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Project Summary

DNAPL Site Evaluation

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Dense nonaqueous-phase liquids (DNAPLs), especially chlorinated solvents, are among the most prevalent subsurface contaminants identified in ground-water supplies and at waste disposal sites. There are several site-characterization issues specific to DNAPL sites including (a) the risk of inducing DNAPL migration by drilling, pumping or other field activities; (b) the use of special sampling and measurement methods to assess DNAPL presence and migration potential; and (c) development of a cost-effective characterization strategy that accounts for DNAPL chemical transport processes, the risk of inducing DNAPL movement during field work, and the data required to select and implement a realistic remedy. This manual provides information to address these issues and describes and evaluates activities that can be used to determine the presence, fate, and transport of subsurface DNAPL contamination. The manual discusses the scope of the DNAPL problem, the properties of DNAPLs and subsurface media affecting DNAPL transport and fate, objectives and strategies for DNAPL site characterization, invasive and non-invasive methods of site characterization, and laboratory methods for characterizing fluid and media properties. The manual concludes with several case histories illustrating problems specific to DNAPL sites and priority research needs for improving DNAPL site characterization.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at the back).

Introduction

Dense nonaqueous phase liquids (DNAPLs), such as some chlorinated solvents, creosote-based wood-treating oils, coal tar wastes, and pesticides, are immiscible fluids with a density greater than water. As a result of widespread production, transportation, utilization, and disposal of hazardous DNAPLs, particularly since 1940, there are numerous DNAPL contamination sites in North America and Europe. The potential for serious long-term contamination of groundwater by some DNAPL chemicals at many sites is high due to their toxicity, limited solubility (but much higher than drinking water limits), and significant migration potential in soil gas, groundwater, and/or as a separate phase (Figure 1). DNAPL chemicals, especially chlorinated solvents, are among the most prevalent ground-water contaminants identified in ground-water supplies and at waste disposal sites.

The subsurface movement of DNAPL is controlled substantially by the nature of the release, the DNAPL density, interfacial tension, and viscosity, porous media capillary properties, and, usually to a lesser extent, hydraulic forces. Below the water table, non-wetting DNAPL migrates preferentially through permeable pathways such as soil and rock fractures, root holes, and sand layers that provide relatively little capillary resistance to flow. Visual detection of DNAPL in soil and ground-water samples may be difficult where the DNAPL is transparent, present in low saturation, or distributed heterogeneously. These factors confound characterization of the movement and distribution of DNAPL even at sites with relatively homogenous soil and a known, uniform DNAPL source. The difficulty of site characterization is further compounded by fractured bedrock, heterogeneous strata, multiple DNAPL mixtures and releases, etc.

Obtaining a detailed delineation of subsurface DNAPL, therefore, can be very costly and may be impractical using conventional site investigation techniques. Furthermore, the risk of causing DNAPL migration by drilling or other actions may be substantial and should be considered prior to commencing field work. Although DNAPL can greatly complicate site char-

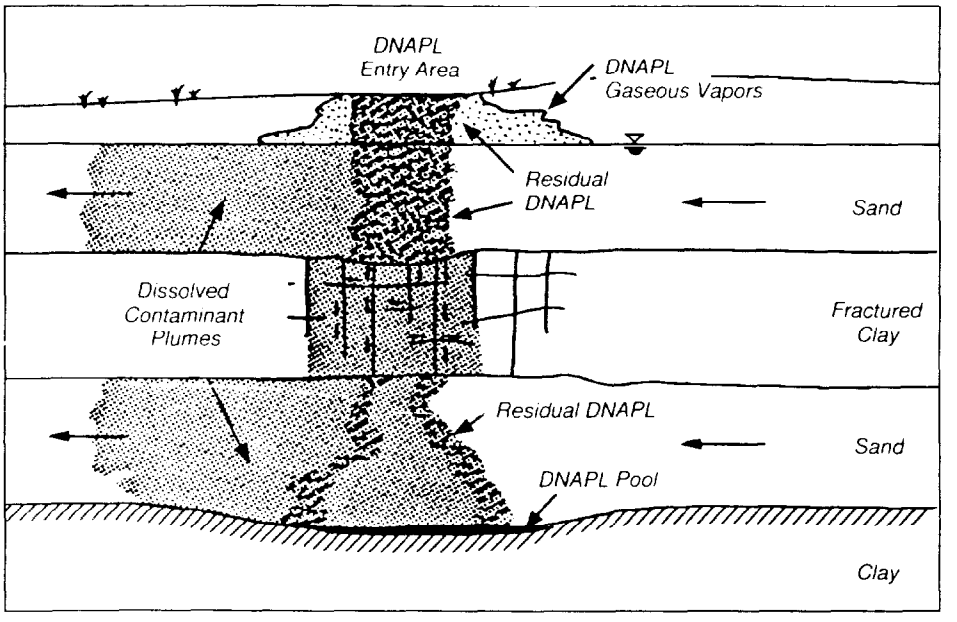

Figure 1. DNAPL chemicals are distributed in several phases: dissolved in groundwater, adsorbed to soils, volatilized in soil gas, and as residual and mobile immiscible fluids (modified from Huling and Weaver, 1991; WCGR, 1991).

acterization, failure to adequately define its presence, fate, and transport can result in misguided investigation and remedial efforts. Large savings and environmental benefits can be realized by conducting studies and implementing remedies in a cost-effective manner. Cost-effective DNAPL site management requires an understanding of DNAPL properties and migration processes, and of the methods available to investigate and interpret the transport and fate of DNAPL in the subsurface.

Lighter-than-water NAPLs (LNAPLs) which do not sink through the saturated zone, such as petroleum products, are also present and cause ground-water contamination at numerous sites. Although many of the same principles and concerns apply at both LNAPL and DNAPL sites, LNAPL site characterization is not specifically addressed in this document.

Objectives

This manual is designed to guide investigators involved in the planning and implementation of characterization studies at sites suspected of having subsurface contamination by DNAPLs. Specifically, the document is intended to

- Summarize the current state of knowledge for characterizing DNAPL-contaminated sites;
- Develop a framework for planning and implementing DNAPL site characterization activities;
- Provide a detailed discussion of the types of data, tools, and methods that can be used to identify, characterize, and monitor DNAPL sites, and an analysis of their utility, limitations, risks, availability, and cost;
- Identify and illustrate methods, including the development of conceptual models, to interpret contaminant fate and transport at DNAPL sites based on the data collected;
- Assess new and developing site characterization methodologies that may be valuable and identify additional research needs; and,
- Review the scope of the DNAPL contamination problem, the properties of DNAPLs and media, and DNAPL transport processes to provide context for understanding DNAPL site characterization.

The primary goal of this manual is to help site managers minimize the risks and maximize the cost-effectiveness of site investigation/remediation by providing the best information available to describe and evaluate activities that can be used to determine the presence, fate, and transport of subsurface DNAPL contamination.

Outlook

Remedial activities at a contaminated site need to account for the possible presence of DNAPL. If remediation is implemented at a DNAPL site, yet does not consider the DNAPL, the remedy will underestimate the time and effort required to achieve remediation goals. Thus, adequate site characterization is required to understand contaminant behavior and to make remedial decisions.

There is no practical cookbook approach to DNAPL site investigation or data analysis. Each site presents variations of contaminant transport conditions and issues. Although there are no certain answers to many of the DNAPL site evaluation issues, this manual provides a framework for their evaluation.

Conclusions and Recommendations

As awareness of DNAPL contamination increased in the 1980s, research was conducted to better understand the behavior of DNAPL in the subsurface. Much of this research was an expansion of the investigations performed by Schwille (1988). DNAPL research is currently focusing on remediation (National Center for Ground Water Research, 1992). Throughout this progression of DNAPL research, relatively little effort has been expended on developing new site characterization tools or methods for DNAPL sites.

What has generally occurred at DNAPL sites is that tools and techniques utilized at contamination sites in general have been applied with varying degrees of success. Additionally, some new tools and methods have been developed and others have been adapted to better satisfy the requirements of a DNAPL site investigation. Site characterization strategies have also evolved to more closely match the special concerns and risks posed by DNAPL presence.

Despite substantial progress, additional research on DNAPL site characterization tools and methods is warranted utilizing a variety of venues: laboratories, controlled field sites with emplaced DNAPL, and uncontrolled contamination sites. Additional research and technology transfer efforts should focus on

1. Well drilling techniques to demonstrate the isolation of DNAPL zones through the use of double-cased wells or other techniques;
2. Well and boring abandonment techniques to demonstrate the efficacy of different grouting mixtures and

methods to prevent preferential vertical fluid migration;

3. The utility of surface and borehole geophysical methods to better characterize DNAPL presence and distribution, and stratigraphic controls on DNAPL movement;
4. The utility of soil gas surveying to better characterize NAPL presence and related chemical migration;
5. Methods to determine *in-situ* NAPL saturation (e.g., borehole geophysics, simple quantitative sample analysis);
6. Techniques to determine field-scale constitutive relationships between saturation, capillary pressure, and relative permeability;
7. Practical field or laboratory techniques to delineate mobile DNAPL from DNAPL in stratigraphic traps from DNAPL at residual saturation;
8. Additional cost-effective methods to determine NAPL presence, composition, and properties;
9. Techniques to better define site stratigraphy, heterogeneity, and fracture distributions;
10. The long-term capacity of capillary barriers (e.g., clayey soil layers) to prevent DNAPL movement, including methods for determining barrier continuity and time-dependent aspects of DNAPL-mineral structure and wettability interactions;
11. Identifying the limited characterization efforts required to determine and implement appropriate remedial measures at DNAPL contamination sites;
12. Further optimization of characterization strategies given different source, hydrogeologic, risk and remedy considerations; and,
13. Refinement of pilot test designs, protocols, and monitoring requirements to determine the feasibility and/or technical impracticality of alternative remedial measures.

References

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The complete report, entitled "DNAPL Site Evaluation," (Order No. PB93-150217; Cost: $44.50, subject to change), will be available only from:
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