



**US Army Corps  
of Engineers**  
Waterways Experiment  
Station

*Installation Restoration Research Program*

# **Review of the Utility of Natural Attenuation for Remediating Contaminated Army Sites**

by *Armand A. Balasco, Richard C. Bowen, Kevin R. Cahill,  
Janet L. Mahannah, Arthur D. Little, Inc.*

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**Installation Restoration  
Research Program**

**Contract Report IRRP-96-1  
August 1996**

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by **Armand A. Balasco, Richard C. Bowen, Kevin R. Cahill,  
Janet L. Mahannah**

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**Final report**

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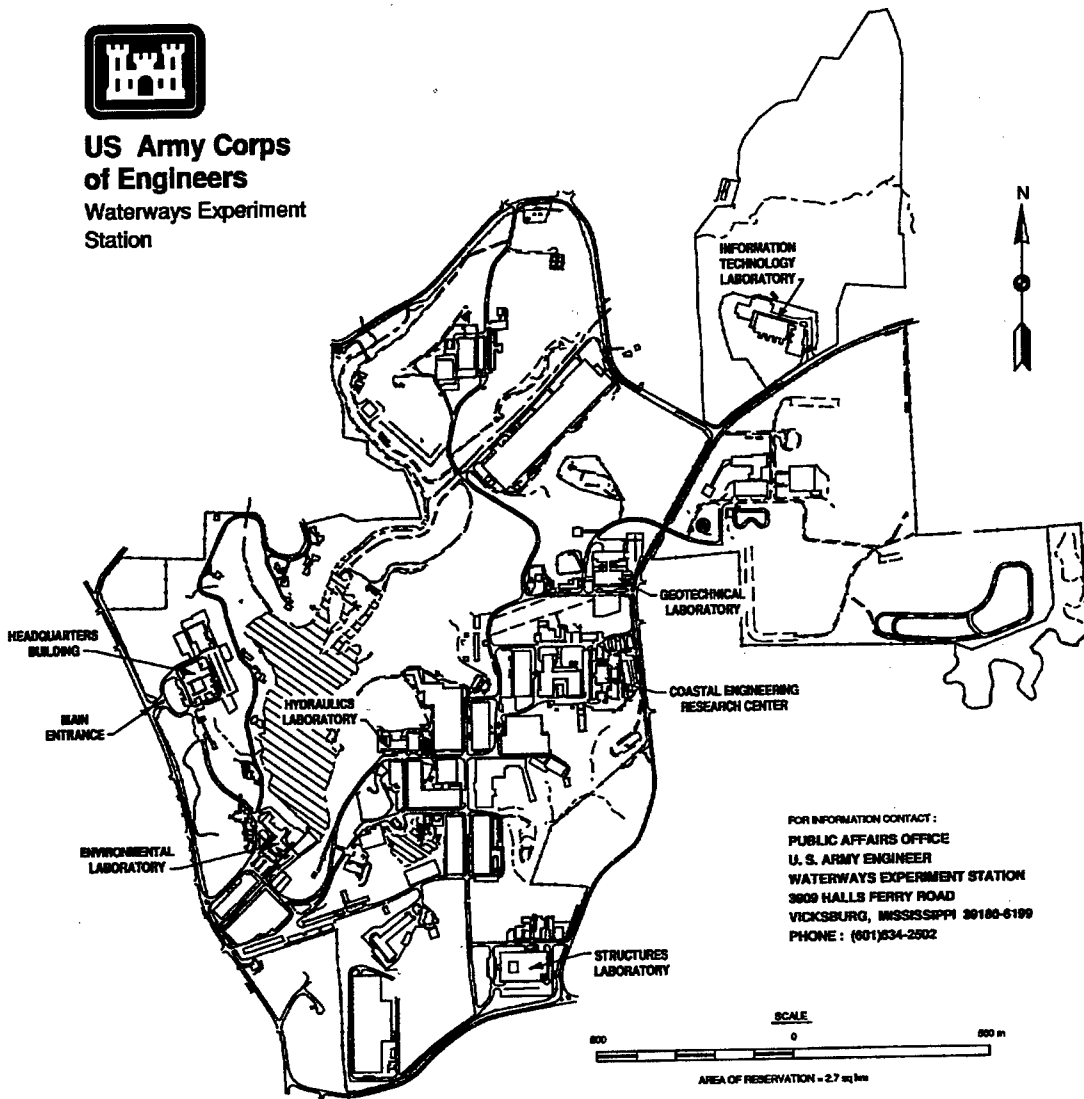
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## Summary

Past waste disposal practices have resulted in soil, sediment, ground water, surface water, and structural contamination at approximately 1,900 Department of Defense (DoD) installations worldwide. At these installations, it is estimated that 11,000 individual sites will require remediation at an approximate cost of \$35 billion (Cullinane, 1995a). Based upon the results of remedial actions at other sites, it has become apparent that traditional approaches to hazardous waste site cleanup may not provide cost-effective permanent solutions. Therefore, this study was conducted to investigate an innovative approach to site remediation known as natural attenuation, or intrinsic bioremediation.

Natural attenuation is the process by which contamination in ground water, soils, and surface water is reduced over time. Although this concept is becoming increasingly popular with both regulators and parties responsible for remediation, there is currently no authoritative definition of natural attenuation. The definition used to complete this study included natural processes such as advection, dispersion, diffusion, volatilization, abiotic and biotic transformation, sorption/desorption, ion exchange, complexation, and plant and animal uptake, but did not include remediation schemes employing enhancements such as addition of oxygen, nutrients, or engineered bacteria.

The study was conducted by reviewing the available scientific literature for sites at which natural attenuation has been observed or selected for implementation. Several databases were searched for references, including the EPA Record of Decision database and comprehensive (commercial and governmental) scientific databases. Contaminant concentrations and hydrogeological conditions at and receptor proximity to the sites were reviewed to determine conditions most favorable for the process and/or regulatory acceptance of this remedial alternative. Federal and state regulators were then interviewed to further qualify the conditions necessary for regulatory acceptance of natural attenuation. Regulators from EPA headquarters, three regions, and four states were asked to identify those contaminant and site conditions which would support the selection of natural attenuation as a site remedy.

The results of the literature review and interviews indicate that natural attenuation of contaminated sites is becoming a more accepted remedial action to the regulators, but that it remains a rarely selected choice. Natural attenuation is considered only for contaminated areas with optimal contaminant and site characteristics and requires a strong technical demonstration to convince the regulators that natural attenuation will be protective of human health and the environment. Given that EPA headquarters has granted flexibility to the EPA regions and the states in the remedial alternative decision-making process, the selection process is remarkably similar in most parts of the country.

Regulators in most regions are most receptive to the selection of natural attenuation for sites where biodegradation is the principal attenuation process, but stated that the presence of nonbiodegradable contaminants does not preclude the selection of natural attenuation. The regulators stressed that the decision to approve or reject natural attenuation is strongly dependant upon site-specific characteristics such as types and concentrations of contaminants, proximity to current and future receptors, and current and future land use.

Regulators also require that extensive site characterizations be completed to support the contention that natural attenuation will be protective of the site in question. This characterization often requires computer modeling efforts to estimate existing contaminant distribution in the subsurface, as well as future contaminant transport and fate processes. Many of the most popular computer modeling packages are currently being upgraded to provide the long term transport and fate data required to support the implementation of natural attenuation. The cost of successfully implementing a natural attenuation remedial action is often closer to the cost of an active remedial option than the "No Action" alternative due to the cost of rigorous upfront and subsequent characterization efforts.

Based upon the research described above, there is a reasonable potential for implementation of natural attenuation at Army sites, provided that site-specific characteristics support its selection. However, based on the regulators' preference for natural attenuation by biodegradation, Army sites with petroleum-based contaminants are the most likely to receive support for the selection of natural attenuation, as these contaminants have previously been demonstrated to be readily biodegradable in the environment. It will be more difficult to implement natural attenuation at Army sites contaminated with military unique compounds (MUCs), as these materials have not been demonstrated to be as susceptible to natural attenuation via biodegradation.

Without data to demonstrate that MUCs are capable of being naturally degraded to less toxic by-products, it will remain difficult to convince regulators that natural attenuation should be selected in lieu of conventional remedial alternatives such as soil excavation and disposal or ground water extraction and treatment. However, there have been cases where natural attenuation has been selected and the major attenuation process was not biodegradation. In these cases, the sites are remote from both human and environmental receptors, and the contamination has been demonstrated to be relatively immobile.

To enhance the viability of natural attenuation for Army sites contaminated with MUCs, it is advantageous for Army representatives to continue laboratory studies and field demonstrations to assess the potential for biodegradation of MUCs. The Army should also enter into discussions with the regulators to set policy for sites which are contaminated with nonbiodegradable, immobile contamination. Regulators are most familiar with the natural attenuation process being proposed for sites with relatively mobile contaminants, such as solvents or petroleum compounds. To be protective of human health and the environment, natural attenuation for such sites must be based upon destruction (e.g., biodegradation) or loss (e.g., volatilization) of the mobile contaminants.

In contrast, for relatively immobile contaminants, the Army should demonstrate that natural attenuation based upon sorption can be just as protective of human health and the environment as biodegradation of mobile contaminants. Therefore, the Army's policy discussions with regulators should be focused on the selection of natural attenuation at sites where sorption is the principal attenuation process, as this is the area where the Army may most benefit from the use of natural attenuation.

## Preface

The study reported herein was conducted as part of the Installation Restoration Research Program (IRRP). Dr. Clem Meyer was the IRRP Coordinator at the Directorate of Research and Development, Headquarters, U.S. Army Corps of Engineers.

Principal Investigators for the study were Messrs. Armand A. Balasco, Richard C. Bowen, and Kevin R. Cahill and Ms. Janet L. Mahannah of Arthur D. Little, Inc., Cambridge, MA.

The research was monitored by Dr. M. John Cullinane, Program Manager, IRRP. Technical review of the report was provided by Drs. Judith D. Pennington, James M. Brannon, and C. R. Lee of the Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES). The work was conducted under the general supervision of Dr. John W. Keeley, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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## 1.0 Introduction

Natural attenuation, the process by which contaminants naturally decrease over time in the environment, is receiving increased attention as a means to decrease the cost of site remediation. This study was undertaken to investigate the current regulatory perception of natural attenuation and to assess the potential applicability of natural attenuation for use as an innovative remedial alternative at Army sites. Technical literature databases were reviewed and Environmental Protection Agency (EPA) regulators were interviewed to determine advantages and limitations of this remedial approach. The result of this effort is a set of recommendations to improve the probability of successfully implementing natural attenuation at contaminated Army sites.

## 1.1 Background

Over the past 200 years, many waste disposal practices have resulted in serious insult to the environment. The Department of Defense (DoD) has not been immune to such practices and the problems they generate. It is estimated that the DoD has approximately 1,900 installations worldwide, containing about 11,000 individual sites, that will require some form of active remedial action (Table 1-1). Much of this contamination resulted from land disposal of explosives and energetics-related wastes; petroleum, oils, and lubricants (POLs); industrial solvents; and other military unique compounds (MUCs).

**Table 1-1: Installation Restoration Program**

Summary of Installations and Sites				
Service	Number of Installations	Number of Sites	Number of Active Sites	Closed-Out Sites (a)
Army	1,265	10,578	5,524	5,054
Navy (b)	247	2,409	1,688	721
Air Force	331	4,354	3,520	834
DLA (c)	34	319	192	127
Total	1,877	17,660	10,924	6,736

(a) Formerly "Sites Requiring No Future Action"

(b) Includes Marine Corps

(c) Defense Logistics Agency

Source: Cullinane, 1995a

Federal, state, and local environmental protection and public health laws specify that the DoD must reduce or eliminate the environmental and health impacts resulting from current and past defense operations. Congress has mandated that the Services comply with all applicable environmental laws and regulations, and the Office of the Secretary of Defense has directed that the Services serve as a model to the civilian community. The

primary thrust of the DoD Cleanup Program is to comply with this mandate to protect human health and the environment.

Cleanup involves the environmental remediation of soil, sediment, ground water, surface water, and structures contaminated with hazardous and toxic materials from past military activities. The cost to complete the DoD Cleanup Program is now estimated to be \$35 billion (Cullinane, 1995a). With approximately 11,000 sites remaining to be cleaned up, an improvement in remediation technology would be beneficial. Traditional approaches to hazardous waste site cleanup may not provide long term protection or cost-effective solutions. Many times such approaches can require large capital outlays and operating costs and often result in moving the problem from one location to another.

It has long been recognized that the environment has some capacity to assimilate natural and anthropogenic contaminants without unacceptable impacts (i.e., natural attenuation). Formal incorporation of natural attenuation's capacity to mitigate environmental impacts is proposed as an acceptable means of protecting the public health and environment while reducing the cost of site remediation. Indeed, the National Contingency Plan (NCP) requires that natural attenuation be considered as a potentially acceptable remediation alternative (Federal Register, 1990a).

## 1.2 Natural Attenuation

Natural attenuation (also known as passive remediation, natural restoration, and the currently popular intrinsic bioremediation) can be defined as the overall process by which contamination in soils and ground water is reduced over time. There is currently no authoritative definition of **natural attenuation**. A reasonably acceptable definition is the **reduction of contaminant concentrations to environmentally benign levels through natural processes**. Individual processes constituting natural attenuation include, but are not limited to: advection; dispersion; diffusion; volatilization; abiotic and biotic transformation (mineralization and degradation); sorption/desorption; ion exchange; complexation; and, plant and animal uptake. The prevailing regulatory climate often tends to limit the definition of natural attenuation to biodegradation of contaminants and most often applies this definition to organic contaminants. For inorganic contaminants or mixed organic and inorganic contaminants, natural attenuation has often tended to include advection, dilution, adsorption and other processes, including biodegradation.

Regardless of the name by which this process is known, it has long been recognized that the environment can withstand significant acute (short-term) or chronic (long-term) contaminant loadings without exhibiting the consequences expected from such occurrences. As the natural diminishing of contaminant concentrations over time was initially being documented, the term passive remediation was most often used. The process was recognized to occur beneath unlined lagoons and landfills, and was recognized as due primarily to advection and diffusion. Metals and other inorganic constituents were monitored in the ground water beneath these surface impoundments, and the plumes were observed to follow the classical diffusion laws.

Later, technical data were developed that indicated that released contaminants were subject to much more than simple dilution. The phrase "natural attenuation" gained acceptance as biodegradation of petroleum- and solvent-based contamination and was documented at uncontrolled hazardous material and waste sites. It remained a process that simply occurred and was documented, rather than being actively selected based upon technical justification. Ground water contaminants were monitored, but the contaminant concentrations and plume size were typically overestimated by the diffusion equations that more accurately predicted the behavior of inorganic contaminants.

The phrase "intrinsic bioremediation" is being used with increasing frequency to describe natural attenuation as it becomes more widely recognized as a viable remedial alternative. Later in this document, information is presented that describes how contaminated sites may be screened for when this "technology" is most applicable, similar to feasibility demonstrations for existing, active remediation schemes. The process is quickly becoming an alternative that is subject to the same screening criteria as active remedial alternatives, rather than simply being an interesting aspect of recently discovered uncontrolled contamination.

### 1.3 Study Description

Under contract DACA 39-92-D-0014 with the U.S. Army Corps of Engineers, Waterways Experiment Station (WES), Arthur D. Little, Inc. has been tasked to perform a "Review of the Utility of Natural Attenuation for Remediating Contaminated Army Sites." The proposal for this task, formally known as Delivery Order Number 006 under contract DACA 39-92-D-0014, was accepted by WES on July 25, 1994.

This study investigates and evaluates the policy and technical issues surrounding the use of natural attenuation for the remediation of contaminated sites, especially the specific concerns for those sites contaminated with MUCs. The Army is aware that significant data is available on the natural attenuation of sites contaminated with degradable contaminants such as petroleum hydrocarbons and chlorinated solvents. This study is an effort to provide input for Army decision makers responsible for making the choice as to whether natural attenuation should be pursued as a primary remediation alternative for sites contaminated with hydrocarbons, solvents, and MUCs.

### 1.4 Project Scope

It is important to understand what was and was not considered as natural attenuation during the conduct of this study, since, as stated in Section 1.2, there is no established definition of natural attenuation. For the purposes of this study, the definition of natural attenuation has been limited to those processes that reduce site contaminant levels or limit the environmental impacts of contaminants through natural means without artificial enhancement. In addition, the processes involved in natural attenuation must be able to be justified through site characterizations and evaluations. The reduction in contaminant concentrations achieved during natural attenuation may be due to various physical and chemical reactions, including advection, biotic and abiotic transformation or degradation, diffusion, dispersion, ion exchange, sorption, and volatilization.

An illustration of where natural attenuation falls on the "remediation activity scale" is presented in Figure 1-1. As shown, natural attenuation falls between the "No Action" alternative and active remedial measures. The natural attenuation remedial alternative differs from the "No Action" alternative referenced in the NCP in the amount of data needed to both support natural attenuation's selection and demonstrate its effectiveness.

Personnel proposing the use of natural attenuation at a contaminated site must be prepared to present adequate data to support their proposal. Minimum requirements often include expensive site and contaminant characterizations as well as a demonstration or confirmation that the alternative will be protective of human health and the environment. If natural attenuation is selected as the remedial alternative, most regulators then require periodic monitoring of the contaminated area to document that the contamination is being degraded and that the area of contamination is not spreading. In addition, regulators also require the use of institutional controls (e.g., deed restrictions, fencing) to limit the potential for human exposure. The "No Action" alternative does not require demonstration that *in situ* attenuation is occurring or that the contamination is immobile.

On the other end, the natural attenuation process does not include remedial alternatives that require an initial or ongoing artificial stimulus or support, as shown in Figure 1-1. Processes using *in situ* bioremediation enhanced through the use of aerating vacuum pumps or nutrient injections, for example, are typically not considered to represent natural attenuation. These **enhanced processes were, therefore, excluded from this study.**

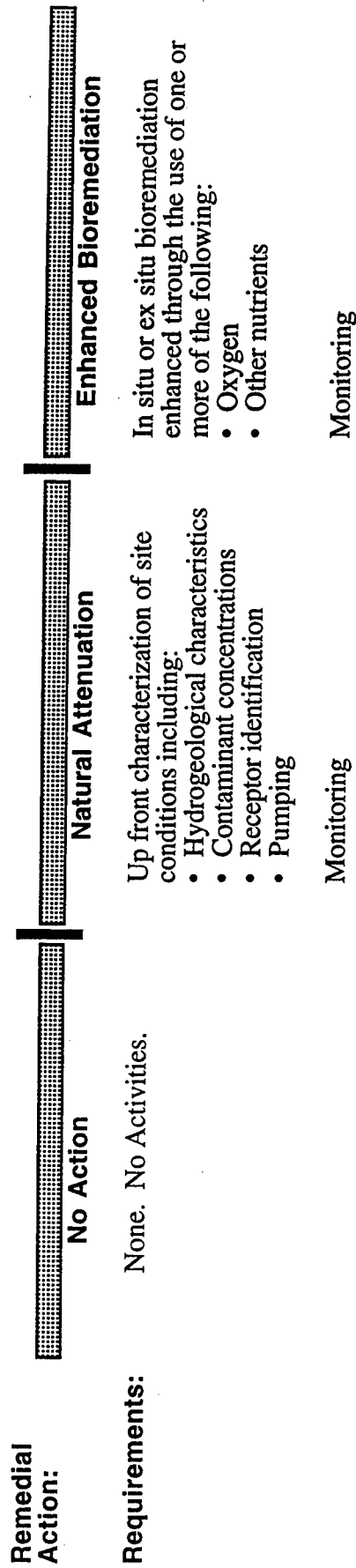
### 1.5 Technical Approach

This study was conducted in three major phases: (1) a literature review, (2) interviews with regulatory staff, and (3) an assessment of the technical data available to support the selection of natural attenuation at contaminated Army sites. The data collected from these three phases were reviewed to assess the potential applicability of natural attenuation for Army sites contaminated with common pollutants and MUCs. Conclusions were then formulated based upon this assessment and recommendations were developed for consideration by the Army. This approach is summarized in Figure 1-2.

This study of natural attenuation was initiated with a literature search to identify references describing where this technique has been observed or selected and implemented. Several databases, including those of the Defense Technical Information Center, National Technical Information Service, and Environmental Information Center, were searched. This research identified a significant number of documents that contain the keywords "natural attenuation," "natural restoration," or other similar terms.

The EPA Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), or Superfund, Record of Decision (ROD) database was the source with the largest number of references. This search revealed more than 250 RODs with references to a selected remedy including no action or some type of natural attenuation. To facilitate this study, this data set was then reduced by examining the ROD abstracts to determine those that actually specified natural attenuation as the

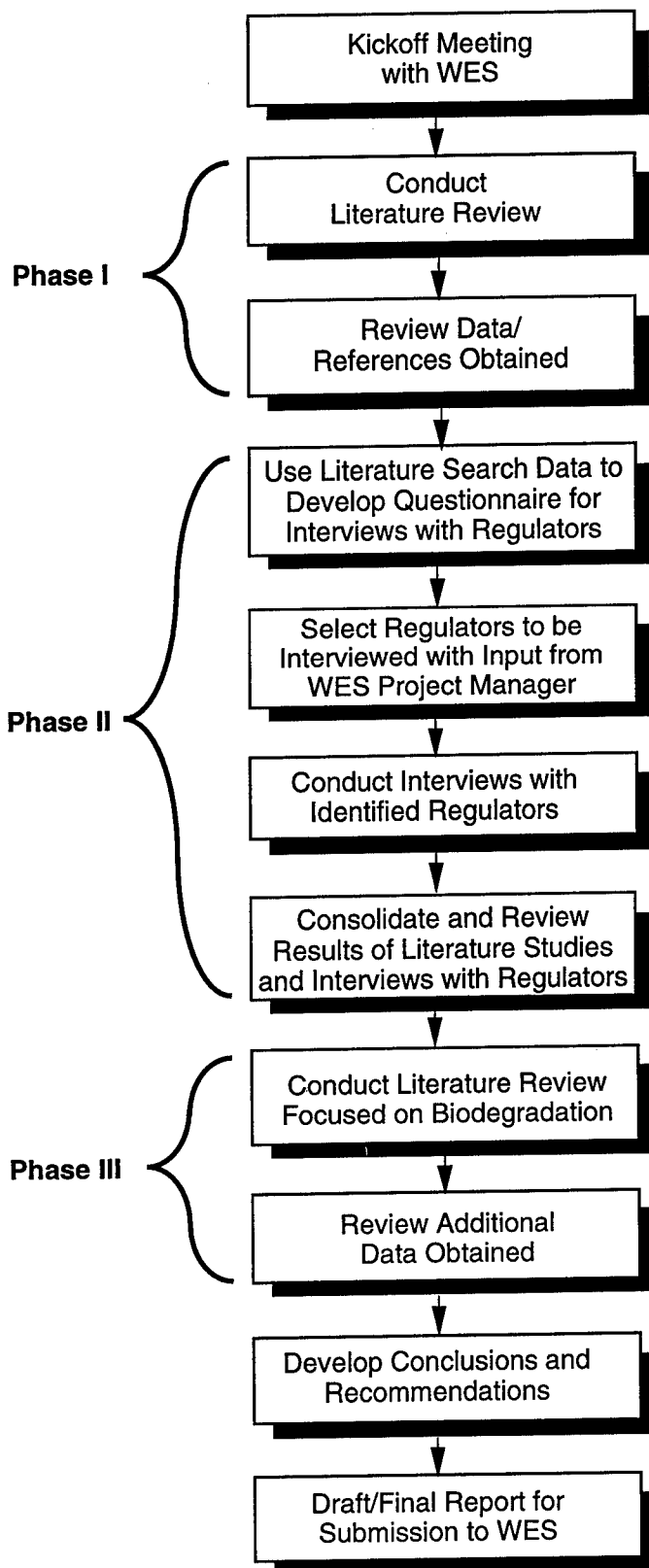
Figure 1-1: Scope of Remedial Activity Considered



The scope of natural attenuation considered in this study is limited to the middle section of the remediation activity scale.

Source: Arthur D. Little, Inc.

**Figure 1-2: Technical Approach for Natural Attenuation Study**



primary or secondary action. The complete RODs for more than 25 of those sites were then obtained for detailed review.

The other databases searched, primarily sources in closely related scientific fields, also yielded sources referencing natural attenuation. The titles and abstracts of these references were then reviewed, and those sources that appeared to be especially pertinent were obtained and reviewed. Special attention was paid to any articles that referred to attenuation of explosives and other MUCs. The overwhelming majority of articles obtained documented observations at sites contaminated with petroleum hydrocarbons or chlorinated solvents.

Few references to MUCs in the initial database searches were noted, so the search parameters were modified to find documentation in this specific area. This additional search resulted in the identification of several references to the biodegradation of MUCs, but these were primarily documentation of laboratory studies, rather than results of field observations. The articles that appeared to present data that might be useful for this study were obtained and reviewed; additional results from this separate literature search are provided in Section 4.0 of this report.

Using the literature review as a basis, a questionnaire for interviews of regulatory staff in several EPA regions and state offices was developed. This questionnaire was based upon trends detected in the articles obtained during the work described immediately above and was designed to elicit comments from the regulators on the current and future use of natural attenuation. The regulators confirmed much of the information found during the literature study, but also added a slightly different perspective. Appendix A provides completed interview questionnaires for interviews conducted.

Using the information developed during each of the three phases described above, it was then assessed where natural attenuation could prove to be a useful tool for the Army. Supporting data is presented where possible, but several of the developed conclusions and recommendations cannot be cross-referenced to hard data; rather they are based on the assessment of the regulatory climate towards natural attenuation and an understanding of remediation technologies.

## **1.6 Report Format**

This report presents the results of this study in the following format: the current regulatory climate towards natural attenuation is discussed; followed by a summary of observations from the literature search; an assessment of the status of MUC biodegradation studies; and a presentation of conclusions and recommendations.

**Section 1.0, Introduction**, describes the contractual background of the study, introduces the topic of the study, and specifies the scope of the study. The definition of the study scope is critical, as natural attenuation is often mistakenly confused with the "No Action" alternative required for consideration by the NCP or an active remediation scheme such as bioventing.

**Section 2.0, Regulatory Considerations**, presents the current regulatory status of natural attenuation, as specified by Federal and state regulations and as reported during telephone interviews of EPA and state regulatory staff. In addition, this section

provides a summary discussion of the Army's remedial alternative selection process and policy trends as they relate to natural attenuation.

**Section 3.0, Case Studies**, presents the results of the literature searches conducted and focuses primarily on the most applicable case studies described in the referenced articles.

**Section 4.0, Related Research on MUCs**, focuses on the technical issues affecting the natural attenuation of MUCs, fuels, and chlorinated solvent contaminants. This section concentrates on attenuation realized through the biodegradation of these contaminants. This section also presents the results of past research conducted in the natural biodegradation or natural attenuation of MUCs and assesses the extent to which this research supplies the data needed by the regulators for approving the use of natural attenuation at appropriate sites.

**Section 5.0, Conclusions and Recommendations**, presents conclusions and recommendations along with views on the potential for implementation of natural attenuation as a remedial alternative at contaminated Army sites.

**Section 6.0, References**, lists all references cited in the body of this report. References for additional supporting documents not cited in the report are provided in Appendix B.

## 2.0 Current Trends in Regulatory Policy

Currently, natural attenuation is required to be considered as a remedial alternative in both Superfund and Resource Conservation and Recovery Act (RCRA) regulations. There is regulatory guidance which documents the viability of the process and how to evaluate the appropriateness of a site for natural attenuation. In general, both state and Federal regulators make the decision to accept or reject natural attenuation based heavily on site-specific factors such as contamination type, contamination concentration, and distance to potential receptors. Where the consideration of natural attenuation is required in the regulations, it is defined broadly to include biodegradation, dispersion, dilution, and adsorption; however, in practice, the regulators have a strong preference for the use of natural attenuation for sites with biodegradable contaminants.

### Recommended Army Actions:

- ✓ Initiate formal discussions with local regulators to support the potential for selection of natural attenuation as a remedial technology. Focus discussions with the regulators on increasing their willingness to approve of natural attenuation at sites contaminated with immobile, sorbed MUCs.
- ✓ Develop guidance for remediation contractors to follow that requires the review of natural attenuation prior to selection of a remedial alternative.
- ✓ Document Army sites where natural attenuation has been selected and ensure that this information is transferred to all Army Project Managers and contractors working on the remediation of sites.

## 2.1 Federal Policy and Guidance

### Superfund

Within the regulatory framework of Superfund, the preamble to the National Contingency Plan (NCP) contains a discussion of the appropriateness of natural attenuation for the cleanup of ground water (Federal Register, 1990a). The EPA acknowledges that natural attenuation may be a viable alternative under certain conditions. Specifically, natural attenuation is recommended "only in cases where active restoration is not practicable, cost-effective, or warranted because of site-specific conditions." EPA stresses that the use of natural attenuation does not imply that the ground water will not be cleaned up, but that various mechanisms (biodegradation, dispersion, dilution, and adsorption) will reduce contaminants to concentrations that are protective of human health in a "timeframe comparable to that which could be achieved through active restoration." Although this preamble does not contain a definition of natural attenuation, one can infer that the Superfund legislation definition includes the mechanisms listed (e.g., biodegradation, dispersion, dilution, and adsorption).

The rationale behind the conditional support of natural attenuation is based on a number of site-specific factors. For example, although ground water extraction and treatment methods are often the most effective methods for reducing concentrations of highly contaminated ground water, they are often less effective in further reducing low levels of contamination necessary to achieve remedial goals. In response, EPA

states that such systems may be periodically evaluated and, when appropriate, natural attenuation may be used to complete the cleanup (Federal Register, 1990a).

Natural attenuation may be considered in instances where active restoration may not be warranted. This may include sites where:

- Ground water is unsuitable for human consumption (due to naturally occurring conditions or where contamination can not be related to a specific source).
- There is no potential for the ground water to affect drinking water sources or environmentally significant ground water.
- Ground water is unlikely to be used in the foreseeable future; therefore, remediation time is not a primary concern.
- There is little likelihood of exposure (provided that further migration of contamination is controlled).

The time required to achieve remedial goals is an issue that may impact the viability of natural attenuation. Current EPA policy is that remediation time frames must be reasonable given specific site conditions. Rapid restoration of ground water is favored where ground water is currently (or likely to be in the near future) the source of a drinking water supply or where ground water feeds into or is connected to sensitive or vulnerable aquatic ecosystems. In contrast, it is acknowledged that factors such as location, proximity to population, and likelihood of exposure may allow for the extended timeframes that are more commonly associated with natural attenuation.

EPA states that natural attenuation will not provide contaminant reduction in all cases and, as such, it may not be appropriate as the sole remedial action. Factors cited as affecting the applicability of natural attenuation include the degradability of the contaminant (biological and chemical), the physical and chemical characteristics of the ground water, and hydrogeological characteristics.

If natural attenuation is considered appropriate and implemented at a site, the use of institutional controls may be necessary to ensure that the contaminated ground water is not used before contaminant levels that are protective of human health are attained.

#### **RCRA Corrective Actions**

Natural attenuation is also addressed in EPA policy regarding RCRA Corrective Actions as presented in the preamble to the proposed Subpart S rule (Federal Register, 1990b). In this context, the policy is similar to that described above (as presented in the preamble to the NCP). Specifically, natural attenuation may be considered in situations where cleanup standards can be achieved in a reasonable time frame and the likelihood of exposure is minimal. This policy goes even further to state that natural attenuation could be "most appropriate" and "play a major role" in the remedy provided that the remedy can be carried out over an extended period of time (Tomassoni, 1994a).

### **EPA/AFCEE Guidance on Implementing Natural Attenuation**

Staff from the EPA and the Air Force Center for Environmental Excellence (AFCEE) recently circulated a draft protocol (Wiedemeier *et al.*, 1994) on how to generate data needed to support the selection of natural attenuation for site remediation. This protocol describes how to assess the site and contaminant characteristics, how to conduct modeling and risk analyses, and how to demonstrate that natural degradation processes are occurring at the site. As such, this document represents one of the first widely publicized efforts to develop a "cookbook," or standardized methodology, to review whether a particular site should be a candidate for natural attenuation. Implementation of this document could be an important step forward for legitimizing the use of natural attenuation as a remedial option.

A note on the cover of the draft protocol states that although EPA researchers cooperated, the protocol represents Air Force guidance, not EPA guidance. However, many regulators are evaluating the study approach proposed in the protocol as a general approach to be followed, even though it was written specifically for personnel interested in remediation of ground water contaminated with fuel-hydrocarbons.

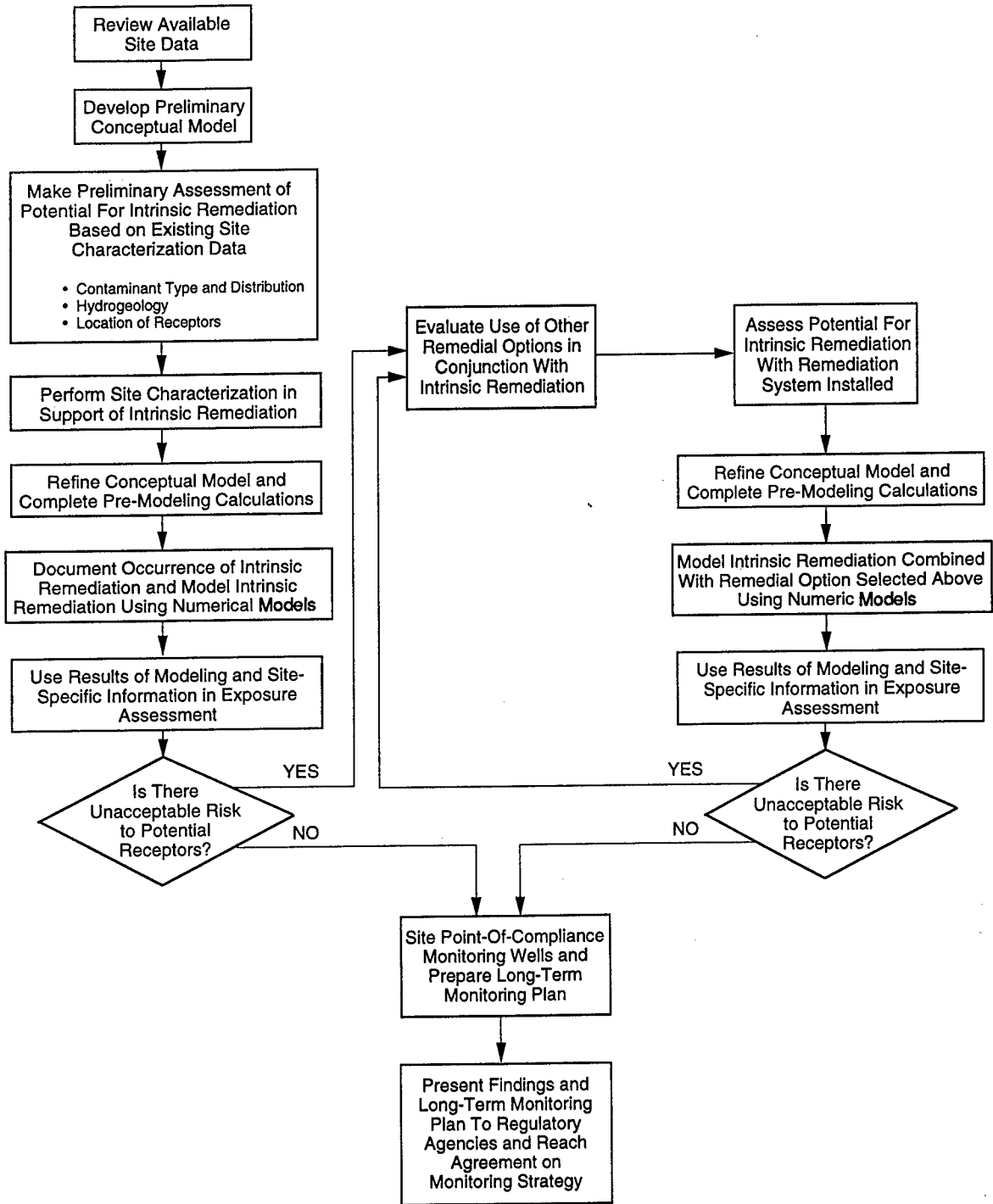
Figure 2-1 presents the flowsheet for implementation of the methodology suggested in the protocol. The protocol suggests following the methodology to ensure that the regulators are provided with sufficient information to approve the use of natural attenuation. Adherence to this methodology should also help ensure that excessive time is not wasted in promoting an inappropriate site for natural attenuation.

As shown in the figure, the methodology includes the following basic steps:

- Review existing site data.
- Develop preliminary model.
- Develop preliminary assessment of potential for natural attenuation.
- Perform specific, focused site characterization.
- Document indicators of natural attenuation.
- Use updated site characteristics to refine model.
- Conduct long-term modeling.
- Assess potential exposures.
- Develop monitoring plan.
- Negotiate with regulators.

This document would be applicable for sites contaminated with materials other than fuel-hydrocarbons as long as appropriate chemical specific natural attenuation mechanisms are considered in this approach. The natural attenuation of other contaminants would follow pathways different from those listed in this document, but the general approach could still be followed. Section 4.0 of this report presents examples of degradation pathways for nonfuel hydrocarbon contaminants that would need to be considered for other classes of contaminants.

**Figure 2-1: AFCEE Flowsheet for Implementation**



### **Other Guidance**

Additional guidance affecting the consideration and applicability of natural attenuation for the restoration of ground water is provided in "Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration" (EPA, 1993a). This guidance provides clarification on how EPA determines whether ground water restoration is technically impracticable and how alternatives must ensure that the final remedy is protective of human health and the environment. In this context, technical impracticability will allow for modification of EPA's goal of restoring contaminated ground water within a reasonable timeframe at Superfund or RCRA sites.

The technical impracticability of ground water restoration is a function of a number of possible site-specific factors including regulatory implications, hydrogeology of the site, and contaminant characteristics. In order to address the potential technical impracticability of a given or proposed remedial action, these factors must be fully characterized and addressed. Specific items that should generally be included in such an evaluation are, at a minimum (EPA, 1993a):

- Identification of applicable or relevant and appropriate requirements (ARARs).
- Determination of the spatial area of application.
- Development of a conceptual model that describes site geology, hydrology, ground water contamination sources, transport, and fate.
- Assessment of the restoration potential of the site.
- Estimation of the cost of the existing or proposed remedy.

Although this document does not include a definition of natural attenuation, it does state that "some of the processes involved in natural attenuation *of petroleum products* include aerobic and anaerobic biodegradation, dispersion, volatilization, and adsorption." Natural attenuation is specifically mentioned in this guidance as potentially applicable as a component of the remedy in certain situations where restoration is technically impracticable. However, sufficient technical information and supporting data must be developed to demonstrate the effectiveness of natural attenuation; there must be assurance that any institutional controls required to prevent exposure will be reliable and enforceable; and contingencies should be incorporated into the remedy. It is important to note that although natural attenuation is a potential alternative strategy when complete restoration is not technically practicable, *technical impracticability is not a precondition for its use.*

Guidance specifically oriented toward RCRA corrective actions is provided in a recent EPA document, "How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers" (EPA, 1994a). This document provides an evaluation of eight strategies (including natural attenuation) for the cleanup of underground storage tank sites and includes guidance on initial screening, detailed evaluation, and monitoring.

This document specifically addresses petroleum hydrocarbon contamination; however, many of the criteria to be evaluated and decision-making aspects apply to other contamination which has similar natural attenuation mechanisms. Key to the

evaluation process is the conduct of the following series of steps to determine the applicability of natural attenuation (EPA, 1994a).

1. Determine if state regulations permit natural attenuation as a remedial option.
2. Perform an initial screening of natural attenuation effectiveness.
3. Perform a detailed evaluation of natural attenuation effectiveness.
4. Evaluate monitoring plans.

The document describes each of these steps as well as various contaminant and site characteristics that will impact the effectiveness of natural attenuation. It gives legitimacy to natural attenuation as a viable option for the cleanup of underground storage tank sites and may help program managers at other sites evaluate natural attenuation.

## **2.2 State and Regional Policy and Guidance**

A recently completed Air Force document, "Review of State Regulations Regarding Natural Attenuation as a Remedial Option" (AFCEE, 1994), provides a summary of state regulations that address natural attenuation as an alternative in contaminated site cleanups. Through a search of state regulations, eight states were identified as having regulations that mention natural attenuation (or a similar term). A majority of these regulations pertain directly to underground storage tank issues and are therefore geared to petroleum hydrocarbon contaminants. A summary of the findings of this review is provided in Table 2-1. It should be noted that although this presentation is heavily oriented toward petroleum hydrocarbon contamination, it does provide some indication as to the relative attitudes the states have with respect to natural attenuation in general.

Based on a series of interviews conducted by Arthur D. Little, the only state that appears to have written guidance prepared specifically to address natural attenuation is Wisconsin (Braden, 1994). This guidance, "Naturally Occurring Biodegradation as a Remedial Action Option for Soil Contamination," provides interim guidance on the use of naturally occurring biodegradation as a remedial action option (Wisconsin Department of Natural Resources (DNR), 1994). As is evident by the title of this document, the emphasis of natural attenuation is placed on naturally occurring biodegradation. In fact, there is a reluctance on the part of state regulators to use the term "natural attenuation" (Braden, 1994). The term "naturally occurring biodegradation" is preferred because it illustrates that contaminants are being destroyed through the process. This implies that the state is more accepting of natural attenuation if it results in contaminant destruction rather than other mechanisms (i.e., adsorption or dilution). In addition, it implies that pursuit of natural attenuation at a site with nonbiodegradable contaminants will be difficult at best. Note that the Wisconsin guidance applies to the cleanup of soil only.

**Table 2-1: Summary of State\* Regulations Regarding Natural Attenuation**

<u>State</u>	<u>Summary/Comments</u>
Wisconsin	Three cleanup options must be evaluated for state-funded petroleum environmental cleanups and one of the options must be "passive bioremediation." If "passive bioremediation" with long-term monitoring is feasible, but not the recommended alternative, rationale must be provided.
Iowa	In cases of significant risk, "passive cleanup" may be allowed in extraordinary circumstances. If significant risk is not present, the responsible person may be required to monitor and manage ground water such that further contamination is minimized.
Delaware	"Passive corrective action" is allowed for two years unless a written consent is issued by the state. "Passive corrective action" may also be used to supplement the active corrective action, either prior to or following.
Florida	A "monitoring-only" approach can be proposed if the site is contaminated by specific petroleum products provided appropriate analytical procedures are performed.
Michigan	If ground water sampling shows evidence of natural attenuation, corrective action may be deferred for 24 months.
North Carolina	Natural attenuation is specifically recognized as an acceptable alternative for restoring ground water quality. Plans for corrective actions at nonpermitted sites may be approved based on natural processes of degradation and attenuation of contaminants. Regulations provide further requirements and restrictions.
Ohio	Remedial action plans for petroleum hydrocarbon-contaminated underground storage tank sites may propose a "monitoring-only" remedial program provided certain conditions are met (conditions pertain to the presence and concentration of petroleum hydrocarbons).
District of Columbia	Monitoring is allowed to ensure that site contamination is controlled under "natural conditions" only when it is not feasible to achieve cleanup standards through corrective actions.

Notes

\* including the District of Columbia

Terms in quotation marks indicate alternative terms used for natural attenuation and demonstrate the variation in what constitutes natural attenuation for these states.

Source: AFCEE, 1994

The Wisconsin guidance states that naturally occurring biodegradation may be applicable at sites where the contaminants are biodegradable, site conditions are favorable, and the time required for cleanup is reasonable (in terms of site-specific requirements). It is recognized that naturally occurring biodegradation may require "years or decades to effect adequate clean-up of a site." In order to determine the applicability of naturally occurring biodegradation, the regulators will examine factors including contaminant characteristics; geologic and hydrogeologic conditions at the site; proximity of human and environmental receptors; proximity to private and public water supplies; potential use of the aquifer(s) in the proximity of the contamination; and reliability and enforceability of institutional controls.

General examples of potentially appropriate uses of naturally occurring biodegradation include (Wisconsin DNR, 1994):

- A primary remedial action at low- and medium-priority sites where contamination is confined to unsaturated soil and levels of contamination are sufficiently low so that ground water is not threatened.
- A second phase of remediation after an active remediation process has sufficiently reduced contaminant concentrations in unsaturated soil to levels where contaminant migration to the ground water does not exceed enforcement standards.
- A component of a more comprehensive remediation plan.

Specific site investigation and characterization requirements are provided in the Wisconsin guidance. These requirements are grouped into the following components:

- Characterization of the contaminants at the site (and a determination of their biodegradability).
- Characterization of environmental parameters (to ensure that physical and chemical conditions are amenable to naturally occurring biodegradation).
- Characterization of microbiological environment (to ensure that suitable microbes are available for degrading the organic contaminants at a site).

Finally, the Wisconsin guidance provides instructions for the preparation of a monitoring plan necessary to track the progress and effectiveness of naturally occurring biodegradation.

### **2.3 Regulatory Attitudes, Philosophies, and Trends**

Arthur D. Little conducted a series of interviews with Federal, state, and regional regulators to qualitatively and quantitatively (to the extent possible) assess the regulatory atmosphere regarding natural attenuation. A list of regulators contacted is

provided in Table 2-2. Summaries of each interview conducted are provided in Appendix A of this report.

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**Table 2-2: Regulators Interviewed**

<b>Name</b>	<b>Organization</b>	<b>Position</b>
Guy Tomassoni	EPA Headquarters Office of Solid Waste, Corrective Programs Branch	Hydrogeologist
Peter Feldman	EPA Headquarters Office of Solid Waste CERCLA Branch	Hydrogeologist
John Shauver	Michigan Department of Natural Resources, Environmental Systems Division	Environmental Quality Manager
Michael Braden	Wisconsin Department of Natural Resources - Solid Waste	Hydrogeologist
Rutherford Hayes	EPA Region IV	Remedial Project Manager
Ken Katen	California Regional (North Coast) Water Quality Control Board	Associated Water Resource Control Engineer
Rosita Clarke	EPA Region V	Superfund Project Manager
John Kuhns	EPA Region V	Superfund Project Manager
Lisa Weers	Colorado Department of Public Health and Environment	RCRA Specialist Engineer
Reuben McCullers	EPA Region III	Corrective Action Officer

(a) see Appendix A for completed interview questionnaires.

Source: Arthur D. Little, Inc., 1995

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Although the interviews were conducted with a limited number of regulators, the general attitudes and philosophies were fairly consistent. The following sections provide a summary of interview findings with respect to the regulatory climate and

trends for considering natural attenuation in site cleanups. Information relating to specific case studies discussed with these regulators is provided in Section 3.0 of this report.

#### **Federal**

EPA headquarters appears to support the consideration of natural attenuation. It is felt that natural attenuation should receive equal consideration as a potential remedial action as other alternatives that employ active measures (Feldman, 1994). It was stated that EPA headquarters wishes to remain flexible regarding the consideration of natural attenuation; thereby, leaving some room for the regions and states to impose more restrictive guidance or policy (Tomassoni, 1994b). This position accentuates the importance of regulatory interfacing and negotiations on a site-specific basis.

Despite the acknowledged support of natural attenuation, it is recognized that there remain a number of obstacles to a generalized acceptance of the alternative. In the view of one regulator, the biggest obstacle may be a lack of technical information (Feldman, 1994). Before regulators "buy off" on natural attenuation, there must be a certain level of technical understanding of the processes involved. For example, critics of natural attenuation often regard the process as dilution. Without identifying the specific processes involved at a given site, it is likely that these critics will remain unconvinced that something positive is actually occurring.

Other identified obstacles include (Tomassoni, 1994a):

- The association of natural attenuation with No Action.
- A preference among regulators for rapid remediation.
- Preferences for zero growth of contaminant plumes.

Overcoming the first of these obstacles can be aided by ensuring that natural attenuation is incorporated as part of an actual cleanup remedy and clearly disassociating it from the No Action alternative. As part of a cleanup remedy, natural attenuation can be further supported by monitoring (a critical requirement) and the imposition of source and institutional controls.

Although natural attenuation is often regarded as a prolonged cleanup remedy, it should be recognized that conventional, active measures for ground water cleanup may also take a long time. Ground water extraction and treatment ("pump and treat") systems are commonly used to remediate contaminated ground water, and are often justified by computer modeling efforts that predict attainment of remedial goals within a relatively short time period. However, many of these pump and treat systems do not achieve remedial goals within the time period predicted due to factors such as residual contamination in source area soils or nonaqueous phase liquids (NAPLs) in the ground water.

In addition, the point is made that there are policies that allow for longer remedial time frames (see discussion in Section 2.1). Additionally, the costs associated with a faster paced remediation may not be justified (Tomassoni, 1994a).

Regulators are reluctant to approve remedial measures that result in significant growth of the contaminated plume (Tomassoni, 1994a). This problem may be alleviated by early source control, the development of contingency active remedies in the event plume growth does occur, and adequate monitoring to ensure protectiveness.

At the Federal level, natural attenuation is seen as an alternative likely to be subject to expanded consideration and implementation in the future. This will particularly occur as the experience base becomes larger and, most importantly, as the technical knowledge of the processes and mechanisms involved in natural attenuation increases.

### **State and Regional**

It is important to emphasize the importance of state and regional coordination in examining the potential for natural attenuation at a given site. As described above, federal policy and guidance leaves the door open for state and regional interpretations and opinions. Among the state and regional regulators interviewed, natural attenuation was consistently identified as a potentially viable alternative. However, those interviewed were typically regulators with an interest in, and knowledge of, natural attenuation.

Attitudes regarding natural attenuation appear to be generally positive. It is seen as a growing trend, continually enhanced by increasing knowledge and experience. Commonly perceived advantages of natural attenuation include cost and technical practicability. Identified disadvantages or obstacles include the time required to effect cleanup and the concern that natural attenuation may be inadequately aggressive.

Natural attenuation is typically found to be attractive at sites where the time to remediate is not critical and there are no threats to human health or the environment as a result of its implementation. In general, natural attenuation is not an acceptable alternative at sites where downgradient receptors or the environment is threatened without intervention.

Natural attenuation is also considered to be most attractive when biodegradation mechanisms are involved (most often with petroleum hydrocarbons). This implies that the potential for natural attenuation is enhanced when the site is biologically active. In addition, it illustrates that natural attenuation may be considered less appropriate for non- (or slowly) biodegradable contaminants (e.g., chlorinated hydrocarbons and explosives). In fact, explosives were explicitly mentioned by one regulator as being unlikely candidates for natural attenuation (Braden, 1994).

The importance of adequate site and contaminant characterization was stressed by each person interviewed. Typically, minimum requirements include:

- Three-dimensional hydrogeological assessments.
- Identification of all potential receptors.
- Chemical and physical characterizations.

To illustrate common themes and variations between the interviewees, a brief summary of each of the interviews is presented in Table 2-3 (full summaries of the interviews are provided in Appendix A).

## 2.4 Summary of Regulatory Implications of Natural Attenuation

Guidance and policy established by EPA on the national level has provided avenues for the consideration of natural attenuation for the cleanup of contaminated sites. Although a majority of this guidance and policy is oriented toward the cleanup of ground water, many of the issues may pertain to other media as well. The guidance and policy developed has illustrated the willingness of the regulators to consider natural attenuation in cases where active remediation is not practicable, cost-effective, or warranted.

The preference of the regulators continues to be that biodegradation constitutes the principal natural attenuation mechanism. This focus has led to beginning to change the nomenclature from natural attenuation to intrinsic bioremediation and has limited the consideration of natural attenuation to biodegradable organics. The use of natural attenuation for inorganic or MUC contamination has not been considered to a large extent by any of the regulators. In fact, most regulators questioned stated that they would be hesitant to consider natural attenuation for nonbiodegradable and relatively nonbiodegradable contaminants.

The position of EPA is to maintain a maximum of flexibility regarding the acceptance of natural attenuation thereby allowing states and regions to apply their own, possibly more restrictive, policy or guidance. The states and regions, in turn, appear to be accepting of the consideration of natural attenuation based on site-specific needs and characteristics. States where cleanup criteria are flexible and allow for site-specific conditions to be incorporated into their development, are further providing opportunities for the consideration of natural attenuation.

The most common requirements for the implementation of natural attenuation include a lack of potential receptors, little likelihood of potential exposures, the ability to control the size of a contaminated ground water plume, and adequate site characterization to accurately predict the effectiveness of natural attenuation in mitigating contamination. The time frame involved in the cleanup may or may not be a deciding factor. Although a rapid remediation has traditionally been the ideal for cleanups (and natural attenuation is most often associated with overly long cleanup times), it appears as though the regulators are willing to consider tradeoffs between time, effectiveness, and cost.

It should be noted that a majority of the Federal and state policies and guidance have been developed based on contamination of soil and ground water by petroleum hydrocarbons. This contamination may represent a "best case" scenario because of the relative biodegradability of the contaminants making them more amenable to destruction by natural attenuation mechanisms. Other contaminants (e.g., chlorinated hydrocarbons and explosives) may require a greater degree of demonstration to determine the technical feasibility of natural attenuation.

Table 2-3: Highlights of State and Regional Regulatory Interviews (a)

<u>State/Region</u>	<u>Comments/Highlights</u>
Michigan Department of Natural Resources (Shauver, 1994)	<ul style="list-style-type: none"> <li>• Currently reviewing AFCEE intrinsic remediation protocol for incorporation into DNR policy (see Section 3.0 of this report).</li> <li>• Three levels of cleanup in soils and ground water: background, risk-based, and long-term containment. Provides opportunities for natural attenuation.</li> <li>• Risk-based cleanup levels are based on extensive aquatic and human risk assessments.</li> <li>• No specific time frames are established for cleanups.</li> <li>• State is very supportive of natural attenuation provided adequate site characterizations are completed.</li> <li>• Strong emphasis placed on biodegradation mechanisms in natural attenuation.</li> <li>• Resources devoted to maintain active research and development activities (four Federal or state-supported laboratories) for the continued study of the applicability and capability of natural attenuation.</li> <li>• Close working relationship with EPA research and development organizations to investigate natural attenuation.</li> <li>• Potential for cost savings seen as important advantage.</li> <li>• View held that, in some cases, natural attenuation may be as effective as active methods.</li> <li>• Trend for consideration of natural attenuation is increasing.</li> </ul>
Wisconsin Department of Natural Resources (Braden, 1994)	<ul style="list-style-type: none"> <li>• Only state identified with specific guidance for natural attenuation (see Section 2.2 of this report).</li> <li>• Terminology is important – use of term “naturally occurring biodegradation” preferred as it indicates that contaminants are being destroyed.</li> <li>• <i>Explosives mentioned explicitly as being unlikely candidates for “naturally occurring biodegradation.”</i></li> <li>• Emphasis on use of natural attenuation is on soil contaminated with petroleum hydrocarbons.</li> <li>• Use of natural attenuation in ground water cleanups is a “harder sell.”</li> <li>• State reluctant to consider natural attenuation in soil if contaminants are not readily biodegradable.</li> <li>• Generic cleanup levels in soil are provided in regulations; however, site-specific cleanup levels may be proposed by responsible parties.</li> <li>• Flexibility is maintained in establishing remediation time frames.</li> <li>• Natural attenuation considered as being high on an upward trend for consideration and implementation.</li> <li>• Recent state-wide survey indicated that approximately 80 sites are employing cleanups involving “natural occurring biodegradation” in soil (a majority of contamination due to petroleum hydrocarbons from leaking underground storage tanks).</li> </ul>
California Regional (North Coast) Water Board (Katen, 1994)	<ul style="list-style-type: none"> <li>• Natural attenuation seen as a remedial alternative with potential for cleaning up the environment without bankrupting responsible parties or the government.</li> <li>• Cleanup goals are established on a site-specific basis; there are no numerical criteria.</li> <li>• Natural attenuation has received favorable comment from citizens groups and individuals.</li> </ul>

(a) See Appendix A for completed interview questionnaires.

Table 2-3: Highlights of State and Regional Regulatory Interviews (a) (continued)

<u>State/Region</u>	<u>Comments/Highlights</u>
California Regional (North Coast) Water Board (Katen, 1994) (continued)	<ul style="list-style-type: none"> <li>• Conduct of "rational demonstration" of the potential effectiveness of natural attenuation given specific and well-defined site characteristics is critical to the acceptance of the alternative.</li> <li>• Natural attenuation is potentially applicable in two scenarios: (1) sites with minor soil contamination and no ground water contamination or no threat of ground water contamination; and (2) sites where a contaminated plume has been well-delineated and proven to be stable in size.</li> <li>• Natural attenuation is not applicable when contamination has affected ground water and the behavior of the contaminated plume has either not been well-documented or is still growing.</li> <li>• Interest in natural attenuation is growing and is likely to continue to do so.</li> </ul>
EPA Region IV, Atlanta, Georgia (Hayes, 1994)	<ul style="list-style-type: none"> <li>• Region IV has actively supported the consideration of natural attenuation.</li> <li>• Incorporation of technical practicability language into Records of Decision (RODs) has enhanced the ability of regulators to consider potentials for natural attenuation.</li> <li>• Consideration of natural attenuation made easier due to revisions in the Hazard Ranking System for NPL sites because of greater focus on targets of contamination (i.e., if there are no receptors of contaminated ground water, the ranking may be less severe).</li> <li>• Natural attenuation being used at two sites with low levels of heavy metals in ground water – modelling used to predict that MCLs will be reached within 2 to 3 years through advection.</li> </ul>
EPA Region V, Chicago, Illinois (Clarke, 1994) and (Kuhns, 1994)	<ul style="list-style-type: none"> <li>• Considerable support within Region V for selective implementation of natural attenuation.</li> <li>• Attractiveness of natural attenuation is typically due to cost considerations.</li> <li>• Risk and exposure-based analyses are used to judge the applicability of natural attenuation.</li> <li>• Natural attenuation is likely to be considered for implementation only where there are no significant health or environmental risks.</li> <li>• Based on interest, support, and demonstrations of effectiveness, natural attenuation will continue to be considered a technically and economically viable alternative in certain instances.</li> </ul>
EPA Region III, Kansas City (McCullers, 1995)	<ul style="list-style-type: none"> <li>• No formal policy regarding natural attenuation.</li> <li>• Consideration of natural attenuation for corrective actions is done solely on a site-by-site basis.</li> <li>• Natural attenuation is best suited for biodegradable contaminants (view of point of contact).</li> <li>• Inorganic contaminants considered for natural attenuation only if the risk is low, where the concentration is close to criteria, and exposure is controlled (view of point of contact).</li> <li>• Institutional controls (including monitoring) are essential to ensure there is no potential for penetration of contaminated site.</li> </ul>

(a) See Appendix A for completed interview questionnaires.

Source: Arthur D. Little, Inc.

## 2.5 The Army Alternative Selection Process and Policy Trends

The Army typically responds to the uncontrolled release of hazardous substances under the requirements of either CERCLA or RCRA. Although the terminology used under each authority is different, in each case the identification and selection of the appropriate response to the release of hazardous substances is conducted in an orderly, phased approach. Figure 2-2 illustrates the similarities and differences between the response action process under each statute. Because of the similarities in the processes and the substantially larger experience base associated with response actions conducted under CERCLA, the following discussion focuses on the CERCLA process and uses CERCLA terminology. Where appropriate, the reader should use Figure 2-3 and Table 2-4 to crosswalk between the CERCLA and RCRA response action processes.

**Table 2-4: CERCLA/RCRA Terminology Crosswalk**

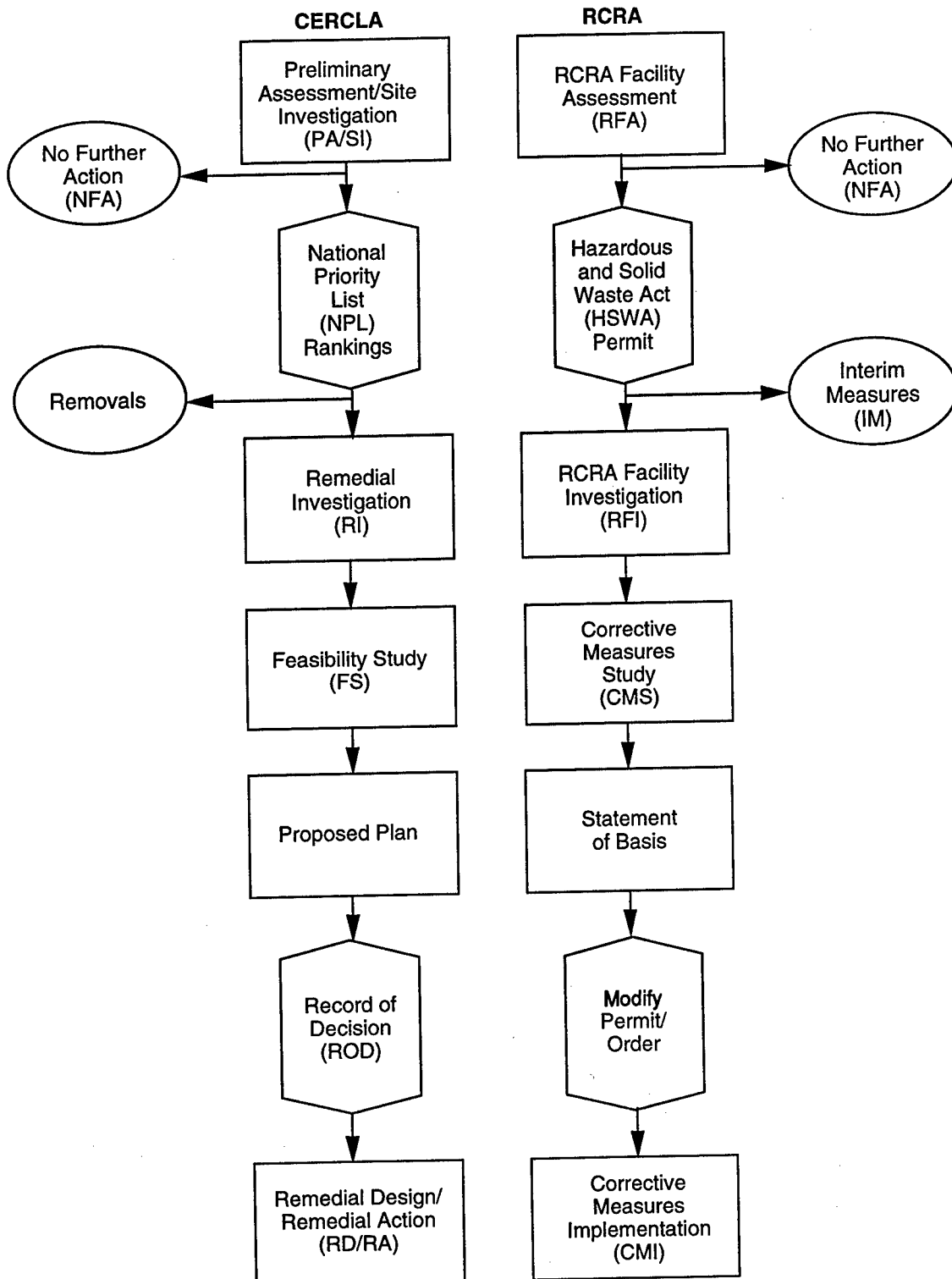
CERCLA Process	RCRA Process	Objective
Preliminary Assessment (PA)	RCRA Facility Assessment (RFA)	Determine the potential for a present or past release—based primarily on historical records
Site Investigation (SI)	See note	Provide sufficient information to determine the need for a full remedial investigation—based on preliminary site data and field sampling for contamination
Remedial Investigation (RI)	RCRA Facility Investigation (RFI)	Characterize the nature, extent, direction, rate, movement, and concentration of releases
Feasibility Study (FS)	Corrective Measures Study (CMS)	Evaluate potential remedial actions and provide sufficient information to decision makers to allow an informed decision

Note: There is no direct RCRA equivalent for the SI. The RFA may have many of the field investigation aspects of the SI.

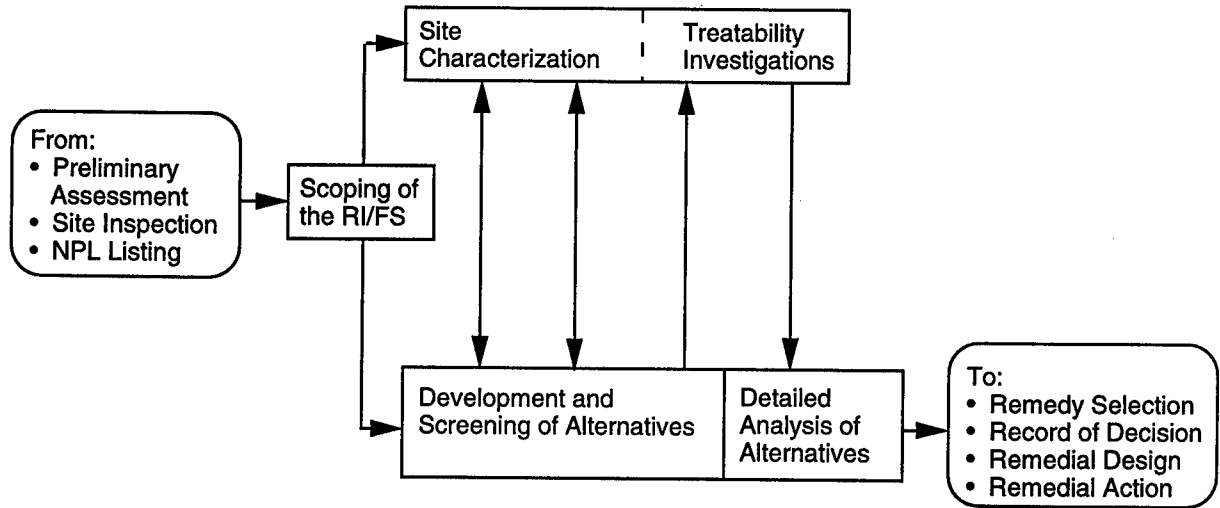
Source: U.S. Army Engineer Waterways Experiment Station, 1994

Under CERCLA, the identification and selection of the appropriate response to the uncontrolled release of hazardous substances is conducted in an orderly, phased

**Figure 2-2: Comparison of RCRA/CERCLA Action Processes**



**Figure 2-3: Remedial Action Evaluation Process**



Source: EPA, 1988a

approach consisting of three steps: (1) the preliminary assessment (PA); (2) the site investigation (SI); and (3) the remedial investigation/feasibility study (RI/FS). The overall process is shown in Figure 2-3.

The Army may also conduct removal actions, requiring engineering evaluation/cost assessments (EE/CA), in lieu of the more formal RI/FS. The key steps in the EE/CA process are listed in Table 2-5. Removals are expedited response actions as opposed to long-term action undertaken through implementation of the RI/FS process. There are two types of removal actions: time critical and nontime critical. RCRA has a parallel authority for implementing short-term responses to a release prior to full implementation of the corrective measure. The RCRA procedure is called an Interim Measure. RCRA Interim Measures must meet the requirements of all Federal, state, and local laws and regulations.

Regardless of whether the RI/FS or EE/CA process is used, alternative selection may be viewed as a series of analytical steps that involve making successively more specific definitions and evaluations of potential remedial activities. The alternative development, screening, and detailed evaluation process follow the general principles found in "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA-Interim Final" (EPA, 1988a).

The alternative development and screening process is illustrated in Figure 2-4. Alternatives passing the screening process are subjected to a detailed evaluation process incorporating nine criteria as shown in Figure 2-5. The interrelationship of the alternative screening and detailed evaluation process is illustrated in Figure 2-6.

At the present time, the Army has no specific policy related to the use of natural attenuation as an appropriate remedial action. As a result, the Army relies on the standard alternative development and selection process to identify appropriate remedies. No special preference is given to natural attenuation.

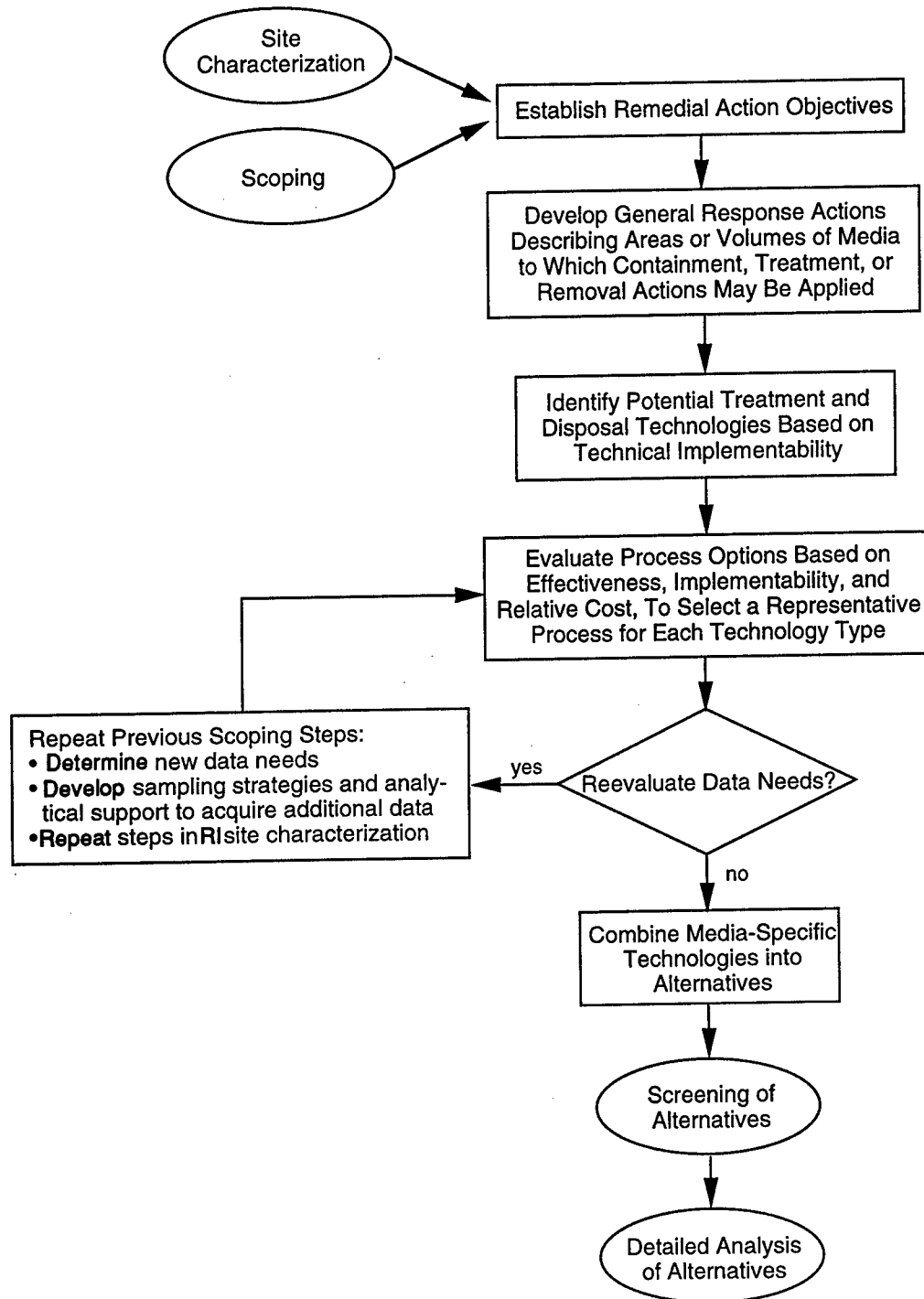
The Army has tasked the Army Science Board (ASB) to assess the applicability of natural attenuation as an appropriate alternative to address cleanup of Army facilities. The ASB will make recommendations on policy issues related to the use of the natural attenuation alternative at Army sites.

**Table 2-5: Key Steps in the EE/CA Process**

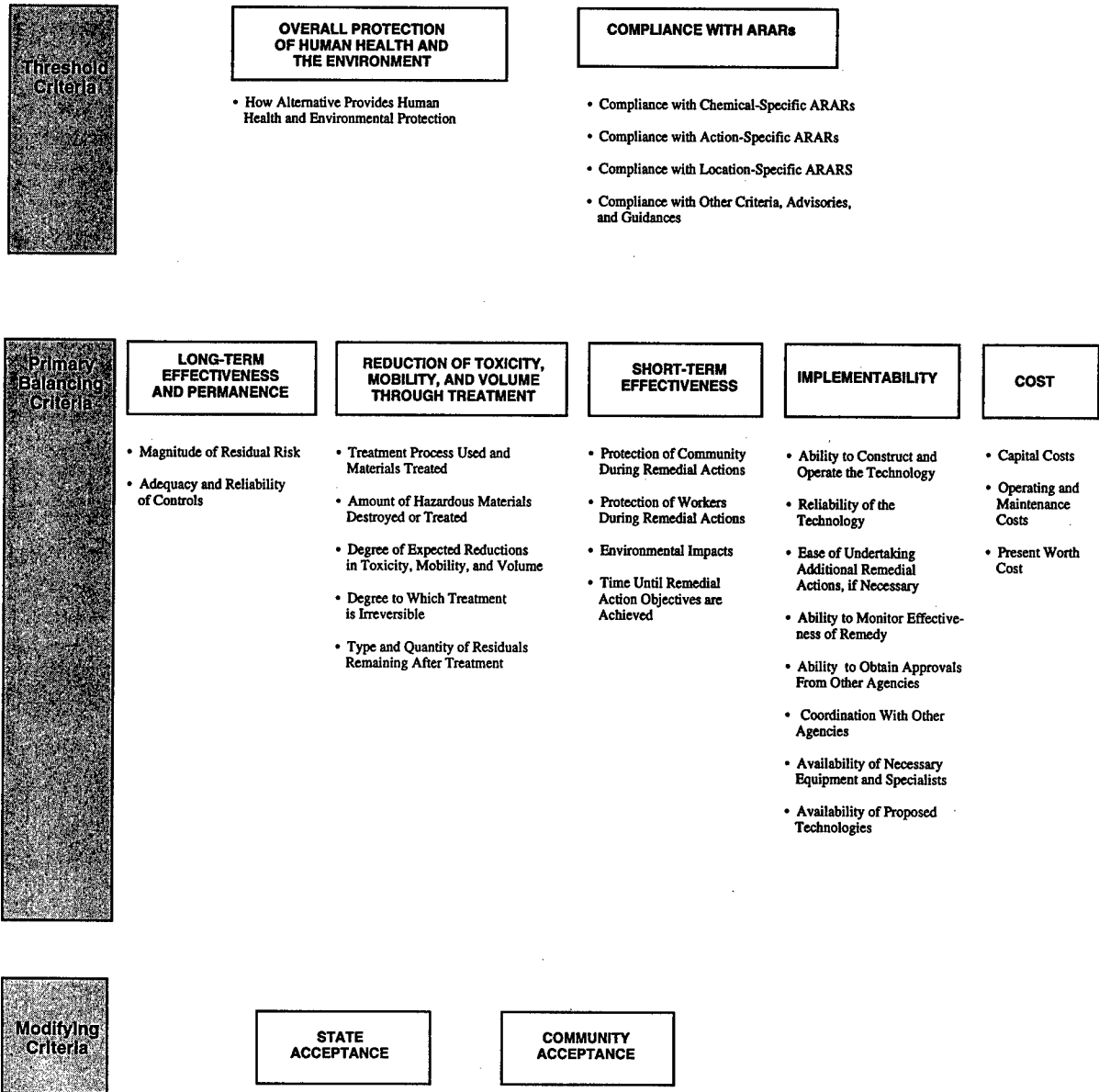
EE/CA Steps	Activities
Site Inspection (SI)	<ul style="list-style-type: none"> <li>• Review removal PA/SI that indicates a removal action is appropriate, but that the threat is not time-critical.</li> </ul>
Potentially Responsible Party (PRP) Notice	<ul style="list-style-type: none"> <li>• Issue a general notice (required) or a special notice (discretionary).</li> </ul>
Approval and Initiation of EE/CA Study	<ul style="list-style-type: none"> <li>• Prepare approval memorandum that documents that the site meets criteria for a removal action and secures management approval to conduct EE/CA.</li> <li>• Designate site spokesman.</li> <li>• Open Administrative Record.</li> <li>• Initiate community interviews.</li> <li>• Prepare Community Relations Plan.</li> </ul>
Complete EE/CA Study and Report	<ul style="list-style-type: none"> <li>• Complete any additional on-site data collection activities necessary to better characterize the waste and define site conditions (see CERCLA Section 104(b)).</li> <li>• Compile all appropriate removal/remedial action alternatives and analyze each for effectiveness, cost, and implementability—conclude with recommended removal/remedial action(s).</li> <li>• Cleanup measures are not permitted.</li> </ul>
Release EE/CA Report	<ul style="list-style-type: none"> <li>• Place EE/CA report in Administrative Record.</li> <li>• Publish notice of report availability and summary.</li> <li>• Complete Community Relations Plan.</li> </ul>
Public Comment	<ul style="list-style-type: none"> <li>• Provide for 30-day public comment period on the EE/CA and other documents in the Administrative Record.</li> </ul>
Action Memorandum	<ul style="list-style-type: none"> <li>• Prepare Action Memorandum describing the proposed removal action and soliciting management approval to implement the action. Attach a Responsiveness Summary (including a summary of significant public comments and responses to these comments).</li> <li>• Close Administrative Record when Action Memorandum is signed.</li> </ul>
Implement Removal Action	<ul style="list-style-type: none"> <li>• Observe conditions of the EE/CA on the implementation of the removal action, but not including any previous Section 104(b) activities.</li> </ul>

Source: U.S. Army Waterways Experiment Station

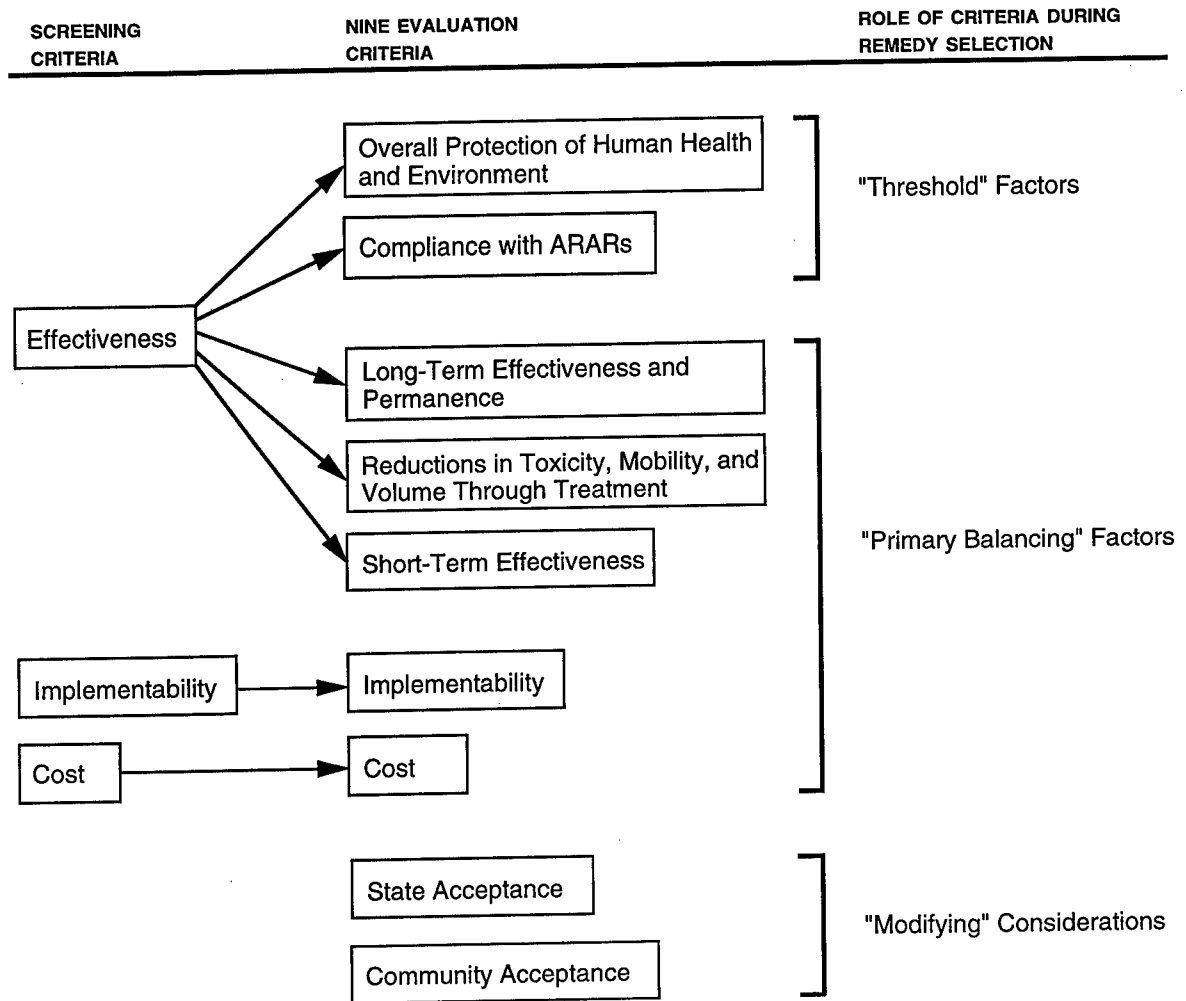
**Figure 2-4: Alternative Development and Screening**



**Figure 2-5: Detailed Analysis of Alternatives**



**Figure 2-6: Relationship Between Screening Criteria and Detailed Evaluation**



Source: EPA, 1988a

### 3.0 Past Applications of Natural Attenuation

By searching the EPA ROD database, 14 sites were found where the ROD used the terminology "natural attenuation" to describe a principal portion of the remedial activity. The majority of these sites were contaminated primarily with low concentrations of biodegradable materials, and many had conclusive data indicating that biodegradation was occurring. In addition to searching the EPA ROD database, the EPA provided a list of sites where they felt that natural attenuation was a principal component of the remediation. The EPA's list of natural attenuation sites was substantially longer (57 sites) than the list developed from the ROD database search. Upon closer review, a number of the sites on the EPA's list did not use the terminology "natural attenuation," but were sites where institutional controls and long term monitoring had been selected. This ambiguity illustrates the need to discuss the use of natural attenuation and its definition with each state and Federal regulator prior to incorporating it into the feasibility study.

#### Recommended Army Actions:

- ✓ Investigate how the governing regulatory agencies for each contaminated Army site define the term natural attenuation, and assess whether implementation appears feasible at the particular site.
- ✓ Identify the state and EPA regional expert(s) overseeing the implementation of natural attenuation, and discuss the use of natural attenuation at the site with them as well as with the specific remedial project manager.
- ✓ Review past RODs for the state and EPA region of concern, and develop a list of sites where "natural attenuation" was used in the past.

Section 3.0 presents the results of the various literature searches conducted on the application of natural attenuation. These searches identified information on two types of sites: (1) sites where EPA made a legal decision to use natural attenuation as a remedial option, and (2) sites where natural attenuation was observed to be occurring but was not "selected." Additionally, information was found describing laboratory studies conducted to test theories based upon field observations. This section only presents information on National Priorities List (NPL), or Superfund, sites where EPA made the decision to use natural attenuation. Information on the other sites is discussed in Section 4.0.

This section is organized according to the source of the case studies documented. Sections 3.1 and 3.2 present the results of the EPA ROD database review. The information obtained from a review of selected RODs is noteworthy, as it provides descriptions of sites where EPA accepted natural attenuation as the remedy of choice. At many of these sites, especially for pre-1990s RODs, the ROD did not use the term "natural attenuation," but referred to the use of long-term monitoring and institutional controls and mentioned that the contamination was expected to naturally decrease over time. It is, therefore, difficult to distinguish between RODs which specify long-term monitoring with institutional controls and RODs which specify natural attenuation as a demonstrated remedial technology. This literature search of the ROD database was not intended as a comprehensive search, but was intended to identify RODs specifying

natural attenuation to develop a composite idea of the “ideal site” for which natural attenuation would most likely be viewed favorably by the regulators.

Section 3.2 also presents site-specific information gathered during the interviews with Federal and state regulatory staff summarized in Section 2.0. The sites referenced are important in that they are viewed by regulators as trial sites for proving the utility of natural attenuation as a remedial alternative. A summary of the ROD for one of the four sites mentioned by the regulators is revealing because it does not specify the use of natural attenuation. This may indicate that although EPA is willing to approve of the natural attenuation concept, it remains unwilling to specify their selected remedy as “natural attenuation” in the formal documentation. Instead, EPA states that institutional controls and long-term monitoring will be used to control risk.

Subsequent to the performance of the literature reviews and ROD searches described in Sections 3.1 and 3.2, a draft list was received from EPA identifying RODs for sites where natural attenuation was a component of the selected remedy. A summary of this output is provided in Section 3.4, and the complete listing is in Appendix C. It is revealing to note that this EPA-provided list and the list generated during this study are not fully compatible. A cursory investigation into this discrepancy indicated that this incompatibility was due to the fact that some of the RODs included in the EPA-provided list did not specify “natural attenuation,” but specified a limited action alternative that would result in the decrease of contaminants over time. This discrepancy again illustrates the breadth of remedial activities that may be referred to as natural attenuation.

### **3.1 Natural Attenuation Use at CERCLA Sites**

The EPA CERCLA, or Superfund, ROD database was the source with the largest number of references to natural attenuation. The CERCLA process culminates in the selection and implementation of a remedial action that the regulators believe will be protective of human health and the environment. This decision is formally presented in a document known as the ROD, which lists the remedy selected and the grounds used by EPA to choose that option.

The search found more than 250 RODs with references to no action or some type of natural attenuation alternative. References to “no action” were searched to identify issues supporting its selection that may be applicable to natural attenuation. The “no action” reference was also searched to identify RODs for sites at which natural attenuation was selected but not identified by name - several sites were found referenced as “no action” sites with long-term monitoring, which is actually natural attenuation. To facilitate this study, this data set was then reduced by examining the ROD abstracts to determine those that actually specified natural attenuation. The complete RODs for those sites (approximately 25) were then obtained for detailed review. References for these RODs are provided in Appendix B. Of the 25 RODs obtained, 14 of these were determined to be written for the selection of a “natural attenuation” alternative as defined for this study.

To facilitate presentation of the data contained within the 14 RODs where natural attenuation was selected, a table was prepared listing characteristics of each site, and is included here as Table 3-1. A review of this table indicates that there are several site characteristics (e.g., limited areal extent of contamination, low concentrations of contaminants, and significant distance to receptors) that enhance the implementability of this remediation technique. Table 3-2 was prepared to summarize features of those sites specified by the regulators (during Arthur D. Little-conducted telephone interviews) as locations where natural attenuation has been implemented.

Several conclusions can be drawn from the literature review, the results of which have been summarized in Tables 3-1 and 3-2. Based upon this review of the ROD database and discussions with Federal and state regulators, natural attenuation appears to have been selected most often for ground water remediation at sites with various combinations of:

- Limited areal extent of contamination (Wilson Concepts, Town Garage, IMC East Plant, and the U.S. Defense General Supply Center sites).
- Low concentrations of ground water contaminants (Wilson Concepts, Twin Cities, Mosley Road, Gulf Coast, Town Garage, IMC East Plant, and U.S. Defense General Supply Center sites).
- Significant distance to the nearest human receptor *or* a nearby unusable ecological receptor (Cannons Engineering, Twin Cities, and Kin-Buc Landfill sites).
- Historical source of contamination (PSC Resources, Town Garage, IMC East Plant, and U.S. Defense General Supply Center sites).
- Ground water monitoring data demonstrating decreasing site contaminant concentrations over time (Cannons Engineering, Wilson Concepts, Gulf Coast, and Town Garage sites).
- As a primary remedial action at low- and medium-priority sites where contamination is confined to unsaturated soil and levels of contamination are sufficiently low so that ground water quality is not threatened (IMC East Site).
- As a second phase of remediation after an active remediation process has sufficiently reduced contamination concentrations in unsaturated soil to levels such that contaminant migration to the ground water is unlikely to exceed ground water quality standards (Mosley Road and Gulf Coast sites).

Table 3-1: Natural Attenuation-Based Records of Decision (RODs)

Site Name	Site Location	Site Type	Detected Contaminants	Contaminant Levels at Site	Contaminant Levels at POC	Distance to Nearest Receptor	Comments
Cannons Engineering	Bridgewater, Massachusetts	Hazardous Waste TSDF	Solvents, Metals, PCBs	> 100 times ARAR	Unknown but >10 times ARARs	< 1/4 mile	Contamination ~ 20 years old; ROD signed; active source control measures; natural attenuation for ground water (Hebert, 1988)
Savage Municipal Water Supply	Milford, New Hampshire	Industrial Facilities	Solvents, Metals	> 10 times ARAR	Unknown but >10 times ARARs	< 1/4 mile	Contamination age unknown; ROD signed; pump and treat for site GW; natural attenuation with deed and GW use restrictions for dilute plume (EPA, 1991a)
Wilson Concepts of Florida	Pompano Beach, Florida	Industrial Facility	Solvents, Metals	ARARs	<ARARs	~ 1/4 mile	ROD concluded that contaminants have undergone natural attenuation; GW monitoring only as part of "No Action" (EPA, 1992b)
Twin Cities AF Reserve	Minneapolis, Minnesota	Landfill	Solvents, Metals	<ARARs	<ARARs	One mile	Contamination ~ 25 years old; ROD specifies access & deed restrictions and SW & GW monitoring; no soils COC (EPA, 1992c)
Mosley Road Sanitary Landfill	Oklahoma City, Oklahoma	Landfill	Solvents, Metals	~ARARs	<ARARs	<1/4 mile	Contamination ~ 15 years old; ROD specifies repair of cap; deed, land & GW use restrictions and GW monitoring. Active remediation will be instituted if 5 yr GW results do not show lower COCs (EPA, 1992d)
Gulf Coast Vacuum Services	Vermilion Parish, Louisiana	Industrial Facility	Solvents, Metals	~ARARs	<ARARs	<1/2 mile	Contamination ~ 30 years old; ROD specifies incinerate & cap for source area, deed & access restrictions, and GW monitoring (EPA, 1992e)
Town Garage Radio Beacon	Londonderry, New Hampshire	Military	Solvents, Metals	<ARARs	<ARARs	<1/4 mile	Contamination > 30 years old; ROD specifies deed restrictions and GW monitoring (EPA, 1992a)

Table 3-1: Natural Attenuation-Based Records of Decision (RODs) (continued)

Site Name	Site Location	Site Type	Detected Contaminants	Contaminant Levels at Site	Contaminant Levels at POC	Distance to Nearest Receptor	Comments
Tri County Landfill	Elgin, Illinois	Landfill	Solvents, Other Organics, Metals	>ARARs; exact concentrations unknown	>ARARs	<1/4 mile	Contamination ~ 30 years old; ROD specifies cap for source, active remediation for site GW, and deed restrictions and GW monitoring for off-site GW (EPA, 1992f)
PSC Resources	Palmer, Massachusetts	Industrial Facility	Solvents, Other Organics, Metals	> 10 times ARARs	Unknown	~1/2 mile	Contamination up to 100 years old; ROD specifies cap for source; deed, GW, and land restrictions; and, GW monitoring (EPA, 1992g)
IMC East Plant	Terre Haute, Indiana	Industrial Facility	Pesticides	<ARARs	<ARARs	~1/4 mile	Contamination up to 50 years old; ROD specifies cap for source, deed and GW restrictions, and GW monitoring (EPA, 1991b)
Kin-Buc Landfill	Edison, New Jersey	Landfill	Solvents, Other Organics, Metals	> 100 times ARARs	~ ARARs	> 1 mile	Contamination up to 50 years old; ROD specifies cap for source, deed and GW restrictions, and GW monitoring (EPA, 1992b)
Alsco Anaconda	Gnadenhuetten, Ohio	Industrial Facility, Landfill	Solvents, Metals	~ 10 times ARARs	< ARARs	~1/2 mile	Contamination up to 30 years old; ROD specifies deed and GW restrictions, and GW monitoring (EPA, 1992h)
Islip Sanitary Landfill	Islip, New York	Landfill	Solvents, Other Organics, Metals	~ 10 times ARARs	~ARARs	<1/4 mile	Contamination up to 30 years old; ROD specifies cap for source; active remediation for hot spots; deed and GW restrictions, and GW monitoring for dilute plume (EPA, 1992i)
U.S. Defense General Supply Center	Richmond, Virginia	Military	Solvents, Other Organics, Metals, Pesticides	> 100 times ARARs	< ARARs	<1/4 mile	Contamination up to 50 years old; ROD applies to soils only; 2/54 samples had inorganics slightly above risk-based action levels; ROD specifies deed and access restrictions (EPA, 1992j)

Source: Arthur D. Little

**Table 3-2: Site Summaries Provided During Interviews with Regulators**

Site Name	Site Location	Site Type	Contaminants Detected	Distance to Nearest Receptor	Comments
Benton Harbor Site	Benton Harbor, MI	Closed Automotive Parts Manufacturer	Organics, Chlorinated Solvents	> 1/4 mile	Site characterization study identified naturally occurring high levels of dissolved oxygen, sulfates, and biological activity
KL Avenue Landfill	Kalamazoo, MI	Municipal Landfill	Organics, Chlorinated Solvents, Metals	≈ 1/4 mile	Site characterization study identified naturally occurring biological activity; plume one-fourth the size expected
ILCO Site	Leeds, AL	Closed Lead Smelter	Lead	None	Modeling indicated that plume will attenuate to MCLs within 2 to 3 years assuming dispersion and to advection
Monsanto Site	Augusta, GA	Industrial Waste Landfill	Metals	Unknown; no contamination off-site	Modeling performed indicated that slug plume would meet MCLs within 2 to 3 years without migration off-site

Source: Arthur D. Little, Inc. (see Appendix A)

The process was also selected at several sites where a concentrated plume was located within a much larger dilute plume. The concentrated plume regions were slated for active remediation, and the much larger dilute portions were allowed to naturally attenuate. The most often cited justification for selection of natural attenuation in such cases was that the cost of active dilute plume remediation was prohibitive due to the size of the plume, questionable effectiveness of pump-and-treat at ppb concentrations, and subsequent cleanup required.

Natural attenuation of ground water appears to be most often used as part of the selected remedy, often in combination with source removal and/or concentrated plume pump-and-treat technologies. Institutional controls such as deed, ground water use, and land use restrictions are almost always included as a requirement for the use of natural attenuation.

The most frequent application of natural attenuation (as encountered in the ROD database) was at municipal landfills nearing their capacity. Removal of all potential source areas (i.e., the landfilled trash) is often judged to be impractical due to the quantity of emplaced material. If the authorities can establish that only one cell or area of the solid waste landfill has been used for industrial waste disposal, excavation and off-site treatment of that particular "hot spot" may be specified. The landfill is therefore required to be capped to limit infiltration through the remaining refuse. If the ground water contamination is not much greater than the identified ARARs, has not spread over a large area, and there are no receptors located immediately nearby, many RODs specify natural attenuation for ground water cleanup.

### **3.2 CERCLA Case Studies**

The review of the RODs revealed both similarities and differences in the specific situations where natural attenuation was chosen, indicating that this option has been specified for sites with widely ranging characteristics. Soils and ground water are typically media of concern at CERCLA sites, as each poses a common contaminant transport mechanism to human and ecological receptors. The review of the RODs focused on the site ground water characteristics (because there are no uniform soil cleanup criteria) and compares ground water contaminant concentrations and distances to nearby receptors.

The review revealed similarities between several of the RODs obtained. Therefore, descriptions of representative sites are included below to avoid repetitive descriptions of sites with similar contaminant or hydrogeologic settings.

#### **3.2.1 Cannons Engineering Corporation**

The Cannons Engineering Corporation CERCLA site is located in Bridgewater, Massachusetts (Hebert *et al.*, 1988). A discussion of this site is included in this report because the Cannons ROD specifies natural attenuation for remediation of the contaminated ground water. The selection of natural attenuation was based upon analytical results which indicated that natural attenuation of contaminants was occurring at this site. Also, modeling studies indicated that there would be no unacceptable risks at the nearest receptor. The feasibility study presented by the

responsible party compared estimates of the time required to meet cleanup criteria and associated cost for three different remedial alternatives. This comparison demonstrated that the two active remediation alternatives did not provide improvements commensurate with the associated increase in cost. A more detailed description of site conditions is provided below.

The Cannons site, located adjacent to a large watershed, was operated as a hazardous waste storage and incineration facility between 1974 and 1980. Surficial deposits at the site consist of unconsolidated sand, gravel, and silt from 11 to 17 feet (3.4 to 5.0 meters) thick. Fill and disturbed soils that occur at the surface across the site contain 20 to 30 percent silt, and range in thickness from zero to six feet. The silt content in the outwash soil ranges from 45 to 75 percent. Ground water surface slopes at an average horizontal gradient ranging from 0.005 to 0.008; flow rates across the site were estimated to vary from two to 15 feet/year (0.6 to 4.6 meters). No potential receptors are presently located in areas downgradient of the facility for at least 2,000 feet (600 meters).

The soil contamination detected at the site includes volatile organic compounds (VOCs) (primarily benzene, tetrachloroethylene, and trichloroethylene), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). The PAH and PCB concentrations were, with two exceptions, less than 10 mg/L.

Ground water was sampled twice in 1984, once in 1985, and once in 1987. Site ground water contamination is limited to VOCs. PAHs and PCBs were not detected in the ground water. VOCs were detected in most of the 15 monitoring wells at the site, indicating a relatively wide-spread plume. Concentrations of VOCs were generally less than 0.05 mg/L. Three wells had VOC concentrations which ranged up to 550 mg/L. Contaminants were detected in the bedrock wells, but only sporadically and at concentrations near the detection limits.

Modeling efforts were conducted at the site to support the development of potential remediation alternatives. An organic leaching model and a vertical and horizontal spread model were used to assess the leaching of contaminants from soil and the dilution of contaminants over time as they dispersed in the aquifer.

The modeling demonstrated that the VOC soil contaminants would have to be removed or treated to ensure future protection of ground water on-site and at the points of compliance (POCs). The modeling also indicated that transport of existing contaminants in the ground water would result in dilution of contaminants to levels protective of public health by the time they reach the vicinity of the POCs. The models used did not account for the occurrence of biodegradation.

Two observations indicated that some type of natural attenuation via biodegradation may be occurring at this site. The benzene concentrations detected in the ground water were lower than expected given the benzene concentrations in the soil. Biodegradation of chlorinated compounds was indicated by the discovery of vinyl chloride only in samples taken in 1987, and not in the 1984 or 1985 sampling rounds.

The researchers concluded that this indicated that anaerobic dechlorination was occurring, and would presumably increase with time.

A Feasibility Study (FS) was conducted at the site to analyze the technical and economic feasibility of various potentially applicable remedial alternatives. Three basic extraction alternatives were investigated: no extraction (natural attenuation); extraction of ground water from a site-wide multiple well system; and extraction of ground water from "hot spots" only. The FS estimated the time required to achieve compliance with the ground water protection standards for each of these three alternatives and compared this time with the cost required to implement the alternative.

The results of this analysis indicated that the restoration rates for the natural attenuation via degradation and multiple well extraction systems would be comparable, but approximately three times slower than that of the hot spots extraction system. However, the costs for the natural attenuation alternative were three to five times less than that of the other two systems. The responsible parties were, therefore, able to present strong technical and economic justification for the selection of this alternative.

The FS then evaluated the extent to which each of the alternatives met EPA guidance criteria and the CERCLA statutory performance criteria listed in the NCP. This analysis indicated that the natural attenuation alternative was comparable to the other two alternatives with respect to these criteria. Using the technical effectiveness and cost comparisons in the FS as data, EPA then selected natural attenuation as the preferred alternative. The ROD written for the site specified removal and treatment of contaminated soils, tanks, and other structures, and natural attenuation for ground water restoration.

### **3.2.2 Savage Municipal Supply**

The Savage Municipal Supply Site is located in New Hampshire. A summary of the ROD (EPA, 1991a) for this site is included because this site represents a case where natural attenuation of a portion of the plume was selected without a demonstration that chemical modification of the contaminants is occurring. The EPA ROD describes modeling conducted to estimate impact to receptors and estimates developed of remedial alternative costs, and concluded that natural attenuation of the extended plume was the most cost-effective method to provide protection of potential receptors. A more detailed description of site conditions is provided below.

The Savage site is located in an area that has been commercialized for greater than 100 years and sits within the 100-year floodplain of the Souhegan River. The ROD reported that process and wastewaters from the industrial facilities were released untreated to the ground water or to surface waters flowing through the site from the 1940s to the 1980s. Several VOCs were detected in water from local area potable water wells in 1983 resulting in the site's inclusion on the NPL.

This site is underlain by unconsolidated overburden materials including glacial outwash deposits up to 130 feet thick (40 meters). Locally those are overlain by surficial alluvium and stream terrace deposits along the Souhegan River and thin (less than 5 feet, or 1.5 meters) layers of organic-rich loam. The glacial outwash deposits consist primarily of noncohesive stratified fine to coarse sands and gravels. Lenses of silt and fine sand have been observed at some locations but are not common. The stratified sands and gravels containing a minimal amount of fine materials comprise a high yield and highly permeable aquifer, and served as the local potable water source.

The contaminants detected at the site at a maximum concentration of 0.1 mg/L or greater consist of tetrachloroethene, trichloroethene, 1,1,1-trichloroethane, trans-1,2-dichloroethene, 1,1-dichloroethane, acetone, and toluene. Of these compounds, tetrachloroethene, trichloroethene, 1,1,1-trichloroethane, and trans-1,2-dichloroethene were detected at 1.0 mg/L or greater, with the tetrachloroethene detected at the maximum single concentration of 19.0 mg/L. These contaminants have formed a plume estimated to be approximately 6,000 feet (1,800 meters) long and 2,500 feet (750 meters) wide.

The ROD describes the thought process that resulted in the selection of the preferred alternative, which consists of pumping and treating the concentrated portion of the plume, and natural attenuation of the extended portion of the plume. This alternative was selected because the agency judged the alternative to be "cost effective in that the overall effectiveness of the remedy is proportional to the cost of the remedy." Other proposed remedies were judged to provide minimal additional benefits for the additional cost, or were unable to meet the statutory requirements of CERCLA or the NCP.

No data was found to indicate that natural attenuation due to biodegradation is occurring at this site. Modelling results indicated that the contamination will undergo advection and dispersion over time due to the hydraulic conductivity of the aquifer. It is interesting to note that natural attenuation is a portion of the selected alternative for this site even though natural biodegradation was not detected or hypothesized.

### **3.2.3 Town Garage Radio Beacon**

The Town Garage Radio Beacon Site is located in New Hampshire (EPA, 1992a). This case represents a site where EPA selected natural attenuation of ground water due in part to the observation that concentrations of 1,1,1-trichloroethane (TCA), the contaminant of concern, were decreasing with time. The ground water monitoring results also show increases in the concentrations of TCA breakdown products, indicating that this decrease is due to biodegradation. This decrease has resulted in the ground water currently meeting maximum contaminant levels (MCLs) in the local area potable water supply wells. A more detailed description of site conditions is provided below.

This site has a long history, and was recently discovered to have VOC-contaminated ground water. From the 1940s to 1968, the area was owned by the Department of Defense who reportedly used it as a radio beacon facility from the 1940s to 1947. The area was transferred to the local town in 1968, and was subsequently used as a garage to store town vehicles, road sand, and road salt.

The contamination detected at the site in 1984 was present at concentrations greater than MCLs for several of the constituents. The state continued to monitor the on-site wells and noted that the concentration of 1,1,1-TCA has steadily decreased while concentrations of 1,1-dichloroethene and 1,1-dichloroethane have steadily increased. The EPA concluded that this demonstrated that a natural degradation process was occurring. This ROD did not comment on the potential human health or environmental impact of the degradation products, but it did comment on calculated risks based upon current site data.

The ROD written for this site specified a remedial action including natural attenuation of the entire ground water plume, implementation of institutional controls, and a long-term ground water monitoring program to ensure that contaminants continue to decrease over time. Currently, none of the local residential potable water supply wells have concentrations above the Federal drinking water standards, so the selected alternative was determined to be protective of human health.

This site represents an example of several trends noted during the review of the ROD database reports. It is a site where the contamination was introduced into the environment some time ago, and has subsequently begun to biodegrade naturally. Also, no receptors are currently affected as the contaminant levels in local resident wells are less than MCLs. The site is also underlain by complex geology, which would limit the effectiveness of ground water extraction systems.

#### **3.2.4 Kin-Buc Landfill**

The Kin-Buc Landfill site is located in New Jersey, and represents a case where natural attenuation via degradation is indicated by ground water monitoring results (EPA, 1992b). The contaminated ground water discharges to a nearby river, where sampling and modeling results indicate acceptable impact to receptors. The site hydrogeology has also been shown to be fairly complex and would make it difficult to operate a conventional extraction system efficiently. A more detailed description of site conditions is provided below.

The 200-acre landfill is located in an area that is predominantly industrial and commercial, with some residences located within 2 miles. No drinking water supply wells are located within a 2-mile radius of the site. The landfill is surrounded by wetlands, and portions of the landfill lie within the 100- or 500-year flood plains.

The landfill site is underlain by siltstone, mudstone, and shale bedrock, which occur at depths ranging between 25 and 46 feet below the site. A sand-and-gravel unit overlies the bedrock at an average thickness of 16 feet. A layer of organic-rich clay and silt known as meadow mat overlies the sand-and-gravel deposit at an average thickness of 7 feet. The refuse layer overlying the meadow mat varies from 10 to 25 feet thick. Each of these four units are water-bearing, although only the bedrock is regionally extensive and used for water supply. The meadow mat acts as a hydraulic semi-confining layer and a contaminant sponge due to the fine-grained organic-rich matrix.

From 1947 through 1977, the landfill accepted industrial and municipal waste including solvents, waste oils, paint sludge, cyanides, metal stripping wastes, and paint thinners. The contaminants of concern at this time include VOCs, primarily benzene and xylenes, PAHs, PCBs, and metals. Ground water contamination has been documented in the refuse, sand-and-gravel, and bedrock units; the concentrations range up to 1,000 times greater than ARARs in the refuse unit (for benzene) and in the sand-and-gravel unit (for iron).

The ROD reviewed for this project was for cleanup of the contaminated ground water and sediments. A previous ROD had specified off-site disposal of the most contaminated source area soils. The ROD for the ground water and sediments specified excavation of the sediments contaminated with PCBs above a 5 mg/kg threshold, and natural attenuation for the ground water.

The selection of natural attenuation was supported by strong evidence that natural attenuation of the contaminants was occurring via biodegradation in the landfill. This evidence includes the observations that vinyl chloride concentrations continue to increase with each subsequent round of sampling, and soluble iron is present in concentrations much higher than expected. The selection was also strengthened by the EPA's belief that the ground water does not currently pose a risk to human health and is not expected to do so in the future. The contaminants are expected to continue to degrade beneath the landfill. The contaminants that do reach the landfill boundary are diluted when the aquifer discharges to a nearby river.

### **3.2.5 ILCO Site**

The Interstate Lead Company (ILCO) site in Leeds, Alabama, is included in this section because it is one of the sites mentioned by a regulator during the telephone interview portion of this project (Hayes, 1994). This site appears to represent a case where natural attenuation was selected for a contaminant (lead) that will not biodegrade and will meet MCLs through dispersion and dilution only. Dispersion modeling indicated that the ground water lead concentrations currently average double the MCL but will attenuate to MCLs in 2 to 3 years. This site is particularly applicable because it represents a case when EPA approved of natural attenuation for a nonbiodegradable compound that is above MCLs and present near receptors.

Although a copy of the September 1991 ROD for the ILCO site was not obtained, a summary of the ROD stated that this site was split into seven areas of concern, or subsites, which are regulated as two operable units. Two of these subsites did not have any ground water contamination, and one other subsite is to be addressed by a later ROD; this ROD only addressed the contamination at the other four subsites. Source areas, defined by the ROD as soils contaminated with greater than 300 mg/kg of lead, were removed, treated by a solidification/stabilization unit, and then replaced at the site.

It is interesting to note that the ROD summary does not specify the use of natural attenuation. Although the regulator stated that this site is an example of where natural attenuation has been successfully implemented, the ROD summary states that "no

ground water remediation activities will be conducted" at the subsites with ground water contamination, but continues to say that "contaminants will naturally attenuate or lessen with time." The ROD summary also specifies that long-term ground water monitoring will be conducted. On the basis of this example, it appears that the EPA may be unwilling to specify "natural attenuation" as a remedial measure at sites where the contaminants are not biodegradable.

### **3.2.6 Monsanto Site**

The Augusta, Georgia, Monsanto site is contaminated with arsenic, chromium, and other metals (Hayes, 1994). This is also a site discussed with a regulator during the telephone interviews conducted. This site represents another instance where the regulators agreed to rely upon advection and dispersion to decrease contaminant concentrations to achieve MCLs. According to the regulator, the contamination is contained in a slug plume that has not migrated off-site and has therefore not impacted any potential receptors. Conservative modeling indicates that natural attenuation via dispersion and advection should reduce the contaminant concentrations to MCLs within 2 to 3 years.

### **3.2.7 Benton Harbor Site**

This site is a closed automobile parts manufacturing site that is contaminated with trichloroethylene (TCE), other chlorinated solvents, and nonchlorinated organics (Shauver, 1994). This is a well-known natural attenuation site due to a fortuitous combination of factors that demonstrate the occurrence of contaminant biodegradation. The site has been demonstrated to be biologically active, contains microbial substrates, produces TCE breakdown products, and has a much smaller plume than predicted by the modeling. The site is adjacent to Lake Michigan, so any contaminants that are released off-site are quickly diluted to a concentration that poses no threat to human health or the environment. It is expected that the site will be cleaned to risk-based standards within 3 to 5 years.

### **3.2.8 KL Landfill Site**

The KL Avenue Landfill in Kalamazoo, Michigan, is a former municipal landfill that is contaminated with metals and a broad range of chlorinated and nonchlorinated organics (Shauver, 1994 and EPA, 1993b). A ROD specifying a clay cap was written for this site, but local residents requested other options be investigated when they realized the amount of clay to be transported through their neighborhood. During this supplemental investigation, the local regulators determined that contamination was being degraded beneath the site and rewrote the ROD to specify the use of natural attenuation. The estimated closure cost has decreased from \$33 million to \$5 million with the change from capping to natural attenuation.

The Michigan DNR conducted a supplemental site characterization after receiving the citizen complaints. Contaminant concentrations in the landfill ranged from mg/L to percent levels, and averaged mg/L levels in the ground water. The contaminants include acetone, methyl ethyl ketone, dichloroethane, benzene, and other organics. The landfill is underlain by sandy soils and has a stream running through its middle that discharges to a lake approximately 1,000 feet downgradient.

After reviewing the area of contamination, contamination characteristics, and precipitation, it was found that the area of organics contamination was significantly less (approximately 25 percent) than that expected given the soil concentrations and the amount of precipitation. As a result, the reviewers suspected that the site was biologically active and that natural attenuation via biodegradation was limiting the spread of contamination. A \$2 million study was conducted that confirmed that anaerobic, aerobic, and anoxic processes were occurring. Data reflected the disappearance of benzene, toluene, ethylbenzene, and xylenes (BTEX), and no contamination was identified in the downgradient lake.

### **3.3 EPA-Provided ROD Database**

Subsequent to the completion of the literature review and ROD searches described in Sections 3.1 and 3.2, output from a draft EPA-maintained database was received. This output included a comprehensive draft list of RODs for sites where natural attenuation was a component of the remedy selected in the ROD. This list is provided in Appendix C and summarized in Table 3-3. Note that the summary provided in Table 3-3 is representative of sites where natural attenuation may be "all" or "part" of the selected remedy. Also note that Table 3-1 is a subset of the sites listed in Table 3-3, but that 3 of the 14 sites listed in Table 3-1 are not listed in Table 3-3.

This list of sites is much more extensive than that developed in the ROD search and evaluation described in Sections 3.1 and 3.2. The discrepancy appears to be due to differences in the terminology used for the database searches and, possibly, differences in the definition of natural attenuation. Several of the RODs listed in the EPA-maintained database were reviewed and reference institutional controls and long-term monitoring, rather than natural attenuation, as the selected remedy. This illustrates a problem frequently encountered when determining where natural attenuation has been used; the accepted terminology for natural attenuation varies from state to state and a uniform definition for the alternative does not exist. Without uniformity of terminology and definitions, there is ambiguity among sites for which natural attenuation has been identified as a selected remedial alternative.

While not all the RODs listed actually specified natural attenuation, there are some items of interest relevant to the potential acceptability of natural attenuation as a remedial remedy. As shown in Table 3-3, the predominant contaminated media is ground water. At only five sites was natural attenuation selected as the remedy for media other than ground water (i.e., surface water and sediment). In addition, the predominant contaminants were organic.

**Table 3-3: Summary of Natural Attenuation Sites**

Site	Date	Media	Contaminant					
			VOC	BNA	PAH	PCB	Metal	Other
Charlevoix Municipal Well Field, MI	1985	GW	X					
A&F Materials Reclaiming, IL	1986	GW	X				X	b
Renora, NJ	1987	GW	X				X	
Highlands Acid Pit, TX	1987	GW	X	X			X	
Cannon Engineering, MA	1988	GW	X					
Marathon Battery, NY	1988	GW	X					
Westline, PA	1988	GW						c
Chistman Creek, VA	1988	SW					X	
Brio Refinery, TX	1988	GW						c
New Castle Spill, DE	1989	GW	X					d
Northside Landfill, WA	1989	GW	X				X	
Sarney Farm, NY	1990	GW	X	X	X		X	
East Mt. Zion, PA	1990	GW	X	X			X	
North Hollywood Dump, TN	1990	GW					X	a
Lewisburg Dump, TN	1990	GW	X	X			X	
Arkwood, AR	1990	GW		X				
Hardage/Criner, OK	1989	GW	X				X	
Fairfield Coal Gasification Plant, IA	1990	GW	X		X		X	
Mystery Bridge, WY	1990	GW	X					
Monolo Pig Farm, NH	1991	GW	X	X			X	
Western Sand & Gravel, RI	1991	GW	X	X	X		X	
Conklin Dumps	1991	GW	X					
Mid-Atlantic Wood Preservers, MD	1990	GW					X	
Interstate Lead (ILCO), AL	1991	GW					X	
Monsanto (Augusta Plant), GA	1990	GW					X	
Oak Grove Sanitary Landfill, MN	1990	GW	X				X	
Central City/Clear Creek, CO	1991	GW					X	b
PSC Resources, MA	1992	GW	X	X				
Town Garage/Radio Beacon, NH	1992	GW	X				X	
Kin-Buc Landfill, NJ	1992	GW	X		X	X	X	
Islip Municipal Sanitary Landfill, NY	1992	GW	X					
Yellow Water Road Dump, FL	1992	GW				X		
Tri County Landfill, IL	1992	GW						c
Twin Cities AF Reserve, MN	1992	GW	X				X	
Absco Anaconda, OR	1992	GW		X			X	b
Gulf Coast Vacuum Services, LA	1992	GW	X	X	X	X		a, b
Mosley Road Sanitary Landfill, OK	1992	GW	X				X	

**Table 3-3: Summary of Natural Attenuation Sites (continued)**

Site	Date	Media	Contaminant					
			VOC	BNA	PAH	PCB	Metal	Other
Farmers Mutual Cooperative, LA	1992	GW	X					a
Denver Radium, CO	1992	GW						c, e
Wyckoff/Eagle Harbor, WA	1992	Sed						c
Peterson/Puritan, RI	1993	GW	X				X	
Novak Sanitary Landfill, PA	1993	GW	X	X			X	
Redwing Carriers/Saraland, AL	1992	GW & SGW	X	X			X	a, b, f
Reeves SE Galvanizing, FL	1993	GW					X	
Anodyne, FL	1993	GW	X				X	
Hercules 009 Landfill, GA	1993	GW	X				X	a
Dakhuc Sanitary Landfill, MN	1993	GW	X	X			X	
Cardington Road Landfill, OH	1993	GW	X	X			X	
Fourth Street Refinery, OK	1993	GW	X	X			X	a
Montana Pole and Treating	1993	Sed & SW		X	X		X	a
Utah Power & Light, UT	1993	GW	X	X	X		X	b
Hanford 1100 Area (DOE), WA	1993	GW	X					b
Fort Lewis Logistic Center, WA	1993	GW	X	X	X		X	
Fairchild Air Force Base, WA	1993	GW	X					
American Crossarm & Conduit, WA	1993	SW		X	X			a

**Notes:**

- Natural attenuation may be all or part of the selected remedy
- Listed sites may include more than one site or operable unit
- Additional details and ROD identifications are provided in Appendix D

**Key to abbreviations:**

GW - Ground water  
 SW - Surface water  
 SGW - Surface ground water  
 Sed - Sediment  
 VOC - Volatile organic compound  
 BNA - Base-neutral and acid extractable organic  
 PAH - Polyaromatic hydrocarbon  
 PCB - Polychlorinated biphenyl

**Key to "Other":**

a - Pesticide  
 b - Inorganic  
 c - NP  
 d - To Be Determined  
 e - Radiation  
 f - Organic

Source: EPA, 1994c

#### 4.0 Natural Attenuation of Military Unique Contaminants – Technical Perspective

Although related laboratory work has been conducted, there is currently a paucity of information on the natural (unenhanced) biodegradation of MUCs in field conditions, including identification of biodegradation intermediates. Since most regulators have stated a preference to limit the selection of natural attenuation to sites with biodegradable contaminants, development of this information is crucial to support the implementation of natural attenuation as an alternative to more costly conventional remedial technologies. An extensive site characterization is also important, as the soil and ground water chemistry and biology greatly impact the contaminant transport and fate.

##### Recommended Army Actions:

- ✓ Continue and expand work on the biodegradation of MUCs to identify biodegradation intermediates and their potential toxicity, and the potential for the destruction of MUCs in field conditions.
- ✓ Perform studies at sites where MUCs have been present in the environment for an extended period of time to determine how these materials behave (e.g., biodegradation, abiotic degradation, absorption) in the environment.
- ✓ Use data developed in field studies to enhance ground water modeling programs to include the natural attenuation process.
- ✓ Conduct preliminary site characterization, including an assessment of soil and ground water chemistry and biology, to determine the potential for natural attenuation at contaminated Army sites.

As discussed in the previous sections of this report, the applicability of natural attenuation has been shown to be dependent in part on site-specific characteristics that impact both the spread of contamination and the potential for future exposures. To address these issues, adequate site characterizations involving physical, environmental, and hydrogeological assessments are required. A second factor in determining the applicability of natural attenuation is a requirement for the accurate prediction or demonstration of its effectiveness. Addressing this issue requires the examination of the contamination characteristics (i.e., type, concentration), mechanisms involved in their attenuation, and the environmental factors that affect their attenuation. This section of this report addresses the latter factor, specifically, the technical issues that affect the attenuation of possible contaminants.

Federal policy acknowledges that various mechanisms (including biodegradation, dispersion, dilution, and adsorption) may be responsible for the attenuation of contaminants in the environment (see Section 2.1 of this report). Of these mechanisms, biodegradation has received the most interest in terms of research and implementation. This is partly due to its demonstrated effectiveness and potential in degrading petroleum hydrocarbons—among the most common contaminants found in soil and ground water. In addition, biodegradation has received considerable attention because it provides for the destruction of the contaminants rather than their displacement through adsorption or dispersion. For these reasons, the primary focus

of this section is oriented toward the research and implementation of natural attenuation through biodegradation.

There has been a large number of research and implementation initiatives regarding the biodegradation of petroleum hydrocarbons (see Section 3.0 of this report for implementation examples). To a lesser extent, the potential for naturally occurring biodegradation of less biodegradable contaminants, such as chlorinated hydrocarbons and PAHs, has been examined.

Contamination at Army sites often involves a wide variety of contaminants including those described above as well as inorganics and MUCs (e.g., propellants, explosives, and their derivatives). The majority of research regarding the biodegradation of the latter group of contaminants (MUCs) is performed assuming that enhanced engineered techniques (e.g., composting, aboveground reactors, injection of oxygen and nutrients) will be required. This assumption may be due to the limited knowledge regarding the naturally occurring biodegradation of these contaminants as well as observations in previous research that the biodegradation of MUCs occurs slowly, if at all. Research addressing the naturally occurring biodegradation of MUCs has been minimal and has, for the most part, been limited to the laboratory. Before natural attenuation of these contaminants can be accepted and implemented, additional research and demonstration will be required.

#### **4.1 Mechanisms of Natural Attenuation**

The overall mechanisms that result in the natural attenuation of various chemicals can be complex in that they are often the result of several concurrent processes. The desired net result of these processes is a reduction (attenuation) of the concentration of the contaminant at the receptor location to acceptable levels. Such reductions in concentration may be the result of mechanisms that do not involve the change in chemical characteristics of the contaminant (i.e., nondestructive) and/or those that result in the change of the chemical characteristics to produce new chemical species (i.e., destructive). In the former category are mechanisms that involve volatilization, sorption, or dilution (dispersion). In the latter category are mechanisms such as biodegradation (aerobic and anaerobic) and abiotic oxidation or hydrolysis. Of these mechanisms, those that involve the actual change or degradation of the contaminant of concern are usually of the most interest because they provide a permanent solution to the problem of contamination and, as a result, are typically preferred by both regulators and principally responsible parties.

A summary of primary natural attenuation mechanisms is presented in Table 4-1. Although this table was prepared to specifically address the natural attenuation of the soluble fraction of petroleum hydrocarbons (typically BTEX), the information presented has relevance to other contaminants as well.

The results of a review of transformation mechanisms that affect the environmental fate, or persistence, of MUCs in the environment is presented in Table 4-2 (CH2MHILL, 1992). The mechanisms addressed in this review include photolysis,

**Table 4-1: Potential Natural Attenuation Mechanisms**

Mechanism	Description	Potential for BTEX Attenuation
<b>Biological</b>		
Aerobic	Microbes utilize oxygen as an electron acceptor to convert contaminant to CO <sub>2</sub> , water, and biomass.	Most significant attenuation mechanism if sufficient oxygen is present. Soil air (O <sub>2</sub> ) ≥ 2 percent. Groundwater DO ≥ 1 to 2 mg/L.
Anaerobic Denitrification Sulfate reducing Methanogenic Iron reducing	Alternative electron acceptors (e.g., NO <sub>3</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , Fe <sup>3+</sup> , CO <sub>2</sub> ), are utilized by microbes to degrade contaminants.	Rates are typically much slower than for aerobic biodegradation: toluene is the only component of BTEX that has been shown to consistently degrade.
Anoxic	Secondary electron acceptor required at low oxygen content for biodegradation of contaminants.	Has not been demonstrated in the field for BTEX.
<b>Physical</b>		
Volatilization	Contaminants are removed from ground water by volatilization to the vapor phase in the unsaturated zone.	Normally minor contribution relative to biodegradation. More significant for shallow or highly fluctuating water table.
Dispersion	Mechanical mixing and molecular diffusion processes reduce concentrations.	Decreases concentrations, but does not result in a net loss of mass.
Sorption	Contaminants partition between the aqueous phase and the soil matrix. Sorption is controlled by the organic carbon content of the soil, soil mineralogy and grain size.	Sorption retards plume migration, but does not permanently remove BTEX from soil or ground water as desorption may occur.

Source: EPA, 1994a

**Table 4-2: Summary of Environmental Transformation Processes of Selected Explosives**

<b>Explosive</b>	<b>Photolysis</b>	<b>Oxidation/ Reduction</b>	<b>Hydrolysis</b>	<b>Biodegradation</b>
TNT	In shallow surface water, photolysis may be the principal process for degradation. Degradation products depend on pH.	Minimal susceptibility to oxidation/reduction.	Not expected to be an environmental degradation pathway.	If sufficient nutrients are present, many types of microbiota can degrade TNT to produce primarily amine and azoxy metabolites.
2,4-DNT 2,6-DNT	In shallow surface water, photolysis may be important. Products stable to further photodegradation are not produced.	Minimal susceptibility to oxidation/reduction.	Similar to TNT.	Both 2,4-DNT and 2,6-DNT are reported to be degraded by the microbiota from a munitions site, but at a somewhat slower rate than TNT.
TNB DNB NB	TNB appears to be stable to photodegradation. The stability of DNB and NB is uncertain.	Minimal susceptibility to oxidation/reduction.	Similar to TNT.	TNB appears to be persistent in soil and ground water. DNB and NB are degraded microbiologically, but their mineralization is uncertain.
RDX HMX	In shallow surface water, RDX and HMX have been observed to degrade in 7 to 10 days.	Minimal susceptibility to oxidation/reduction.	Similar to TNT.	Both RDX and HMX are susceptible to biodegradation. For biodegradation to occur, there appears to be a need for significant nutrient augmentation.
Tetryl	In shallow surface water, tetryl has been observed to degrade to n-methylpicramide within 20 days.	Minimal susceptibility to oxidation/reduction.	The hydrolytic half-life is about 10 months. The products are picric acid and methylnitramine.	Susceptibility unknown.

Source: CH2M HILL, 1992

oxidation/reduction, hydrolysis, and, biodegradation. Of these, biodegradation appears to have the best potential for transforming MUCs in the environment.

In general, the mechanism with the best potential for application in a natural attenuation scenario is biodegradation (see Section 2.2 for a discussion of the desirability of biodegradation from the point of view of the state of Wisconsin). In addition, considerable research has been conducted to evaluate the effectiveness of biodegradation (natural and enhanced) with a wide variety of contaminants. For these reasons, the rest of this discussion addresses the biodegradation/transformation mechanisms associated with natural attenuation.

#### **4.2 Biodegradation/Transformation Mechanisms**

The goal of bioremediation is to degrade organic contaminants to the point where they are no longer hazardous to human health or the environment. This is accomplished through the breaking down of the organic material to support the metabolism of microorganisms. This can occur through aerobic processes where the microorganisms use oxygen to survive or through anaerobic processes where the microorganisms propagate in the absence, or near absence, of oxygen. Both aerobic and anaerobic processes are likely to factor into the feasibility of natural attenuation. Newly contaminated sites with low levels of contamination may be able to take advantage of oxygen-rich environments because no or little oxygen depletion has occurred. Anaerobic environments normally exist when contamination is high (McCarty, 1991) and where contaminants have migrated to depths where diffusion of oxygen is limited.

In the natural environment, the contaminant may not be completely degraded but transformed to intermediate products that may be less, equally, or more hazardous than the original compound. If complete degradation of organic contaminants occurs, the products of aerobic processes will include carbon dioxide and water. Ultimate products of anaerobic processes include incompletely oxidized organic substances such as organic acids as well as other products such as methane or hydrogen gas.

The specific mechanisms of biodegradation are affected by the type and quantity of the contaminants, the presence of electron donors (e.g., iron(II), sulfide, ammonia, and organic carbon), and the presence of electron acceptors (e.g., oxygen, nitrate, nitrite, iron and manganese oxides, and sulfate). These reactants can be present either in the dissolved state (or aqueous phase) or in the soil phase.

The reactions involved in biodegradation give rise to indicators that biodegradation has occurred. Such indicators include increases in the concentrations of the potential products of degradation (i.e., carbon dioxide, organic acids, and methane) as well as increases in the concentrations of dissolved iron (II), and hydrogen sulfide; and/or decreases in the concentrations of nitrates, sulfates and oxygen.

A requirement for the occurrence of natural biodegradation is the presence of microorganisms with novel catabolic functions which have changed through the process of selection (EPA, 1994b). The primary group of bacteria responsible for biodegradation of organics, termed heterotrophic bacteria, derive their energy from

oxidation or decomposition of organic matter. Most common elements that are required for bacterial growth include carbon, hydrogen, sulfur, nitrogen, and phosphorous. Under contaminated conditions, carbon and hydrogen are usually not limiting (although carbon may be limiting in aquifers), and sulfur is usually present. Growth can be limited by the availability of nitrogen and phosphorous.

Near neutral pH is usually more advantageous for biodegradation than extreme (acidic or basic) conditions. The redox conditions at the site affect the degradation paths, but different paths can be operative at a site where the redox conditions are changing with time.

Other factors that can impact microbial activity include temperature, the relative ability of bacteria to attach to a molecule, and steric limitations. One of the more important factors for microbial activity and degradation rates is the ground water temperature. Besides affecting other reactions such as sorption equilibria and volatilization rates, lower temperatures decrease the rates of microbial reactions. Typically a 10-degree drop in temperature will half the degradation rate (EPA, 1994b). The ability of bacteria to attach, adsorb, or enzymatically attach to a molecule may be hindered by strong sorption of molecules onto underlying strata. Additionally, some molecules are resistant to degradation because they are too large to enter bacterial cells or have functional groups which make it difficult for enzymes to attack.

Potential contaminants at Army facilities include petroleum hydrocarbons resulting from leaking underground tanks and spills, chlorinated solvents generated during cleaning and maintenance operations, and MUCs resulting from munitions production and maintenance processes. Of these potential contaminants, petroleum hydrocarbons and chlorinated hydrocarbons have been subjected to a significant level of study and demonstration that has illustrated their biodegradability in the natural environment. Less is known about the biodegradability of MUCs. In fact, research involving the degradation of MUCs is typically focused on engineered and enhanced biotechnology in recognition of their greater recalcitrance. The paragraphs below provide a summary of the state of knowledge and demonstration regarding the three groups of potential contaminants.

#### **4.2.1 Biodegradation of Petroleum Hydrocarbons**

The most prevalent contaminants found in soil and ground water are petroleum hydrocarbons. These organic compounds often include the soluble components of gasoline, including BTEX, which typically degrade under aerobic conditions. Anaerobic degradation of these aromatic hydrocarbons does occur, but the degradation rates are slow. The slow growth rates of the degrading microorganisms make research of the anaerobic degradation of these contaminants difficult (McCarty, 1991).

Investigations of several sites containing petroleum derived hydrocarbons have shown degradation in ground water environments. The extent of their removal has been quantified in subsequent field and laboratory investigations. Examples of field studies of the natural biodegradation of fuels is provided in Section 4.5 below.

#### 4.2.2 Biodegradation of Chlorinated Solvents

The biodegradation of chlorinated solvents has been observed at sites where other contaminants are also present and where these other contaminants are the primary species supporting the metabolic and energy needs of the microorganisms (EPA, 1994b). The efficiency of biodegradation of the chlorinated solvents then depends on the relative amount and presence of these other species.

The biodegradation of the chlorinated solvents (e.g., chlorinated aliphatic hydrocarbons) may be observed when their partial biodegradation transformation products are present and concurrent changes are noted in the other indicators of biological activity (e.g., disappearance of oxygen, nitrates, and sulfates; and production of iron(II) and methane).

Chlorinated solvents used in various degreasing operations include carbon tetrachloride (CT), tetrachloroethene (PCE), trichloroethene (TCE) and 1,1,1-trichloroethane (TCA). These compounds can be transformed by chemical and biological processes to other types of chlorinated aliphatic hydrocarbons including chloroform (CF); methylene chloride (MC); cis- and trans-1,2 dichloroethene (c-DCE, t-DCE); 1,1 dichloroethene (1,1 DCE); vinyl chloride (VC); 1,1 dichloroethane (DCA); and chloroethane (CA); as well as ethene gas. Complete oxidation would, of course, result in the formation of carbon dioxide, water, and chloride ions. The transformations are brought about by co-metabolism or through interactions with enzymes and cofactors produced by the microorganisms for other reactions.

In addition to biodegradation, chemical reactions can also occur. For example, TCA can be hydrolyzed to acetic acid and chloride. Chloroethane can be hydrolyzed to ethanol, which is then converted to acetic acid.

The presence of degradation products down gradient of the plume, especially vinyl chloride (if previously unseen at a contaminated site), has been used to indicate biotransformation. The presence of incomplete degradation products is of significance as their hazard to and persistence in the environment need to be considered.

The transformation of the chlorinated solvents under various conditions is summarized below [EPA, 1994b]:

##### Carbon tetrachloride:

Denitrification redox conditions: CT to CF

Sulfate redox conditions: CT to  $\text{CO}_2 + \text{Cl}^-$

##### 1,1,1 Trichloroethane:

All redox conditions: TCA to 1,1 DCE and acetic acid.

Sulfate redox conditions: TCA to 1,1 DCA

Methanogenesis redox conditions: TCA to  $\text{CO}_2 + \text{Cl}^-$

##### Tetrachloroethylene:

Sulfate redox conditions: PCE to 1,2 DCE

Methanogenesis redox conditions: PCE to ethene

Trichloroethylene:

Sulfate redox conditions: TCE to 1,2 DCE

Methanogenesis redox conditions: TCE to ethene

#### 4.2.3 Biodegradation of Explosives

Many laboratory studies have been performed to acquire a better understanding of the microbial breakdown of explosive compounds such as TNT (2,4,6 trinitrotoluene); HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7 tetrazocine); RDX (hexahydro-1,3,5 trinitro-1,3,5-triazine); as well as nitro-aromatic compounds, in general, under various conditions (Kaplan, 1992).

In general, nitroaromatic compounds and many of their metabolic products have been shown to be toxic. In addition, metabolic products have been shown to be resistant to microbial degradation under most conditions. Due to the complexity of the system and the number of steps required to achieve biodegradation products acceptable for bioremediation, many laboratory studies have been performed to identify the particular combination of conditions required to achieve complete biodegradation of these nitro-aromatics.

There are few studies on the behavior of these compounds under field conditions. The numerous laboratory studies suggest that complete biodegradation of these compounds may require a particular set of field conditions consisting of combinations of various microorganisms and the availability of various nutrient or co-metabolites, as well as the proper sequences of anaerobic and aerobic conditions. The transformation of site conditions from anaerobic to aerobic may result in the formation of compounds resistant to microbial degradation under most conditions.

The importance of long-term bioassays then becomes obvious as short-term bioassays cannot provide the time frame required for metabolism and biotransformation of the diverse intermediates.

The complexity of the biodegradation of these compounds and the relative toxicity of possible side products (e.g., metabolites) require a much more detailed and accurate assessment of the conditions present at the sites than would be required for simpler compounds. An incomplete understanding of the system can result in the underestimation of the impact of the toxic by-products and efficacy of the bioremediation (Liu *et al.*, 1990).

**4.2.3.1 Aerobic Degradation of Nitroaromatics.** Removal of the aromatic ring substituents (e.g., nitro groups) is often required before the aromatic ring can be converted to hydroxylated compounds that can mediate additional ring cleavage for further biodegradation (Duque *et al.*, 1993, and Ramos *et al.*, 1994). Conditions for achieving this can be quite elusive. The complexity and number of intermediates that can be formed is exemplified by the following:

TNT is degraded by *Pseudomona*-like bacteria forming products such as 2,2',6,6'-tetranitro-4,4'-azoxytoluene; 2,2',4,4'-tetranitro-6-azoxytoluene; 4,6-dinitro-2-aminotoluene; 2,6-dinitro-4-hydroxyl-aminotoluene; and nitrodiaminotoluene (Kaplan *et al.*, 1982). Some of these azoxy compounds, however, can be formed by direct

reaction (abiotically). In addition, monoamines are significant and common products of the degradation of TNT, especially the 4-amino-2,6-dinitrotoluene.

It has been suggested that avoiding the reduction reaction by prevailing pseudomonades would be advantageous in the aerobic treatment of nitroaromatics since under these conditions aromatic amines are produced. Aromatic amines can easily polymerize instead of releasing nitro groups and cleaving of the rings.

Studies on the biodegradation of (RDX) under aerobic conditions have shown little degradation. This, however, may be a reflection of the systems studied rather than RDX reactivity (McCormick, 1981).

**4.2.3.2 Anaerobic Degradation of Nitroaromatics.** A depiction of the anaerobic/anoxic model system (Han, 1993) for biodegradation of TNT is as follows:

TNT (and related nitroaromatics) ----->

Microbial reduction in anaerobic system ----->

Intermediate products (Aminoaromatics) ----->

Ring cleavage and mineralization  
in denitrifying system ----->

Final Products (mineralization)

Although the biodegradation of TNT has been extensively studied (relative to other nitroaromatics), the mechanism of biodegradation is not well known and is the subject of current research. Some observations on the biodegradation of nitroaromatics follow.

The anaerobic degradation of TNT is initiated with the reduction of the nitro group into an amino group. Literature reports reference many di- and tri-nitro aromatic compounds, such as 2,4 dinitrophenol and TNT, being transformed into a variety of products without cleavage of the ring. Nitroso compounds have been suggested as one of the major intermediates in their reduction.

The aminoaromatic compounds, formed from reduction of the nitroaromatics, are highly reactive and easily polymerize to form azoxy compounds in the presence of oxygen. In aerobic soils the azoxy compounds can react with humic acids to form extremely difficult-to-degrade products. Thus, anoxic conditions are necessary for further degradation of the aminoaromatic intermediates.

TNT is much less amenable to biodegradation than other nitroaromatics containing a single nitro group or other chemical substituents (e.g., carboxyl) because of steric hindrance and electronic deactivation by the three nitro groups.

Recently, a combination of five bacterial cultures in an anaerobic, methanogenic bench-top bioreactor have been shown to utilize TNT as a sole source of carbon and

nitrogen (Pumfrey *et al.*, 1993; Crawford, 1994). This combination of cultures was speculated to be capable of mineralizing TNT by reduction of the nitro groups to amino groups, replacement of the amino groups with hydroxyl groups, followed by replacement of the hydroxyl groups by hydrogen. Key intermediates appear to be 2,4-diamino-6-nitrotoluene; 2,4,6-trihydroxytoluene; and 4-methyl-phenol (p-cresol). The p-cresol is ultimately fermented to volatile organic acids, particularly acetate. The study suggests that no polymeric materials are formed in the treatment of TNT, Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), or RDX.

The biodegradation of RDX has been studied less frequently than that of TNT. Most of the RDX biodegradation studies utilize anaerobic degradation, as the studies that have used aerobic degradation have shown little biodegradation. A study of degradation of RDX under anaerobic conditions yielded many intermediate products including hexahydro-1-nitroso-3,5 dinitro-1,3,5 triazine; hexahydro-1,3-dinitroso-5-nitro-1,3,5 triazine; hexahydro-1,3,5 trinitroso-1,3,5 triazine; hydrazine; 1,1-dimethylhydrazine; formaldehyde; and methanol (McCormick, 1981). Many of the products are mutagenic or carcinogenic. The incomplete biological degradation may cause a more serious toxicological problem than RDX itself.

**4.2.3.3 Other Factors Affecting Degradation.** As previously mentioned, many chemical reactions can also occur between intermediate compounds and the environment. These include reaction with humic materials and electron transfer reactions that can be mediated by other chemical species (e.g., hydrogen sulfide). The presence of other chemical species in the environment is then a contributing factor to the formation of acceptable bioremediation products.

### 4.3 Case Studies

A majority of the citations identified in the literature search document the transport and fate of chlorinated solvents or petroleum contaminants. A limited number of references was also identified describing the transport and fate of inorganic or non-petroleum/nonsolvent organic compounds. Of particular note is the first case study that describes the implementation of natural attenuation at an Army site. This and other case studies where natural remedial processes have been observed and evaluated are described below.

#### 4.3.1 Case Study No. 1

This case study represents an example of a natural attenuation remedy implemented at an Army installation (Cullinane, 1995b). The Army received approval to finalize the ROD for natural attenuation and degradation at Sierra Army Depot (SIAD) in Herlong, California. This significant accomplishment is the first ROD for natural attenuation in the state of California and the first Army ROD in the United States where natural attenuation is the primary treatment alternative selected for ground water contaminants.

The natural attenuation alternative meets remedial objectives and is estimated to save the Army \$10 to \$15 million over pump and treat alternatives at SIAD (the net present worth cost of the alternative is estimated at \$1.9 million). In a public meeting

held in November 1994, the nine Executive California Regional Water Quality Control Board (CRWQCB) members unanimously voted in favor of the alternative after presentation of the natural attenuation and degradation alternative.

Operations occurring in the 1940s at SIAD resulted in ground water contamination under the TNT Leaching Beds Area. Remedial investigations showed that a commingled plume, extending 22 acres radially from the two contaminant sources, currently exists at the site. The plume consists of explosives and VOCs with 1,3,5-TNT and TCE contributing the highest individual concentrations.

SIAD is a non-NPL facility with a Federal Facility Site Remediation Agreement between the Army and the two primary California regulatory agencies. Therefore, SIAD is regulated by both the CRWQCB and the Department of Toxic Substances Control (DTSC) without EPA overview. Initially, the state of California was strongly opposed to the natural attenuation and degradation alternative despite the overwhelming supportive site-specific conditions. However, after negotiations and discussions, the Army was able to reach agreement with the state to implement natural attenuation at SIAD.

The TNT Leaching Bed Area at SIAD has extremely favorable site-specific conditions that support the use of natural attenuation. The Army's justification for the selection of natural attenuation included the following factors:

- Negligible horizontal and vertical plume movement.
- No current or future potential receptors.
- Limitations of pump and treat alternatives.
- Cost benefits.
- Assurances through reevaluation.
- Natural attenuation and degradation evaluation program.

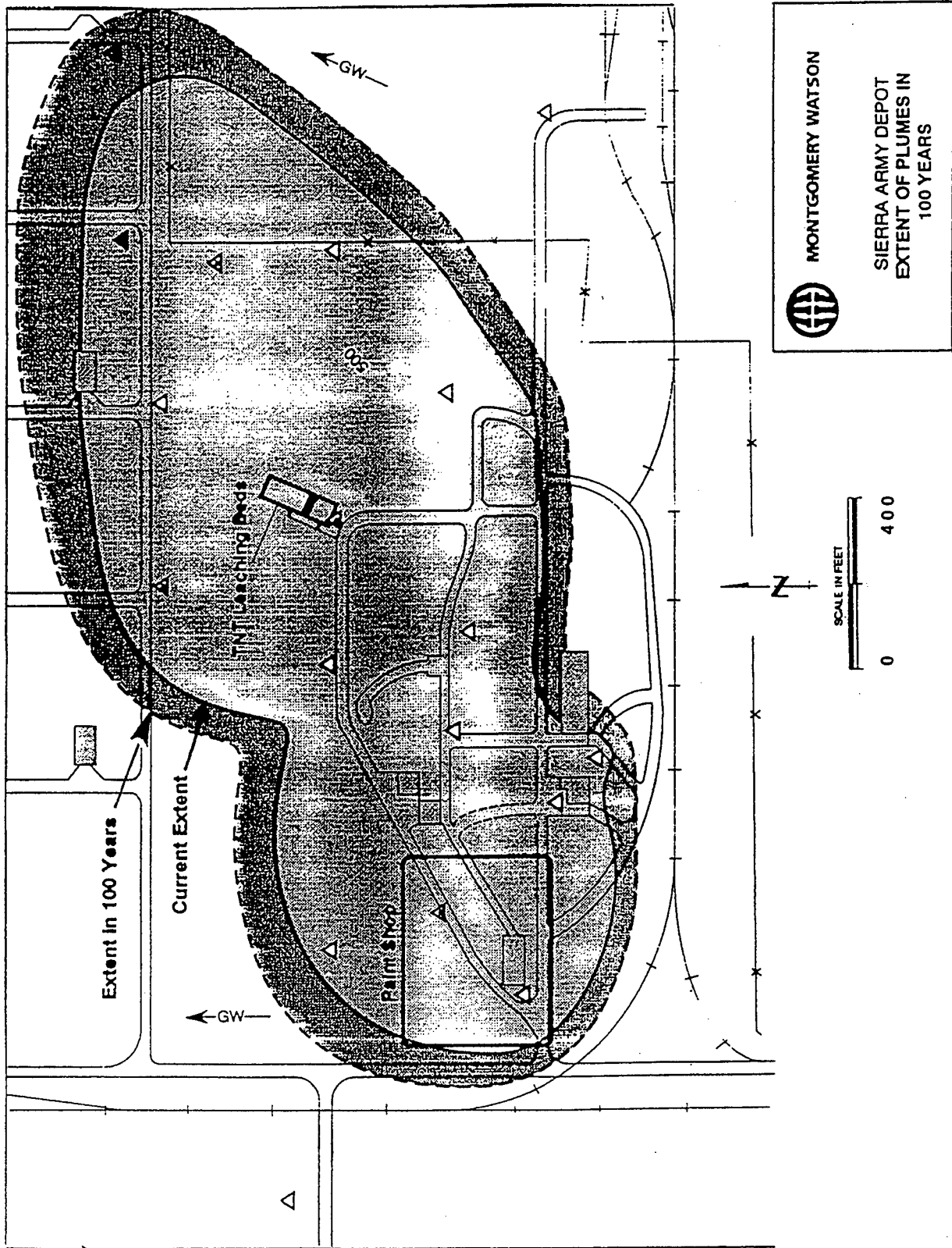
Hydrogeologic studies, cost evaluations, and records searches were used to address these factors. To illustrate the first factor, ground water modelling was performed to estimate the extent of plume growth in 100 years. The results of this model are presented in Figure 4-1. This figure illustrates that the plume size is not expected to expand significantly even after a century.

The natural attenuation alternative being implemented at SIAD incorporates the restoration of ground water by attenuation and degradation processes that naturally occur within the aquifer. Specific elements of the alternative include:

- Further characterization of the hydrogeology of the site.
- Institutional controls to minimize exposure to ground water contaminants at the site.
- Ground water monitoring to measure contaminant degradation and migration rates.

The proposed program of further hydrogeologic characterization includes drilling, logging, and sampling of six deep soil borings. Additional ground water monitoring wells will be installed and ground water samples will be collected at various depths

Figure 4-1: Results of Ground Water Modelling at SIAD



Source: Cullinane, 1995a

and locations throughout the TNT Leaching Beds Area. The number of borings, monitoring wells, and ground water samples will depend on the types of sediments and extent of ground water contamination encountered. The proposed program may include up to 15 deep soil borings, 36 monitoring wells, and 15 ground water samples collected by drive samplers.

During the first year of ground water monitoring, monitoring data will be collected on a quarterly basis. From the first to fifth year, ground water monitoring data will be collected on an annual basis. A list of monitoring parameters and the rationale for monitoring those parameters is provided in Table 4-3. The Army will submit status reports on the results of ground water monitoring to the state of California 18 months, 36 months, and 5 years after the effective (final signature) data of the ROD. Additional details on the monitoring program will be provided in the Comprehensive Basewide Ground Water Monitoring Plan that will be prepared for SIAD.

**Table 4-3: TNT Leaching Beds Area Ground Water Monitoring Parameters**

<b>Parameter</b>	<b>Rationale for Monitoring</b>
Volatile organic compounds	Measure contaminant concentrations in aquifer
Explosive compounds	Measure contaminant concentrations in aquifer
Total petroleum hydrocarbons	Measure contaminant concentrations in aquifer
Dissolved oxygen	Determine if aerobic or anaerobic conditions prevail in ground water
Oxidation potential (Eh)	Determine if aerobic or anaerobic conditions prevail in ground water
Alternative electron acceptors (e.g., nitrate, sulfate/sulfide, iron III, carbonate, ammonia, phosphate, manganese)	Ensure that alternative electron acceptors, necessary for anaerobic biodegradation, are present
Methane	Identify the presence of this characteristic of anaerobic biodegradation through methanogenesis
Conductivity (EC)	Help determine the stability of ground water prior to sampling
pH	Help determine the stability of ground water prior to sampling as well as help determine if the ground water is conducive to microbial activity
Additional explosives analyses (possibly a Reverse Phase-HPLC method)	Use intermittently on selected wells to determine the presence of 1,3,5-trinitrobenzene degradation products not targeted with method 8330

Source: Cullinane, 1995a

Following completion of the 5-year ground water monitoring program, the Army and state of California will review all hydrogeologic and chemical data to determine whether further implementation of the natural attenuation and degradation alternative is appropriate. If the extent of horizontal and vertical contaminant migration and apparent rates of contaminant migration and degradation are not acceptable to either the Army or state, a contingency alternative will be implemented. The contingency alternative includes ground water extraction and treatment with air stripping and granular activated carbon adsorption. However, the Army may propose a new, superior contingency alternative prior to the end of the 5-year study period. The Army will continue to periodically review the feasibility of natural attenuation and degradation and other potential remedial technologies. If any action taken during the 5-year period leads to a dispute, such dispute will be resolved through the Dispute Resolutions clause of the SIAD Federal Facility Site Remediation Agreement.

If, following completion of the 5-year ground water monitoring program, the extent of horizontal and vertical contaminant migration and apparent rates of contaminant migration and degradation are acceptable to the Army and state, long-term ground water monitoring and institutional controls will be implemented. The frequency of subsequent ground water monitoring will be determined following a review of site data conducted 5 years after implementation of the natural attenuation alternative. Future site review activities will be conducted every 5 years pursuant to CERCLA §121(c) to assure that contaminant migration and degradation rates are within ranges that are acceptable to the Army and state. Institutional controls would restrict the use of ground water at the site during the long-term ground water monitoring.

#### **4.3.2 Case Study No. 2**

This case study describes a refinery site in the U.S. that was operated from 1919 until 1932 (Senn *et al.*, 1991). Gas oil, diesel fuel, and gasoline were produced during this operating period, but no records are available to determine volumes or relative percentages of refined products. The authors of the article noted that the refinery was located near a major railroad line, and inferred that diesel fuel was a major product of this refinery.

The former refinery is located in the alluvial valley of a river which flows through the site. The alluvium consists of alternating layers of fine to coarse sand, gravel, and lesser amounts of silt and clay, and varies from less than 3 feet (1 meter) to 25 feet (8 meters) across the site. A slug test program determined the average hydraulic conductivity at the site to be 20 feet per day ( $7.1 \times 10^{-3}$  centimeters per second). Using the average hydraulic conductivity value, a hydraulic gradient of  $1.5 \times 10^{-3}$ , and an average porosity of 0.25, the estimated average ground water velocity was calculated to be 45 feet per year (14 meters per year).

The authors of the study reviewed noted that the sand in the capillary fringe over a wide area was mixed with a grey to black-stained material resembling degraded petroleum hydrocarbons. The affected area was reported to be 1,500 feet (460 meters) long and 500 feet (150 meters) wide, and extended 4 to 8 inches (10 to 20 centimeters) above the existing water table. The authors concluded that the area represents the remnants of a free liquid hydrocarbon plume that formerly existed at the site.

Six samples of the stained material were analyzed along with samples from 30 monitoring wells. The results of the analyses indicated that no VOCs were present in the material, and that only one of the six samples had detectable semi-volatile organic compounds (SVOCs). Of the 30 ground water samples, only three had detectable VOC concentrations, and only one sample had detectable concentrations of any SVOCs. The insignificant concentrations of organic compounds in the ground water and stained materials indicated that the site currently presents minimal adverse health or environmental impacts.

The researchers conducted additional analyses to determine the fate of the contaminants expected to be seen in the soils and ground water at this site. Two additional samples were analyzed for 35 VOCs and 65 SVOCs. This second round of analyses confirmed the results of the initial testing, as no VOCs were detected, and only five SVOCs were detected in one of the two samples. Bacteriological screening and nutrient interaction evaluation of these two samples of site soils indicated they were biologically capable of degrading the "missing" petroleum hydrocarbon contamination. The laboratory reported that the soil harbored a large population of petroleum acclimated heterotrophic bacteria, and concluded that the indigenous bacteria had adapted to degrade the hydrocarbons by using them as a carbon source.

The site soils were also determined to contain measurable concentrations of phosphate and ammonia nitrogen. In addition, the highest concentrations of soluble iron were from wells near and downgradient from former waste holding areas. The concentrations of phosphate nitrogen, ammonia nitrogen, and soluble iron are all important indicators that natural attenuation continues to occur at this site as previously discussed in this section.

#### **4.3.3 Case Study No. 3**

This case study (Stauffer *et al.*, 1994) describes the results of a carefully designed experiment to monitor the fate of chemicals injected to a previously uncontaminated aquifer. The study was designed to quantify those properties which significantly control the propagation of dissolved contaminants in ground water systems. The researchers used a site in Mississippi at which 328 multilevel monitoring wells and 56 BarCad® samplers had been previously installed.

The site is underlain by a shallow unconfined aquifer which consists of alluvial terrace deposits averaging approximately 36 feet (11 meters) in thickness. The mean hydraulic conductivity along the tracer travel path increases from approximately 3 feet per day ( $10^{-3}$  cm/sec) near the injection point to 30 feet per day ( $10^{-2}$  cm/sec) further downgradient. Total organic carbon analysis of 50 samples of alluvium indicated organic carbon ranging from 0.02 to 0.06 percent by weight. Based upon analyses of 84 minimally disturbed soil cores, the sample mean bulk density was 110 lbs/ft<sup>3</sup> (1.77 g/cm<sup>3</sup>), the mean particle density was 160 lbs/ft<sup>3</sup> (2.57 g/cm<sup>3</sup>), and the porosity was 0.35. A mean Darcy's Law ground water velocity of 0.05 ft/day (5 m/yr) near the injection wells and greater than 4 ft/day (400 m/yr) further downgradient were calculated based upon these porosity and hydraulic conductivity measurements.

Four dissolved aromatic organic compounds (benzene, naphthalene, p-xylene, and o-dichlorobenzene) were injected into the aquifer and monitored as they flowed through the aquifer by the network of monitoring wells. A quantity of  $^{14}\text{C}$ -labeled p-xylene was included in the injection solution to let the researchers distinguish solute degradation from losses due to sorption, dilution, or evaporation, and to permit the detection of degradation products. The initial concentrations of the compounds in the solution ranged from 7 to 70 mg/L. A two-day pulse of 2,500 gallons (9.7 cubic meters) of tritiated water and the four compounds in a dilute aqueous solution was injected into the aquifer. This injection was made into five wells, screened over a 2 foot (0.6 meter) interval of the aquifer saturated zone, spaced 3.1 feet (1 meter) apart and aligned transverse to the ground water flow direction.

Several measures were undertaken to ensure that the data obtained during the study were calculated accurately and based upon defensible assumptions. Dissolved oxygen measurements were performed at 2- to 3-month intervals at selected locations to demonstrate whether aerobic conditions were maintained during the experiment. Soil samples were taken at various locations and depths and analyzed for various physical parameters to ensure that values used in calculations were correct. Finally, a set of piezometers was used to measure fluctuations in the hydraulic gradient of the aquifer.

The results of this test were impressive. The aromatic hydrocarbon concentrations decreased significantly during the experiment, and data strongly supported the contention that this decrease was due to biodegradation. Analysis for the degradation products of  $^{14}\text{C}$  p-xylene revealed that approximately 80 to 90 percent of the  $^{14}\text{C}$  present was associated with dissolved  $^{14}\text{CO}_2$  and intermediate products, indicating aerobic degradation of the p-xylene. This observation was supported by sampling results that indicated that dissolved oxygen in the "plume" maintained aerobic conditions throughout the experiment and was always greater than 2.6 mg/L. Degradation kinetics calculated from the whole-field data set were determined to be approximately first order, and the shapes of the degradation rate curves were consistent with microbial degradation processes.

The researchers noted that sorption had an effect on the transport of the injected organic compounds, but concluded that it was a relatively minor process compared to the degradation. Mean retardation factors for benzene, naphthalene, p-xylene, and o-dichlorobenzene were calculated to be 1.20, 1.45, 1.16, and 1.33, respectively. The study concluded that these low retardation factors demonstrate that retardation cannot be responsible for the loss of compound mass detected.

#### **4.3.4 Case Study No. 4**

The site, as presented in a paper from the general literature (Chiang *et al.*, 1989), describes the natural biodegradation of contaminants in an aquifer beneath a gas plant facility in Michigan. The benzene, toluene, and xylene (BTX) contamination of the aquifer was monitored by 42 wells over 3 years to determine and quantify the fate of this contamination. The maximum total BTX concentration detected was less than 10 mg/L; the maximum benzene concentration detected was 0.1 mg/L. Dissolved oxygen (DO) was also monitored to correlate with any changes observed in the BTX contamination.

Soil boring data indicated that the site is underlain by a medium to coarse sand with interbeds of small gravel and cobbles. A relatively impermeable silty clay at 29 to 52 feet (8.8 to 15.8 meters) below land surface underlies most areas of coarse sand. Analysis of the subsurface soils showed that the aquifer contained 97 to 99 percent sand, and 0.5 percent silt and clay. The organic carbon content of the soil was less than 0.01 to 0.08 percent. The depth to water table ranges from 10 to 25 feet (3 to 7.6 meters), and the slope of the water table was estimated as 0.006. The hydraulic conductivity of the aquifer was determined to be 310 ft/day ( $1.1 \times 10^{-1}$  cm/sec) by pump tests at three wells.

The researchers conducted ten sampling rounds over a 3-year time period to determine the reduction in total benzene mass with time in the ground water. Sampling of the plume conducted in November 1984, January 1985, October 1985, and January 1986 indicated benzene masses of 21.6, 12.4, 4.99, and 4.95 pounds (9.83, 5.66, 2.27, and 2.25 kg), respectively. The researchers noted that this decrease must have been the result of one or more natural attenuation processes, as no active treatment or remediation was conducted on the ground water during this time. They then attempted to quantify what percentage of this decrease was due to biodegradation, volatilization, sorption, and dilution.

The researchers used ground water sampling data to develop a relatively complex mathematical matrix to represent the mass of benzene in the aquifer. The changes in benzene concentration over time were then input to the matrix, and the matrix was solved using a nonlinear least squares algorithm to determine the mass flux rate and apparent attenuation rate. The attenuation rate was determined to be first order, and was calculated to be 0.0095 per day. The researchers then calculated the ratio of volatilization to total mass flux and determined that volatilization was responsible for 5 percent, maximum, of the total benzene mass disappearance. Sorption was also determined to be an unlikely mechanism for the soluble benzene mass decrease due to the low organic carbon content of the soil.

The researchers then attempted to support the idea that biodegradation was responsible for the disappearance of the benzene. DO concentrations in nonimpacted areas were found to vary from 9 to 10 mg/L during February and July 1987 sampling. During this same time period, DO concentrations in the most contaminated well were below the detection limit (0.01 mg/L) and 0.3 mg/L during the February and July 1987 sampling events, respectively. The researchers attributed this apparent decrease in DO content to the aerobic soil microorganisms present in the soils. As an additional point, it was noted that BTX was absent whenever DO was observed at concentrations greater than 0.9 mg/L.

The final portion of the former gas plant study investigated whether the soil supported microorganisms capable of degrading the BTX contaminants. Borings in the unsaturated and saturated zones were made with a hollow stem auger, and cores were obtained within sterile Shelby tubes placed inside split spoon samplers. The microbial populations were then enumerated by tube extinction dilution methods. Not surprisingly, aerobes were the predominant organisms in the sandy subsoil, followed by anaerobes and acid-tolerant bacteria and sulfate-reducers. Denitrifiers and methanogens were not detected in the soil samples enumerated. Experiments were

then conducted to determine the limits to microbial degradation in soils when DO levels are varied.

The results of the microbiological studies indicated that the microorganism-enriched soil samples with ground water DO levels  $\geq 2$  mg/L degraded 80 to 100 percent of the BTX (0.12 to 16.0 mg/L) with a hydrocarbon half-life of 5 to 20 days. The microorganism-enriched soil samples with ground water DO levels  $< 2$  mg/L degraded 0 to 60 percent of the BTX (0.12 to 16.0 mg/L) with hydrocarbon half-lives ranging between 10 and 60 days. Little to no degradation of hydrocarbon occurred when the DO was 0, 0.1, or 0.5 mg/L. Little to no loss (6 to 10 percent) of hydrocarbon was observed in the sterile soil sample analyzed as a control. The researchers concluded that a minimum DO threshold concentration (2.0 mg/L) may exist at this site to ensure that the microbes are capable of sustaining the rapid natural degradation of BTX contaminants.

#### **4.3.5 Other Case Studies**

Additional illustrations of sites and conditions where natural biodegradation (or attenuation) has been observed are presented in Section 2.0 of this report.

#### **4.4 Conclusions**

Based on the findings of this review, many research and implementation initiatives pertaining to the biodegradation of petroleum hydrocarbons and chlorinated solvents have been identified. In fact, natural biodegradation has been documented so often for sites with petroleum hydrocarbon and, to a lesser extent, chlorinated hydrocarbon contamination that natural attenuation must be accepted as a viable destruction process, not simply a result of advection, dispersion, and volatilization. Sweeping generalizations cannot be made for all sites due to the uniqueness of each particular situation, but solid science has convincingly demonstrated that biodegradation is often the main process responsible for the loss of contaminant mass.

The literature also contains several references documenting that aerobic conditions promote the rate of petroleum hydrocarbon biodegradation, and that anaerobic environments will degrade even chlorinated solvents given enough time. Sites with a historical source of contamination (e.g., greater than 20 years old) often are found to support significant colonies of bacteria capable of using the contamination as a food source.

Less information is available to document the biodegradation of MUCs—particularly in the environment. Several efforts have been undertaken on the laboratory scale to examine the degradation characteristics of explosives. However, field demonstrations and applications of bioremediation of MUC-contaminated sites have, for the most part, been limited to enhanced bioremediation techniques (e.g., composting).

Despite the limited experience with natural attenuation at MUC-contaminated sites, a recent ROD was developed for the use of natural attenuation and degradation to remediate ground water contaminated with VOCs and explosives at SIAD. The description of the SIAD ROD (see Section 4.3.1) illustrates the level of detail and

effort that may be required for implementation of the natural attenuation alternative at an Army site. It should be noted that the arguments used by the Army to support the selection of natural attenuation (e.g., minimal growth of the contaminated plume and lack of current and future receptors) as well as the site characterization, monitoring, and institutional control requirements for the acceptance of the alternative, parallel the findings of the regulatory reviews as described in Section 2.0. This case study illustrates clearly that the natural attenuation alternative is neither a No Action nor a "no cost" alternative.

A shortcoming that affects all of the potential applications of natural attenuation is the absence of an accurate method of mathematically representing (and thereby predicting) the biodegradation process in the environment. Among the tools used to assess the applicability of natural biodegradation are mathematical models of water flow and chemical transport. The models require capability in assessment of both transport and chemical fate of the contaminants. In general, field applications of models as prediction and design tools have many limitations due to factors including heterogeneity of the sites, determination of species and concentrations, and estimation of products and reaction rates. Extrapolation of laboratory studies to field conditions represents a major limitation due to the incomplete description of the field condition in the laboratory studies. Field verification of these models helps to verify the assumptions and data used to generate the model. Existing biodegradation models include BIOPLUME, BIO1D, BIOPLUME II, BIOPLUS, and ULTRA. Difficulty in the application of these models to field sites has occurred due to the lack of biodegradation parameters and the fall back position of using first order decay or no kinetic factors to represent the biodegradation process (EPA, 1994b).

The limited number of studies performed to date on MUCs has not been sufficient to identify many of the positive situations where natural biodegradation may be appropriate for MUCs. This is in part due to the large number of bio-organisms present in natural systems as well as the long time frames required for adaptation of natural systems. Short-term laboratory studies appear to be only a first step. Increased effort in the assessment of field sites that have been in existence for a long time may greatly help assess the extent of natural biodegradation of MUCs as well as the presence and persistence of their by-products. The laboratory experimentation has identified the complexity of the problem as well as some of the parameters that affect the reactions. However, due to the complexity of the system and the number of interdependent issues, actual field assessments will be required, and these may provide a more expedient approach to assess the conditions where natural attenuation may be useful both as a total or partial solution to bioremediation at Army sites.

## 5.0 Conclusions and Recommendations

The EPA appears to be most interested in natural attenuation for sites where active remediation is impracticable and the predominant contaminant is biodegradable. As additional sites are found to have conditions conducive for biodegradation or have biodegradation actually occurring, EPA will more likely select natural attenuation as a component of the remedial scheme. If biodegradation is unlikely, due to either site or contaminant characteristics, natural attenuation may remain a viable alternative due to factors such as low contaminant concentrations or a large distance to the nearest potential receptor.

### Recommended Army Actions:

- ✓ Develop a requirement that remediation contractors must assess conditions at each contaminated Army site to determine whether active remedial measures are economically or technically impracticable; if impracticable, natural attenuation is more viable.
- ✓ Identify local regulators supportive of the natural attenuation alternative and develop a relationship with these regulators. This dialog will ensure that the regulatory community understands Army-specific remediation issues such as the number of contaminated sites and the limited amount of available remediation resources and gives appropriate consideration to the natural attenuation alternative when site conditions support its implementation.
- ✓ Perform field and laboratory studies to determine the fate and transport of MUC in the environment. The focus of these studies should be the naturally occurring degradation of these compounds as well as their sorption in site soils. Lobby the regulators to give increased consideration to the approval of natural attenuation for sites contaminated with nonbiodegradable, immobile compounds.

This section presents conclusions drawn from the information described in the previous four sections and provides some recommendations that may assist the Army in determining the applicability of natural attenuation at contaminated Army sites and the future direction to be taken to improve the potential for implementation of natural attenuation at contaminated Army sites.

## 5.1 Conclusions

### 5.1.1 Trends in Regulatory Policy

EPA headquarters (HQ) has established guidance and policy to facilitate and support the consideration of natural attenuation, as illustrated by the Federal Register documents cited in Section 2.0. The EPA clearly wants natural attenuation to be considered where active means of remediation are impracticable and has documented the course of action to determine when active remediation is impracticable (EPA, 1993a). Natural attenuation is cited as a specific alternative to be considered in the cleanup of underground storage tank sites (EPA, 1994a). Although not an official EPA document, the AFCEE protocol discussed in Section 3.2 was prepared with input from EPA staff. The protocol provides guidance for the selection and support of natural attenuation as a remedial alternative.

EPA HQ has expressed a desire to keep some flexibility at the Federal level for the consideration of natural attenuation. This unofficial policy gives states and regions some leeway in establishing their own policies and guidance. Given this flexibility, there does not appear to be a significant degree of variability across the country. Most regions and states believe it to be an attractive option for specific sites. Of the limited number of states contacted (four), only Wisconsin was fairly limited and restrictive in their approach - but they still recognized the viability of the alternative. Each regulator contacted stressed that the decision to accept or reject natural attenuation is made based upon site-specific characteristics, making it difficult to state with conviction beforehand when natural attenuation will or will not be acceptable. These site-specific characteristics may include:

- Types and concentrations of contaminants.
- Presence and proximity of current and future receptors.
- Current and future land use.
- Cost-effectiveness and practicability of active remediation.
- State or regional policy.

Although the type of contamination is an important factor in considering natural attenuation, in many states and regions it does not appear that any particular contaminant will immediately rule out the possibility of implementing natural attenuation. As illustrated in Table 3-3, natural attenuation has been selected at sites (as all or part of a remedial alternative) with a wide range of contaminants—from VOCs to metals. However, there does appear to be a preference for considering natural attenuation at sites where the predominant contamination is biodegradable (i.e., organic). In fact, the state of Wisconsin apparently limits natural attenuation to such sites.

There appears to be some flexibility in establishing cleanup standards based on site-specific factors including future site use and time to impact potential receptors. This flexibility may provide some support for the consideration of natural attenuation in certain instances.

One of the most frequently mentioned site-specific characteristics that impacts the consideration of natural attenuation is the potential for contamination to impact receptors. This factor, in turn, is closely related to current and future land use issues as well as time constraints placed on remediation. The presence of receptors may require that a more active remediation be implemented in order to adequately protect human health and the environment. In addition, a rapid restoration of contaminated ground water is favored by EPA where the ground water may affect drinking water sources or environmentally significant ground water.

The cleanup time frame alone is not necessarily a strong deterrent to the consideration of natural attenuation because pump-and-treat methods for ground water remediation may take almost as long. In addition, if there is no potential threat to human health or the environment, then active remediation may not be justified. Based upon telephone interviews, many regulators appear to be sensitive to the costs and technical concerns associated with long-term pump-and-treat systems and the trade-offs associated with

natural attenuation. This sensitivity may become more prevalent as state cleanup resources are depleted.

The cost of natural attenuation may often be closer in magnitude to an active remedial approach than a No Action approach due to the effort required to support the selection of natural attenuation. In order to address the feasibility of natural attenuation with respect to the site-specific characteristics mentioned above, extensive site assessments will typically be required prior to remedial selection. Such assessments will include thorough contaminant and hydrogeologic characterizations designed to illustrate and/or demonstrate that natural attenuation will be protective of human health and the environment. Such a comprehensive assessment may often be more rigorous than that required to support an active remedial alternative (and therefore more expensive). In addition, the cost of natural attenuation may be impacted by requirements to implement long-term monitoring and periodic reevaluation programs to ensure protectiveness.

One similarity between active and natural attenuation remedial schemes is that both require the use of institutional controls such as fencing, ground water use restrictions, and deed restrictions. Institutional controls limit the amount of potential risk because the location of the "hypothetical receptor" is moved from on top of the site to a more distant receptor point. This change in distance effects a decrease in the risk, often increases the allowable cleanup time, and often reduces the severity of the cleanup criteria.

#### **5.1.2 Trends in Technical Demonstration**

The natural attenuation of contaminants has become an acknowledged process at several locations where a combination of factors produces conditions conducive for biodegradation. Demonstrations proving that contaminants are biodegraded under natural conditions are becoming more frequent and are often required to prove the acceptability of natural attenuation. The methods used to demonstrate that natural attenuation is occurring due to biodegradation are become more standardized. For example, decreases of oxygen, nitrate and sulfate in ground water downgradient of a contaminant plume and increases in carbon dioxide, vinyl chloride, methane, and iron(III) indicate biodegradation.

Several studies have been conducted to demonstrate the natural biodegradation of some of the contaminants typically found at contaminated Army sites. The contaminants most frequently shown to be degradable in the field include fuel hydrocarbons—especially BTEX. Field studies have also shown that chlorinated solvents such as trichloroethene and trichloroethane may be degraded anaerobically, albeit at much slower rates than the aerobic degradation of BTEX.

The same level of field demonstration has not been observed for the degradation of explosives under natural conditions. The results of the literature review described in Section 4.2.3 indicate that relatively slow progress is being made in the laboratory as various combinations of bacteria and substrates are tested for their ability to degrade these contaminants. It is likely that additional data and demonstration of the behavior of MUCs in the field will be required before a widespread acceptance of natural attenuation at MUC-contaminated sites can be achieved.

Regulators are not likely to select natural attenuation as a remedial alternative unless the site has been thoroughly characterized to allow for modelling of contaminant transport and fate. The ability to model contaminant transport and fate is currently barely sufficient to satisfy the demands of the regulators. Many of the ground water models typically used do not model biodegradation effects well. As a result, popular programs such as BioPlume II are being upgraded to improve the model's predictive capabilities. Researchers at the EPA Kerr Laboratory are reportedly developing a BioPlume III model that will be able to account for biodegradation losses and provide more of the data requested by regulators.

## **5.2 Potential Applicability of Natural Attenuation at Army Sites**

It is believed this study shows that there is a reasonable potential for implementation of natural attenuation at Army sites depending, of course, on site-specific factors. Important site-specific characteristics that affect the acceptability of natural attenuation are summarized graphically in Figure 5-1. Most importantly, the contamination must not be at a concentration or in a location such that it has the potential to affect a receptor in a short time frame. Army sites contaminated with fuels and solvents that are located far away from potential receptors, are well characterized, and demonstrate signs of existing contaminant biodegradation may be more readily acceptable to regulators as candidates for natural attenuation.

Where the acceptability of natural attenuation is heavily dependent on the biodegradability of the contaminant(s), sites contaminated with MUCs may be less likely considered appropriate for natural attenuation. Without data to demonstrate that MUCs are capable of being degraded under field conditions, it would be difficult to convince regulators that natural attenuation should be selected in lieu of conventional active remedial alternatives. The regulators' view, however, could be changed if they are presented with data demonstrating that immobile contaminants do not pose a risk to human health or the environment.

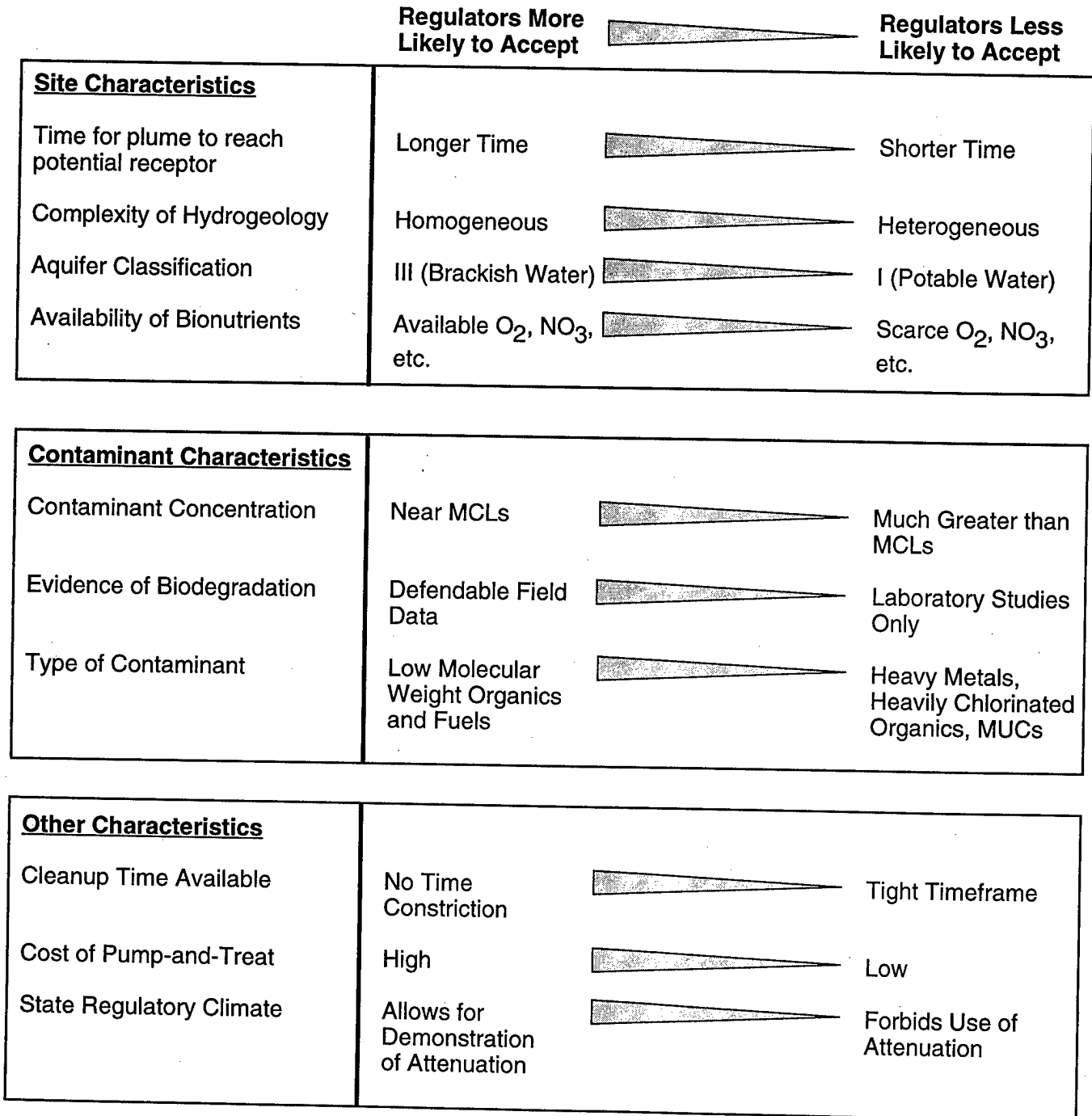
Despite the potential reluctance for considering natural attenuation at MUC-contaminated sites due to the lack of data to support the degradation of MUCs, it may be possible to implement natural attenuation if the site is contaminated with low concentrations of MUCs and there are no nearby receptors. This may be a realistic consideration at Army sites, as many are located in remote areas where there are no adjacent receptors. Also, the sites themselves may be so large that migration of the contaminants off site may not be realistic in the time frames considered, due to sorption and other retardation effects. Despite these potentially favorable characteristics, the feasibility of long-term monitoring and periodic reevaluations required by natural attenuation must be taken into consideration.

Because some of the reluctance to accept natural attenuation is based on a lack of understanding of sites and contaminants, Army sites may present a greater challenge for implementation of natural attenuation as the preferred alternative. Army sites are often contaminated with a wide range of chemicals ranging from solvents to explosives to unexploded ordnance, and therefore contain a broad diversity of chemical compounds, typically at various concentrations. The diversity of chemicals

**Figure 5-1: Examples of Factors Affecting Selection of Natural Attenuation**

The acceptance of natural attenuation is dependent on site-specific factors. The following chart illustrates the affect of selected generalized factors on the likelihood that natural attenuation will be approved as a remedial alternative.

**Generalized Scale of Potential for Acceptance of Natural Attenuation as a Remedial Alternative**



in a single location may add to the complexity and difficulty in finding sites with optimal conditions for the diverse range of chemical characteristics desirable to support the implementation of natural attenuation. In addition to the fact that MUCs have not been shown to degrade in the field, the degradation pathway has not been conclusively demonstrated. There is concern that the degradation products may be more toxic than the MUCs themselves. Even less is known about the potential for field biodegradation of MUCs in a complex, diverse mixture of contaminants.

It is important for Army representatives to work with regulators to ensure that each side becomes familiar with the potential for implementing natural attenuation at Army sites. To do this, the Army must be prepared to present the regulators with information supporting the viability of natural attenuation including the lack of impacted receptors, well-defined site characteristics, verification that contamination will not spread, and any available data showing that contaminant attenuation will occur. The Army and its contractors must understand what information the regulators need to approve the selection of natural attenuation as a remedial option, and develop this information to the maximum extent possible *before* they begin regulatory negotiations.

The Army would also benefit from providing specific guidance to contractors regarding the potential of natural attenuation and how it should be evaluated. Any data developed or acquired by the Army should be provided to contractors for use in evaluating natural attenuation. For example, if the Army acquires data suggesting that MUCs are capable of being degraded by natural field microorganisms, that data should be immediately forwarded to contractors working on MUC-contaminated sites. To further support the implementation of natural attenuation, the Army should require all contractors to demonstrate why natural attenuation was not selected (or evaluated) for use at a given site.

Laboratory and field studies to document the extent to which MUCs are degraded in field situations are needed. Further, if degradation is observed in either the laboratory or the field, the intermediate and final breakdown products must be identified. Such information is crucial, as the regulators have indicated that the selection of natural attenuation must be supported by data. Natural attenuation will be evaluated with respect to technical merit as are other remedial alternatives.

### **5.3 Implementation of Natural Attenuation at Army Sites**

#### **5.3.1 Evaluation of Natural Attenuation as a Remedial Alternative**

The evaluation of natural attenuation for implementation in the cleanup of an Army site should follow the same path taken to evaluate No Action and active remedial alternatives as described in Section 2.6. As part of the evaluation, a two-phase approach consisting of an Initial Screening and Detailed Analysis should be taken.

The Initial Screening should be a qualitative review of the site according to established screening criteria (see Figure 2-4) to determine the appropriateness of natural attenuation for the given site. In order to effectively screen natural attenuation at this phase, the following activities should be performed:

- Identify and define contaminant and hydrogeologic characteristics.
- Review available data regarding the degradation or transformation of contaminants.
- Initiate discussions with local regulators regarding the applicability of natural attenuation and additional supporting data requirements.

The first step in this process is to gather all available site data and review it to determine whether natural attenuation may be applicable. Applicable information may be found in records of work previously conducted at the site, such as feasibility studies, boring logs, soil and monitoring well sampling logs, and field observations. Much of the information may be easily determined such as the distance from contamination to the nearest potable water well or surface water body, the distance from contamination to nearest property boundary, possible contaminants present, and the relationship with state regulators.

This step may require some time to complete, as documents will need to be located and reviewed, and staff will need to be interviewed. The importance of this step cannot be overemphasized because it may become immediately apparent that the natural attenuation option is not applicable for this particular site. Identifying this fact early in the process could potentially save the cost of an expensive site characterization required to more fully evaluate natural attenuation. Examples of information that could eliminate natural attenuation from consideration are those shown in Figure 5-1, such as a significant potable water well field near the suspected area of contamination, a nearby neighborhood or other significant potential receptor, or ground water data indicating high concentrations of toxic metals.

Unless the data and information collected in the first step indicate a "fatal flaw," the second step should be completed to determine if the contaminants at the site are amenable to natural attenuation. As discussed in Section 4.0, petroleum hydrocarbons have been shown to biodegrade under field conditions. Chlorinated solvents will also biodegrade in natural settings if the site conditions are conducive to abiotic or anaerobic reactions. No data were identified to indicate that MUCs degrade completely in the environment without intervention.

At this point, the regulatory climate for natural attenuation should be evaluated by reviewing where and how natural attenuation has been implemented in the past, identifying any state or regional guidance on natural attenuation, discussing the feasibility of natural attenuation with the regional and state points of contact, and determining specific data required by the regulators for the approval of natural attenuation.

To further support the selection of natural attenuation, the Army may wish to identify and contact a regulator known to be a natural attenuation supporter in the state or region in which the site is located. This regulator may be able facilitate discussions with the remedial project manager, who may not be as aware of the natural attenuation selection process.

If this Initial Screening phase proves that natural attenuation is a potential remedy at the site, a Detailed Analysis will be required. In this phase, natural attenuation will be subjected to a quantitative analysis in accordance with the criteria presented in Figure 2-4. As part of this analysis, more detailed discussions should be held with the regulators to review the methodologies and supporting data used to evaluate natural attenuation.

It is likely that this phase of the evaluation will require the performance of a comprehensive site characterization developing as much of the following information as possible:

- All sources of contamination.
- Contaminants present in significant concentrations.
- Up- and down-gradient ground water concentrations of oxygen, iron, nitrate, and sulfate.
- Up- and down-gradient soil vapor concentrations of oxygen, carbon dioxide, and methane.
- A three-dimensional representation of the contaminant concentrations.
- Hydrogeologic parameters such as soil types, hydraulic conductivity, and confining layers.
- Ground water flow rates and seasonal flow directions.
- Distance to nearest potable water wells, surface water bodies, or other receptors.

Ground water modeling should be performed to allow for the development of an estimate of travel time to receptors and maximum concentrations expected to reach receptors. These data will be used to determine whether natural attenuation is feasible in the time frame necessary for remediation. Natural attenuation is much more likely to pass regulatory scrutiny if modeling indicates a long time period until potential impact to receptors. In addition, ground water modeling will provide an indication of the potential for and magnitude of growth of the contaminated plume under natural attenuation.

Data should be identified or generated to demonstrate that natural attenuation of the contaminant(s) will occur. For example, changes in the ground water concentrations of DO, iron, and nitrate could indicate that natural biodegradation is already reducing the contaminant concentrations. A study of the microorganisms beneath the site may be warranted if the results strongly indicate the occurrence of natural biodegradation.

The site characterization, modeling, and technical data should be summarized for presentation to the regulators to assess the degree of regulatory acceptance for natural attenuation.

### **5.3.2 General Recommendations**

Based on the findings and evaluations performed in this study, the following recommendations are offered. These recommendations describe actions that the Army may take to further the understanding and acceptance of natural attenuation:

- (1) Develop a policy that *requires* the inclusion of natural attenuation in the Initial Screening of remedial alternatives at all sites.

- (2) Develop Army guidance on the evaluation of natural attenuation for distribution to Army remedial project managers and contractors.
- (3) Establish a formal and on-going dialogue with regulators to discuss the use of natural attenuation. Attempt to expand the current regulatory willingness to accept both biodegradation and sorption as viable mechanisms for the natural attenuation of MUCs.
- (4) Develop a process to transfer evaluations of natural attenuation among project managers and contractors.
- (5) Develop laboratory and, more importantly, field data on the natural degradation of MUCs in ground water, seeps, soils, wetlands, surface water, and other environmental receptors.
- (6) In coordination with regulators, develop methodologies for establishing land use guidelines and determining environmental risks to further qualify instances when natural attenuation may and may not be implementable.

## 6.0 References

The following are references cited in the body of this report. For a complete bibliography of all documents obtained and reviewed during the course of this study, see Appendix B.

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## **Appendix A**

### **Completed Questionnaires from Telephone Interviews with Regulators**

- EPA - Headquarters (Corrective Programs Branch)
- EPA - Region IV (Superfund Branch)
- EPA - Region V (Superfund Branch)
- EPA - Region V (Superfund Branch)
- California Regional Water Quality Board (Underground Storage Tank Unit)
- Colorado Department of Public Health and Environment (RCRA Branch)
- Michigan Department of Natural Resources (Environmental Systems Division)
- Wisconsin Department of Natural Resources (Solid Waste Division)

## Interview 1

**Date of Interview: 10/18/94**

### 1. Background Information

- a. Name of person interviewed                      Guy Tomasoni
- b. Title or position                                      Hydrogeologist, Corrective Programs  
Branch
- c. Specific agency, region, office, etc.      Headquarters, Environmental Protection  
Agency, Office of Solid Waste,  
Washington, D.C.
- d. Phone number    (703) 308-8622

### 2. Regulatory Framework

- a. What regulations, published by this agency/office, apply specifically to natural attenuation as a remediation technique? Include both prohibitions and exemptions for this remediation alternative.

Contact has conducted an overview of regulatory framework affecting the consideration and use of natural attenuation (paper presented at AFCEE conference). Will provide copy of briefing slides. Regulatory aspects that impact natural attenuation include those from RCRA, UST, and CERCLA legislation.

- b. If natural attenuation regulations have not been promulgated, is the agency working on the development of such legislation? If not, are there plans to do so in the future?

Contact is unaware of any formal developments that are in the works or planned. "Positions" are currently being developed by HQ.

- c. If not a federal agency, does this agency have remediation regulations more stringent than existing federal regulations? For example, has the agency finalized soil or non-MCL ground water cleanup criteria? (Obtain a summary of and specific citation for any regulations.)

NA.

### 3. Philosophical Framework

- a. What is the current philosophy within the agency regarding the use of natural attenuation at contaminated sites? Is it being supported by the agency?

There is considerable interest in HQ regarding the potential for use of natural remediation (intrinsic remediation). Position of HQ is to support and purposely remain flexible to allow regions and states to establish more critical positions if desired.

It is important to note that the applicability/acceptability of natural attenuation will be heavily dependent on regional and state attitudes. Contact stated that no assumptions or predictions should be made based on HQ positions alone. It will be necessary to consult with regions and states on a site-specific basis.

b. Under what conditions is natural attenuation considered the most attractive?

Referred to regulatory guidance – NCP and proposed Subpart S rule. NCP states that natural attenuation is generally recommended only when active restoration is not practicable, cost-effective, or warranted based on site-specific conditions (e.g., where ground water is not a likely source of drinking water), or where natural attenuation could achieve goals in a reasonable time frame.

c. Under what conditions is natural attenuation considered the least attractive?

See response to 3b.

d. What does contact and/or agency believe could be done to enhance the ability to implement this remedial alternative?

Contact feels that natural attenuation should receive the same degree of consideration and evaluation as any other remedial alternative.

e. What does contact and/or agency believe to be the trend of this remedial alternative; will it be used more in the future, and if so, for what types of sites?

Increasing interest in alternative. Likely to be considered more in the future.

f. What groups is contact aware of that are actively promoting the use of natural attenuation as a remedial alternative? Is contact aware of any military/industrial/regulatory cooperative groups studying how to enhance the ability to implement this alternative?

Air Force has taken the lead in examining the potential of natural attenuation for sites contaminated with petroleum hydrocarbons.

#### **4. Application Examples**

a. Where has natural attenuation been implemented as all or part of the remedial action?

Contact has been involved only in the policy area of natural attenuation, referred to Peter Feldman ([703] 603-8768) at HQ EPA for additional information.

## Interview 2

**Date of Interview: 10/26/94**

### 1. Background Information

- a. Name of person interviewed                      Rutherford Hayes
- b. Title or position                                      Remedial Project Manager - Superfund
- c. Specific agency, region, office, etc.      U.S. Environmental Protection Agency,  
Region IV, Atlanta, GA
- d. Phone number    (404) 347-4103

### 2. Regulatory Framework

a. What regulations, published by this agency/office, apply specifically to natural attenuation as a remediation technique? Include both prohibitions and exemptions for this remediation alternative.

There are informal policies that have been developed by the ground water control section. The policies are focused not so much on restrictions to consideration of natural attenuation, but rather on what site-specific issues will provide the greatest likelihood that natural attenuation will be an acceptable alternative. These issues include:

- If there is no active ground water use in areas adjacent to site, natural attenuation should be evaluated (i.e., considered applicable for contaminated Class IIb ground water).
- There must be some quantitative evaluation of the time frame required to achieve cleanup goals. If the time frames to clean to goals are comparable for natural attenuation and active remediation, then natural attenuation may be more favorable.
- If adequately strong institutional controls can be used in conjunction with natural attenuation and health and environment protection maintained, then natural attenuation may be an acceptable alternative.

b. If natural attenuation regulations have not been promulgated, is the agency working on the development of such legislation? If not, are there plans to do so in the future?

Region IV has been fairly active in developing or advancing policy regarding natural attenuation; however, there appears to be little incentive to address the issue from a regulatory perspective (EPA). Contact stated that without reauthorization of Superfund, relevant regulations are not likely to be developed by EPA.

c. If not a federal agency, does this agency have remediation regulations more stringent than existing federal regulations? For example, has the agency finalized soil or non-MCL ground water cleanup criteria ? (Obtain a summary of and specific citation for any regulations.)

NA.

### 3. Philosophical Framework

a. What is the current philosophy within the agency regarding the use of natural attenuation at contaminated sites? Is it being supported by the agency?

The interest in and support of natural attenuation has definitely increased over the past five years; however, there are still skeptics and critics. Although there may be some reluctance (or suspicion of motive) for natural attenuation when the alternative is proposed by the PRP, there is a definite willingness to discuss the potentials for the alternative. Contact feels that the attitude in Region IV toward natural attenuation is closely aligned with EPA HQ.

b. Under what conditions is natural attenuation considered the most attractive?

See response to 2a. Natural attenuation is most attractive where there is no use of ground water, where the time required to cleanup is comparable to that via active remediation, and where institutional controls can be applied to provide adequate protection.

In addition, the alternative may be more attractive at those sites where contamination is relatively close to MCLs.

c. Under what conditions is natural attenuation considered the least attractive?

Reverse of response to 3b.

d. What does contact and/or agency believe could be done to enhance the implementability of this remedial alternative?

Contact feels that stronger and consistent policy regarding natural attenuation is needed from EPA HQ. Such policy should include a statement of the level of documentation needed for the acceptance of natural attenuation, guidelines as to what situations and characteristics are more amenable for the consideration of natural attenuation, and specific waiver guidance. It is felt that current policies are inconsistent between different EPA functions.

e. What does contact and/or agency believe to be the trend of this remedial alternative; will it be used more in the future, and if so, for what types of sites?

It is felt that natural attenuation will continue to be an attractive alternative for specific situations.

f. What groups is contact aware of that are actively promoting the use of natural attenuation as a remedial alternative? Is contact aware of any military/industrial/regulatory cooperative groups studying how to enhance the implementability of this alternative?

EPA.

#### 4. Application Examples

a. Where has natural attenuation been implemented as all or part of the remedial action?

##### SITE A

- i. Name of Site and main PRPs  
ILCO Site  
Leeds, Alabama
- ii. Type of Site (Landfill, Military, Industrial)  
  
Former lead smelter. Unit includes the actual smelter plant site as well as various sites located around the town where slag was used as fill. It is these off-plant sites where natural attenuation was implemented.
- iii. Contaminants of Concern (Metals, Solvents)  
  
Primary contaminant is lead.
- iv. Media of Concern (Soils, Ground Water)  
  
Contamination in ground water.
- v. Contamination levels  
  
Lead concentrations in the 0.02-0.03 mg/L range (slightly above the cleanup level of 0.015 mg/L).
- vi. Distance to nearest receptor  
  
Adjacent to sites.
- vii. Entire or component of site remedy  
  
Natural attenuation is entire component of remedy.
- viii. Auxiliary support mechanisms  
  
None.
- ix. Data/technical reasoning to support decision/Other Comments  
  
A dispersion model was run at these off-plant sites that indicated that the contaminated plume will attenuate to MCL levels in 2 to 3 years. The conservative model assumed that dispersion of the contaminant is through advection.

##### SITE B

- i. Name of Site and main PRPs  
Monsanto Site  
Augusta, GA
- ii. Type of Site (Landfill, Military, Industrial)

Industrial waste landfill.

iii. Contaminants of Concern (Metals, Solvents)

A variety of metals including arsenic and chromium.

iv. Media of Concern (Soils, Ground Water)

Ground water.

v. Contamination levels

Metals concentrations in the range of 0.05-0.10 mg/L.

vi. Distance to nearest receptor

No contamination off site.

vii. Entire or component of site remedy

Entire.

viii. Auxiliary support mechanisms

None.

ix. Data/technical reasoning to support decision/Other Comments

Contamination contained in a slug plume. Modelling performed that conservatively estimated that natural attenuation would provide for cleanup to MCL in 2 to 3 years with no danger of off-site migration of contaminants.

b. At what sites has natural attenuation been considered and rejected?

In general, the alternative is rejected when there is immediate need for use of affected ground water.

**5. Other Comments**

Contact stated that cost is an important factor in the attractiveness of natural attenuation. He feels that regulators are now realizing that money saved at sites employing natural attenuation may be more effectively used at sites that require immediate intervention.

There are a number of signs that EPA HQ is moving to make natural attenuation more attractive. Examples include:

- The use of Technical and Practicability language in RODs (allowing for greater opportunities to demonstrate that natural attenuation may be effective).
- Revisions in the Hazard Ranking System for NPL sites. The ranking has been revised to reflect less of a focus on ground water contamination and more of a focus on targets of contamination. In other words, if there are no receptors of contaminated ground water, the ranking may be less severe.

### Interview 3

**Date of Interview: 10/25/94**

#### 1. Background Information

- a. Name of person interviewed                      Rosita Clarke
- b. Title or position                                      Superfund Project Manager
- c. Specific agency, region, office, etc.      Environmental Protection Agency, Region V, Chicago, IL
- d. Phone number                                        (312) 886-7251

#### 2. Regulatory Framework

- a. What regulations, published by this agency/office, apply specifically to natural attenuation as a remediation technique? Include both prohibitions and exemptions for this remediation alternative.

Not aware of any written policy regarding the use of natural attenuation.

- b. If natural attenuation regulations have not been promulgated, is the agency working on the development of such legislation? If not, are there plans to do so in the future?

Unknown.

- c. If not a federal agency, does this agency have remediation regulations more stringent than existing federal regulations? For example, has the agency finalized soil or non-MCL ground water cleanup criteria ? (Obtain a summary of and specific citation for any regulations.)

NA.

#### 3. Philosophical Framework

- a. What is the current philosophy within the agency regarding the use of natural attenuation at contaminated sites? Is it being supported by the agency?

The contact is fairly new to the Superfund program, but has observed that, although there is evidently no written guidance or policy at the region, natural attenuation is considered favorably in certain situations.

- b. Under what conditions is natural attenuation considered the most attractive?

Contact feels that the use of natural attenuation is most attractive in cases where the contaminants levels are low and where there are no receptors.

c. Under what conditions is natural attenuation considered the least attractive?

Where there are receptors (private wells, public water supplies) or where local communities are affected.

d. What does contact and/or agency believe could be done to enhance the ability to implement this remedial alternative?

Unknown.

e. What does contact and/or agency believe to be the trend of this remedial alternative; will it be used more in the future, and if so, for what types of sites?

Contact feels that opinions of the appropriateness of the remedy in some situations will continue to be favorable.

f. What groups is contact aware of that are actively promoting the use of natural attenuation as a remedial alternative? Is contact aware of any military/industrial/regulatory cooperative groups studying how to enhance the ability to implement this alternative?

Unknown.

#### **4. Application Examples**

a. Where has natural attenuation been implemented as all or part of the remedial action?

#### **SITE A**

i. Name of Site and main PRPs  
Wheeler Pit, Janesville, Wisconsin  
RP - General Motors

ii. Type of Site (Landfill, Military, Industrial)

A former sand/gravel pit used by GM for the disposal of paint and chemical wastes.

iii. Contaminants of Concern (Metals, Solvents)

Organics (VOCs, PAHs) and a variety of metals.

iv. Media of Concern (Soils, Ground Water)

Contamination in soils and ground water.

v. Contamination levels

Organics in soil to percent levels. Metals in soils - mg/L range. Ground water contamination slightly above or below MCLs (e.g., xylene-0.006 mg/L; ethyl benzene 0.0008 mg/L).

vi. Distance to nearest receptor

Two private wells located approximately 2 miles from site perimeter.

vii. Entire or component of site remedy

Component.

viii. Auxiliary support mechanisms

Site remedy (based on signed ROD) – contaminated soils were consolidated in one area and the area was capped. Ground water monitoring – no active ground water remediation. Site is in second year of O&M.

ix. Data/technical reasoning to support decision/Other Comments

Active remediation of ground water (pump and treat) was rejected because the plume was not adequately well-defined and because the low level of contamination did not warrant pump and treat from technical and economic perspectives.

b. At what sites has natural attenuation been considered and rejected?

Unknown.

**5. Other Comments**

Other potential points of contact at Region V:

Terese VanDonsel	(312)353-6564
John Kuhns	(312)353-6556
Daniel Cozza	(312)886-7252

## Interview 4

Date of Interview: 10/26/94

### 1. Background Information

- a. Name of person interviewed                      John Kuhns
- b. Title or position                                      Superfund Project Manager
- c. Specific agency, region, office, etc.      Environmental Protection Agency, Region V, Chicago, IL
- d. Phone number    (312) 353-6556

### 2. Regulatory Framework

- a. What regulations, published by this agency/office, apply specifically to natural attenuation as a remediation technique? Include both prohibitions and exemptions for this remediation alternative.

Not aware of any formalized policy regarding the use of natural attenuation.

- b. If natural attenuation regulations have not been promulgated, is the agency working on the development of such legislation? If not, are there plans to do so in the future?

Apparently there is no policy under development.

- c. If not a federal agency, does this agency have remediation regulations more stringent than existing federal regulations? For example, has the agency finalized soil or non-MCL ground water cleanup criteria ? (Obtain a summary of and specific citation for any regulations)

NA.

### 3. Philosophical Framework

- a. What is the current philosophy within the agency regarding the use of natural attenuation at contaminated sites? Is it being supported by the agency?

There is a substantial level of support in the Region for selective implementation of natural attenuation. A lot of this support is based on cost-effectiveness.

- b. Under what conditions is natural attenuation considered the most attractive?

Contact uses risk/exposure-based analyses to judge the applicability of natural attenuation. Natural attenuation may only be considered in cases where there are no significant health or environmental risks.

c. Under what conditions is natural attenuation considered the least attractive?

See response to 3b.

d. What does contact and/or agency believe could be done to enhance the ability to implement this remedial alternative?

Continue risk/exposure-based assessments to determine feasibility.

e. What does contact and/or agency believe to be the trend of this remedial alternative; will it be used more in the future, and if so, for what types of sites?

Based on interest, support, and demonstrations of effectiveness, natural attenuation will continue to be considered a technically and economically viable alternative in certain cases.

f. What groups is contact aware of that are actively promoting the use of natural attenuation as a remedial alternative? Is contact aware of any military/industrial/regulatory cooperative groups studying how to enhance the ability to implement this alternative?

Contact feels that the joint and cooperative groups that are looking at natural attenuation are pretty loosely organized (despite the conference).

#### **4. Application Examples**

a. Where has natural attenuation been implemented as all or part of the remedial action?

##### **SITE A**

i. Name of Site and main PRPs  
Charlevoix Municipal Well, Mich.  
No RPs identified for site

ii. Type of Site (Landfill, Military, Industrial)

Former municipal water supply. Well ran along lakefront (Lake Michigan) and took both lake water and ground water. Ground water heavily contaminated by industrial discharges and spills.

iii. Contaminants of Concern (Metals, Solvents)

Primarily VOCs.

iv. Media of Concern (Soils, Ground Water)

Ground water.

v. Contamination levels

VOC concentrations as high as 0.10 mg/L at the tap.

vi. Distance to nearest receptor

Was public water supply located on Lake Michigan.

vii. Entire or component of site remedy

Component.

viii. Other components/Auxiliary support mechanisms

Upon discovering the contamination, crude air stripping was performed at the well head. Two RODs were developed and signed. The first ROD was to provide for interim remedial measures that consisted of replacing the water supply (replaced with lake water) and monitoring. The second ROD was a "No Action" ROD that provided for natural attenuation to occur with five year reviews and yearly monitoring.

ix. Data/technical reasoning to support decision/Other Comments

Since the water supply had been replaced, it was determined (through a risk/exposure-based analysis) that there would be no threat to health or the environment if the ground water was allowed to naturally attenuate. Calculations indicated that if the ground water were to be flushed out to the lake (naturally) there would be a high degree of confidence that the lake water quality would be unaffected. The calculations indicate that the ground water would be remediated to MCLs within 50 years.

b. At what sites has natural attenuation been considered and rejected?

Typically, natural attenuation is eliminated early on in the analysis due to unacceptable risks to health or the environment.

**5. Other Comments**

Contact cited the St. Joseph, Michigan, site as a very good example of the use and benefits of natural attenuation (see description of that site in Michigan DNR Interview Summary)

## Interview 5

**Date of Interview: 10/27/94**

### 1. Background Information

- a. Name of person interviewed                      Ken Katen
- b. Title or position                                      Associate Water Resource Control Engineer
- c. Specific agency, region, office, etc.      California Regional (North Coast) Water Quality Control Board (UST Unit)
- d. Phone number    (707) 576-2800

### 2. Regulatory Framework

- a. What regulations, published by this agency/office, apply specifically to natural attenuation as a remediation technique? Include both prohibitions and exemptions for this remediation alternative.

Contact is not aware of specific agency guidelines, policies, or regulations that directly pertain to consideration of natural attenuation.

- b. If natural attenuation regulations have not been promulgated, is the agency working on the development of such legislation? If not, are there plans to do so in the future?

Contact does not foresee any such development.

- c. If not a federal agency, does this agency have remediation regulations more stringent than existing federal regulations? For example, has the agency finalized soil or non-MCL ground water cleanup criteria ? (Obtain a summary of and specific citation for any regulations)

Chapters 15 and 16 of the California Water Code provide for the establishment of cleanup goals on a site-specific basis. The code does not provide for any numerical criteria. California has a "Non-degradation Policy" (State Board Policy, number unknown) that states that state waters with beneficial use can't be compromised and must be cleaned up.

### 3. Philosophical Framework

- a. What is the current philosophy within the agency regarding the use of natural attenuation at contaminated sites? Is it being supported by the agency?

Within California there is a strong active interest in natural attenuation as a remedial alternative with potential for cleaning up the environment without bankrupting RPs (or government). In general, it is recognized that natural attenuation should be investigated as a possibly viable cleanup alternative, but special attention must be paid to ensure that it will be protective of ground water quality. In other words, natural attenuation is viable, but must be demonstrated.

b. Under what conditions is natural attenuation considered the most attractive? The least attractive?

Contact stated that he feels there are three kinds of sites relevant to natural attenuation:

- (1) Sites with minor soil contamination and no ground water contamination and no threat of ground water contamination.
- (2) Sites at which contamination has affected ground water and the behavior of the contaminated plume has either not been well-documented or is still growing.
- (3) Sites where a contaminated plume has been well-delineated and proven to be stable in size.

Of these sites, natural attenuation may be applicable to conditions (1) and (3). It will not be applicable to condition (2).

c. What does contact and/or agency believe could be done to enhance the ability to implement this remedial alternative?

RPs and consultants need to better comprehend the importance of conducting a "rational demonstration" of the applicability of natural attenuation. Such a rational demonstration would include (at a minimum):

- Description of hydrogeology.
- Description of the hydraulic cycle (does ground water fluctuate or remain at stable levels).
- Well-defined vertical and horizontal limits of contamination.
- Demonstration that the plume is not (or has stopped) growing.
- Ability to make a realistic prediction that natural attenuation will occur.

d. What does contact and/or agency believe to be the trend of this remedial alternative; will it be used more in the future, and if so, for what types of sites?

Contact feels that consideration and use of natural attenuation will definitely increase in the future.

e. What groups is contact aware of that are actively promoting the use of natural attenuation as a remedial alternative? Is contact aware of any military/industrial/regulatory cooperative groups studying how to enhance the ability to implement this alternative?

Contact is unaware of specific technical or regulatory groups that actively support the use of natural attenuation. However, he has noticed that some citizens groups and individuals appear to prefer its consideration.

#### 4. Application Examples

a. Where has natural attenuation been implemented as all or part of the remedial action?

From an UST perspective, contact stated that the idea and acceptance of natural attenuation is too recent for there to be formal decisions to incorporate it as an actual remedy. However, contact is confident that there are sites that may be candidates for the approach once it has been adequately demonstrated.

b. At what sites has natural attenuation been considered and rejected?

See response to 4a.

**5. Other Comments**

When questioned, contact stated that he feels EPA Region IX is in support of the consideration of natural attenuation at specific sites. He feels it is in conformance with EPA's increasing emphasis on accelerated site assessments and cleanups.

Note that this contact represents UST/petroleum hydrocarbon issues only. I was referred to Susan Warner, Senior of the Site Mitigation Unit (707) 576-2697 for additional information on other types of sites (She will be out of the office until November 5).

## Interview 6

Date: 10/25/94

### 1. Background Information

- a. Name of person interviewed Lisa Weers
- b. Title or position RCRA Specialist-Engineer
- c. Specific agency, region, office, etc. Colorado Department of Public Health & Environment
- d. Phone number (303) 692-3451

### 2. Regulatory Framework

- a. What regulations, published by this agency/office, apply specifically to natural attenuation as a remediation technique? Include both prohibitions and exemptions for this remediation alternative.

Contact was unaware of any such regulations.

- b. If natural attenuation regulations have not been promulgated, is the agency working on the development of such legislation? If not, are there plans to do so in the future?

Unknown.

- c. If not a federal agency, does this agency have remediation regulations more stringent than existing federal regulations? For example, has the agency finalized soil or non-MCL ground water cleanup criteria ? (Obtain a summary of and specific citation for any regulations.)

Referred to Superfund specialist, Lynn Olson, (303) 692-3391.

### 3. Philosophical Framework

- a. What is the current philosophy within the agency regarding the use of natural attenuation at contaminated sites? Is it being supported by the agency, and if so, what guidance has been provided as to when it is most attractive?

Natural attenuation is seen as an alternative of interest if time is not a consideration and if the site is not to be reused. There is probably greater applicability for LUST responses.

- b. What does contact and/or agency believe could be done to enhance the ability to implement this remedial alternative?

No response.

- c. What does contact and/or agency believe to be the trend of this remedial alternative; will it be used more in the future, and if so, for what types of sites?

See response to 3a.

d. What groups is contact aware of that are actively promoting the use of natural attenuation as a remedial alternative? Is contact aware of any military/industrial/regulatory cooperative groups studying how to enhance the implementability of this alternative?

Air Force and EPA.

#### **4. Application Examples**

a. Where has natural attenuation been implemented as all or part of the remedial action?

Contact aware of UST site where natural attenuation is part of a cleanup. The UST contained waste oil that had contaminated surrounding soils and ground water. Active bioremediation was used initially with final cleanup to be achieved by natural attenuation. Contact had no further details available. Was referred to contractor responsible for cleanup, Christopher Nelson, Groundwater Technology, (303)779-0755.

b. At what sites has natural attenuation been considered and rejected?

Unknown.

#### **5. Other Comments**



- No time frame is established for cleanup (this allows for greater opportunities to consider natural attenuation).

### 3. Philosophical Framework

- a. What is the current philosophy within the agency regarding the use of natural attenuation at contaminated sites? Is it being supported by the agency?

The Michigan DNR appears to be a leader in supporting the consideration of natural attenuation as a remedial alternative. It recognizes that natural attenuation can provide a technically sound and cost-effective solution. The DNR will support natural attenuation providing that adequate site investigations are performed. Minimum investigation requirements include hydrogeological assessments (with characterization and modelling in three dimensions), chemical characterizations, and some degree of demonstration that natural attenuation has and/or will occur at the site.

The contact feels that cleanups at many sites where active bioremediation is being considered may actually be more successful if natural attenuation (or passive bioremediation) is implemented. He feels that intervention may destroy or impair some of the naturally occurring degradation mechanisms already in place.

- b. Under what conditions is natural attenuation considered the most attractive?

Natural attenuation is considered attractive at sites where bioremediation is feasible, where there is proof that the site is biologically active, where the time to remediate is not critical, and where there are no threats to downgradient receptors or the environment as a result of its implementation.

The impression was given that contaminant levels and types may not be the most critical issues if the site is biologically active.

- c. Under what conditions is natural attenuation considered the least attractive?

Natural attenuation cannot be considered at sites where downgradient receptors or the environment is threatened without intervention.

- d. What does contact and/or agency believe could be done to enhance the ability to implement this remedial alternative?

Michigan has devoted resources to maintain an active research and development organization within DNR as well as in state and federally supported laboratories (there are four such labs located in Michigan). Continued research allows for greater insight into the applicability and capability of natural attenuation.

- e. What does contact and/or agency believe to be the trend of this remedial alternative; will it be used more in the future, and if so, for what types of sites?

The Michigan DNR apparently feels that natural attenuation should, and will be, considered as a viable option at contaminated sites. Supporting evidence includes a potential dramatic decrease in remedial costs (see example Site B-below) and effectiveness that rivals active remediation alternatives.

f. What groups is contact aware of that are actively promoting the use of natural attenuation as a remedial alternative? Is contact aware of any military/industrial/regulatory cooperative groups studying how to enhance the ability to implement this alternative?

The EPA and Air Force were cited by the contact as agencies/organizations that are furthering the concept and acceptability of natural attenuation.

#### 4. Application Examples

a. Where has natural attenuation been implemented as all or part of the remedial action?

##### SITE A

i. Name of Site and main PRPs  
St. Joe/Benton Harbor Site  
EPA and DNR are co-RPs

ii. Type of Site (Landfill, Military, Industrial)

Closed/abandoned automobile parts manufacturing site.

iii. Contaminants of Concern (Metals, Solvents)

Primary contaminant of concern is TCE; however, there is a wide assortment of other chlorinated and nonchlorinated organics in soil and ground water at the site.

iv. Media of Concern (Soils, Ground Water)

Contamination in soils and ground water.

v. Contamination levels

There are percent concentrations of TCE (and other organics) in soil.  
Contamination in ground water is in parts per million.

vi. Distance to nearest receptor

Contaminated plume migrates toward Lake Michigan (adjacent to site).

vii. Entire or component of site remedy

Site remedy consists of natural attenuation and monitoring.

viii. Auxiliary support mechanisms

Monitoring only.

ix. Data/technical reasoning to support decision/Other Comments

During the first investigation of the site, it was suspected that contaminants were being biologically degraded under natural conditions due to the absence of any contamination in the adjacent Lake Michigan. Subsequently, extensive monitoring and investigation of the site was performed that further demonstrated that natural attenuation was occurring. Despite large concentrations of organic contaminants in the soil, the contaminated ground water plume is much smaller than might be anticipated (roughly 1,500 feet by 200 feet by 30-80 feet deep). Based on results so far, it is anticipated that the site will be cleaned up to risk-based standards in 3 to 5 years. This site has been extensively studied and has been identified as a very biologically active site (due to a broad range of organics, the presence of sulfates, and adequate naturally occurring levels of dissolved oxygen) and ideal for successful natural attenuation.

**SITE B**

i. Name of Site and main PRPs

KL Avenue Landfill, Kalamazoo

RP's include UpJohn, General Motors, and the state of Michigan

ii. Type of Site (Landfill, Military, Industrial)

Municipal landfill.

iii. Contaminants of Concern (Metals, Solvents)

A broad range of chlorinated and nonchlorinated organics (including acetone and BTEX). Metals in the landfill are not migrating.

iv. Media of Concern (Soils, Ground Water)

Ground water. The landfill was established in a ravine with a stream running through it. Part of the landfill contents are in the ground water. Landfill soils are very sandy.

v. Contamination levels

Concentrations in the landfill range from mg/L to percent. Ground water concentrations in the mg/L range.

vi. Distance to nearest receptor

The site is located in a residential subdivision. Although there are 30 to 40 homes in the range of the contaminated plume, the city has extended the public water supply, so there is no exposure. A lake is located downgradient from the site (~ 1,000 ft).

vii. Entire or component of site remedy

Proposed site remedy consists of natural attenuation and monitoring (see response to question ix).

viii. Auxiliary support mechanisms

Monitoring only.

ix. Data/technical reasoning to support decision/Other Comments

An ROD for this site was prepared specifying capping (clay cap) as the remedial alternative of choice. The estimated total cost of the remediation was approximately \$33 MM. Local residents became outraged by the large amounts of clay to be brought onto the site (i.e., transported through their neighborhood) and demanded that the ROD be reviewed. During this review, the DNR examined site-specific information and data including area of contamination, contamination characteristics (types and concentrations), and precipitation. It was found that the area of contamination was significantly less (about 25%) than that expected given the soil concentrations and the amount of precipitation. As a result, the reviewers suspected that the site was biologically active and that natural attenuation was succeeding in limiting the spread of contamination. \$2 MM was spent to conduct a thorough site investigation that confirmed that anaerobic, aerobic, and anoxic processes were occurring. Data reflected the disappearance of BTEX and no contamination was identified in the downgradient lake. The site has been established as a demonstration site for natural attenuation and, if successful (as expected), natural attenuation and monitoring will be included in a new ROD. It is now estimated that the cost of completing the remediation will be \$5 MM.

b. At what sites has natural attenuation been considered and rejected?

Natural attenuation is considered a potential alternative at all sites where bioremediation has potential applicability. However, it is rejected for further consideration immediately in cases where there is any potential threat to downgradient receptors or the environment. Examples of sites where natural attenuation is eliminated as an alternative are those where private wells, public water supplies, wetlands, or waterways may be affected. At these sites, some sort of physical intervention will usually be required because natural attenuation cannot "act fast enough" to mitigate threats.

**5. Other Comments**

None.



### 3. Philosophical Framework

a. What is the current philosophy within the agency regarding the use of natural attenuation at contaminated sites? Is it being supported by the agency?

Natural attenuation has gained fairly wide acceptance within the state agency. There is considerable interest and support throughout the agency for consideration of the use of natural attenuation in soils contaminated with petroleum hydrocarbons. There is less interest and support to consider alternative in ground water cleanups or in soil cleanups where there are chlorinated hydrocarbons or other less biodegradable contaminants (e.g., explosives).

b. Under what conditions is natural attenuation considered the most attractive?

Natural attenuation is considered potentially applicable in situations where:

- There are no receptors.
- A ground water plume is well-defined.
- Conditions are appropriate for degradation to proceed (i.e., adequate nutrients and aerobic [for non-Cl hydrocarbons] environments).
- There is a commitment to provide adequate monitoring.

Contact stated that there is flexibility within the DNR regarding the time frame associated with cleanup - time may not be a limiting factor to considering natural attenuation. However, it was stated that the time frame may be a bigger concern of RPs than regulators.

c. Under what conditions is natural attenuation considered the least attractive?

Natural attenuation is less likely to be a viable alternative where:

- There are immediate receptors.
- The environmental conditions are not appropriate for degradation to occur.
- Other, nonpetroleum hydrocarbons (e.g., Cl hydrocarbons, explosives) are contaminants.

d. What does contact and/or agency believe could be done to enhance the ability to implement this remedial alternative?

To sell natural attenuation to a regulatory agency, the following activities are important:

- Understand the plume.
- Identify all potential receptors.
- Identify any limiting factors.
- Consider benefits of enhancing natural biodegradation.

e. What does contact and/or agency believe to be the trend of this remedial alternative; will it be used more in the future, and if so, for what types of sites?

Contact feels that consideration of natural attenuation is high on an upward trend ("high on a steep learning curve"). It is felt that natural attenuation (i.e.,

natural biodegradation) must be considered as an option for remediating petroleum hydrocarbons in soil.

f. What groups is contact aware of that are actively promoting the use of natural attenuation as a remedial alternative? Is contact aware of any military/industrial/regulatory cooperative groups studying how to enhance the ability to implement this alternative?

Contact feels that the natural attenuation "spark" is occurring in a lot of places. Recent EPA/AFCEE symposium was first effort to bring things together. EPA Ada lab (specifically, John Wilson) cited as leader in understanding and development.

#### **4. Application Examples**

a. Where has natural attenuation been implemented as all or part of the remedial action?

Contact is more of a technical consultant to DNR program managers and people in the field and, as such, is not intimately familiar with specific site applications. However, he cited a recent survey conducted by DNR to assess the status of natural biodegradation. A 50% response to the survey indicated that approximately 80 sites in Wisconsin are using natural biodegradation in soil and ground water. A vast majority of these cleanups involve petroleum hydrocarbons. Contact has been approached for information about the applicability of natural biodegradation to clean up other organic contaminants, but he is not aware that anything has come of such efforts.

#### **5. Other Comments**

Wisconsin appears to have a fairly well developed attitude regarding the applicability of natural attenuation. The following points are of interest:

- Specific written guidance has been developed.
- There is reluctance to use the words "natural attenuation" to describe the process. Rather, from a regulatory (and legal) standpoint, the words "natural biodegradation" are preferred. The primary reason behind this preference is that the regulators and lawyers would prefer that it be made clear that contaminants are being destroyed through the process. Natural attenuation is much less desirable when attenuation of contaminants is accomplished through non-destructive methods.
- The emphasis on natural biodegradation is for the remediation of soils. There is less enthusiasm for application of the alternative to ground water. "Ground water is not an easy sell." The primary concern with ground water is that the plume may not be adequately characterized.
- Since the emphasis is on biodegradation, it follows that less- or nonbiodegradable contaminants are less likely to be considered for natural attenuation.

- Based on the interview, it appears that the DNR regulators may be interested in some sort of enhanced bioremediation at sites where natural bioremediation may be feasible.

## Interview 9

**Date of Interview:** 1/13/95

### 1. Background Information

- a. Name of person interviewed                      Reuben McCullers
- b. Title or position                                      Corrective Action Officer
- c. Specific agency, region, office, etc.      EPA Region III, Kansas City
- d. Phone number    (913) 551-7455

### 2. Regulatory Framework

- a. What regulations, published by this agency/office, apply specifically to natural attenuation as a remediation technique? Include both prohibitions and exemptions for this remediation alternative.

Not aware of any formalized policy regarding the use of natural attenuation.

- b. If natural attenuation regulations have not been promulgated, is the agency working on the development of such legislation? If not, are there plans to do so in the future?

No actions underway to develop policy. Natural attenuation is too dependent on site-specific, situation-specific factors, that policy is not practical.

- c. If not a federal agency, does this agency have remediation regulations more stringent than existing federal regulations? For example, has the agency finalized soil or non-MCL ground water cleanup criteria ? (Obtain a summary of and specific citation for any regulations.)

NA.

### 3. Philosophical Framework

- a. What is the current philosophy within the agency regarding the use of natural attenuation at contaminated sites? Is it being supported by the agency?

There appears to be no general philosophy within the region (at least with respect to corrective actions). There is no particular support for the alternative over other alternatives. Natural attenuation is considered on a site and situation-specific basis. The point of contact will consider natural attenuation, but only when there is no potential for exposure or risk. Decision to pursue natural attenuation referred to as a "judgment call."

b. Under what conditions is natural attenuation considered the most attractive?

Where there is no potential for exposure of contaminated water to humans or the environment. Point of contact considers "true" natural attenuation to consist of the biodegradation of contaminants only. If natural attenuation is a result of dispersion (or dilution), the contact is not generally favorably disposed to the alternative.

In the case of inorganic contaminants, natural attenuation might be considered if the risk is low, where the concentration is close to criteria, and exposure is controlled.

c. Under what conditions is natural attenuation considered the least attractive?

- Where nonbiodegradable contaminants are present
- Where the source of contamination is still present
- Where attenuation of contaminants is due to dispersion ("dilution").

d. What does contact and/or agency believe could be done to enhance the ability to implement this remedial alternative?

NA.

e. What does contact and/or agency believe to be the trend of this remedial alternative; will it be used more in the future, and if so, for what types of sites?

NA.

f. What groups is contact aware of that are actively promoting the use of natural attenuation as a remedial alternative? Is contact aware of any military/industrial/regulatory cooperative groups studying how to enhance the ability to implement this alternative?

EPA, Air Force.

#### 4. Application Examples

Contact not aware of examples at this time. However, natural attenuation is being considered at a few refinery sites. No details provided.

#### 5. Other Comments

Because of the absence of general region-wide policy regarding natural attenuation, the point of contact wanted to make it clear that he was speaking only for himself and not reflecting any regional opinion.

The point of contact seems to have a very rational approach to natural attenuation. He will consider it at any site, but is reluctant to approve it in certain cases. These include where the source is still present, where contamination may be in a pocket, and where the contaminants do not biodegrade.

**Issues identified by the point of contact include:**

- **Biodegradation will not occur readily when contaminants are too concentrated. Therefore, in order for natural attenuation to be acceptable, the contamination needs to be adequately dispersed prior to any potential point of exposure.**
- **There are two very different conditions to consider. The first of these is where the source is still present – in this case, the remedial activity should concentrate on source removal. The second condition is when all of the contamination is in the plume. This latter is a complicated scenario. The applicability of natural attenuation will depend on the depth of the contaminated plume, the type of soil, other hydrogeological features, the level of risk, potential for exposure, concentration of contaminants, and the ease with which the contaminants can be recovered (will pump and treat work).**
- **The public is taking more of a risk when contaminants are metals because of the persistence of the metals.**
- **The placement of institutional controls (including monitoring) is an absolute requirement to natural attenuation. This is to ensure that there is no potential for penetration of contaminated site, exposure to contamination, or spread of contamination.**

## **Appendix B**

### **Bibliography**

## Appendix B - Bibliography

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**Appendix C**

**EPA-Provided Natural Attenuation ROD List**

**CONTAMINATED MEDIA, CHEMICAL GROUP AND SELECTED REMEDIES IN FY 1982 - FY 1993  
RECORDS OF DECISION FOR SITES WHICH USE NATURAL ATTENUATION AS THE SELECTED  
REMEDY**

<u>REG</u>	<u>EPA ID</u>	<u>SITE NAME</u>	<u>DATE SIGN</u>
5	MID980134390 MEDIA GW	Charlevoix Municipal Well Field <b>CHEMICAL GROUP</b> VOC	9/30/95 <b>SELECTED REMEDY</b> Natural Attenuation
5	ILD980397079 MEDIA GW GW GW GW GW GW	A&F Materials Reclaiming <b>CHEMICAL GROUP</b> Metal VOC Metal Inorganic VOC Metal	8/14/86 <b>SELECTED REMEDY</b> Natural Attenuation Natural Attenuation Natural Attenuation Natural Attenuation Natural Attenuation Natural Attenuation
2	NJDO70415005 MEDIA GW GW	Renora <b>CHEMICAL GROUP</b> Metal VOC	9/29/87 <b>SELECTED REMEDY</b> Natural Attenuation Natural Attenuation
6	TXD980514996 MEDIA GW GW GW GW	Highlands Acid Pit <b>CHEMICAL GROUP</b> Metal VOC Metal BNA	6/26/87 <b>SELECTED REMEDY</b> Natural Attenuation Natural Attenuation Natural Attenuation Natural Attenuation
1	MAD079510780 MEDIA GW	Cannon Engineering <b>CHEMICAL GROUP</b> VOC	3/31/88 <b>SELECTED REMEDY</b> Natural Attenuation
2	NYD010959757 MEDIA GW	Marathon Battery <b>CHEMICAL GROUP</b> VOC	9/30/88 <b>SELECTED REMEDY</b> Natural Attenuation
3	PAD980692537 MEDIA GW	Westline <b>CHEMICAL GROUP</b> NP	6/29/88 <b>SELECTED REMEDY</b> Natural Attenuation
3	VAD980712913 MEDIA SW	Chismon Creek <b>CHEMICAL GROUP</b> Metal	3/31/88 <b>SELECTED REMEDY</b> Natural Attenuation
6	TXD980625453 MEDIA GW	Brio Refinery <b>CHEMICAL GROUP</b> NP	3/31/88 <b>SELECTED REMEDY</b> Natural Attenuation
3	DEP058980442 MEDIA GW GW	New Castle Spill <b>CHEMICAL GROUP</b> TBD VOC	9/28/89 <b>SELECTED REMEDY</b> Natural Attenuation Natural Attenuation

**CONTAMINATED MEDIA, CHEMICAL GROUP AND SELECTED REMEDIES IN FY 1982 - FY 1993  
RECORDS OF DECISION FOR SITES WHICH USE NATURAL ATTENUATION AS THE SELECTED  
REMEDY**

<u>REG</u>	<u>EPA ID</u>	<u>SITE NAME</u>	<u>DATE SIGN</u>
10	WAD980511778 <b>MEDIA</b> GW GW GW	Northside Landfill <b>CHEMICAL GROUP</b> VOC Metal VOC	9/30/89  <b>SELECTED REMEDY</b> Nat Alt (+)/NP Nat Alt (+)/NP Nat Alt (+)/NP
2	NYD980535165 <b>MEDIA</b> GW GW GW GW GW	Sarney Farm <b>CHEMICAL GROUP</b> VOC BNA PAH BNA Metal	9/27/90  <b>SELECTED REMEDY</b> NatA NatA NatA NatA NatA
3	PAD980690549 <b>MEDIA</b> GW	East Mt. Zion <b>CHEMICAL GROUP</b> Metal	6/29/90  <b>SELECTED REMEDY</b> Cap/NatA
3	PAD980690549 <b>MEDIA</b> GW GW GW GW	East Mt. Zion <b>CHEMICAL GROUP</b> Metal VOC BNA VOC	6/29/90  <b>SELECTED REMEDY</b> NatA NatA NatA NatA
4	TND980558894 <b>MEDIA</b> GW GW	North Hollywood Dump <b>CHEMICAL GROUP</b> Metal Pest	9/13/90  <b>SELECTED REMEDY</b> NatA NatA
4	TND980729115 <b>MEDIA</b> GW GW GW GW	Lewisburg Dump <b>CHEMICAL GROUP</b> VOC BNA VOC Metal	9/19/90  <b>SELECTED REMEDY</b> NatA NatA NatA NatA
6	ARD084930148 <b>MEDIA</b> GW	Arkwood <b>CHEMICAL GROUP</b> BNA	9/28/90  <b>SELECTED REMEDY</b> NatA
6	OKD000400093 <b>MEDIA</b> GW GW	Hardage/Criner (Amendment) <b>CHEMICAL GROUP</b> VOC Metal	11/22/89  <b>SELECTED REMEDY</b> NATA + TBD/OFDR NATA + TBD/OFDR
7	IAD981124167 <b>MEDIA</b> GW GW	Fairfield Coal Gasification Plant <b>CHEMICAL GROUP</b> PAH VOC	9/21/90  <b>SELECTED REMEDY</b> CAAd/OND + NatA CAAd/OND + NatA

**CONTAMINATED MEDIA, CHEMICAL GROUP AND SELECTED REMEDIES IN FY 1982 - FY 1993  
RECORDS OF DECISION FOR SITES WHICH USE NATURAL ATTENUATION AS THE SELECTED  
REMEDY**

<u>REG</u>	<u>EPA ID</u>	<u>SITE NAME</u>	<u>DATE SIGN</u>
7	IAD981124167 <b>MEDIA</b> GW GW GW	Fairfield Coast Gasification Plant <b>CHEMICAL GROUP</b> Metal VOC Metal	9/21/90 <b>SELECTED REMEDY</b> Filt/Sed/OND + NatA Filt/Sed/OND + NatA Filt/Sed/OND + NatA
8	WYD981546005 <b>MEDIA</b> GW	Mystery Bridge at Highway 20 <b>CHEMICAL GROUP</b> VOC	9/24/90 <b>SELECTED REMEDY</b> ONT/AS/NatA/ONDR
8	WYD987546095 <b>MEDIA</b> GW	Mystery Bridge at Highway 20 <b>CHEMICAL GROUP</b> VOC	9/24/90 <b>SELECTED REMEDY</b> ONT/AS/NatA/ONDR
1	NHD980503361 <b>MEDIA</b> GW GW GW GW	Mottolo Pig Farm <b>CHEMICAL GROUP</b> VOC Metal BNA VOC	3/29/91 <b>SELECTED REMEDY</b> NatA NatA NatA NatA
1	RID009764929 <b>MEDIA</b> GW GW GW GW GW GW GW GW GW GW	Western Sand & Gravel <b>CHEMICAL GROUP</b> VOC BNA PAH BNA PAH BNA VOC BNA Metal	4/16/91 <b>SELECTED REMEDY</b> NAtA NAtA NAtA NAtA NAtA NAtA NAtA NAtA NAtA NAtA
2	NYD981486947 <b>MEDIA</b> GW	Conkilo Dumps <b>CHEMICAL GROUP</b> VOC	3/29/91 <b>SELECTED REMEDY</b> NATA
3	MDD064882889 <b>MEDIA</b> GW	Mid-Atlantic Wood Preservers <b>CHEMICAL GROUP</b> Metal	12/31/90 <b>SELECTED REMEDY</b> NatA
4	ALD041906173 <b>MEDIA</b> GW	Interstate Lead (ILCO) <b>CHEMICAL GROUP</b> Metal	9/30/91 <b>SELECTED REMEDY</b> NatA-ONT/TBD + ONDR
4	GAD001700699 <b>MEDIA</b> GW	Monsanto (Augusta Plant) <b>CHEMICAL GROUP</b> Metal	12/7/90 <b>SELECTED REMEDY</b> NatA-OFD + OFT/POTW

**CONTAMINATED MEDIA, CHEMICAL GROUP AND SELECTED REMEDIES IN FY 1982 - FY 1993  
RECORDS OF DECISION FOR SITES WHICH USE NATURAL ATTENUATION AS THE SELECTED  
REMEDY**

<u>REG</u>	<u>EPA ID</u>	<u>SITE NAME</u>	<u>DATE SIGN</u>
5	MND980904056 <b>MEDIA</b> GW GW GW GW	Oak Grove Sanitary Landfill <b>CHEMICAL GROUP</b> Metal VOC Metal VOC	12/21/90 <b>SELECTED REMEDY</b> NatA NatA NatA NatA
8	COD980171551 <b>MEDIA</b> GW GW GW	Central City-Clear Creek <b>CHEMICAL GROUP</b> Metal Inorganic Metal	9/31/91 <b>SELECTED REMEDY</b> NatA + Act/Sed + OND + OFD NatA + Act/Sed + OND + OFD NatA + Act/Sed + OND + OFD
1	MAD980731483 <b>MEDIA</b> GW GW	PSC Resources <b>CHEMICAL GROUP</b> BNA VOC	9/??/92 <b>SELECTED REMEDY</b> NatA NatA
1	NIID981063860 <b>MEDIA</b> GW GW GW GW	Town Garage/Radio Beacon <b>CHEMICAL GROUP</b> Metal VOC Metal VOC	9/30/92 <b>SELECTED REMEDY</b> NatA NatA NatA NatA
2	NJD049860836 <b>MEDIA</b> GW GW GW GW	Kin-Buc Landfill <b>CHEMICAL GROUP</b> VOC PAH PCB Metal	9/22/92 <b>SELECTED REMEDY</b> NatA NatA NatA NatA
2	NYD980506901 <b>MEDIA</b> GW	Islip Municipal Sanitary Landfill <b>CHEMICAL GROUP</b> VOC	9/31/92 <b>SELECTED REMEDY</b> NatA
4	FLD980844179 <b>MEDIA</b> GW	Yellow Water Road Dump <b>CHEMICAL GROUP</b> PCB	6/30/92 <b>SELECTED REMEDY</b> NatA
5	ILD048306138 <b>MEDIA</b> GW	Tri County Landfill <b>CHEMICAL GROUP</b> NP	9/31/92 <b>SELECTED REMEDY</b> NatA
5	MN857002427S <b>MEDIA</b> GW GW GW	Twin Cities AF Reserve (SAR Landfill) <b>CHEMICAL GROUP</b> Metal VOC Metal	3/31/92 <b>SELECTED REMEDY</b> NatA NatA NatA

**CONTAMINATED MEDIA, CHEMICAL GROUP AND SELECTED REMEDIES IN FY 1982 - FY 1993  
RECORDS OF DECISION FOR SITES WHICH USE NATURAL ATTENUATION AS THE SELECTED  
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<u>REG</u>	<u>EPA ID</u>	<u>SITE NAME</u>	<u>DATE SIGN</u>
5	OBD051243610	Alsop Anaconda	9/30/92
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW	Metal	NatA
	GW	Inorganic	NatA
	GW	BNA	NatA
6	LAD980750137	Gulf Coast Vacuum Services (Operable Unit 1)	9/30/92
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW	VOC	NatA
	GW	BNA	NatA
	GW	PAB	NatA
	GW	Pest	NatA
	GW	PCB	NatA
	GW	Pest	NatA
	GW	Metal	NatA
	GW	Inorganic	NatA
	GW	Metal	NatA
	GW	Pest	NatA
6	OKD980620868	Mosley Road Sanitary Landfill	6/29/92
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW	Metal	NatA
	GW	VOC	NatA
	GW	Metal	NatA
	GW	VOC	NatA
7	IAD022193577	Farmer's Mutual Cooperative	9/29/92
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW	VOC	NatA
	GW	Pest	NatA
8	COD980716955	Denver Radium (Operable Unit 8)	1/28/92
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW	Radiation	NatA
	GW	NP	NatA
10	WAD009248295	Wyckoff/Eagle Harbor	9/29/92
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	Sediment	NP	NatA
1	RID055176283	Peterson/Puritan	9/30/93
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW3	VOC	NatA
	GW3	Metal	NatA
3	PAD079160842	Novak Sanitary Landfill	9/30/93
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW	BNA	NatA
	GW	VOC	NatA
	GW	Metal	NatA
	GW	VOC	NatA

**CONTAMINATED MEDIA, CHEMICAL GROUP AND SELECTED REMEDIES IN FY 1982 - FY 1993  
RECORDS OF DECISION FOR SITES WHICH USE NATURAL ATTENUATION AS THE SELECTED  
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<u>REG</u>	<u>EPA ID</u>	<u>SITE NAME</u>	<u>DATE SIGN</u>
4	ALD980844385	Redwing Carriers/Saraland	12/15/92
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW	Pest	NatA
	GW	VOC	NatA
	GW	Metal	NatA
	GW	BNA	NatA
	GW	VOC	NatA
	GW	BNA	NatA
	GW	Metal	NatA
	GW	Inorganic	NatA
	GW	BNA	NatA
	GW	VOC	NatA-Pump + Trmt
	GW	Metal	NatA-Pump + Trmt
	GW	VOC	NatA-Pump + Trmt
	GW	Metal	NatA-Pump + Trmt
	GW	BNA	NatA-Pump + Trmt
	GW	Metal	NatA-Pump + Trmt
	GW	VOC	NatA-Pump + Trmt
6	OXD980696470	Fourth Street Abandoned Refinery	9/30/93
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW	Metal	NatA
	GW	BNA	NatA
	GW	Pest	NatA
	GW	VOC	NatA
	GW	Pest	NatA
	GW	VOC	NatA
	GW	BNA	NatA
	GW	VOC	NatA
	GW	Pest	NatA
	GW	VOC	NatA
8	MTD006230635	Montana Pole and Treating	9/21/93
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	Sediment	Metal	NatA
	Sediment	Pest	NatA
	Sediment	Metal	NatA
	SW	Metal	NatA
	SW	PAH	NatA
	SW	BNA	NatA
	SW	PAH	NatA
	SW	BNA	NatA
	SW	Metal	NatA

**CONTAMINATED MEDIA, CHEMICAL GROUP AND SELECTED REMEDIES IN FY 1982 - FY 1993  
RECORDS OF DECISION FOR SITES WHICH USE NATURAL ATTENUATION AS THE SELECTED  
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<u>REG</u>	<u>EPA ID</u>	<u>SITE NAME</u>	<u>DATE SIGN</u>
8	UTD980667240	Utah Power & Light/American Barrel	7/7/93
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW	VOC	ONT/AS-GAC/OFDR + NatA + OFT + TBD
	GW	PAH	ONT/AS-GAC/OFDR + NatA + OFT + TBD
	GW	BNA	ONT/AS-GAC/OFDR + NatA + OFT + TBD
	GW	Metal	ONT/AS-GAC/OFDR + NatA + OFT + TBD
	GW	Inorganic	ONT/AS-GAC/OFDR + NatA + OFT + TBD
	GW	Metal	ONT/AS-GAC/OFDR + NatA + OFT + TBD
10	WA4890090075	Hanford 1100-Area (DOR)	9/24/93
	GW	VOC	NatA
	GW	Inorganic	NatA
10	WA7210090067	Fort Lewis Logistic Center	9/24/93
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW2	VOC	NatA
	GW2	PAH	NatA
	GW2	BNA	NatA
	GW2	Metal	NatA
10	WA9571924647	Fairchild Air Force Base 4 Areas (Operable Unit 2)	7/14/93
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	GW1	VOC	NatA
	GW3	VOC	NatA
	NAPLs	VOC	ONT/Recy/OFD + NatA
	NAPLs	Organic	ONT/Recy/OFD + NatA
10	WAD057311094	American Crossarm & Conduit	6/30/93
	<b>MEDIA</b>	<b>CHEMICAL GROUP</b>	<b>SELECTED REMEDY</b>
	SW	PAH	NatA
	SW	Pest	NatA
	SW	BNA	NatA

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<b>13. ABSTRACT (Maximum 200 words)</b> Natural attenuation, or intrinsic bioremediation, was investigated as an innovative approach to site remediation. This process, based on the concept that contamination in ground water, soils, and surface water can be reduced to environmentally benign levels through natural processes, is becoming increasingly popular with both regulators and the parties responsible for remediation.  A review was conducted of the available scientific literature for sites at which natural attenuation has been observed or selected for implementation, including several database searches. In addition, Federal and state regulators were interviewed to identify the conditions necessary for regulatory acceptance of natural attenuation. The final phase of the study involved assessing the available technical data to support the selection of natural attenuation at contaminated Army sites.  The study results demonstrate reasonable potential for implementation of natural attenuation at Army sites, provided that site-specific characteristics support its selection. Laboratory studies and field demonstrations are recommended to assess the potential for biodegradation of military unique compounds such as explosives and energetics, since these materials have not been demonstrated to be as susceptible to natural attenuation via biodegradation.				
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