Strategies for Monitoring the Performance of DNAPL Source Zone Remedies

August 2004

Prepared by
The Interstate Technology & Regulatory Council
Dense Nonaqueous-Phase Liquids Team

EXECUTIVE SUMMARY

Introduction

The environmental problems associated with DNAPLs (dense, nonaqueous-phase liquids) are well known—they can be extremely difficult to locate in the subsurface; small amounts of DNAPL can contaminate large volumes of an aquifer; they are not amenable to conventional groundwater extraction technologies (e.g., "pump and treat"); restoration of DNAPL sites to drinking water standards or maximum contaminant levels is considered unattainable. These problems are the foundation of many technical and regulatory barriers to DNAPL cleanup attempts. Since 1999, the DNAPLs Team has been trying to ease some of these barriers by informing the regulatory community of developments in innovative approaches to DNAPL source zone characterization and remediation. To this end we have written four guidance documents that provide an overview of the problem and guide the reader through the process of site characterization, technology selection, and implementation. This, our fifth document, provides guidance on assessing the performance of DNAPL source zones remedies.

DNAPLs can be treated by implementing one of several or a combination of aggressive in situ technologies, including surfactant/cosolvent flushing, in situ chemical oxidation, and in situ thermal remediation. Less aggressive technologies for treating DNAPLs, such as bioremediation, are typically designed to address the dissolved plume but show some promise in treating sources. Although the long-term containment option will likely remain a viable remedial strategy at most complex DNAPL sites, the advent of aggressive source zone treatment technologies has caused a reevaluation of the conventional wisdom that significant source removal is "technically impracticable" at all DNAPL sites. Despite the ever-increasing number of field applications of DNAPL removal technologies, many unanswered questions remain regarding the effectiveness of these technologies and how best to measure their performance with respect to site-specific remedial objectives. Furthermore, there is no consensus on the most appropriate set of performance metrics with which to evaluate the benefits of mass removal from the DNAPL source zone, particularly the short and long-term impacts on the rate of contaminant mass discharge or flux emanating from the source zone.

This document is intended for regulators and others interested in learning about approaches to performance monitoring while implementing various in situ technologies for the treatment of DNAPLs. In this document, we present a number of ways in which the success or failure in treating a DNAPL source zone has been measured. Because the vast majority of experience in DNAPL source zone remediation has been in unconsolidated geologies, such as sands and silts, many of the conclusions, recommendations, and lessons learned presented in this document do not necessarily transfer to performance assessment in fractured bedrock, karst, or other consolidated geologies.

What Is Performance Assessment?

The task of evaluating the efficiency and effectiveness of a remedial action in meeting the remediation and operational objectives established for the project is termed "performance assessment." System effectiveness is the ability of the system to achieve remediation goals at a given site, while "efficiency" refers to the optimization of time, energy, and cost toward the achievement of effectiveness. The EPA defines performance monitoring as "the periodic measurement of physical and/or chemical parameters to evaluate whether a remedy is performing as expected." In terms of DNAPL source zone treatment, performance assessment involves the collection and evaluation of conditions following treatment and the comparison of that information to pretreatment or baseline conditions.

Measuring performance can be a difficult undertaking, particularly when clear, measurable goals or metrics are not specified. According to the National Research Council (NRC), verifying the effectiveness of a remedial action typically involves quantifying reductions in "contaminant mass, concentration, mobility, and/or toxicity" following implementation and evaluating whether the performance objectives established for the project were achieved. Consistent with the NRC's definition of technical performance, we consider effectiveness to be the degree to which a technology application achieves risk reduction goals by reducing contaminant mass, concentration, mobility, and/or toxicity while preventing the uncontrolled mobilization or further spread of contaminants.

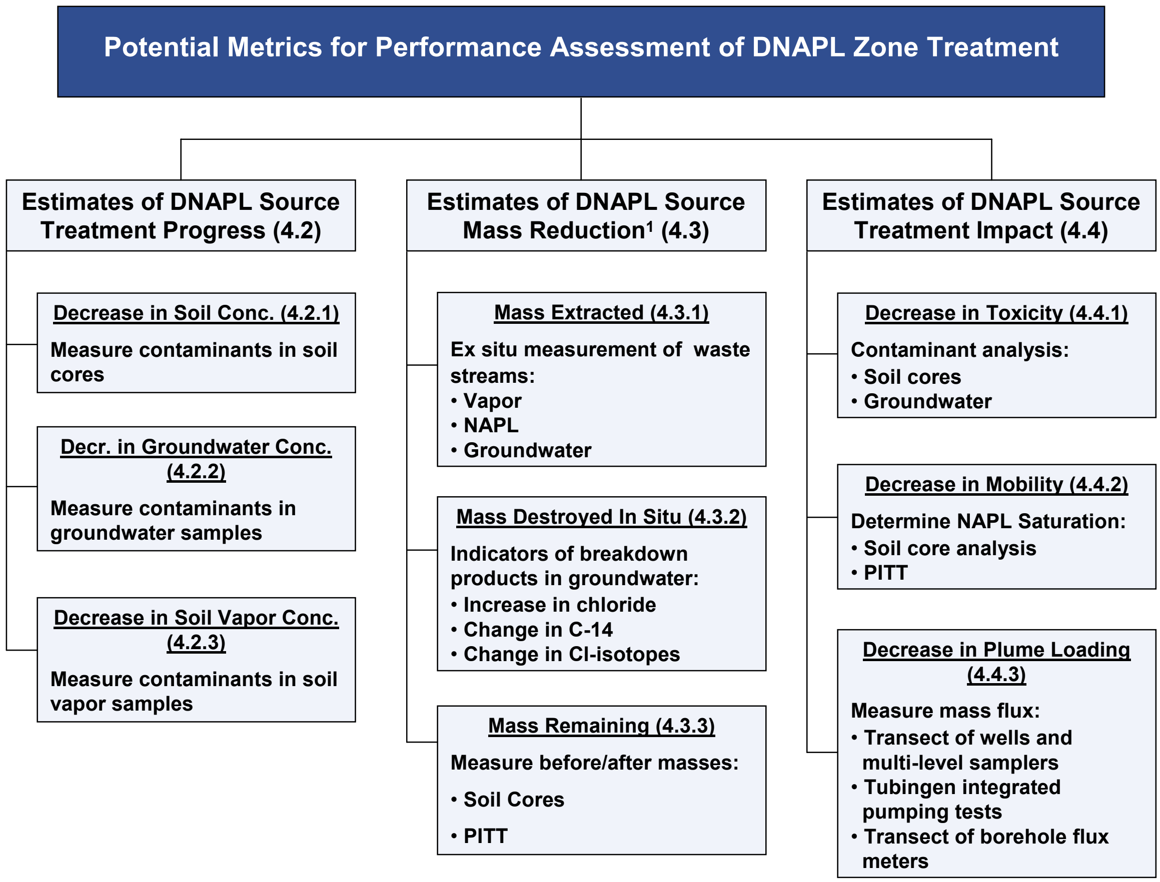
Establishing Performance Goals

Goals for a DNAPL source zone cleanup generally fall into three categories: short-term, intermediate, and long-term performance goals. Short-term goals focus on controlling DNAPL mobility and mitigating the potential for further contaminant migration. Long-term goals typically target the achievement of compliance with regulatory criteria applicable to contaminated media at the site, such as restoration of groundwater to drinking water standards. Intermediate performance goals are appropriate when guiding cleanup at a DNAPL source zone, where complete removal of the source in one aggressive remedial effort is typically not feasible yet the levels of contamination left behind are unacceptable. Examples of intermediate performance goals might include depleting the source sufficiently to allow for natural attenuation, preventing the migration of contaminated fluids beyond the treatment zone, reducing dissolved-phased concentrations outside the source zone, or reducing the mass discharge rate or flux emanating from the source. According to EPA, a "phased approach" to site cleanup generally accelerates risk reduction and achievement of long-term goals. For each phase, performance goals should be selected to guide the interim remedial action. Selection of an appropriate set of performance goals is discussed in Section 3 of the document.

Categories of Performance Metrics

Depending on the goals of the remedial project, different field parameters or metrics are measured and used to confirm attainment of those objectives or to evaluate progress. Typically, this process involves collecting groundwater or soil samples before and after treatment and comparing contaminant concentration levels. Applying these metrics and designing a performance monitoring program are discussed in Section 4. Although concentration data are useful, there are serious deficiencies to relying solely on such point measurements to evaluate the effectiveness of a source zone remedy. Fortunately, there are numerous other metrics for measuring performance which are discussed in terms of their utility in estimating source treatment progress, source mass reduction, and source treatment impact. Each metric has its advantages and limitations; no one metric is appropriate for all cases. To offset the limitations and uncertainties in relying on any one measure of success, it is suggested that several lines of evidence be used.

Figure 4-1 in the document (reproduced below) illustrates the various categories of performance metrics for assessment of DNAPL source zone treatment and directs the reader to the applicable section of the document where further details and references can be found.



Performance Monitoring Tools

Although standard protocols for measuring the performance of DNAPL source zone treatment technologies have not been established, a variety of assessment tools have been applied to making performance measurements and are the focus of this document. Groundwater sampling, soil core analysis, and partitioning tracer tests are just a few examples of methods currently being used to evaluate the effectiveness of source treatment. These tools yield information about changes in the concentration of contaminants in groundwater or the amount of mass remaining in the source zone following treatment, but they do not provide direct evaluation of the flux of contaminants being released from the source following treatment. Attempts to determine this latter property have led to a new type of performance measure—contaminant mass flux—that currently is the subject of intensive research, development, and field evaluation.

Technology-Specific Monitoring Considerations

Ideally, the effectiveness of any one DNAPL remediation technology should be evaluated using the same performance goals and metrics as other technologies being considered so their relative performance and benefits can be evaluated independent of the technology. Methods for monitoring system efficiency, however, must address technology-specific considerations. For instance, the effectiveness of a thermal technology like steam injection should be judged based on technology-independent criteria such as how much the source strength was depleted or how much contaminant mass was removed from the ground, but the program for monitoring system efficiency must be technology specific.

Section 5 provides a brief description of some technologies employed for DNAPL source zone remediation and offers some suggestions on the types of monitoring that may be appropriate for each technology. The information in Section 5 is intended as "suggested monitoring requirements" for planning purposes—actual monitoring varies depending on site-specific conditions and the technology being deployed.

Case Studies

Appendix B is intended to highlight the various approaches to performance assessment being used to measure success at some recent DNAPL source zone treatment projects. It contains several succinct case studies that cover remedial goals and objectives, performance monitoring and verification, and lessons learned. The reader is encouraged to contact the technical or regulatory person listed at the end of each case study for more detailed information.

Summary

Currently, there is no clear consensus based on objective guidelines as to the best way to evaluate treatment performance and balance performance objectives against site-specific stratigraphy, measurement uncertainties, regulatory acceptance, and cost. At present, the best approach is for site owners, regulators, and stakeholders to understand the options available and the benefits and limitations of each so that informed decisions can be made. The primary purpose of this document is to provide that knowledge base.

It is essential to recognize that development of effective DNAPL source treatment assessment tools is a work in progress. Every assessment tool discussed in this document has both strengths and weaknesses that must be considered when selecting a performance assessment strategy for a site. There is a significant amount of research currently under way at the federal level, much of it funded through the Department of Defense's Strategic Environmental Research and Development Program, which is focused on developing assessment tools for measuring the impacts of DNAPL source zone treatment that cut across technologies and allow objective comparisons of performance and cost among remedial alternatives to be made.