Evaluating the Progress of Natural Attenuation in Groundwater

Course Number: EN-02-907

PDH: 4

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SECTION 1

USING THE EDIBLE OIL PROCESS

1.1 INTRODUCTION

Management of groundwater contaminated with chlorinated solvents is one of the country's greatest environmental challenges. A variety of chlorinated solvents have been used for years in both the military and commercial sectors for cleaning and degreasing many products and equipment ranging from aircraft engines, automobile and truck parts, electronic components and clothing. The number of sites contaminated with chlorinated solvents is likely second only to petroleum, oil, and lubricant (POL) sites.

The Edible Oil Process is part of an initiative by the Air Force Center for Engineering and the Environment to develop and demonstrate new technologies for the remediation of chlorinated solvents in groundwater.

Because of their physical and chemical properties, most chlorinated solvents are relatively recalcitrant in the subsurface, are more difficult to access once they are in the ground, and take longer to remediate. Consequently, the cost of remediating chlorinated solvents sites may significantly exceed the cost of remediating POL sites.

Specifically, if chlorinated solvents are released to the subsurface as a dense non-aqueous phase liquid (DNAPL), the density of the DNAPL relative to water will lead to a complex distribution of the contaminant in the vadose and saturated zones (Schwille, 1988; Kueper, *et al*., 1993). Chlorinated solvents are oxidized man-made compounds, which makes them susceptible to degradation by reductive processes under anaerobic conditions, either ambient or enhanced. In contrast, POL contaminants are derived from naturally-occurring hydrocarbons that are lighter than water and are degradable under a wide spectrum of geochemical conditions ranging from highly aerobic to highly anaerobic. Thus, as compared to POL contamination, the *in-situ* treatment of chlorinated solvents often requires a more sophisticated approach to effective delivery of remedial reagents and to manipulate and control subsurface geochemical conditions.

To address this problem, the Air Force Center for Engineering and the Environment (AFCEE) in Brooks City-Base, Texas, undertook several initiatives. First, AFCEE and its technology partners developed and demonstrated new remediation technologies at Air Force bases nationwide. Second, AFCEE transferred the technologies to the bases, resulting in implementation and on-site evaluation of many innovative cleanup approaches. And finally, based on this experience, AFCEE supported the development of several documents and tools to assist environmental managers with their decision-making process when faced with subsurface impacts from chlorinated solvents at their base.

The first document, titled "*Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents*" (*i.e.*, the Principles and Practices document) was published in cooperation with the Naval Facilities Engineering Service Center (NFESC) and the Environmental Security Technology Certification Program (ESTCP) in August 2004 (AFCEE *et al*., 2004). The Principles and Practices document describes the scientific basis of enhanced anaerobic bioremediation of chlorinated solvents and summarizes relevant site selection, design, and performance criteria for various engineered approaches to stimulate and enhance the *in-situ* biodegradation of chlorinated solvents in groundwater. It is not intended to be a protocol to implement enhanced *in situ* bioremediation, but rather an overview of the technology.

The document in hand, titled "*Protocol for In Situ Bioremediation of Chlorinated Solvents using Edible Oil*" (*i.e.*, the Edible Oil Protocol), follows directly from the content of the Principles and Practices document. As described in the Principles and Practices document, there are a variety of methods for addition of an organic substrate to the subsurface to stimulate *in situ* anaerobic bioremediation. In all of these processes, the organic substrate is fermented to hydrogen and low molecular weight organic acids (*i.e.*, electron donors) to support anaerobic reductive dechlorination as the primary process for degrading chlorinated solvents in groundwater. This particular protocol focuses on the application of pure edible oil and edible oil emulsions to provide a long-lasting organic substrate for enhanced *in situ* anaerobic bioremediation of chlorinated solvents.

1.2 INTENDED USE OF THIS DOCUMENT

The addition of pure liquid edible oil and edible oil emulsions, referred to as the edible oil process, has been used to stimulate the *in situ* anaerobic biodegradation of chlorinated solvents and related contaminants at commercial, industrial and military sites throughout the United States. The protocol presented in this document is intended to assist base managers and project engineers in 1) determining if the edible oil process is appropriate for their site; 2) designing and implementing an edible oil engineered system; and 3) evaluating and optimizing remedial performance over time. This protocol also provides background information on the development and scientific basis of this technology.

The intended audience for this document is DoD personnel and their contractors, scientists, consultants, regulatory personnel, and others charged with remediating groundwater contaminated with chlorinated compounds and other contaminants that are susceptible to anaerobic degradation processes. This protocol is intended for use within the established regulatory framework appropriate for selection of a remedy at a particular hazardous waste site.

It is not the intent of this course to prescribe a course of action, including site characterization, in support of all possible remedial technologies. Instead, this protocol is another remediation tool similar to other AFCEE Technology Transfer protocols for natural attenuation of chlorinated solvents (developed with and published by the United States Environmental Protection Agency [USEPA], 1998), natural attenuation of fuel hydrocarbons (Wiedemeier *et al*., 1995), bioventing (Hinchee *et al*., 1992) or free-product recovery protocol (AFCEE, 1995). This protocol allows practitioners to gain an in-depth understanding of the edible oil process, decide how best to apply it, and then design and implement the technology for site remediation. The protocol illustrates how the hydrogeological, biogeochemical, and contaminant data collected as part of the site characterization are critical to the feasibility assessment and design of an edible oil application.

This document describes 1) development of the edible oil process and its effectiveness for stimulating biodegradation of chlorinated solvents, 2) site conditions that should be evaluated when considering the use of the edible oil process, 3) various configurations that can be applied, 4) hydrogeological and engineering considerations for developing an injection layout, 5) methods for applying the substrate to the subsurface, 6) methods to measure and evaluate multiple lines of contaminant, biogeochemical, and microbial parameters, and 7) methods to evaluate and optimize remedial performance over time. Some information in this protocol overlaps material discussed in greater detail in the Principles and Practices document. Wherever possible, extensive repetition has been minimized by referring to the Principles and Practices document. However, sufficient information is retained so that the reader of this protocol can understand the background of the edible oil process without reading the Principles and Practices document.

Readers of this protocol should also note that the procedures and applications of edible oil for the anaerobic bioremediation of chlorinated solvents are applicable to numerous other contaminants subject to anaerobic biodegradation processes such as nitrates, perchlorate, and energetics (*e.g.*, hexahydro-1,3,5-trinitro-1,3,5-triazine [RDX] or trinitrotoluene [TNT]). In addition, AFCEE is investigating the natural and enhanced biogeochemical reduction of chlorinated solvents as an extension of its "*Aqueous Mineral Intrinsic Bioremediation Assessment (AMIBA) Protoco*l" (AFCEE, 2000a). AFCEE field applications have demonstrated the ability of edible oil, lactate, and organic mulch to promote the formation of reactive iron sulfide minerals and the resultant abiotic dechlorination of chlorinated solvents.

1.3 FOLLOWING THE EDIBLE OIL PROCESS

The edible oil process can be a powerful tool for remediating groundwater contaminated with chlorinated solvents in groundwater. Section 1 of this course provides an overview of the edible oil process. Subsequent sections provide greater detail into the scientific and engineering background of the technology. These sections (listed below) should be used to gain more in-depth understanding of one or more areas of particular interest to the reader.

- **Section 2** provides procedures for preliminary screening and determining the suitability of a site for the edible oil process.
- **Section 3** describes the steps required for planning and implementation of an edible oil pilot test.
- **Section 4** describes planning and detailed design of a full-scale edible oil remedy.
- **Section 5** describes the field methods used to implement an edible oil application.
- **Section 6** discusses data evaluation and reporting.
- **Section 7** presents the references used in preparing this document.

- **Appendix A** contains a list of key project members in the development of this protocol document.
- **Appendix B** contains a summary table listing DoD edible oil applications that have been implemented as of the publication of this document.
- **Appendix C** contains a list of vendors that provide edible oil substrates or products closely related to edible oil.
- **Appendix D** discusses the impact of edible oil on contaminant transport and fate. It includes information on the chemical, physical, and biological properties of edible oil and oil-in-water emulsions. In addition, Appendix D presents information on the injection and distribution of edible oil in the subsurface including background information on the subsurface transport of pure edible oil and oil-in-water emulsions.
- **Appendix E** contains additional background information on the microbiology of reductive dechlorination.
- **Appendix F** presents analytical protocols useful for preparing a sampling and analysis plan.
- **Appendix G** includes an example spreadsheet that may be used to determine the amount of edible oil to use for a given application.
- **Appendix H** provides case studies with data, techniques, and performance results from two AFCEE Technology Transfer field test sites for chlorinated ethenes, and one application for chlorinated ethenes at an industrial site.

A decision to select enhanced *in situ* bioremediation as a remedial alternative should be site-specific within the context of engineering feasibility and cost-effectiveness in relation to other technologies. Project personnel should conduct a preliminary screening (**Section 2**) to evaluate whether this approach is appropriate for their site. Once this screening is complete, a preliminary conceptual design should be developed for the site and compared against other alternatives. If appropriate, a pilot test (**Section 3**) may be conducted to evaluate the performance of the edible oil process at the site. Pilot test monitoring results should then be evaluated to determine if performance is acceptable and to and to determine the optimal approach for a full-scale application (**Section 4**). Methods to implement the edible oil process are described in **Section 5**. **Figure 1.1** shows a road map that site managers can follow to develop remedial designs and to implement the edible oil process at their site.

1.4 DEFINING REMEDIAL OBJECTIVES

The edible oil process is a flexible technology that can be used in a variety of different configurations to treat contaminated aquifers, including source area treatment and bio-barriers. Potential benefits of this process include reduced source longevity, reduced contaminant mass discharge, enhancement of ongoing natural attenuation, and/or control of dissolved plume migration. The desired benefits of using this technology will influence the injection system layout and the method used to inject the oil.

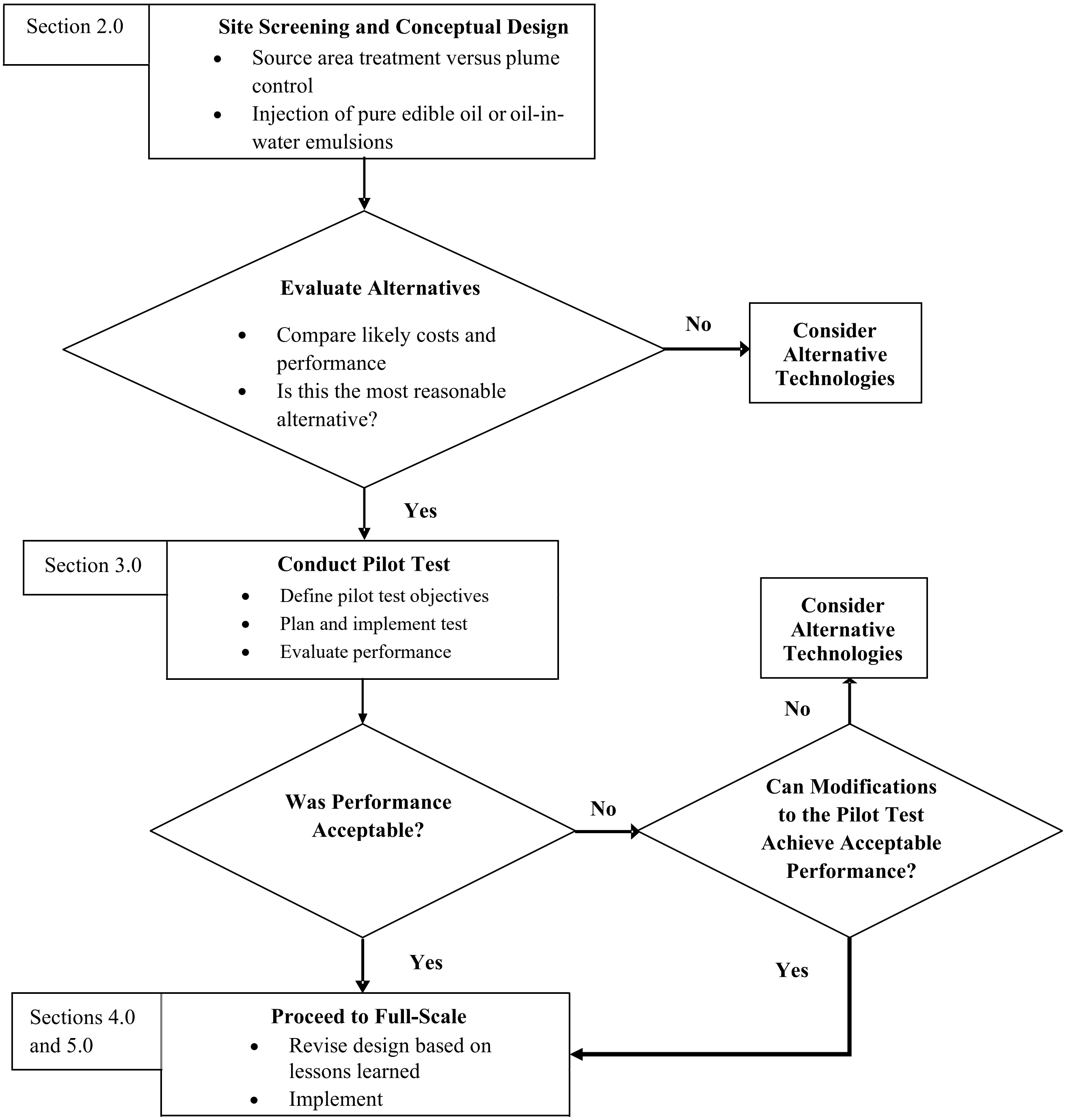

Figure 1.1 Road Map for Implementation of the Edible Oil Process

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