation of variances, this would encourage the implementation of innovative technologies.

6.2.5 Increased Public Participation

Particularly during the ROD approval process, public participation is key. Without their approval, the ROD process can be slowed, if not halted. However, this process is the community’s main opportunity to voice their concerns. Bringing the public into the decisionmaking process earlier will minimize complications and delays during the ROD process. At the very least, educating the public early on about the available options, especially in the case of innovative technologies, is needed. Without public education, communities would be more resistant to implementing a technology lacking complete performance data. Taking this time to consult the community, especially when desirous of implementing an innovative technology, will provide additional confidence in the ROD and those involved with the cleanup. The ramifications of increased confidence and trust will also save time in future remedial efforts.

6.2.6 Protection from Liability

Liability is always a factor in all research and development industry. Protection from liability is necessary for those who develop and use these innovations. The issue of liability
discourages potential developers and users from creating and implementing hazardous waste technologies.

Understandably, those impacted by failures of a technology will desire compensation. However, for a developer or user to carry the burden alone can be disastrous, especially for small businesses. Ideally, a mechanism can be created where the USEPA can share the liability for a remedial technology. Perhaps this shared liability can follow technology verification through a standardized process at a national demonstration site. By sharing the liability with the USEPA, the insurance companies may be more likely to provide insurance to those involved with hazardous waste at a reasonable cost.
7.0 SUMMARY OF FINDINGS

Superfund sites continue to challenge the technological innovations designed to remove the contamination and restore the land for future use. Many conventional technologies that are currently applied to the hazardous waste sites are neither time efficient nor cost effective. Thus, there is a need for more effective and efficient mechanisms. While this need is recognized by both public and private sectors, innovative technologies have not been widely developed and implemented.

This research examines one technology and its transfer history at a Superfund site, the permeable reactive wall at the Massachusetts Military Reservation (MMR). From this, the scope was expanded to examine the innovation of environmental technology in the entire United States. The existing innovation environment and obstacles are discussed. Suggestions are provided to address this need for change.

Technical Working of the Reactive Wall

This study examines the technical workings of one promising innovative technology, the permeable reactive wall. The wall was developed by Dr. Robert Gillham of the University of Waterloo (CANADA) in 1990. This passive technology provides flexibility in its implementation and application for treating contaminated groundwater. The reactive media in the wall acts on the contaminants as the groundwater flow passes through. 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.

For the purposes of this study, the use of zero-valent iron was examined for its ability to degrade halogenated aliphatic contaminants, namely chlorinated volatile organic compounds (VOCs). The exact degradation process of the VOCs are still unclear. As for the exact chemical pathway of degradation, Gillham and O’Hannesin concluded that the contaminants are degraded through reductive dehalogenation that may or may not require the hydrolysis of water (Gillham and O’Hannesin (1994), 965). Gillham and O’Hannesin also found the reaction follows a first order rate constant and is abiotic (Gillham and O’Hannesin (1992), 15). The reaction rate is slowed by low temperatures and high pH levels (Personal Communication with John Vogan; Gillham et al., 5).

Site selection, wall design, and system configuration must be considered to design an effective remediation scheme. Designing an effective wall design requires careful attention to the following factors:

- hydrogeologic characteristics of the site and plume
- contaminant level in the groundwater
- maximum contaminant level goal following treatment.

Implementation of the reactive wall requires a high initial capital investment, but minimal operation and maintenance cost because of its passive nature. In comparison to the conventional method of pump-and-treat, the reactive wall provides a more cost-effective method. In addition, the reactive wall destroys the contaminants rather than transfers the contaminants to another media; such as the activated carbon of pump-and-treat. However, the wall is not more time
efficient in its required cleanup time, since it relies on the groundwater flow to bring the
contaminated water to the wall.

Transfer History of the Reactive Wall to the MMR

The transfer history of the wall at the MMR, a Superfund site, was examined. To bring
the technology from the University of Waterloo to the MMR has taken approximately six years
thus far. Over this period of time, feasibility studies were conducted to select a site for
implementation. The time consuming process is attributed to negotiation of and bureaucratic
loops. In the early stages, formulation of a reasonable list of tasks for the University of Waterloo
to achieve required a significant amount of time. Further delays resulted as a result of the EPA
contracting constraints on sole source procurement. The reactive wall is solely commercialized
through EnviroMetal Technologies Inc. by the University of Waterloo. In order to contract such
a technology, a slow process was undertaken to justify the selection of the technology. Other
bureaucratic delays may result from adding a level of management by placing this demonstration
in the EPA’s Public Private Partnership administered by Clean Sites Inc.

Some delays were beyond the bureaucratic process. As in all Superfund sites, site
characterisation is never complete—limited by technological capabilities and financial constraints.
This was seen in the unsuccessful pile drivability at the Chemical Spill 10 plume area.

After six years, the reactive wall has yet to be installed at MMR. This past March, the
site for implementation has been selected—the Chemical Spill 10 source area. Since the funnel-
and-gate system planned for the MMR has been successfully implemented at other sites, current
plans are to implement the wall with an innovative delivery system.
Assessment of Obstacles Limiting the Demonstration and Implementation of Innovative Environmental Remedial Technologies in the United States

Expanding the scope of this case study to the entire United States, the current innovation environment for technology developers in the field of hazardous waste technologies was examined. This environment is shaped by the environmental legislation, especially those that set standards in accordance to current technology capabilities. In particular the U.S. Environmental Protection Agency (USEPA) provides numerous obstacles to the innovation environment. The USEPA is understaffed and lacks “institutional memory” as a result of their high turnover rate. There are also inconsistencies among regional USEPA offices in terms of acceptance of technologies across the different regions. Legislation and Record of Decisions discourage the implementation of new technologies for fear of not meeting the requirements and incurring penalties. Thus, many technology users return to the proven conventional methods. In addition, procedural requirements regarding contractors and sole source procurement can either delay or remove the option to implement an innovative technology.

Current programs also lack standardized data collection on performance and cost. Technology developers must also face concerns about insurance, funding, and bonding. The existing environmental technology centers and demonstration sites have failed to accelerate the process thus far. Negative public sentiments towards innovative technologies may also slow or stall their implementation at sites.
Suggestions for Changes to Better Support Technological Innovation in the Hazardous Waste Industry

The thesis concludes with recommendations for increased communication, funding, and flexibility to improve the environment for increased innovation. There are currently programs in place that do encourage the development of technologies. These include the SITE program and the Public Private Partnerships. The positive aspects of these programs are the increased communication across the public and private sectors and the partial funding of the development and demonstration of innovative technologies. There is also encouragement for innovation through legislation, particularly with the RCRA and CERCLA amendments through the "land ban" provision and creation of the SITE program respectively.

But additional changes are necessary to accelerate the innovation of technologies to remediate hazardous waste sites. Developers require support throughout the entire process. This includes funding, insurance, regulatory backing, and flexibility. For instance, the funding provided through the SITE program covers the cost of monitoring and reporting of performance. This is minimal to the overall cost of implementation and equipment necessary for a demonstration. Funding must also be available of a period of years since the development to demonstration process typically requires several years.

In addition, investors are wary of financing in a product that may be successfully demonstrated in one state or through one program and not accepted by other states and program. Such a fragmented market limits the potential of finding investors. There is a need for standardized procedures for verification of technologies to help remove this barrier to potential funding and implementation.
While cost and performance data is available for some innovative technologies, regulators and technology developers are wary of their use. A standardized data collection and verification program would increase the confidence and implementation of technologies.

7.1 FINAL THOUGHTS

These suggestions are entirely personal-based on research and discussions. It is in the opinion of the author that these changes will facilitate and accelerate the innovation of environmental technologies in the United States. Not only will this provide a significant addition to the U.S. economy, but also bring the necessary technologies to cleanup the ever increasing number of hazardous waste sites.
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Appendix A: Group Project


Including a Case Study:

Fuel Spill 12 at the Massachusetts Military Reservation

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EXECUTIVE SUMMARY

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. One plume in particular, Fuel Spill 12 (FS-12), is the result of a fuel pipeline break. This leaked approximately 70,000 gallons of JP-4 fuel into the subsurface, and ultimately the aquifer. The resulting contamination includes benzene, a fuel component, and ethylene dibromide (EDB), a fuel additive. Both are known carcinogens. The contamination of groundwater by this plume, as well as others, has affected the local water supplies, initiating the closure of municipal and private wells.

This project focuses on FS-12 as a case study to assess the movement and treatment of fuel-contaminated groundwater plumes. In addition, water supply issues related to regional groundwater contamination are investigated. These issues include an assessment of alternatives to replace lost water supplies and the role of public perception in selecting these. Finally, the previous remediation decisions at the MMR and FS-12 are analyzed from an economic standpoint.

Fuel Spill 12 - Model Results

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.
Fuel Spill 12 - Treatment Alternatives

Four treatment techniques for fuel-contaminated groundwater are assessed: (1) natural attenuation i.e. "do nothing" alternative, (2) air sparging & soil vapor extraction, (3) extraction well fence, and (4) reactive wall.

- 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.

- 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.

- 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.

**Massachusetts Military Reservation - Water Supply Issues**

- 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 the major constraint on future water supply expansion—the lack of access to land to drill new wells. In this respect, there is a clear need to protect groundwater resources by establishing zones of groundwater protection, and land acquisition near wellfields.

- 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.

- The public perception of drinking treated groundwater is assessed by interviewing local environmental groups, involved citizens, and local water district superintendents. The public is unwilling to drink treated groundwater for four reasons: (1) they believe their current water supply is pristine; (2) they believe the carbon treatment system cannot remove contaminants to a non-detect level; (3) they do not fully trust the MMR's statements about the cleanliness of the treated water; and (4) they would prefer that new wells be drilled to find clean sources of water instead of treating water from existing wells.

**Massachusetts Military Reservation - Cost-Benefit Analysis**

Current plume containment plans are estimated to cost $250 million. A cost-benefit analysis was completed to compare this expense to other alternatives. A review of costs and benefits of the plume containment program disproves the following myths:
• The plume containment plan will address public health and environmental hazards. The threat to public health has already been partially addressed by alternative water supply. Therefore, risks could be essentially eliminated for an additional investment of less than $10 million.

• 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.

• The plume containment scheme will preserve valuable water resources. 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.

Based on the above analysis, the 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.

FS-12 - Cost-Benefit Analysis

The high cancer risk and the uncertainties associated with the do nothing alternative would call for the implementation of cleanup measures. Plume containment alternatives, for example the well extraction fence, may be more beneficial than source control alternatives, such as air sparging. This depends on the value placed on the groundwater contaminated by further plume migration.
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1. Introduction

The Massachusetts Military Reservation (MMR), located in Cape Cod, Massachusetts, has housed numerous branches of the military since 1911. Military activities on the reservation have been extensive, impacting the natural resources of Cape Cod. Because of the significant contamination, the MMR has been included as a Superfund site. The site cleanup is being handled by the Installation Restoration Program (IRP) with offices located on the reservation. The current action to remediate the 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.

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 project uses FS-12 as a case study to assess various remediation techniques and their applicability to a fuel-contaminated groundwater site. The project also examines water supply issues for the entire region. Specifically, the objectives are:

- To determine the movement of FS-12 and its potential effects on Snake Pond;
- To compare the "do nothing" alternative to treatment with three types of remediation schemes: extraction well fence, air sparging & soil vapor extraction, and permeable reactive wall technologies;
• To identify the water supply issues surrounding groundwater contamination including alternatives for water supply replacement and the public perception surrounding use of treated groundwater;

• To evaluate the decision to remediate at the MMR through a cost-benefit analysis.
2. Study Area Characterization

This section provides background information on the Massachusetts Military Reservation (MMR), as well as details on Fuel Spill 12 (FS-12). It covers physical and sociological features of the local region.

2.1 The Massachusetts Military Reservation Superfund Site

2.1.1 Physical Characteristics

2.1.1.1 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 1).

2.1.1.2 Topography and Geology

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.
2.1.1.3 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. 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 2). Flow is generally radially outward from this mound. The ocean forms the lateral boundary of the aquifer on three sides.

Figure 2 - Hydrogeology of the MMR
2.1.1.4 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.

2.1.1.5 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)

2.1.2 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.

2.1.2.1 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. 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). 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, see Section 3.4.2.2).

2.1.2.2 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).

2.1.2.3 Economy

The Upper Cape economy was valued at $600 million in 1992; more than 60% was derived from tourists, seasonal residents, and retirement-based income (see Section 3.4.2.2). 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).
2.1.3 History

2.1.3.1 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).

2.1.3.2 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).
2.1.3.3 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 3) 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)
Figure 3 - Plume Area Map

Massachusetts Military Reservation
Cape Cod, Massachusetts
2.2 The Fuel Spill 12 - A Case Study

2.2.1 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.

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 (Stone & Webster, 1995) Figure 4.
2.2.1.1 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).

2.2.1.2 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 1:

<table>
<thead>
<tr>
<th>Kr horizontal conductivity (ft/day)</th>
<th>Kz / Kr horizontal/vertical conductivity ratio (ft/day)</th>
<th>Ss Specific Storage</th>
<th>Sy Specific Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>236.75 - 368.21</td>
<td>0.05 - 0.55</td>
<td>0.000001 - 0.00058</td>
<td>0.008 - 0.184</td>
</tr>
</tbody>
</table>

(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).
2.2.2 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.

2.2.3 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 4) 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 B. 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)

2.2.4 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, section 3.2.2.

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 will be presented throughout this paper.
3. Findings

The results from the study of the FS-12 plume are presented in the sections below. First, the model of the plume is completed and analyzed for its effects on local surface water bodies. Second, four treatment alternatives are assessed for potential applications. Finally, water supply issues including future water supply and public acceptance of drinking treated groundwater are discussed. See the appendices for further details on the analyses.

3.1 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.

3.1.1 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, 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 5 and Figure 6) 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 5- Area Map: Plume Location and Extent of Contamination
Figure 6- 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 7).

![Figure 7 - Cross-Section Showing Layers and Materials](image-url)
To account for minor clay/silty lenses, several sub-layers were included in the top and medium layers. An additional level was built directly below the ground surface to model the ponds' location and hydrologic characteristics at an average depth of 35 feet (Advanced Science, Inc., 1993). Layers generally follow the ground surface topography with the exception of the lower fine sand. This sand layer is bounded between 70 feet below MSL and bedrock at the top and bottom, respectively.

The hydraulic conductivity of the aquifer decreases with depth, and the clay/silty lenses exhibit significantly lower conductivities. Because of the coarse grained quality of the upper sand, the major layer was assigned a horizontal conductivity of 355 feet/day. The medium layer, being slightly less conductive, was assigned a horizontal hydraulic conductivity of 275 feet/day. Since the bottom layer was composed mostly of fine sand with some silty deposits, it was modeled as only one homogenous material with a conductivity of 50 feet/day. The clay/silty lenses were included as one small area in the major medium layer on the east side of Snake Pond where several observations detected clay/silty soil. The horizontal conductivity of the clay/silty soil was set to 19 feet/day. The vertical conductivity was defined in each layer by using the appropriate anisotropy ratio for the Cape Cod aquifer (Advanced Science, Inc., 1993; Masterson and Barlow, 1994) which is 3:1, horizontal:vertical. The elemental model was also set to have a recharge of 23 inches/year (Masterson and Barlow, 1994). The ponds were modeled by attributing a “water” material to the elements that contained the ponds in the sub-layer directly below the ground surface. To represent the action of the ponds correctly, the “water” material was defined to be ideally 100% conductive by setting the horizontal hydraulic conductivity equal to 100,000 feet/day. An additional layer was included beneath the “water” layer to describe the sediments of the ponds. Initially, the conductivity of the sediments was specified to be lower than that of the sand materials. However, in the final model it was set equal to the hydraulic conductivity of the upper sand. This change was made because the sediment layer with lower conductivities does not have a significant effect on the flow field. The elemental grid and layers were then simulated and calibrated for natural flow.
3.1.2 Assessment Of Model Results

3.1.2.1 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 8) 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.

3.1.2.2 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 9. A cross-section parallel to the plume is also shown (Figure 10).
Figure 8 - Water Table Elevations (feet)
Figure 9 - Simulated Benzene Particles
Figure 10 - 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.

3.1.3 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 11) 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 11 - Cross-Section Across Snake Pond Showing Particles
3.2 Treatment Alternatives

Two primary goals of the IRP are to control the source of contamination and contain the plume's movement. The first treatment alternative presented in this section is the "do nothing" alternative. It is used as a comparative analysis for remedial action extraction. The study also includes an air sparging system to control the source, a well fence and a reactive wall technology for plume containment.

3.2.1 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.

3.2.1.1 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:

- 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

3.2.1.2 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. 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.

3.2.1.3 Application at FS-12

The IRP gave little consideration for the no-action alternative for natural
restoration and impacts on environment and human health. The long range model depicts
key facts about the FS-12 plume (Figure 12):
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 2- Contaminants of Concerns: Comparison of Average and Maximum Concentrations in the FS-12 Plume Against Established MCLs

<table>
<thead>
<tr>
<th>Contaminant of Concern</th>
<th>Average Concentration (µg/L)</th>
<th>Maximum Concentration (µg/L)</th>
<th>MCL (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>65.1</td>
<td>1550</td>
<td>5</td>
</tr>
<tr>
<td>EDB</td>
<td>21.4</td>
<td>578</td>
<td>0.05</td>
</tr>
</tbody>
</table>

(Operational Technologies Corp., 1995)

The contaminants of concern in the FS-12 plume are benzene and EDB (Table 2). 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 2 compares the average and maximum concentration levels with the MCLs (Operational Technologies Corp., 1996).

Assuming first order decay, the time required for complete dissolution of contaminants to MCLs was calculated as 4.5 years for EDB and 8.3 years for benzene. According to these biodegradation rates, the maximum additional extension of the plume exceeding MCL limits is 1000 feet downstream of the current plume toe.

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.

3.2.2 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.

3.2.2.1 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.

3.2.2.2 Process Description

Air sparging involves the injection of a hydrocarbon free gaseous medium (typically air), under pressure, into the saturated soil zone (see Figure 13). 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.

3.2.2.3 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
Figure 13 - Combined Air Sparging/Vacuum Extraction Diagram
advevtive 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, 1944). 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).

### 3.2.2.4 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).

3.2.2.5 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. See appendix B for more comparative data. 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).
3.2.2.6 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. (See Appendix B for details). 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.

3.2.2.7 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 $1.33 \times 10^{-6}$ in order for an equivalent groundwater near the source to measure below the MCL of 5 ppb. According to the graphs in Appendix B, 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/liter of contaminated water.

Air sparging may not be as effective if there are significant amounts of less-volatile compounds present in the plume. As seen from the graphs in Appendix B, 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. More detailed explanations of the modeling process and results can be found in Appendix B.

### 3.2.3 Plume Containment

#### 3.2.3.1 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 an 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.
3.2.3.1.1 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).

3.2.3.1.2 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
3.2.3.1.3 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 3.1). 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.

3.2.3.1.4 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 15. Figure 16 and Figure 17 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 wells needed to be water. In the vertical direction, the well fence influence is approximately limited to the curve extent is just enough to completely contain the plume without pumping clean capture of the contaminated water. 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. Further details on the extraction well fence design can be found in Appendix C.
Figure 15 - Extraction Well Fence and Observed Plume Location

Figure 16 - Plan View of Particle Capture by Extraction Well Fence
3.2.3.2 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. For additional details about the reactive wall and implementing innovative technologies at Superfund sites, see Appendix D.
3.2.3.2.1 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.

Figure 18 - Permeable Reactive Wall Used in Conjunction with Funneling Barriers
3.2.3.2.2 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).

3.2.3.2.3 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. For further details about various configurations, see Appendix D.

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.”

3.2.3.2.4 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 3.1, the plume does not enter Snake Pond. Thus, application of this technology is not possible at the FS-12 site.

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. Public acceptance issues surrounding the use of treated groundwater are also assessed.

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 E 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 $10-15 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 will be analyzed in Section 3.3.4. 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 3) (Operational Technologies Corp., 1995)

Table 3 - An Assessment of Water Reinjection/Extraction Ratios and Water Costs

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

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).

3.3.4 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. For more discussion concerning these interviews, see Appendix E.

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. For further details about educational programs, see Appendix E.
3.4 Cost-Benefit Analysis

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. 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 must not be influenced by cost or an economic impact analysis. 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)

This chapter 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 chapter is comprised of three parts:

- definition of the evaluation process and determination of the parameters for the cost-effectiveness and cost/benefit analyses
- application of the methodology to the entire MMR Superfund site
- detailed analysis of the case study at FS-12

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. However, the magnitude of the cost and benefits is of primary importance.
3.4.1 Cost-Benefit Analysis: General Issues And Methodology

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. The most ambitious of the techniques to value the benefits from environmental improvement is cost-benefit 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.

The following steps have been taken:

- 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

3.4.2 Cost-Benefit Analysis: The MMR Superfund Site

This section only addresses cost-benefit 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.
3.4.2.1 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 (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%.

3.4.2.2 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 (see appendix F for more details).

3.4.2.2.1 Direct Primary Benefits

Water Supply

As shown in Section 3.3.3.1, avoided costs (compared to no action alternative) due to the plume containment alternative would be $10 million.
3.4.2.2.2 Indirect Primary Benefits

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 19).

**Figure 19 - No Action Alternative- Number of Additional Cancers Developed Over the Next 25 Years**

[Bar chart showing number of additional cancers for different locations, with Assumptions: Probable risk. Public and private wells contaminated to plume concentration levels, exposed population supplied from contaminated wells]
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). For further details about costs and exposed population, see Appendix F.

Health risks could be essentially eliminated if the contaminated water supplies would be replaced as shown in section 3.3.3. 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 cost-benefit 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 Figure 20.

**Figure 20 - Loss on Property Values Due to MMR Contamination ($ million)**

![Figure 20](image)

Assumption: 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 expansion of the contaminated area. Therefore, the avoided cost due to plume containment would be $17 million.
All primary benefits identified are summarized in Figure 21. 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 21 - Primary Benefits Accruing Over 1995-2020 ($ million, cumulative)**

3.4.2.2.3 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) (see Figure 22).
More than 80% of the economic base can be considered highly sensitive to perceived risk of groundwater contamination (tourism, retirement-based income, business, commuters). 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 4 - Impact of Perceived Risk on Economic Base

<table>
<thead>
<tr>
<th>Yearly Growth</th>
<th>3.0 %</th>
<th>2.9 %</th>
<th>2.8 %</th>
<th>2.7 %</th>
<th>2.6 %</th>
<th>2.5 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic base decrease ($ million)*</td>
<td>0</td>
<td>-119</td>
<td>-236</td>
<td>-351</td>
<td>-463</td>
<td>-572</td>
</tr>
</tbody>
</table>

* 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.

**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. 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.

### Costs versus Benefits

Benefits and costs can be compared to obtain the net benefit (see Table 5).

**Table 5 - Discounted Costs and Benefits for the Period 1995-2020**

<table>
<thead>
<tr>
<th>I = 5%, n=25 years</th>
<th>No Action (baseline)</th>
<th>Water Supplies Replacement</th>
<th>Plume Containment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COSTS</strong></td>
<td>0</td>
<td>15</td>
<td>250</td>
</tr>
<tr>
<td><strong>BENEFITS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Supply</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Health Risks</td>
<td>0</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Property Value</td>
<td>0</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>Economic Base</td>
<td>0</td>
<td>0</td>
<td>0 to 250 ?</td>
</tr>
<tr>
<td>Non-Use Values</td>
<td>0</td>
<td>0</td>
<td>0 to 150 ?</td>
</tr>
<tr>
<td>NET BENEFIT</td>
<td>0</td>
<td>2</td>
<td>-210 to 190</td>
</tr>
</tbody>
</table>

175
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.

3.4.3 Economic Analysis: A Case Study Of The Fuel Spill 12

This section provides a synthesis of the findings presented in section 3.2 from an economic perspective. The different remediation technologies are analyzed in terms of
cost-effectiveness. Finally, using the methodology developed in Appendix F, several remediation alternatives are assessed in terms of costs and benefits.

3.4.3.1 Cost-Effectiveness Analysis

The goal of the cost-effectiveness analysis is to determine which treatment alternative meets the 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 6).

<table>
<thead>
<tr>
<th></th>
<th>Natural Attenuation</th>
<th>Natural Attenuation and Water Supply Replacement</th>
<th>Pump and Treat</th>
<th>Product Recovery and Air Sparging</th>
<th>Reactive Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td>0.6</td>
<td>1.6</td>
<td>5.0</td>
<td>2.0</td>
<td>na</td>
</tr>
<tr>
<td>Time to Reach MCLs</td>
<td>&gt; 10</td>
<td>&gt; 10</td>
<td>15</td>
<td>**</td>
<td>na</td>
</tr>
<tr>
<td>(years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plume migration</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes (limited)</td>
<td>no</td>
</tr>
<tr>
<td>Human health risks</td>
<td>not acceptable</td>
<td>acceptable</td>
<td>acceptable</td>
<td>acceptable</td>
<td>acceptable</td>
</tr>
</tbody>
</table>

** 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.

3.4.3.2 Cost-Benefit Analysis

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

3.4.3.2.1 Primary Benefits

Water Resources

As shown in Section 3.3.4, 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 (Figure 19). Resulting costs to society would amount to $11 million.

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 $2.7 million in the case of the do nothing alternative, and $4 million if the plume is contained. Therefore, the plume containment would yield a benefit of $1.3 million.

3.4.3.2.2 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.

3.4.3.2.3 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.
4. Conclusions and Recommendations

The Massachusetts Military Reservation (MMR), located on Cape Cod, is listed on the National Priority List as a Superfund site. A variety of military activities have produced extensive contamination of the groundwater underlying the reservation. The nature of contaminants is varied and different for the nine plumes. This report focuses on a fuel spill, Fuel Spill 12 (FS-12), resulting from a leak in a pipeline which transports JP-4 fuel to the MMR.

FS-12 was used as a case study to assess the movement of a fuel contaminated plume; and to determine the efficacy of various remediation techniques on the contaminated groundwater. Within the alternatives for remediation two classes of option were suggested: source control, and leading edge containment. In addition, a study was conducted about regional water supply issues concerning alternate water supply and public perception of the alternatives.

The groundwater flow field was studied and modeled to determine the migration of the observed plume. The effects and possible hazards of the contaminants reaching the neighboring water bodies were also assessed using the model. Currently, soil vapor extraction and air sparging is being applied as a method for source remediation. However, it was further studied and analyzed to determine the appropriateness and applicability at FS-12. To determine the most efficient method to contain and control the migration of the leading hedge of contaminated groundwater, two techniques were analyzed: pump and treat of the contaminated water and the permeable reactive wall. To correctly evaluate the various remediation techniques the “do nothing” alternative was analyzed as the baseline for comparison. In light of the do nothing alternative, the possibility of alternative water supplies were also studied. A cost-benefit analysis was conducted for the entire MMR to determine and compare the value of remediating the site and of using alternative water supplies. In addition, the public perception of treated drinking water was surveyed and evaluated.
The extensive investigation produced various answers and insights regarding the different remediation alternatives, the possible alternatives for water supplies including the public perception. The results of this study are summarized below:

- The flow field is directed in a southeastern direction. The spreading and migration of the plume follows the groundwater flow. Thus the plume does not have any significant effects on Snake Pond. The simulation resulted in safe levels of contamination in the pond. In addition, it was determined that the plume, if left untreated, would eventually reach the other water bodies in the East, particularly Mashpee Pond. However, this does not pose any serious threat as the contaminants level would be very low, thus safe.

- Natural restoration (i.e. do nothing alternative) of the FS-12 site could be an attractive clean-up strategy given the high costs associated with active remediation of contaminants. Due to a lack of information, further investigations would be needed to quantitatively assess the consequences of this strategy

- The air sparging/soil vapor extraction design for the remediation of the FS-12 source area was found to be highly effective. The number of wells and their radii of influence were determined to extend over a five acres area for an effective remediation of the source and corresponding free product. However, the time of required to reach the MCL level of 5 ppb, was determined to be 9 years as opposed to 2 years as suggested by the IRP study.

- The proposed method of containment is pump and treat. A pump and treat system consisting of an extraction well fence and granular activated carbon was found to be appropriate. The recommended design includes eleven extraction wells surrounding the toe of the plume and pumping at a rate of 800 gallon per minute.
• The reactive wall could not be used to degrade benzene. It was found, however, to be an excellent alternative for the remediation and control of EDB. In the final containment design the reactive wall could not be applied because of the extreme depth of the plume.

• One objective of the plume containment scheme is to protect the Upper Cape water resources. However, only a very small fraction will be preserved by the proposed plan. In addition, the scheme does not address the major constraint on future water supply expansion - the lack of accessibility to groundwater due to land development. In this respect, there is a clear need to protect groundwater resources by establishing zones of groundwater protection, and land acquisition near wellfields.

• The public perception and acceptability of drinking treated groundwater was investigated by interviewing members of the Long Range Water Supply Process Action Team and Team 2. The perception and acceptability of treated water by the public is very important for developing future water sources. Currently, the local residents are not willing to drink treated water from the MMR or from the treatment of existing wells. In the future, educational programs can be implemented to increase the public acceptance of this idea.

• One of the greatest myths about the current operation of the MMR remediation 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 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 a cost of only $10 million. 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 human and nonhuman species. Another underlying objective is driven by political and economic motivations: the reduction of perceived risk that may cause extensive damage to the Upper Cape's quality of life and economy. The question that policymakers need to address is how much society and taxpayers are willing to pay now to protect the cleanliness of groundwater supplies for unspecified future uses and the assurance of knowing that the groundwater is clean.
REFERENCES


Appendices are the individual theses of each of the group members. These theses can be acquired through the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology.

Appendix A: Dimitris Traintopoulos

Appendix B: Karen Jones

Appendix C: Vanessa Riva

Appendix D: Holly Goo

Appendix E: Judy Gagnon

Appendix F: Christophe Bosch
Appendix B: Breakdown of Tetrachloroethene to Vinyl Chloride
The breakdown of this volatile organic compounds is a systematic breakdown. The
above figure is a simple diagram of this degradation process. For a more detailed
description of this degradation can be found in Skiadas (1996).
Appendix C: Formulas Used to Calculate Required Wall Thickness
1. Calculate reaction rate \( k \) using half life time in reactive media (time_1/2) using

\[
c(t) = c_0 e^{-kt},
\]

where \( c_0 \) is the initial concentration of the contaminant and \( c(t) \) is the concentration at time \( t \).

2. Using the value \( k \), calculate the required time \( t_{req} \) in the reactive media

\[
c_{MCL} = c_0 e^{-kt}
\]

where \( c_{MCL} \) is the maximum allowable contaminant level.

3. Use the calculated time required, find the required thickness \( b \) of the wall given a unit surface area \( A \), wall porosity \( n \), and flowrate \( Q \).

\[
b = \frac{Qt_{req}}{An}
\]
Appendix D: Various Configurations for Implementing the Reactive Wall
Figure 1: Simple Reactive Wall Configuration

![Figure 1: Simple Reactive Wall Configuration](image)

(Blowes et al., 1589)

Figure 2: Fully Penetrating and Hanging Gates

![Figure 2: Fully Penetrating and Hanging Gates](image)

(Starr and Cherry, 466)
Figure 3: Funnel-and-Gate Configurations

(Starr and Cherry, 466)
Appendix E: Funding the Environmental Technologies Center: Massachusetts Military Reservation (Cape Cod, MA)
This paper is a work in progress. But this paper does contain key information about additional state and federal programs which support the development and demonstration of technologies. Also available in this document is specific amounts available to fund technology developers.
FUNDING THE ENVIRONMENTAL TECHNOLOGY CENTER:
MASSACHUSETTS MILITARY RESERVATION
(CAPE COD, MASSACHUSETTS)

Holly S. Goo
January 23, 1994
Prof. David Marks
Mr. Shawn Morrissey
Mr. Mark Forest
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Introduction

Environmental Technology Initiative & Environmental Technologies Bill
  Background
  Impact on the Environmental Technology Center at the MMR

Technology Demonstration Programs

Technology Demonstration Programs
  McClellan Air Force Base, California
  Canadian Forces Base Borden, CANADA
  North Island Naval Base, California

Environmental Technology Programs

Federal Programs
  U.S. Environmental Protection Agency
  Department of Commerce
  Department of Defense
  Department of Energy
  National Science Foundation
  Small Business Administration

State Programs
  Strategic Environmental Partnership
  Other State Programs and Initiatives

International Environmental Programs
  Japan
  Canada
  European Community

Appendix A: Environmental Technology Center Statement of Mission
Appendix B: Environmental Technology Center White Paper
  (provided by Foster-Miller)
Appendix C: Summary of the Environmental Technologies Bill
Appendix D: Pertinent Excerpts from the Environmental Technologies Bill
Introduction

At the Massachusetts Military Reservation (MMR) in Cape Cod, Massachusetts, the Innovative Technology Process Action Team (ITPAT) proposes an Environmental Technology Center (EnviroTech Center). Earlier this year, Congress appropriated $1 million for the planning of this center. This research involved identifying programs and related initiatives that would support the proposed EnviroTech Center.

The research included looking at the Clinton Administration’s Environmental Technology Initiative (ETI) which is to be led by the U.S. Environmental Protection Agency (EPA). In addition, a review of the proposed Environmental Technologies Bill that is currently passing through Congress and analysis of its possible effects it may have on the EnviroTech Center were completed. The main portion of the research was to identify state and federal programs and funds available to support an environmental technology center at the MMR. The report has also included information on a few technology development centers, including McClellan Air Force Base and Canadian Forces Base Borden. Finally, the report concludes with a summary of a few environmental ministries of different industrialized countries.

The information sources for this project has been organized in binders located at the Ralph M. Parsons Laboratory at the Massachusetts Institute of Technology (Cambridge, MA).
ENVIRONMENTAL TECHNOLOGY INITIATIVE AND ENVIRONMENTAL TECHNOLOGIES BILL
Environmental Technology Initiative

The EPA led Environmental Technology Initiative (ETI) was announced by President Clinton on February 17, 1993. Through the promotion of technology development, demonstration, and commercialization will be promoted, the initiative hopes to improve environmental quality as well as foster job and business growth. This EPA-led effort will coordinate the efforts of federal agencies, academia, and businesses of all types.

Environmental Technologies Bill

As a result of this initiative, the Environmental Technologies Bill has been proposed in Congress. Through this bill, the framework is outlined for numerous programs and incentives (in the form of recognition awards) for the development, demonstration, and commercialization of innovative environmental technologies. Most of these programs will be headed by the EPA, but a few will be led by the Department of Energy (DOE) and Department of Commerce (Commerce). In addition to these programs, the EPA will coordinate the technology and environment efforts of DOE and the Department of Defense (DOD) with their own for maximum efficiency and effectiveness. Further summary of the Environmental Technologies Bill can be found in Appendix C.

Application to the MMR and the Environmental Technology Center

With this developing interest in innovative environmental technologies and the continuing efforts to restore the MMR, an EnviroTech Center has been proposed. Through this Center, programs are planned to support development, demonstration, and commercialization of environmental technologies and processes. While the organization of the structure has not
been finalized, the proposed center includes representatives from EPA, the Installation Restoration Program, Massachusetts Department of Environmental Protection, as well as the environmental managers from the U.S. Air Force and Army. It is hoped that housing these integral members of the MMR restoration efforts in a single building will provide a more effective and efficient cleanup process. Foster Miller has voluntarily completed a summary of the programs to be offered by the EnviroTech Center, as well as proposed an organizational structure (Appendix B).

With the Administration's interest in remediation of the environment, preservation of environmental integrity and development of environmental technologies in international markets, this is a key time to lay the foundation for the proposed EnviroTech Center. The momentum started by the ETI has increased awareness of the technology needs and developments in the area of environmental remediation technologies. But beyond the general support of the Administration, funding is a key concern.

In order to fund such a center, sources must be identified and legislation must support such initiatives set forth for the EnviroTech Center. Not only does the Center provide a means for developing innovative environmental technology, but also for demonstrating these promising technologies and educating students in a real world situation. The Environmental Technologies Bill is a start to identifying programs to support the EnviroTech Center. As mentioned earlier, the bill outlines numerous support programs led by the EPA, DOE and Commerce. Other funding and support programs, federal and state, are discussed later in the program.
TECHNOLOGY DEMONSTRATION PROGRAMS
There are similar technology centers to the EnviroTech Center located in the U.S. and worldwide. While their centers are similar to the EnviroTech Center, the programs offered through the proposed center is unique. This center would provide the opportunity for both technology development and demonstration on site. In addition, educational programming is another key value to this center. Further description of the objectives for the Center is located in Appendices A and B. Mentioned below are a few of the prominent centers that also demonstrate environmental technologies.

McClellan AFB, California

MARK FOREST WILL SUPPLY INFORMATION

Canadian Forces Base Borden, CANADA

The Canadian Forces Base Borden (Borden) is being used as a demonstration and test site for technologies. Many entities are involved in the testing and demonstrations of technologies on Borden. These include University of Waterloo, Stanford University, State University of New York at Buffalo, and Environment Canada. But, the owner and ultimate authority for this site is the Canadian Department of National Defense. Regulatory approval is linked with site management. As of 1992, Environment Canada has become heavily involved in the regulation of the testing activities on the base. Further discussion of Environment Canada will follow in a later section under International Programs.

North Island Naval Base, California

MARK FOREST WILL SUPPLY THE INFORMATION
ENVIRONMENTAL TECHNOLOGY PROGRAMS:
FEDERAL AND STATE PROGRAMS
Both the federal government and the Commonwealth of Massachusetts offer numerous programs that support different aspects related to innovative environmental technology and technology transfer. Support and funding is available for development, demonstration, evaluation, and commercialization of environmental technologies. Described below are programs that directly relate to the planned programs for the EnviroTech Center at the MMR. This section has been separated into federal and state programs. Each program details (as much as possible) its objectives and priorities, funding available, and application process for funding. Summary of funding sources and amounts are summarized in Table 1.

Table 1. Summary of Possible Funding Sources for the EnviroTech Center

**** Table to be completed ****

Federal Programs

The federal government offers numerous programs through many of its agencies. These agencies include the EPA, DOD, DOE, Commerce, and the National Science Foundation (NSF). In addition, the Small Business Administration also has its own programs which include partnerships with other agencies to aid small businesses. Furthermore, some of the agencies have established joint programs; such as the Superfund Environmental Research and Development Program (SERDP), to maximize efficiency and effectiveness of technology development and application.
U.S. Environmental Protection Agency

The EPA supported multiple related programs. While some provide funding for different aspects of environmental technology development and demonstration, other programs serve as think tanks as a means of support.

Environmental Technology Initiative

This Environmental Technology Initiative (ETI) is fairly new, having been established by the Clinton Administration in 1993. The ETI has, as its charter, the development, evaluation, demonstration and commercialization of innovative technologies; it also provides assistance and guidance to firms in bringing their product to market. The funding for this program is provided by the EPA from Congress. The funding allotted for this program in fiscal year 1994 was $36 million. This program focuses both on environmental policy and technology issues.

The priority policy areas focus towards technology innovation and economic competitiveness. This includes adapting the EPA’s policy framework to promote innovation, as well as strengthen the capacity for developers and users the ability to succeed in environmental technology innovation. This was promoted through investment of EPA funds into technology development and commercialization of promising technologies. The ETI is to also assist in the diffusion of these innovative technologies.

In terms of primary themes of the ETI in 1994, there was a focus on Environmental Restoration Technologies, Clean Technologies for Small Business, Improving Competitiveness of US Environmental Technologies, and Gaps, Barriers, and Incentives to Environmental Technology Innovation. The ETI accomplishes these primary objectives by funding various programs,
each of which is involved in the development of a number of individual technologies.

Of these four themes, the area of significant interest to the EnviroTech Center is the Environmental Restoration Technologies area. This area can then be further categorized into three subcategories; (i) Monitoring, (ii) Control Related Technologies, and (iii) Remediation-Related Technologies.

In terms of application for these funds, proposals must address critical needs of individual and/or multiple EPA programs. In addition, funding is allotted proportionally to how promising a technology seems and how likely it is to spark a technological breakthrough.

Office of Technology Assessment

The Office of Technology Assessment (OTA) is a policy oriented think tank who examines existing programs and large scale issues surrounding technology development and implementation. There is no direct funding for technology development, demonstration, evaluation, or commercialization of environmental technologies. However, the OTA supports various federal agencies with technology assessment studies. In addition to technology assessments and technology demonstration and implementation studies, the OTA is also involved in the analysis of other environmental programs including the EPA's SITE program. Many times these program analyses are delivered to Congress for their use.

Superfund Innovative Technology Evaluation Program

The Superfund Innovative Technology Evaluation (SITE) Program was established in 1986 by the EPA. In this program, the EPA enters into cooperative agreements with technology developers to refine their
innovative technologies at bench- or pilot-scale and/or demonstrate them with EPA support, at hazardous waste sites. In addition through the SITE program, EPA collects and publishes engineering performance and cost data to aid future decision making for hazardous waste site remediation. In addition, the program supports two main functions, providing financial support of promising emerging technologies and supporting demonstrations of viable technologies.

The funding for this program is between $10- $15 million from which approximately $2 million allocated to emerging technologies. The identified priority areas are biological technologies, physical/chemical technologies, materials handling technologies, solidification/stabilization technologies, and thermal technologies.

In support of emerging technologies, the program aids developers (i.e. not for profit organizations, small businesses, etc.) with limited financial resources to receive EPA funding for testing and evaluation of their technology, which appears to work based on limited operating data. Each September pre-proposals are submitted, from which about 20 are invited to prepare a formal detailed cooperative agreement proposal. From these agreements, 10-15 proposals are selected; each receiving approximately $150,000 a year for two years for the purpose of testing and monitoring the technology.

To support the demonstration of viable technologies already matched with a testing facility, the SITE program helps formulate a test and operation plan and a monitoring plan to evaluate the system performance. At the end of testing each system, a newsletter is published documenting its performance. No direct monies are made available to the developer(s), but the EPA does spend its own resources in the test, monitoring, and evaluating
phase. For application for this support, proposals are received throughout the year. Successful proposals are usually already matched with a testing facility. In addition, preference for funding is given to those technologies with a good probability of being the most cost effective and leading to technological breakthroughs.

Technology Innovation Office

The Technology Innovation Office (TIO) defines innovative technologies as technologies that, due to a lack of published operating data, have a diminished use at remediation sites. The TIO's goal therefore is to disseminate this information to the user community (Project Managers at the Federal, State and private level). In other words, the TIO is essentially an information broker and/or technology advocate. In fact, they publish the VISITT database program among other things.

Their implicit goal is technology commercialization. TIO's focus is a 50-50 split between remedial technologies as applied to water and dirt.

The total funding for this program is $5 million. This office works closely with the EPA's Office of Research and Development. In addition, many people requiring funding apply after having participated in the SITE program.

Clean Sites, Inc.

This nonprofit organization is a separate entity that is in agreement with the EPA's Technology Innovation Office (TIO). The current role of this organization is to facilitate information exchanges and cooperative efforts among the private and public sectors. One example of cooperation among the
public and private sectors is the encouragement of third party evaluation. Their priority area is remediation of federal facilities.

The overall goal of Clean Sites is to collect and transfer meaningful cost and performance information on innovative technologies and treatment trains that are tested under real-world, full scale conditions while at the same time fitting into the facility's existing restoration program. The funding of the organization is from multiple sources including to the EPA's TIO, which amounts to $6 million. As for portioning out funding, Clean Sites is selective in choosing their technology development projects and currently has four "partnerships" (including McClellan AFB, CA; Pinellas Plant, FL; Lasagna Project, KY). It is strongly anticipated that their fifth partnership will be at the MMR regarding the Reactive Wall from the University of Waterloo; their sixth partnership is expected to be North Island in San Diego, California.

As for the actual programs offered through this organization, they pick up where the EPA's SITE program leaves off. Clean Sites' strategy is very broad based as the technology or process units would be designed and constructed to remediate an entire site or significant portion thereof. Evaluation of the full scale cleanup technology is undertaken until the necessary performance and cost information is obtained. At that point, a joint decision is made by the stakeholders as to whether the technology is to be for the remainder of the site.

Department of Commerce

The Department of Commerce (Commerce) has numerous programs available relating to development and commercialization of innovative environmental technologies. They also play a leading role in administering interagency efforts.
The National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) office of Ocean Resources and Assessment's Coastal Resources Coordination (CRC) Program provides technical assistance and support to many aspects of the EPA's Superfund Program. These areas include site characterization, ecological risk assessment and remediation. Funding from this office is usually site-specific; however there is funding for broader research and assessment projects.

The International Trade Administration

This Administration is implementing a strategy that promotes the domestic and international competitiveness of U.S. environmental technologies. However, it does not involve itself in the development and demonstration of innovative environmental technology. In terms of funding through this office, none is available, but there is a mandate for this.

Economic Development Administration

The Economic Development Administration (EDA) supports demonstrations of technology initiatives. This is usually in the form of grants. Support is available for technology innovation, transfer, and commercialization. While this program does support and funds these functions, there is no specific environmental technology aspect to it.

National Institute of Standards and Technology (NIST)

This Institute offers twelve programs ranging in focus from technology funding programs and licensing to technical support to publications. Two of
particular interest to the planned EnviroTech Center would be the Advanced Technology Program (ATP) and the Manufacturing Extension Program (MEP).

**Advanced Technology Program**

Under NIST, this program provides funding to single businesses and industry-based joint ventures for technology development through cooperative research agreements. ATP gives funding to for-profit organizations of all sizes. Non-profit organizations can participate in ATP projects as subcontractors or administrators of joint ventures. Application for funding is a highly competitive process whereby projects are selected on both their technical and business merit.

Recipients of funding must share in the costs of ATP projects. The funding provided by the ATP is for the development of a laboratory prototype rather than product development. In addition, funding can be awarded to prove technical feasibility, but not commercialization. In fact, individual companies can receive up to $2 million over three years for direct use on only research and development costs. Meanwhile, the joint ventures can be for up to five years, but must still provide over 50 percent of the resources for the project.

**Manufacturing Extension Program**

The Manufacturing Extension Program (MEP) was established to support U.S.-based manufacturer in increasing their competitiveness nationally and internationally through ongoing technological advancements. This program consists of four major elements: Manufacturing Technology Centers (MTCs), satellite operations affiliated with MTCs, State Technology Extension Program (STEP), and the Link Program. MTCs are regionally based
centers that provides hands-on technical assistants to manufacturers. Through a cost share program, the NIST will also fund 50 percent of the cost for facilities for satellite operations affiliated with MTCs. Again through a cost share program, the NIST will fund 50 percent of the cost of the STEP program, which provides grants to help states build an infrastructure necessary for technology transfer efforts. The LINK Program pulls together (electronically) information on a local network.

Other Programs of Interest

The NIST also has a SBIR program which offers small businesses up to $50,000 for Phase I projects and $250,000 for Phase II projects. In 1994, NIST made 30 Phase I and six Phase II awards, totaling to approximately $3 million. By 1997, the program expects the total SBIR awards to amount to $18 million.

Department of Defense

Waiting for information to be sent from Department of Defense.

Department of Energy

Like the EPA, the Department of Energy (DOE) is a large funding source for support of the development of environmental technologies. In fact, they have set a goal to have all DOE facilities within EPA regulations by the year 2019. The program described below supports various aspects of technology development.
Office of Technology Development

Within the Office of Environmental Restoration and Waste Management of the Department of Energy (DOE), the Office of Technology Development (OTD) focuses on research, development, demonstration and technology evaluation (RDDTE) of innovative environmental technologies. The OTD has the five following "focus areas" or priority areas for their funding: (i) Contaminated Plume Containment, (ii) Mixed Waste Characterization, Treatment, and Disposal, (iii) High Level Waste Tank Remediation, (iv) Landfill Stabilization, and (v) Facility Transitioning, Decommissioning, and Final Disposal. Development efforts have been split into two parts, integrated demonstrations (IDs) and integrated programs (IPs). IDs aim to address the problems at a particular site using combinations of technologies, while IPs focus on specific technology needs for common environmental problems of the DOE.

The funding to this office has increased from $385 million for fiscal year 1993 to $418.8 million for fiscal year 1995. Of particular interest to the EnviroTech Center is the funding amount to the Contaminated Plume Containment focus area. For this past fiscal year 1994, about $100 million dollars was allotted to this focus area. Applicants for these funds include states, Indian tribes, regional organizations, affected local governments, secondary education institutions with Office of Environmental Management related programs, two-four year higher education institutions, private non-profit organizations, and unaffiliated individuals.

The main application process begins with a "Call for Technical Task Plans" in the Federal Register or Commerce Business Daily. This will outline the identified environmental technology needs of the DOE. Unsolicited proposals are also welcome. In addition, if a further technology or research
need arises, a announcement for proposals will be printed in the Federal Register and the Commerce Business Daily. Other opportunities for funding sources is subcontracting through the DOE national laboratories and operating contractors.

**National Science Foundation**

The National Science Foundation (NSF) also provides the sources of funding for environmentally related technology and process development in the particular areas of remediation and restoration technologies and pollution avoidance and control. This past fiscal year (1994) NSF has allotted $26 million dollars to academic institutions, nonprofit and small businesses, as well as large profit oriented companies (usually in conjunction with university researchers). Proposals are accepted year around with no major call for proposals like many other agencies. The proposals are then peer reviewed. If approved, funding is allotted in the form of three year grants. The actual amounts awarded is on a project-to-project basis.

**Small Business Administration**

This Small Business Administration (SBA) provides support, financial and otherwise, to ensure that small business are able to compete with larger businesses and to bring their promising technologies to demonstration level. Most of the funding for this program is through the ETI mainly for the purposes of education and technology transfer. The technology priorities are identified by the "common sense initiative."

In addition, the SBA has a Memorandum of Understanding (MOU) with the EPA to "ensure that the U.S. Government effectively encourages, supports and enables U.S. small businesses to develop market and/or adapt cost-
demonstrate technologies and processes for a more effective and efficient cleanup of soil, sediment, surface water, and structures with hazardous waste. Application for this funding is in response to the Requests for Proposals (RFPs) printed in the Commerce Business Daily. Unsolicited proposals are also welcome. While the lead research must be from a federal entity (for example a federal research lab), businesses of all types and academia can link up with these federal research bodies. Other partnerships and agreements come in the form of Technical Assistance Agreements and Cooperative Research and Development Agreements (CRADAs). Additional funding sources include the annual Congressional earmarks from those funds allocated to SERDP. It has been predicted that there will be no general call for proposals during FY95 and a limited call in FY96.

State Programs

The Commonwealth of Massachusetts is also supportive of developing innovative environmental technologies. In addition, the state government is aware of the developing industry of environmental technologies. Thus, they are currently developing programs to keep the Commonwealth of Massachusetts up-to-date and competitive nationally and internationally.

Strategic Envirotechnology Partnership (STEP)

The Strategic Environmental Partnership (STEP) is a recently established state program that is a combined effort by both the Commonwealth of Massachusetts Executive Office of Environmental Affairs and the Executive Office of Economic Affairs, as well as the University of Massachusetts (UMass) system. The goals of this program are to assist in the development, assessment, and demonstration of innovative environmental
effective environmental technologies." In this regard, the SBA is a watch dog for the small business community. However, through this MOU there is no available funding.

As for an application process, there is not one specifically for SBA support. However, it seems as if they submit joint Requests for Proposals with the EPA for technology transfer.

Joint Agency Programs

A few joint federal agency partnerships have been established over the years to aid each other in combating similar environmental problems, in particular the Strategic Environmental Research and Development Program (SERDP) which combines the efforts of the Department of Energy (DOE), Department of Defense (DOD), and the U.S. Environmental Protection Agency (EPA). The goals of these federal partnerships is to expedite the development process, as well as avoid repetition of research efforts.

Strategic Environmental Research and Development Program - EPA, DOD, DOE

As mentioned earlier, the SERDP program combines the efforts of three federal agencies: the EPA, the DOE, and the DOD. Over the past three years the budget has decreased from $180 million in fiscal year 1993 (FY93) to $61.9 million in fiscal year 1995 (FY95). The funds are distributed among six major "thrust areas": (1) Global Environmental Change, (2) Alternate Clean Energy, (3) Cleanup, (4) Pollution Prevention, (5) Compliance, and (6) Conservation. The thrust area that pertains to the planned efforts of the EnviroTech Center is the Cleanup thrust area. In FY93, this area was allotted over $30 million, while in FY95 the projected allocation is near $15 million. The goals for this thrust area are aimed to develop, identify, improve, and
technologies. In addition, this partnership hopes to support and stimulate the environmental technologies market and commercialization through partnerships with federal agencies.

Already $9 million dollars in open space bonds has been designated to the Boston, Dartmouth, and Amherst campuses of UMass system to set up the technology centers and fund the research at each of these campuses. The technology centers have set a portion aside to hire personnel for the Technology Review Board. This Board along with the Energy Technology Review Panel will review proposals seeking funding on a merit based system. While the innovative technology research seems to be channeled through the UMass campuses, industry and organizations can become involved during the independent assessment and monitoring phases of the development of these technologies.

Other State Programs and Initiatives

Information on other state programs and initiatives are forthcoming.
INTERNATIONAL PROGRAMS
Numerous countries have become more environmentally conscious in the past decade. Many have set up environmental ministries which analyze current environmental situations within their own borders, as well as globally. This section is to contrast the environmental programs to our own. In particular, we are looking at Japan, Canada, and the European Community.

Japan

Currently Japan, along with Germany, have been identified as the leader in innovative environmental technologies. Japan has organized a Environment Agency within its government structure, but in actuality the bulk of the funding for environmental technology development falls under the Ministry of International Trade and Industry (MITI). The focus of the research and development efforts, supported by government funding, is in the area of renewable energy and environmentally and economically effective manufacturing processes.

In particular, MITI manages two programs heavily involved in research and development: New Energy Development Office (NEDO) and Research Institute of Innovative Technology for the Earth (RITE). NEDO has a tight relationship with industry, where most of the research and development is handled by industry and little by national laboratories. Meanwhile RITE is a program that involves numerous partnerships including industry and academia with funding for the projects in the form of matching grants from the government. The total fiscal year budget for NEDO is $1.76 billion with approximately $77 million directly focused on environmental technologies. As for the RITE program, their fiscal year budget was $88 million with $60 million from the $77 million NEDO funding allotted for environmental technologies. The successful technology developments from
these programs can be easily commercialized through other agencies within MITI to export this commodity.

Germany
INFORMATION TO BE SUPPLIED THROUGH MARK FOREST

Canada
Canada’s programs is somewhat similar to the United States. Comparable to the EPA, Canada has an agency, Environment Canada, that oversees much of the cleanup and other environmental efforts. Currently Canada has a program in place, ____________________________ ( ), which is similar to our Superfund program. The Government of Canada has devoted $125 million to this program, while the individual provinces have given $125 million to make the total budget for the cleanups $250 million. The 50/50 cost share is one identifying feature of this Canadian program. Beyond this $250 million, the Environment Canada has allotted another $25 million to cleanup the severely contaminated federal crown lands.
Appendix A: Statement of Mission for the Environmental Technology Center at the MMR
MISSION STATEMENT
ENVIRONMENTAL TECHNOLOGY CENTER

The Environmental Technology (EnviroTech) Center will be organized at the Massachusetts Military Reservation (MMR) to assist in the development of innovative technology in the fields of monitoring, investigating, remediating, operating, characterizing, and containing contamination on the base. The EnviroTech Center will combine the efforts of the tenants of the MMR, which include Massachusetts Air National Guard, Massachusetts Army National Guard, U.S. Air Force, and the U.S. Coast Guard with the efforts of the U.S. Environmental Protection Agency, and the Massachusetts Department of Environmental Protection. Along with educational institutions, private businesses, such as the Small Business Innovative Research (SBIR) and the Regional Employment Board; and local employment and training agencies, including Bay State Skills and Job Training Center, will provide integral support of this process.

The Center will be a coordinated effort initially led by the Innovative Technology Process Action Team, which represents a cross section of the private and public sectors. The EnviroTech Center will attract financial and technological support from various sources and combine these efforts with government agencies and the military. By placing all parties in one building and coordinating their efforts, the Center will increase the efficiency and cost-effectiveness of the remediation process. To complement these improvements, the Center will also contain the necessary materials and facilities; such as computers and laboratories.

In addition to expediting the remediation process, the EnviroTech Center will provide educational and employment opportunities. Schools, such as the Massachusetts Institute of Technology, the University of Massachusetts, Cape Cod Community College, and the Massachusetts Maritime Academy, will offer internship programs at the Center to provide hands-on experience to their students interested in the environmental fields. This Center will also provide new job openings of all types to the Cape Cod community. As a result, not only will Cape Cod be known as a beautiful vacation place, but also as a leader in environmental technologies.
Thus, the EnviroTech Center has set forth the following goals:

1. Develop and use improved technology for more efficient and effective remediation efforts on the MMR.

2. Coordinate the innovative technology efforts of private industry and government agencies in monitoring, investigating, remediating, preventing, characterizing, and containing contamination on the base.

3. Provide a central building which brings together all parties and materials necessary for successful development and employment of remediation technology.

4. Train future environmental workers, including engineers and technicians, through real world experience.

5. Become a respected source of information in the fields of monitoring, investigating, remediating, preventing, characterizing, and containing contamination in similar circumstances.

The Center hopes to serve as an example of a positive working relationship among the military, government agencies, the academic community, and the private sector for the benefit of Cape Cod and the United States as a whole. In addition, the EnviroTech Center hopes to become a recognized source of information nationwide, if not worldwide. With the movement towards preserving the environment, we believe this Center will be a significant contributor to the field of environmental remediation and contamination prevention.
Need to evaluate/determine space requirements before contracting for design of a building.

Need to do above independent-partially within PAT, but need someone committed ($10K/6 months)-then responsible for reporting to PAT.

Need large contractor (Stone and Webster) after planning for details and final design/construction.
Appendix B: White Paper on
Environmental Technology Center at the MMR
(Completed by Foster Miller)

DRAFT VERSION
Statement of Need

(1) Accelerate the demonstration, certification, and deployment of new and emerging environmental technologies for Containment, Monitoring, and Remediation for the purposes of:

a) Enabling complete restoration of contaminated sites (such as MMR) which are beyond the capability of current available technology. New technologies are needed to approach the goal of total clean-up.

b) Reducing the staggering potential cost of C, M, and R at the large number of contaminated sites across the nation.

c) Promoting the growth of area businesses, jobs, export potential, education, and technology transfer.

d) In keeping with the Administration's sustainable development initiative it is the objective of this program to accelerate the market entry of indigenous American environmental technologies.

(2) Current barriers to acceptance of new technologies for C, M, and R are:

a) Lack of access to suitable demonstration sites in EPA Region 1 for innovative organizations.

b) Difficulty and length of time associated with obtaining EPA certification for new technology. California is addressing this via legislative initiative AB 2060 which, while accelerating the acceptance of new technologies in California, will do little to insure their use in other states.

c) Limited interaction/cooperation between technology innovators and technology users (major remediation contractors).

d) Liability/risk associated with use of new and unproven technology at contaminated sites. This discourages major remediation contractors from trying new technology.

e) Public resistance to new and unproven technology -"not in my backyard".

f) Lack of government funding to bridge the gap between development and deployment combined with lack of private financing.
due to uncertainties and delays associated with certification and acceptance of new technology.

(g) Limited availability of reliable performance data under realistic field conditions.

Goals and Objectives

In order to meet the need and overcome the barriers described above the Innovative Technology PAT is proposing to establish an EviroTech Center at MMR, the primary objective of which is to assure the fast track deployment of innovative US. environmental technology. Specific objectives of the Center are as follows:

1) Support and facilitate the demonstration, evaluation, and verification of new technologies with potential for direct economic or environmental impact at MMR. This would include technologies which would reduce the cost of containment and monitoring as well as those which would enable remediation of existing plumes and associated source areas for which no known methods are adequate. This objective would require the identification and capture of funds both to establish and operate the Center and also to fund selected demonstration programs (jointly with industry).

2) Facilitate and assist in the demonstration, evaluation, and verification of new technologies of indirect benefit to MMR, which have potential for broad impact at multiple sites and, for which, the conditions (e.g. soil, types of contaminants, concentrations, etc.) extant at MMR would enable a conclusive demonstration. The Center would provide access for demonstration and independent verification of the technology. The Center would also provide assistance in identifying funds (SBIR, TRP, ATP, SERDP, etc.) for demonstration purposes but would not fund these activities directly.

3) Consistent with objectives 1 and 2, the Center would establish an independent entity, within the center, with responsibility for measuring, verifying, and, to the maximum extent practicable, certifying the performance of technologies demonstrated at MMR. This entity would operate with the consent of and under the jurisdiction (via appropriate agreements) of both the Massachusetts DEP and the EPA region 1 Administrator. The primary objective of establishing this verification entity would be to accelerate the certification and use of new environmental technology.

4) Provide an educational, professional training, and informational resource to area businesses, universities, the military, and the public. This would involve.
a) Providing on-site student training in conjunction with area universities and technical institutes as part of Associate, B.S., or M.S., or ScD. Degree programs.

b) Creating an informational exchange forum to facilitate and encourage the formation of collaborative teams for demonstration and eventual implementation of new technologies, and to disseminate information on the performance of technologies.

- Meeting facilities
- Computernet
- Newsletter
- Informational Briefings
- Assistance in identifying team members, sponsors, regulators, etc.

c) Through the Technical Environmental Affairs Committee (TEAC) obtain public participation and support for the demonstration of innovative environmental technologies at MMR. Public participation will greatly accelerate acceptance and use of technology. The TEAC has become a national model for community participation in environmental remediation/policy decisions and provides a unique opportunity to explore new technology with the support and involvement of surrounding communities.

Additional subordinate objectives of the EnviroTech Center are:

(5) **Technology Development.** Although the primary objective of the Center is technology demonstration, in some cases, the Center may identify innovative technologies with potential major impact/benefits to the clean-up at MMR but which are not sufficiently mature for demonstration. The Center would allocate a small portion of its total funding, and/or assist parties in finding outside financing for laboratory scale evaluation of such technologies.

(6) **MMR Technology Fund.** An MMR technology fund is proposed using a combination of Federal, State, and Private Capital, which would assist in financing demonstration programs wherever necessary and invest in commercialization of technologies with significant domestic and export potential. In later years this fund could continue to operate and pay back investors via royalties and/or stock proceeds from successful ventures.

**Center Organizational Structure**

The Center organizational structure is illustrated conceptually in figure 1. The Center would be composed of several distinct and relatively independent elements reporting to a board of directors composed of representatives of each of the major stakeholders. At present 3 representatives from government
and 3 representatives from the private sector are proposed. The Board could be expanded to include additional stakeholders as required. Figure 2 shows how the center might be organized.

Administration. The Center administration would be responsible for coordinating the operation of the various groups as well as those of Center support contractors and would provide the primary interface with the Board of Directors. Each group would also interface directly with the Board at regular intervals. Administrative support functions associated with center operation (e.g. legal, contract administration, accounting, office services, etc.) would be subcontracted to a site support contractor. The Administration would also coordinate with the TEAC to obtain public review and comment on new technologies being considered for or evaluated by the Center.

Regulation. The Center regulation group would provide independent technical evaluation, verification, and certification of technology. In each area of technology pursued by the Center, an ad hoc working group composed of both center scientists and experts from the government and private sectors would be established. Each ad hoc evaluation group would be chaired by a dedicated Center representative who would be the primary interface with the Center administration and Board. The purposes of this ad hoc group would be:

i) Proposal evaluation and selection
ii) Establishment of performance objectives for Tech Demo
iii) Oversight of Tech Demo
iv) Review of data and interpretation of results
v) Independent verification of results using accepted EPA (CLP, RCRA, etc.) methods
vi) Approval of technology for use at DOIT sites (DoD, DOE)

The Center would subcontract for on-site laboratory analytical services to support objective (v). Specific technical evaluation tasks in support of objectives i) - iv) could be subcontracted to the Center technical support contractor at the discretion of the working group.

Technology Demonstration. The Demonstration Group would provide site access and support to collaborative demonstration programs selected by the Center. This group would be composed of a small core of full time Center staff either hired by the Center or assigned to the Center by the ANG. These full time staffers would be supported by the site technical support contractor and additional MMR ANG employees as required. Each demonstration program would be assigned a program manager from either the Center, the ANG, or the technical support contractor. The PM would supervise planning
and coordination of site demos, oversee the conduct of the actual demos, provide facilities and technical support to teams, and assist the teams in liaison with the independent ad hoc evaluation working groups. The PM would also provide regular progress briefing to the Center administration and the Board. The PM would be responsible for participating in TEAC briefings when and as requested by the Center Administration.

**Education.** The Center would obtain funding from a variety of sources to support an educational component consistent with objective (5). The Educational component would develop course and event curriculums in support of Associate, B., and/or M.S. degree programs at area Colleges and Universities. Initial curriculum development would be supported by the Center. Once established, the students and their institutions would reimburse the Center for a major portion of the cost of their course programs. As a not for profit entity the Center could also seek tax deductible grants or endowments to support the educational component. The development and operation of the educational component would be lead by MIT (and U of Mass??).

The Center would also provide support and assistance for the formation of collaborative enterprises whose primary objective is technology demonstration. In support of this objective the center would provide meeting facilities, publish a newsletter, assist in computer networking of Center participating organizations, informative technology seminars for both participating organizations (for payment) etc., etc. *Needs input from Ann and Shawn.*

**Funding Assistance.**

A separate funding assistance component would be established to assist team collaboratives in organizing and costing proposed projects and in identifying funding sources for the demonstration of innovative technology. The Center also intends to play a major proactive role in identifying both government and private sector capital to finance demonstration projects. In addition, the Center would entertain externally funded collaborations (in other words teams which have already identified possible funding sources and need access primarily to a demo site and a certification entity).

It is anticipated that substantial government funding would be made available through a combination of reprogramming of MMR funds (a cut of the top of each contract awarded by the IRP office) and new allocations of IRP or ANG funds. Additional government funding could flow from Congressional initiative H.R. 4799 either by direct appropriation for MMR or indirectly via programs such as the TRP, ATP, SERDP or other similar programs yet to be established. All of these programs would require some
form of private sector cost sharing. Additional discussion on center financing is provided in the following section.

**MMR Technology Fund.** An MMR technology fund is proposed using a combination of Federal, State, and Private Capital, which would assist in financing demonstration programs wherever necessary and invest in technologies with significant domestic and export potential. In later years this fund could continue to operate and pay back investors via royalties and/or stock proceeds from successful ventures.

For the fund to successfully attract investors it will have to be managed by well known and respected members of the venture capitalist community, and The Center will have to adequately address the current barriers to commercialization (primarily certification) which exist in the environmental arena.

A similar approach is being pursued in California. Massachusetts has a successful track record of attracting investment in biotechnology, where return on investment is comparatively long term. These models will be evaluated for possible application to the MMR Center.

**Support Contractor(s)**

The center would subcontract for administrative/office, contracts, legal, laboratory analytical, and technical support as described previously. Preferably all required services would be provided by a single site support contractor. This would minimize the number of full time and/or ANG employees assigned to the center.

**Technology Thrust Areas**

The PAT has identified five technology thrust areas for the Center which we have attempted to list in descending order of importance in terms of perceived impact at MMR:

a) **In situ containment** refers to innovative technologies which isolate, contain or immobilize contaminants to retard or prevent migration to the surrounding environment.

b) **In-situ Remediation** refers to innovative technologies for treatment of contaminated soils or groundwater without removal from the subsurface including removal of contaminants with minimal or no excavation and in-situ degradation or neutralization of contaminants.
c) In-situ Characterization, Sensors and Monitoring refers to innovative technologies for on-site determination of contamination levels in air, soil, and groundwater. This includes both surface and subsurface measurements.

d) Water treatment/purification includes innovative alternatives for the treatment and purification of contaminated municipal or private drinking water supplies primarily with the objective of reducing the cost of such purification.

e) Soil treatment/decontamination includes innovative alternatives to conventional soil treatment options such as incineration or thermal desorption. These options (as distinct from item b) would involve excavation, treatment and replacement of contaminated soils.

In the event the Center concept is endorsed by the ANG, the PAT recommends that a Center Steering Committee be established which would oversee incorporation of the Center, select the Board of Directors, establish rules of operation, pursue funding, and also set up independent ad hoc working groups in each of the five technology thrust areas. These independent working groups would then identify and recommend specific innovative technologies for demonstration/deployment at MMR.

Center Financing

Two types required

- Funding for center set-up, operation and maintenance
- Funding for individual technology demonstration projects.

We need to identify rough dollar amounts by year for Center Operation and Demo Projects.

We also need to specify how long the Center will have to be in operation in order to fulfill its mission (not less than 5 years and not more than 10). How is total government funding in the Center expected to decline with time as private sector funding increases? What will be the government payback in terms of reduced clean-up cost over the life of the MMR project?

Possible Sources

Government

- ANG reprogramming (tax on IRP)
- Funding for innovative Environmental Technology (ATP, TRP, SBIR etc.)
State

Private

- Cost Sharing on Programs
- Venture Capital
- Private Grants/Endowments
- Fees for services
Figure 1. EnviroTech Center - Organizational Structure
Appendix C: Summary of the Environmental Technologies Bill
Environmental Technology Bill-Summary

In response to the Clinton Administration's Environmental Technology Initiative, an Environmental Technologies Bill is under Congressional consideration. This bill covers numerous programs that will be established to support the development of environmental technologies. While many of the responsibilities laid out in this bill fall under the responsibilities of the U.S. Environmental Protection Agency (EPA), this bill requires the support and cooperation of numerous Federal agencies, including the Department of Energy, Department of Commerce, Department of Defense, and the Department of Agriculture. Not only will this bill serve to promote and support research, development, and demonstration of innovative environmental technologies, but it will also coordinate the technology development efforts among the Federal agencies. The support, promotion, and coordination of environmental development efforts will be consistent with "Federal strategy" or Federal environmental vision.

It is through this bill that the support of research, development and demonstration of effective and efficient technologies will expedite the clean up of federal and private contamination sites, as well as develop the economic sustainability of the United States through export of these technologies to the international markets. The following will summarize the programs and main ideas of the Environmental Technologies Bill.

During the development of a technology, the government will encourage life cycle assessments, which will allow the prediction of the waste production and recycling abilities and determination of the environmental impacts of the particular technology. This effort will be coordinated within each Federal agency, as well as with the state and local government programs. In addition, these life cycle assessments will allow further involvement of industry, private and non-profit, as well as other professional entities in the technology development and analysis process.

In attempts to aid the development of technologies, the EPA will disseminate information and other useful data to U.S. companies through
available networks and databases. These data sources will eventually include the information gathered through the life cycle assessments. In addition, there will be an attempt to combine and coordinate the environmental technology information available at each Federal agency. In time, this coordinated information will include data on environmental technologies or "protocols" developed, tested, verified, and certified through this bill and be shared with U.S. companies through an outreach program.

For those who are looking to the federal agencies, namely the EPA, for support of their proposals, the bill includes assurances of a "competitive merit-based process" in which financial support is awarded. There are priority research areas which can affect the selection of proposals, but all must be in the spirit of the federal strategy. Funds can be allocated for up to three to five years depending on the type of partnership formed. The funds provided as support can only amount to a minimal share of the overall cost to the partnership. Furthermore, as part of the provisions to receive financial support, there is some recoupment involved when a supported technology is marketed and used (This can be waived at the discretion of the EPA administrator.).

Certain eligibility requirements are involved to qualify for these Federal funds. In addition, there will be special consideration for those socially and economically disadvantaged individuals, such as women and small businesses. While there will be support of reasonable proposals, this bill does not allow funds to be used for construction of new facilities.

On the other hand, there are allowances to use Federal laboratories and facilities for demonstrations, which are as follows: 1) the technology will contribute to contamination control and remediation efforts at that facility, 2) the technology would be advanced through the use of the facilities, or 3) the technology has significant potential to contribute to economic development or remediation efforts. In addition, the EPA can release information on site characterization, and the expertise and facilities available at federal facilities, which may be of use to technology
demonstrations. During development and demonstration of a technology, precautions also must be made to ensure the protection of human health and the environment.

As research, developments, and demonstrations result from this bill, the EPA will determine the necessary verification and certification criteria. The EPA has the right to select the appropriate entities to evaluate the capabilities, including the technology's life cycle assessment, of supported technologies that are ready for verification and certification.

Beyond funding available through the EPA, the President can give out Total Environmental Quality Awards and National Environmentally Sound Technology Awards. These awards are aimed to stimulate U.S. companies to participate in environmental technology research, development, and demonstration efforts. In addition, these awards are to provide recognition of achievement and establish guidelines and criteria for quality technology. The recipients of the awards are chosen by the EPA administrator and heads of other Federal agencies.

Not only does this bill intend to provide further support for the development of environmental technologies and economic sustainability of the United States, but it attempts to better understand the barriers and incentives out there to become involved with environmental technology research and development. A study is planned to determine the impacts this technology innovation will have on the government, the economy, competition, and finances. This study is to be completed by the the National Research Council in agreement with the EPA within two years of the enactment of this bill.

While the EPA takes the lead of this environmental initiative, other federal agencies also have integral parts that will aid in the success of this bill. The National Science Foundation, with collaboration of other federal agencies, will also support research activities that will "advance the integration of engineering practices and environmental protection in the development of advanced technology." The Secretary of Commerce will determine/clarify the performance measurements of technologies with
help from the appropriate federal agencies. The Department of Energy (DOE) is heading the Environmental Technology Development Program, which provides support of research, development and demonstration of environmental technologies related to waste minimization and environment restoration. This program also focuses on reducing the occupational hazard involved with site remediation. The DOE is planned to support the Environmental Restoration and Waste Management Program, a recycling demonstration program for uncontaminated and decontaminated metal and equipment. For three years, this is to be in place at at least three National laboratories, that is to use this metal and equipment. This program is to also promote development of decontamination technology. The budget for this Environmental Restoration and Waste Management Program is to increase until it consists of at least ten percent of the DOE budget (assuming that this does not affect the quality of its other programs).

As seen here, the environmental technology effort requires a collective effort from all federal agencies and private industry. This bill will aid the dissemination of information and data that will help in the development of better technology and improved processes. This Environmental Technology Bill provides a framework for bringing together multiple federal agencies and coordinating their environmental technologies to eventually realize the federal strategy.
Appendix D: Pertinent Excerpts from the Environmental Technologies Bill
SEC. 202. LIFE-CYCLE ASSESSMENTS.

(a) FINDINGS.—The Congress finds the following:

(1) Consideration of life-cycle consequences of the development of a technology can greatly assist in the achievement of more environmentally sound products, processes, and services and enhanced industrial efficiency. Life-cycle assessments and other
design-for-environment resources can facilitate this achievement by clarifying materials flows and energy flows and by enhancing capabilities to assess these flows in the design of such products, processes, and services.

(2) Methods of life-cycle assessment and other design-for-environment resources are underused in both the public and private sectors, particularly as applied to sustainable economic development.

(3) The data necessary for meaningful life-cycle assessment and other design-for-environment resources are often difficult to acquire, and no system exists to make such data readily available to public and private groups.

(b) LIFE-CYCLE ASSESSMENT COORDINATION.—

(1) IN GENERAL.—As part of, and consistent with, the overall Federal environmental technology strategy established in section 201, the Director of the Office of Science and Technology Policy or other entity designated by the President shall, in collaboration with the heads of other appropriate Federal agencies (including the Secretary of Commerce, the Secretary of Energy, and the Secretary of Defense), coordinate Federal activities and resources that are applied to life-cycle assessment and other design-for-
environment resources in order to maximize the contribution of life-cycle assessments and other design-for-environment resources to the efficient design, development, and use of technologies, and to sustainable economic development.

(2) IMPLEMENTATION.—In carrying out this subsection, the Director of the Office of Science and Technology Policy or other entity designated by the President shall—

(A) ensure that the life-cycle assessment and other design-for-environment resources of each Federal agency are developed and disseminated in a coordinated fashion, partitioning agency responsibilities where appropriate;

(B) coordinate with State and local governments developing life-cycle assessment and other design-for-environment resources; and

(C) consult with industry, professional, nonprofit, and other appropriate private-sector organizations to take into account the life-cycle assessment and other design-for-environment capabilities of the private sector in carrying out this section.

(3) OTHER ACTIVITIES.—In carrying out this subsection, the Director of the Office of Science and
Technology Policy or other entity designated by the President shall also encourage appropriate Federal agencies—

(A) to collect and disseminate information regarding analytic methods (and, as required, to develop such methods) that will significantly enhance the ability of United States companies and other organizations to evaluate materials extraction, materials conversion, transportation, energy use, end use, recycling, and disposal, and their associated costs and environmental impacts;

(B) to utilize, to the fullest extent practicable, existing networks and supporting databases which provide access to publicly available information that will facilitate the use of life-cycle assessments and other design-for-environment resources;

(C) to sponsor demonstrations for public policy and business decisionmakers of the effective use of life-cycle assessment and other design-for-environment data and methods described in this section; and

(D) to ensure that private-sector life-cycle assessment and other design-for-environment
capabilities are, and continue to be, fully integrated into activities under this section.

(4) LIMITATION.—Nothing in this section shall be considered to require the use of life-cycle assessment or other design-for-environment data or methods by any Federal agency.

(c) ANNUAL REVIEW.—The Director of the Office of Science and Technology Policy or other entity designated by the President shall annually submit to the Congress a report containing an evaluation of the life-cycle assessment or other design-for-environment activities of the Federal Government.
SEC. 212. INNOVATIVE ENVIRONMENTAL TECHNOLOGY PROGRAM.

(a) ESTABLISHMENT.—The Administrator, in collaboration with the heads of other appropriate Federal agencies (including the Secretary of Commerce, the Secretary of Energy, and the Secretary of Defense), shall conduct an interagency innovative environmental technology program to develop or demonstrate advanced precommercial environmental technologies and which, to avoid redundancy and ensure efficiency, will be a part of and consistent with, the overall Federal environmental strategy established in section 201.

(b) ELIGIBILITY FOR FINANCIAL ASSISTANCE.—An entity shall be eligible for financial assistance to conduct a demonstration or development project under the pro-
gram established under subsection (a) only if the entity is either a single United States company or a partnership which—

(1) includes two or more United States companies; and

(2) may include, as determined appropriate by the Administrator, a Federal laboratory or laboratories, United States nonprofit organizations, United States institutions of higher education, agencies of States governments, and other entities that participate in the partnership by supporting the activities conducted by such companies or corporations under this section.

(c) CRITERIA FOR SELECTION OF PROPOSALS.—The Administrator shall give priority consideration to the following criteria in evaluating proposals for financial assistance under this section:

(1) Contribution to the priorities established pursuant to section 201(a)(2).

(2) Significant improvement in environmental soundness of the production process.

(3) Contribution to industrial competitiveness, including new markets, reduced production costs, and enhanced global competitiveness.
(3) The Federal share of the cost of a project conducted by a partnership under this section may exceed the limitation described in paragraph (2) if—

(A) the partnership is composed entirely of small business concerns; or

(B) the Administrator determines that it would be appropriate under the circumstances and would serve the purpose of the program to provide more than a minority cost-share of the project conducted by the partnership.

(4) The Administrator has determined that—

(A) an applicant for any such assistance has made reasonable efforts to obtain non-Federal funding for the Federal cost share sought to be received under this section; and

(B) such non-Federal funding could not be reasonably obtained.

(5) Each project under this section shall be carried out under such terms and conditions as the Administrator shall require to ensure the protection of human health and the environment.

(e) EVALUATION.—As part of the annual evaluation referred to in section 211(e), the Administrator shall conduct an evaluation of—
(4) Improvement in the environment of the workplace.

(5) Applicability to other industrial processes.

(6) Improvement in technological capability to recycle complex combinations of materials.

(7) Innovative application of post-consumer materials.

(8) Direct application to environmental technologies needed for United States business and industry.

(9) Other criteria established by the Administrator.

(d) AWARD CONDITIONS.—Financial assistance provided under this section shall be subject to the following conditions:

(1) Such assistance may be made for not more than three years for single United States companies and not more than five years for partnerships.

(2) Except as provided in paragraph (3), the Federal Government may provide financial assistance to a partnership under this section in an amount that is not more than a minority share of the cost of the project conducted by the partnership.
(1) the extent to which technologies developed pursuant to the program established under subsection (a) are used;

(2) the contribution of such technologies to reduced pollution and the more efficient use of energy and materials; and

(3) the contribution of such technologies to economic development.
SEC. 215. USE OF FEDERAL FACILITIES FOR ENVIRONMENTAL TECHNOLOGY DEMONSTRATION.

(a) ESTABLISHMENT.—The Administrator shall establish a program, in collaboration with the heads of appropriate Federal agencies (including the Secretary of Energy, the Secretary of Commerce, and the Secretary of Defense) as part of, and consistent with, the overall Federal environmental technology strategy established in section 201, to demonstrate the performance of environmental technologies at Federal laboratories and other Federal facilities.

(b) QUALIFYING TECHNOLOGY DEMONSTRATION PROJECTS.—Technologies that qualify for demonstration under such program include—

(1) environmental technologies that can be applied to a major pollution control or remediation need at a Federal laboratory or other Federal facility;

(2) environmental technologies the development of which would be significantly advanced by unique facilities or capabilities of a Federal laboratory or other Federal facility; and
(3) other environmental technologies that have significant potential as an environmental technology that will contribute to sustainable economic development or that will make a significant contribution to the cleanup of communities significantly affected by pollution.

(c) ADMINISTRATION.—As part of the program established under this section, the Administrator—

(1) may enter into a cooperative agreement with any other Federal agency to make available, as appropriate, any expertise, site, or facility under the jurisdiction of such agency to an eligible entity under subsection (d) for the purpose of demonstrating the performance of an environmental technology;

(2) shall establish application procedures for an eligible entity under subsection (d) to apply to demonstrate an environmental technology at an available site or facility, including—

(A) provisions for sharing the cost of demonstrating the technology with an applicant that limit the Federal share of the cost to not more than 50 percent of the total cost of demonstrating the technology; and

(B) provisions that provide special consideration of the needs of small business concerns;
(3) shall establish criteria for verification of the efficacy of demonstrated environmental technologies;

(4) shall establish specific procedures for the management and oversight of demonstration activities conducted under this section;

(5) shall, pursuant to section 214, in consultation and collaboration with other Federal agencies, and consistent with the Federal environmental technology strategy established in section 201, make available for entities eligible under subsection (d) information regarding—

(A) the facilities and expertise available at Federal laboratories that would be valuable to the demonstration of environmental technologies; and

(B) sites at Federal laboratories or other Federal facilities potentially available for demonstrating environmental technologies, characterized by specific site characteristics, including site geology and site contaminants where appropriate;

(6) shall document the performance and cost characteristics of each environmental technology demonstrated pursuant to this section; and
(7) shall list and disseminate, pursuant to section 214, nonproprietary information regarding the performance and cost characteristics of the environmental technologies demonstrated pursuant to this section.

(d) Entities Eligible for Participation.—Entities eligible to carry out a demonstration project as part of the program established under subsection (a) are United States companies (including small business concerns), United States nonprofit organizations, United States institutions of higher education, and other entities that the Administrator considers appropriate.

(e) Program Evaluation and Reporting.—In the report required by section 211(e), the Administrator shall evaluate the performance of the program established under this section, including an evaluation and statement of—

(1) the number of environmental technologies demonstrated and the type of problems addressed;

(2) the Federal and non-Federal financial resources committed to the program; and

(3) the extent to which technologies demonstrated pursuant to this section are used.

(f) Savings Provision.—Nothing in this section shall be construed to supersede any other provision of law
that provides authority to a Federal agency to demonstrate environmental technologies. Technologies eligible for demonstration under this section that are also eligible for demonstration at sites under section 311(b) of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (42 U.S.C. 9660(b)) shall be subject to the limitations and requirements of that section. Demonstration projects and activities under this section shall not alter or interfere with the conduct or expeditious completion of response actions at facilities proposed for or listed on the National Priorities List.
SEC. 302. VERIFICATION OF ENVIRONMENTAL TECHNOLOGIES.

(a) DESIGNATION OF ENTITIES TO PERFORM ENVIRONMENTAL TECHNOLOGY VERIFICATION.—The Administrator may, in accordance with this section and as part of, and consistent with, the overall Federal environmental technology strategy developed in section 201, designate entities to perform the functions described in paragraphs (1) through (3) of subsection (b). The Administrator may
enter into joint agreements with Federal agencies, State and local governments, and nonprofit, private-sector representatives to support entities designated by the Administrator under this section.

(b) FUNCTIONS.—Each entity designated under subsection (a)—

(1) shall verify, evaluate, and, to the maximum extent practicable, certify the performance, cost-effectiveness, and ecological benefits of environmental technologies:

(2) shall disseminate information on the characteristics referred to in paragraph (1), including information that describes whether each environmental technology evaluated and verified—

(A) meets the performance criteria of applicable law (including regulations issued by the Administrator) under tested conditions at comparable or lower costs than other existing environmental technologies; and

(B) constitutes a significant advance in the development of environmental technologies with broad applicability;

(3) shall submit to the Administrator data and other information compiled by the entity with re-
spect to each environmental technology verified and evaluated by the entity under this section; and

(4) may use support provided under this section to develop technologies necessary for effective verification and evaluation under paragraph (1) and may charge appropriate fees for such verification and evaluation.

(c) REVIEW BY ADMINISTRATOR.—After receiving data and other information from an entity designated under subsection (a) with respect to an environmental technology under subsection (b)(1), the Administrator shall conduct appropriate review of the data, other information, and protocols developed by such entity with respect to such technology.

(d) ADMINISTRATION.—In carrying out this section, the Administrator shall—

(1) by rule establish competitive procedures for soliciting applications for and selecting, pursuant to criteria referred to in subsection (e), entities to perform functions described in subsection (b) and, as appropriate, designate model entities;

(2) by rule establish eligibility criteria for entities to be designated under this section;

(3) in collaboration with the heads of other appropriate Federal agencies, including the Director of
the National Institute of Standards and Technology, certify, and as appropriate, develop common protocols to evaluate the cost and performance of environmental technologies;

(4) make generally available through guidance manuals or other appropriate methods information regarding testing protocols for environmental technologies and establish a regular process for approving and updating such protocols;

(5) ensure that information regarding environmental technologies verified and evaluated under this program is disseminated pursuant to section 214;

(6) develop mechanisms to facilitate the verification of—

(A) environmental technologies developed or demonstrated by small business concerns, nonprofit organizations, and United States institutions of higher education; and

(B) environmental technologies that provide source reduction; and

(7) consult with the heads of other Federal agencies to make available, through cooperative agreements with the entities designated under this section, sources and expertise of Federal laboratories
for use by such entities in performing the functions described in subsection (b).

(e) SELECTION CRITERIA.—The Administrator, in consultation with the heads of other Federal agencies, State and local governments, and private sector organizations, shall select entities under this section based on the following criteria:

(1) The capabilities of the applicant to provide a thorough and credible technical and financial evaluation of environmental technologies.

(2) The clarity and efficiency of the proposed procedures for the receipt and review of applications for technology verification.

(3) The likelihood of the continued viability of the entity.

(4) The existence of a plan for disseminating nonproprietary information regarding technologies verified by the entity.

(5) Other criteria that the Administrator considers appropriate.

(f) MERIT-BASED SELECTION PROCESS.—Entities supported under this section shall be selected only through a merit-based selection process established by the Administrator, pursuant to the criteria described in subsection (e).
(g) **AUTHORITY OF ADMINISTRATOR.**—The Administrator may, consistent with applicable provisions of law and this section, enter into cooperative agreements and contracts to carry out this section.

(h) **DIRECT VERIFICATION.**—If the Administrator determines that entities designated under this section cannot adequately verify the performance of environmental technologies because of scale or complexity, the Administrator may, consistent with applicable provisions of law and this section, enter into direct agreements to verify the performance of such technologies.

(i) **REVIEW.**—

(1) **IN GENERAL.**—Any action by the Administrator to verify or evaluate a technology (or to review a verification or evaluation) under this section shall not constitute a final action by the Administrator and shall not be subject to judicial review.

(2) **FAILURE TO COMPLY.**—If a technology verified, evaluated, or reviewed pursuant to this section fails to comply with any applicable law (including regulations issued by the Administrator), the verification, evaluation, or confirmation shall not constitute a defense in an enforcement action or suit and shall not create a cause of action against the Environmental Protection Agency.
(3) DISCLAIMER.—Nothing in this section may be construed to authorize the Administrator to grant a seal of approval of any kind for any entity or technology, to create any competitive advantage or disadvantage for any entity, to authorize the Administrator to require any person to install or use any technology pursuant to any program administered by the Environmental Protection Agency, or to designate any technology as meeting a regulatory requirement.

(j) REPORT.—The Administrator, in consultation with the heads of other appropriate Federal agencies, and industry, nonprofit, and other appropriate organizations, shall annually submit to the Congress a report that evaluates the implementation of this section. The report shall include a description of the technologies verified pursuant to this section, the number of the technologies verified, and the extent of their use.