Guidance to Site Managers at Army Installations:

Groundwater Evaluation and Development of Remediation Strategies Where Aquifer Restoration May Be Technically Impracticable

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1.0 INTRODUCTION AND OVERVIEW

1.1 INTRODUCTION

Federal, State and local environmental protection and public health laws require that the Army reduce or eliminate current or future environmental and health impacts caused by past defense facilities operations. In response, the Army has implemented an environmental restoration program to address the cleanup or restoration of environmental media including groundwater contaminated with hazardous and toxic materials from past military activities. The Army is responsible for a number of contaminated facilities with histories of prolonged releases and these sites are distributed throughout a wide array of geologic terrains.

At most of these sites, the Army has already implemented remedial actions designed to meet agreed upon cleanup goals for contaminated soil or groundwater. At other sites, remedial actions are either under evaluation or are in the implementation stage. At all sites where groundwater has been directly impacted, or is likely to be impacted in the future, achieving cleanup goals presents a number of difficult challenges. Sites with limited groundwater impacts may achieve stringent cleanup goals (such as drinking water standards) within a reasonable timeframe. Sites that are impacted by chemicals that degrade readily (such as some petroleum hydrocarbon based compounds) may also achieve cleanup goals. At many other sites, however, meeting these goals may not be technically practicable with either existing or new and innovative technologies for groundwater remediation. The term "technical impracticability" implies that while cleanup may be possible, it is highly impractical due to the associated cost and/or timeframe required for remediation. The definition of technical impracticability is discussed further in **Section 2**. Contaminant properties, the amount and distribution of contaminants released and hydrogeologic conditions, among other factors, can combine to render groundwater restoration impracticable. Under these conditions, sites must consider long-term institutional controls in conjunction with appropriate technologies to ensure long-term protection of human health and the environment.

This predicament has concerned many stakeholders, including regulatory agencies and public entities such as Restoration Advisory Boards established at many Army bases to provide stakeholder oversight of the site restoration program. The limitations of long-term institutional controls are recognized, particularly at Army sites expected to be converted to non-military uses in the near future. One option is to apply more effective technologies, if available, thereby overcoming the apparent infeasibility of aquifer restoration. Numerous technical innovations have been achieved over the past ten years in groundwater remediation, and the number of technical tools available has increased substantially beyond the traditional use of groundwater extraction and treatment (i.e., “pump-and-treat”). However, even with the application of innovative technologies, groundwater restoration at numerous sites may still be technically impracticable. Thus, the Army is faced with the difficult task of determining whether the application of new technologies can substantially reduce the risks to human health and the environment compared to pump-and-treat or other containment systems. Where it appears that such technologies can reduce risk, mainly by accelerating the time to cleanup sites, it is still uncertain whether the cost and the risk of failure of new technologies can be reconciled with the costs and uncertainties associated with long-term institutional controls.

This document has been prepared to address this predicament by providing information and guidance to base environmental coordinators, site project managers and other decision makers within the Army for the purposes of improving the decision making process at sites with contaminated groundwater. The document provides background information on the limitations to groundwater cleanup in highly complex and heterogeneous aquifer systems that are impacted by non-aqueous phase liquids (NAPL). A decision framework is proposed consistent with regulatory guidance on the issue of technical impracticability to assist the site manager or other designated person in selecting a cost effective groundwater remedial strategy that can be accepted by all stakeholders. The primary objective of the document is to ensure that the Army, while fulfilling all its legal obligations at impacted sites, achieves an acceptable balance between expenditures, based on lifecycle costing, and reduction in risks to human health and the environment.

1.2 GOALS OF THE ARMY ENVIRONMENTAL RESTORATION PROGRAM

The goals of the Army environmental restoration program (“program”) are consistent with regulatory guidance arising from the main federal statutes, namely the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA). One of the key documents driving the program is the *National Oil and Hazardous Substances Pollution Contingency Plan* (NCP). For contaminated groundwater sites, site response objectives under CERCLA are outlined in the *Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Groundwater at CERCLA Sites* (1996). Site response objectives for contaminated groundwater sites under RCRA generally follow the Advanced Notice of Proposed Rulemaking published by the USEPA in the Federal Register (61 FR 19432 May 1, 1996), but never promulgated by the USEPA. The Army must also assure that public funds invested in environmental restoration are managed responsibly. Therefore, remedial actions designed to achieve aquifer restoration must have a reasonable expectation of successfully meeting cleanup goals.

1.3 DOCUMENT BACKGROUND AND OBJECTIVE

The Army Environmental Center convened a panel of experts (Edward Bouwer, Gaynor Dawson, Thomas Gillespie, Michael Kavanaugh and David McWhorter) to assist in the development of this document in an effort to ensure that the material presented within is technically defensible. This document was revised and edited by the Army Environmental Center and Malcolm Pirnie, Inc. The overall objective of this document is to provide environmental restoration project managers with the following:

- An overview of EPA’s guidance for site response actions to address contaminated groundwater;
- An overview of the potential impacts of complex hydrogeology and contaminant properties and distribution on groundwater restoration efforts;
- A decision making framework to assist in evaluating alternative site response actions to meet program objectives;
- A process for selecting the appropriate strategy for managing contaminated groundwater at sites where aquifer restoration may be technically impracticable.

2.0 REGULATORY REQUIREMENTS FOR GROUNDWATER REMEDIATION

2.1 PROGRAMMATIC EXPECTATIONS

Site response actions are based on programmatic expectations as stated in the *National Oil and Hazardous Substances Pollution Contingency Plan* (NCP). The NCP (55 FR 1830, March 8, 1990) states the following:

> *"EPA expects to return usable groundwater to their beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site. When restoration of groundwater to beneficial uses is not practicable, EPA expects to prevent further migration of the plume, prevent exposure to the contaminated groundwater, and evaluate further risk reduction."*

EPA's *Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Groundwater at CERCLA Sites* (EPA, 1996) outlines the following objectives for site response actions, which are generally applicable for all sites with contaminated groundwater:

- Prevent exposure to contaminated groundwater, above acceptable risk levels;
- Prevent or minimize further migration of the contaminant plume (plume containment);
- Prevent or minimize further migration of contaminants from source materials to groundwater (source control);
- Return groundwaters to their expected beneficial uses wherever practicable (aquifer restoration).

2.2 CERCLA REQUIREMENTS

2.2.1 Setting Cleanup Standards

The NCP requires that the selection of a CERCLA remedy be based in part on two threshold criteria: (1) overall protection of human health and the environment and (2) compliance with applicable or relevant and appropriate requirements (ARARs). Where an aquifer is a current or potential future source of drinking water, relevant ARARs typically include either Maximum Contaminant Levels (MCLs) or Maximum Contaminant Level Goals (MCLGs) for regulated chemicals, which are promulgated under the Safe Drinking Water Act or more stringent state standards. The restoration of an aquifer to its highest beneficial use is accomplished when groundwater ARARs or other risk-based groundwater concentrations are achieved.

For CERCLA sites, there are two possible approaches to consider when MCLs or other health-based standards may not be appropriate. These are alternate concentration limits (ACLs) and ARAR waivers. ACLs are risk-based concentrations that will not pose a substantial hazard to human health or environmental receptors (given exposure pathways and other factors). An ACL replaces an ARAR as the new regulatory-approved cleanup concentration, as opposed to waiving the ARAR entirely. ARAR waivers can be granted based on six factors, as discussed below, but the most widely used ARAR waiver is based on a technical impracticability (TI) evaluation. EPA guidance documents have established the conditions under which each option should be considered.

2.2.2 Alternate Concentration Limits

Under CERCLA Section 121 (d) (2) (B), ACLs may be considered as part of response actions in place of ARAR cleanup levels (e.g., MCLs). In order to consider ACLs, several criteria must be met including the following:

- Contaminated groundwater must discharge to surface water;
- Such groundwater discharge does not lead to "statistically significant" increases of contaminants in the surface water;
- Enforceable measures (i.e., institutional controls) can be implemented to prevent human exposure of the contaminated groundwater at any point between the facility boundary and all known and projected points of entry of such groundwater into surface water.

In general, ACLs may be used where the preceding three conditions are satisfied and where restoration of the groundwater is "deemed not practicable" based on a balancing of the remedy selection criteria defined by the NCP. ACLs have been selected as part of CERCLA response actions in three general scenarios as follows:

- As final cleanup standards where groundwater concentrations will remain stable and no human or environmental exposure to the contaminated groundwater is anticipated;
- In conjunction with institutional controls where restoration of groundwater is deemed not practical through the CERCLA response selection process;
- As interim cleanup levels to be met while monitored natural attenuation is being implemented as a remedy.

2.2.3 ARAR Waivers

According to CERCLA and the NCP, once a standard is determined to be “applicable or relevant and appropriate” to a remedial action, it must be attained by the response action. However, a remedial action may be selected that does not attain an ARAR if one of six various criteria are met (40 CFR 300.430(f)(1)(ii)(C)). This requires a decision known as an ARAR waiver. The Army, as the lead agency, has authority to waive an ARAR but is required to publish the findings indicating that the criteria for a waiver have been met together with an explanation as well as appropriate documentation. The USEPA has final approval of the overall remedy selection including ARAR waivers. Technical impracticability is one of six ARAR waivers established under CERCLA and is the most widely used ARAR waiver. The six ARAR waivers are listed below (CERCLA 121(d)(4)):

- Interim Measure Waiver;
- Equivalent Standard of Performance Waiver;
- Greater Risk to Health and the Environment Waiver;
- Technical Impracticability Waiver;
- Inconsistent Application of State Standard Waiver;
- Fund Balancing Waiver.

Since the Technical Impracticability Waiver is the most common ARAR waiver invoked, it is the only type of ARAR Waiver that will be discussed in this document.

2.2.4 Defining Technical Impracticability

The 1980 CERCLA statute incorporated ARAR waivers where "compliance with… requirements is *technically impracticable* from an engineering perspective" (CERCLA, 1980). This became known as a Technical Impracticability (TI) Waiver. In 1993, after much experience with ineffective remedial systems, the EPA clarified the process of granting TI Waivers in a guidance document titled *Guidance for Evaluating the Technical Impracticability of Groundwater Restoration* (EPA, 1993). The guidance document focused on site characteristics contributing to technical impracticability, the evaluation procedure and the review process. Through the year 2000, the EPA has granted TI waivers for over 48 CERCLA sites. An updated guidance document for the pursuit of TI waivers at Army installations is currently in preparation by the Army Environmental Center.

The document provided by the EPA (1993) identifies several factors that increase the difficulty of groundwater restoration. These factors are grouped into two general categories:

- Hydrogeologic factors;
- Contaminant-related factors.

Groundwater restoration has proven to be the most difficult in the complex hydrogeologic environments that are typical of karst, fractured rock and deep alluvial aquifer systems (NRC, 1994). Highly heterogeneous, multi-layer alluvial aquifers also pose significant remediation challenges. The efficacy of any technology to achieve aquifer restoration is also complicated by contaminant-related factors when non-aqueous phase liquids are present. Both light ("LNAPLs") and dense ("DNAPLs") NAPLs can significantly complicate any remedial response option. **Appendix D** summarizes the influence of contaminant properties and hydrogeology on groundwater restoration potential.

If a groundwater site is considered to be a candidate for an ARAR waiver due to technical constraints, the impracticability of attaining the ARAR for each contaminant must be documented and included in the administrative record. According to EPA guidance, (EPA, 1993), one of two criteria needs to be met in order to apply for a technical impracticability (TI) waiver, (1) engineering infeasibility and (2) unreliability. A remedial action can be considered infeasible from an engineering perspective if current engineering methods designed to meet the ARAR cannot be reasonably implemented. An action can be considered unreliable if it is shown that existing remedial alternatives are not likely to be protective in the future. EPA's guidance documents provide a detailed elaboration on the documentation needed to support a TI Waiver. Together, these two criteria define the term "technical impracticability from an engineering perspective."

A TI waiver is, by necessity, both contaminant-specific and location-specific. This means that a TI Waiver is tied to one or more contaminants at one or more specific areas of the site. Impracticability is in part dependent upon the physical and chemical properties of the contaminants of concern because such properties influence the success of remediation. Furthermore, a TI Waiver is granted for a designated portion of the site known as the TI Zone. This zone is spatially defined in three dimensions. Contamination outside of the TI Zone is still subject to ARARs.

It is important to note that the term "technical impracticability from an engineering perspective" refers specifically to an ARAR waiver. The term "not practicable" in the context of ACLs as previously discussed refers to an overall finding of the appropriateness of groundwater restoration based upon evaluating remedial alternatives using applicable CERCLA remedy selection criteria, especially as they pertain to "balancing" and "modifying" criteria (defined in the NCP). Therefore, where an ACL is established, an ARAR waiver is not necessary. Conversely, where an ARAR is waived due to technical impracticability, there is no need to establish CERCLA ACLs.

2.2.5 Stakeholder Roles

CERCLA and RCRA statutory requirements include stakeholder involvement in decision making. Remedial action decisions based on the impracticability of aquifer restoration are likely to generate stakeholder comment. This may then require providing the stakeholders with additional justification to support a TI waiver or an ACL, and sufficient detail on the alternative remedial strategies being proposed as part of the site strategy. Specifically, the assessment of risk from future exposure pathways via all reasonable migration mechanisms should be developed with full consideration of stakeholder preferred future land use or groundwater beneficial use assumptions.

2.3 RCRA REQUIREMENTS

Technical impracticability waivers of cleanup requirements can also be obtained for Resource Conservation and Recovery Act (RCRA) sites. It is one of three ways to waive cleanup standards listed in RCRA Subpart S. The EPA conducts the TI evaluation process using consistent criteria whether the site is being remediated under CERCLA, a RCRA permit or a RCRA corrective action order. ACLs are also applicable to RCRA sites.

2.3.1 Setting Media Cleanup Standards

The Resource Conservation and Recovery Act (RCRA) established procedures for the permitting of hazardous waste transport, storage and disposal facilities (regulated units). Media cleanup standards (MCSs) that must be documented to obtain "clean closure" of a regulated unit are broad cleanup objectives that incorporate specific criteria including cleanup levels, points of compliance and compliance timeframes. Under RCRA, groundwater cleanup levels may be set at background concentrations, at the maximum concentrations established in 40CFR 264.94 or at risk-based concentrations developed from exposure scenarios that are appropriate for current and future land use and aquifer beneficial uses (i.e., ACLs as discussed). If MCSs are exceeded at a regulated unit, permit conditions require the implementation of a RCRA Facility Investigation (RFI), Corrective Measures Study (CMS) and Corrective Action which must restore groundwater to the level required by the permit. Under RCRA, aquifer cleanup levels are under no legal requirement to meet ARARs, only MCSs. However, EPA often requires adherence to ARARs to maintain consistency with CERCLA response actions even though the site is being regulated under RCRA.

A facility can also become responsible for aquifer cleanup requirements by being named in a correction action order (CAO or RCRA 3008(h) order). Risk-based cleanup levels can be developed for either permit-driven or CAO-driven corrective action.

Where aquifer restoration is deemed technically impracticable from an engineering perspective at a RCRA site, a TI determination may be made. Under RCRA, a TI determination indicates that no fixed MCS, point of compliance or compliance timeframe need be established. Alternatively, instead of an MCS, a non-risk-based performance measure could be established. The TI determination must apply to a defined volume of the plume. Areas of the groundwater plume outside the TI zone are subject to remediation to established MCSs.

2.3.2 Alternate Concentration Limits

For regulated units under RCRA, ACLs are one of the three possible approaches for establishing concentration limits for the contaminants of concern (COCs) in groundwater. The use of ACLs is not strictly limited to cases where contamination discharges to surface water, or to cases where groundwater restoration is considered "not practicable," as is the case in CERCLA. An ACL under RCRA must be "protective of human health and the environment", but attenuation is allowed as part of its evaluation in many cases. Therefore, ACLs allow decision-makers to consider natural attenuation as an alternative for groundwater remediation at RCRA sites.

2.3.3 Stakeholder Roles

Under RCRA permit regulations, stakeholder participation in corrective action decisions is required. For corrective action under RCRA CAOs, there is no regulatory requirement for stakeholder participation but the EPA encourages the owner/operator to solicit stakeholder comment through public notices and adherence to identified comment periods. Remedial action decisions based on risk-based cleanup levels other than acknowledged ARARs, as well as decisions involving technical impracticability of aquifer restoration, are likely to generate stakeholder comment. As noted under CERCLA sites, this may require providing the stakeholders with additional justification to support a TI analysis, and sufficient detail on the alternative remedial strategies being proposed.

2.3 REQUIREMENTS UNDER STATE LEADS

A preliminary review of available information indicates that a minimum of seven states (Missouri, Texas, Georgia, North Carolina, Wyoming, Illinois and Mississippi) and the District of Columbia consider technical impracticability in their corrective action policies. In addition, California has a "Containment Zone Policy" that is essentially a technical impracticability policy. **Appendix H** presents brief discussions for each of the seven states, California and the District of Columbia.

2.4 ALTERNATIVE REMEDIAL STRATEGIES

Where the requirement for cleanup levels in the TI zone can be waived, EPA guidance for evaluating technical impracticability (EPA, 1993) provides for the development of alternative remedial strategies consistent with the program objectives listed in the NCP. Alternative remedial strategies should address three types of problems at contaminated groundwater sites: (1) prevention of exposure to contaminated groundwater (exposure control); (2) remediation of contamination sources (source control); and (3) remediation of aqueous contaminant plumes (EPA, 1993). Key components of EPA's alternative remedial strategy approach are summarized below:

- **Exposure control**: The primary objective of any remedial strategy is overall protectiveness. Therefore, where necessary, exposure prevention must be achieved in an alternative remedial strategy. Exposure control may be provided by institutional controls such as deed restrictions and restrictions on water supply well construction or use, as well as provisions for alternative water supplies.

- **Source Control**: EPA (1993) states that sources should be located and treated or removed where feasible and where significant risk reduction could result. Where sources cannot be treated or removed, effective source containment may be critical to the long-term effectiveness and reliability of an alternative groundwater remedy. However, EPA recognizes that under some conditions source containment may also not be feasible. EPA (1996) identifies source control as a remedial action objective primarily because aquifer restoration will not be possible unless further leaching of contaminants to groundwater is controlled.

- **Aqueous Plume Remediation**: In general, EPA expects that aqueous phase plumes be remediated if possible. However, technical constraints in some cases make it infeasible to remediate the plume. In such cases, options for alternative remedial strategies include hydraulic containment of the leading edge of the plume, establishing a less stringent cleanup level that could be accomplished throughout the plume, and natural attenuation.

3.0 IMPACTS OF TECHNICAL LIMITATIONS TO GROUNDWATER RESTORATION PROGRAMS

3.1 TECHNICAL LIMITATIONS TO GROUNDWATER RESTORATION

In general, technical impracticability is driven by the combination of complex hydrogeologic conditions (i.e., heterogeneity) such as fractured bedrock, karst formations or low permeability aquifers, and the presence of problematic contaminants, particularly in the form of dense non-aqueous phase liquids (DNAPLs). A brief review of the technical limitations to groundwater restoration is provided below.

3.1.1 Complex Hydrogeology

Complex hydrogeologic conditions, as they pertain to aquifer restoration, arise from local variations in porosity and hydraulic conductivity that originate from the natural development of geologic systems. Thus, such conditions make predictions of variations in the distribution of hydraulic head, groundwater flow and contaminant transport difficult. Often, most of the water flow (and thus contaminant transport) occurs in a relatively low percentage of the aquifer volume. Thus, a remedial action designed to target permeable pathways may maximize the effectiveness of restoration efforts. However, in most complex hydrogeologic settings, the significant transport zones are often difficult to locate. Complexities also arise from vertical hydraulic connections in multi-aquifer systems, and from the influence of groundwater production wells on the direction and rate of movement of the groundwater and contaminants.

3.1.2 Dense Non-Aqueous Phase Liquids

Dense non-aqueous phase liquids (DNAPLs) are organic liquids that are heavier than water and often have a distinctly different viscosity relative to water. Examples include chlorinated solvents such as tetrachloroethylene (PCE) and trichloroethylene (TCE). These physical properties pose particular problems in site characterization and remediation efforts because mobile DNAPLs can migrate both horizontally and vertically. Vertically migrating DNAPL can pool on low permeability zones and leave behind relatively immobile contaminants trapped in pore spaces or fractures by capillary forces. The long-term dissolution of pooled or residual DNAPL thus can provide a long-term source of aqueous phase contamination.

3.1.3 Other Limitations

Groundwater restoration may often be impracticable due to diffusion-limited or sorption-limited contaminant behavior. Contaminants that reside in low permeability strata or small fractures are difficult to flush by groundwater pumping. In many cases, contaminants enter aquifer materials through the slow process of molecular diffusion. The removal of these contaminants at a rate greater than molecular diffusion requires the use of technologies that can increase the relative permeability of the contaminant or the permeability of the aquifer (e.g., fracturing techniques, application of heat, etc.). Strongly sorbed organic compounds also desorb slowly from the aquifer matrix. Both conditions create long-term sources of aqueous contamination that may not be amenable to removal within a reasonable timeframe (Reynolds and Kueper, 2002).

3.2 PROBLEMS WITH KARST, FRACTURED BEDROCK AND DEEP ALLUVIAL AQUIFERS

In karst, fractured bedrock and deep alluvial aquifers, aquifer restoration remedies are often unsuccessful because the continued sources of groundwater contamination described above are present in inaccessible or difficult to identify locations. Site characteristics that contribute to the technically impracticability of groundwater restoration in deep alluvial, fractured rock and karst aquifers are discussed below.

Deep alluvial aquifers, which can extend hundreds of meters below the surface, commonly comprise multiple geologic strata of widely varying permeabilities and attenuation capacities.

Large plume volumes coupled with heterogeneous conditions (e.g., low permeability lenses, multiple contaminated aquifers), strongly sorbed compounds, and/or DNAPL contamination are the causes of unreasonably long (on the order of decades) restoration timeframes.

Fractured rock environment comprise water-filled fractures separated by blocks of low porosity rock matrix. Groundwater flow and contaminant transport occur predominately through the fractures while contaminant storage can occur predominately in the rock matrix. This heterogeneity makes characterization of contaminant distribution and the effective delivery of remedial fluids difficult. Failure to remove these inaccessible contaminants will result in an ongoing contamination problem because the remediation of contaminants (particularly NAPLs) from the non-fractured rock matrix is often diffusion-limited and will require long remediation timeframes.

Karst environments with open conduit flow pose difficulties in the characterization of contaminant distribution and groundwater flow paths, and in the identification of potential receptors. Contaminants that reach an aquifer in karst regimes can behave differently from those in granular or fractured rock aquifers. Significant contaminant storage can occur in the vadose zone and in the bedrock overburden contact zone (epikarst zone) where some portion of the contamination is periodically flushed into the bedrock aquifer by seasonal or storm-related recharge. Groundwater flow in the bedrock is convergent toward conduits (e.g., subterranean caverns) where rapid flow can occur over large distances toward receptors. Groundwater flow in this regime can be turbulent and therefore not characterized using the basic equations for groundwater flow. In each of these environmental settings, the presence of DNAPLs contributes an additional factor increasing the difficulty of aquifer restoration.

3.3 REPORTED FIELD EXPERIENCE

Groundwater contamination is present at most Superfund and RCRA corrective action sites. Experiences at these sites provide information on the impact of complex hydrogeology and contaminant-related factors on groundwater restoration efforts. The following sections briefly describe experiences at selected Army installations and non-military CERCLA or RCRA sites, based on available information.

3.3.1 Military Sites

A preliminary review by the Army Environmental Center of environmental cleanup efforts at 127 Army installations with a projected cost-to-complete greater than $1,000,000 indicates that aquifer restoration may be technically impracticable at approximately 34 installations (Department of Defense, 1999). Approximately 15 of these installations are located in areas that are known to be underlain by karst aquifers, 11 are located in areas underlain by fractured rock aquifers and at least 4 may be underlain by deep alluvial aquifers. Aquifer restoration at many of these installations is further complicated by the known or expected presence of DNAPLs. Four additional installations, although located in hydrogeologic environments where restoration has been shown to be feasible, may have technical impracticability issues due solely to the presence of DNAPLs.

The total projected cost to complete the Army's environmental restoration program is estimated to be approximately $6 billion (FY98 constant year dollars, as reported in the FY99 Report to Congress). The projected total costs for the 34 installations that may have technical impracticability constraints are approximately $3 billion dollars or 50 percent of the Army's total projected environmental restoration costs.

Information obtained from a review of the FY2000 Installation Action Plans for six Army installations located in areas that are likely to have complex subsurface environments and/or DNAPL source areas provides some insight into the estimated cost of these actions. At one installation, three pump-and-treat systems to remove DNAPL from the subsurface have been built and one additional system is planned for the future. The total cost of these systems is approximately $27,000,000 in constant 1999 dollars. At three of the six installations, pump-and-treat systems are programmed into the cost-to-complete database at a cost of approximately $41,000,000. At four of the six installations, additional source area remediation is planned using hydrogen peroxide injection into the bedrock. The estimated cost for these actions ranges between $9,000,000 and $24,000,000 per installation. One installation prepared a feasibility study in which the estimated cost to remediate DNAPL in a shallow alluvial aquifer was $15,000,000. It is presumed that in these examples, costs refer to constant dollars for a specific year, usually in the 1998 to 2000 timeframe.

These cost estimates, however, are in no way certain. Cost-to-complete estimates at many installations are highly variable and have changed significantly over the last three years. Given the uncertainty associated with locating and remediating contamination at these sites, highly variable cost estimates can be expected. The uncertainties in future cost estimates are likely to continue unless a systematic approach can be developed to manage contamination at these sites.

Given currently available remediation technologies, it is highly likely that aquifer restoration will not be achieved in a reasonable timeframe at many of these sites. It will therefore be necessary for the Army to provide long-term management options at the site and to protect receptors into the future by using alternative water supplies, groundwater use restrictions or wellhead treatment, in addition to active remediation efforts

3.3.2 Non-Military CERCLA and RCRA Sites

The USEPA Office of Solid Waste and Emergency Response (OSWER) recently published a study that examined operating experiences at twenty-eight sites across the United States (mostly CERCLA sites) at which ongoing groundwater cleanup programs are in place or have been completed (EPA, 1999). The twenty-eight case studies represent a range of the types of cleanup efforts typically used at sites with contaminated groundwater. At twenty-one of the sites, pump-and-treat systems were used as the only remediation technology. Geologic complexity and technical impracticability were listed in the study as the factors responsible for controlling the cost and performance of the remediation system. Specifically, the study suggested that source control, hydrogeology and remedial goals were the most critical elements impacting remediation effectiveness. Source control factors are generally those related to the presence of NAPL and the application and timing of source control.

At eighteen of the twenty-eight sites, NAPL was observed or suspected to be a source of groundwater contamination. At several sites, efforts were made to remove or isolate the NAPL to minimize its contact with the groundwater. Such efforts required significant capital expenditures. If NAPL was not removed or isolated, the groundwater remediation efforts were reported to be slower than projected. Examples of difficulties experienced at three of the twenty-eight sites are discussed below.

At the Solvent Recovery Services of New England, Inc. Superfund Site in Connecticut, DNAPL is present in both the overburden and the bedrock aquifers and is a continuous source of a dissolved plume. Despite three years of a groundwater pump-and-treat operation, the complex hydrogeology and DNAPL present at this site have resulted in continued high concentrations of total VOCs in the groundwater. The facility plans to apply for a TI Waiver because of the presence and impact of DNAPL.

At the Solid State Circuits Superfund Site in Missouri, the groundwater system is a leaky artesian system in karst formations with contamination in multiple aquifers thereby requiring groundwater extraction at several depths. Remedial goals that have not been attained include restoration of the aquifer to MCLs (rather than less-stringent cleanup levels), restoration of the entire aquifer (rather than partial cleanup) and the anticipated restoration timeframe.

At the Western Processing Superfund Site in Washington, an aggressive pump-and-treat system consisting of more than two hundred groundwater extraction points pumping approximately 265 gpm was installed to achieve aquifer restoration goals. After approximately seven years of operation, the focus of the remediation strategy was changed from restoration to containment. The pumping activity of the system was then reduced from 265 to 80 gpm. This modification significantly reduced the annual operating costs of the system, but the site will now require long-term management. The expected duration of this remediation system is unknown

3.3.3 NATIONAL REVIEW OF GROUNDWATER CLEANUP STRATEGIES

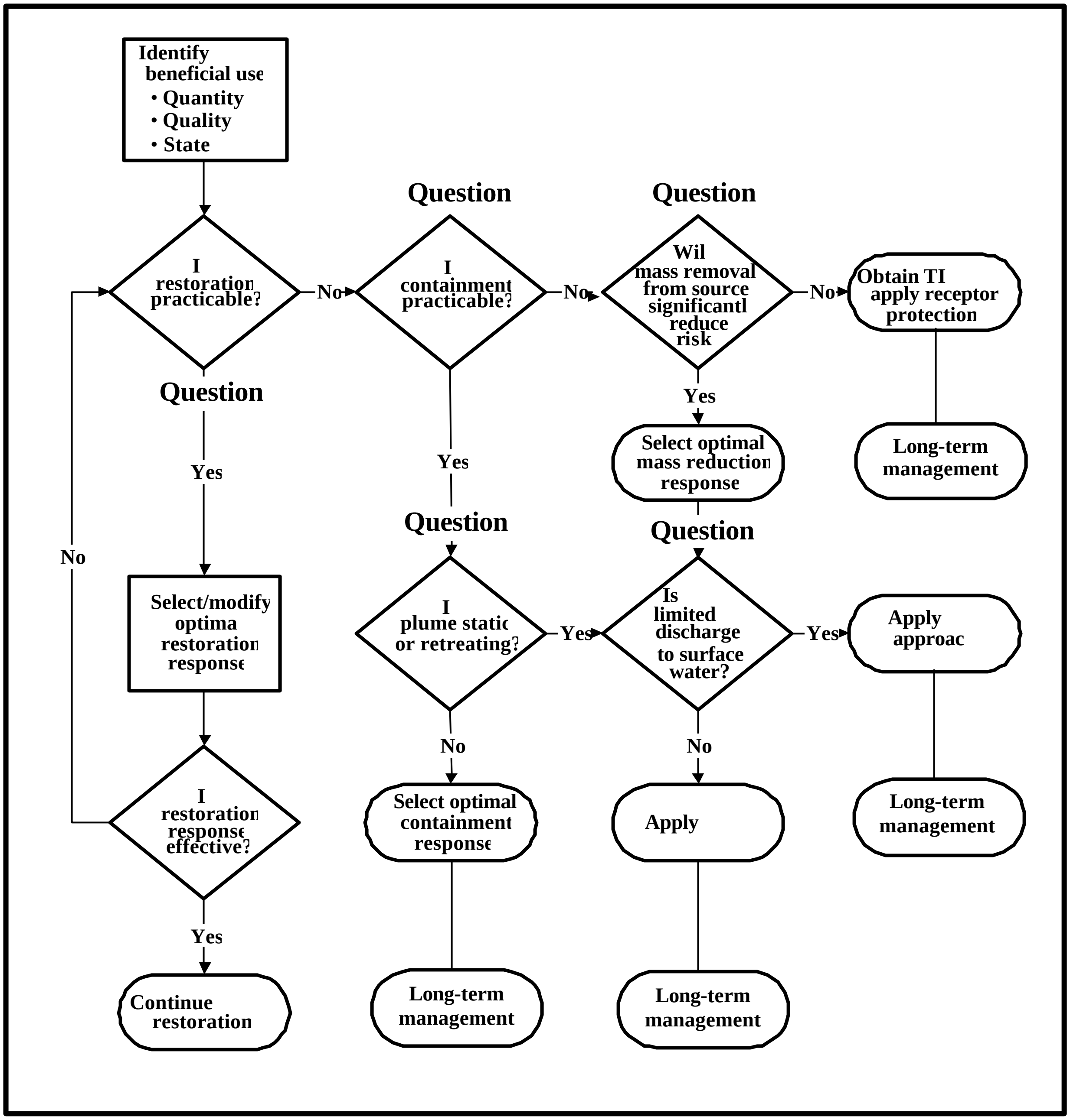
The National Research Council report, *Alternatives for Groundwater Cleanup* (1994), summarized the difficulty of cleaning up sites with either LNAPLs in fractured rock aquifers or DNAPLs in heterogeneous or fractured rock aquifers relying on pump-and-treat as the predominant remedial strategy. The report indicated that at many sites requiring groundwater cleanup, some areas would remain contaminated above health-based standards for the foreseeable future even when best available technologies were used. Since publication of that report, new and innovative technologies for groundwater remediation have been tested in the field (e.g., NRC, 1997 and NRC, 2000). Despite many significant advances in groundwater remediation technologies in the past decade, achieving MCLs and restoring the entire volume of a contaminated aquifer remains an elusive goal, and few examples of such restoration have been reported. In particular, removing NAPLs from karst systems, fractured rock and deep heterogeneous alluvial aquifers poses the most extreme example of technical limitations to aquifer restoration. In such situations, the site manager must decide if long-term institutional controls in conjunction with a containment technology will be the most prudent use of Army financial resources. The following section of this document provides a decision framework to guide the site decision maker through the process of analyzing alternative groundwater remediation strategies.

4.0 ALTERNATIVE APPROACHES AT INSTALLATIONS WHERE AQUIFER RESTORATION MAY BE TECHNICALLY IMPRACTICABLE

Lessons learned from past and on-going groundwater restoration efforts in the U.S., some of which were reviewed in **Section 3.0**, suggest that many of the currently available groundwater remedial technologies may not be able to achieve aquifer restoration in complex hydrogeologic systems or at sites with significant remaining DNAPL sources. At such sites, there is often a continuing discussion on whether innovative technologies may overcome these known technical limitations to aquifer restoration. Site managers are then asked to compare the costs of additional active remediation using new or innovative technologies and the reduction in lifecycle costs for cleanup compared to other alternative strategies. These alternative strategies could include source control (either containment or removal), plume containment and natural attenuation which may also provide lifecycle cost reductions while maintaining remedial action objectives of no unacceptable impacts to human health and the environment.

Figure 4.1 proposes a decision framework for addressing contaminated groundwater at Army installations where aquifer restoration may be technically impracticable. The decision process is facilitated by the development of a conceptual site model, which is discussed in **Section 4.1**. Discussions of alternative remedial strategies are presented in **Section 4.2** through **Section 4.4**.

Figure 4.1. Recommended Decision Framework for Addressing Contaminated Groundwater



4.1 CONCEPTUAL SITE MODEL

The conceptual site model (CSM) provides the conceptual framework for evaluating alternative remedial strategies. The objectives of developing a conceptual site model at any site are to address site investigation and remediation in the most cost effective manner, to facilitate a common understanding of site conditions among all stakeholders, and to focus the regulatory process, as early as possible, on establishing appropriate remedial action objectives. All CSMs should include a description of the release mechanism, the source area, migration pathways, exposure pathways and receptors. Such a description summarizes the scientific basis for site management decisions. Preparation of a CSM facilitates consideration of the five questions posed in **Figure 4.1** and further discussed below.

4.2 AQUIFER RESTORATION

In order to establish an appropriate strategy for investigating and remediating an aquifer, it is necessary to evaluate the feasibility of aquifer restoration. This is designated by Question 1 in the decision framework for addressing contaminated groundwater as depicted in **Figure 4.1**. Before aquifer restoration standards are set, the highest potential beneficial use for the aquifer should be determined based on the physical and chemical characteristics of the aquifer as well as on state groundwater laws. In general, aquifers are not considered potential sources of drinking water if they have excessive salinity or if they cannot yield sufficient quantities of water. The actual threshold values for quality and yield differ from state to state and must be determined on a site-specific basis. However, the existence of such thresholds establishes two important information needs, (1) ambient water quality with respect to salinity and any naturally occurring toxins (e.g., arsenic and chromium) and (2) aquifer yield. If restoration of the aquifer is the objective, cleanup goals will usually be set at MCLs, risk-based standards if MCLs are not available or at background concentrations if state laws permit no degradation of subsurface waters. If the aquifer is of a quality that does not support potable use, it will be necessary to determine the aquifer classification, the standards which apply to that classification and whether any contaminants exceed their respective standard. In general, if no contaminants are present above the standard, no restoration is required.

If the aquifer could support potable use, or if leakage from the contaminated aquifer threatens an underlying potable aquifer, an evaluation of the feasibility of aquifer restoration is necessary. In general, restoration is more easily accomplished in aquifers that are homogeneous, isotropic and highly conductive. Similarly, restoration is easiest when contaminants are highly soluble in water and have low sorption coefficients and high target cleanup concentrations. Restoration becomes more difficult with increasing subsurface heterogeneity and anisotropy, and with decreasing aquifer permeability, contaminant water solubility and contaminant target concentrations (NRC, 1994).

A number of technologies are capable of removing mass from source zone areas. However, these technologies face significant barriers. Important considerations with respect to currently available groundwater remedial technologies include the following:

- Pump-and-treat will flush the permeable conduits while contaminant migration from less permeable zones will be diffusion-limited and may sustain very low (µg/L) concentrations indefinitely within the aquifer of interest and downgradient of the source area;

- The difficulty in locating DNAPLs and the high degree of DNAPL removal required to have a measurable impact on downgradient concentrations of the contaminants may limit the applicability of any remediation technologies including innovative and aggressive technologies such as in-situ thermal technologies;

- If reagents (such as chemical oxidants, surfactants, etc.) are not significantly more mobile than contaminants, or if the introduction of reagents reduces subsurface permeability, in-situ approaches based on the introduction of chemicals (e.g., in-situ chemical oxidation, surfactant enhanced aquifer restoration) may not reduce the restoration timeframe sufficiently to justify the cost of the technology or the risk of technology failure.

- Passive remedies such as permeable treatment walls require the contaminants to travel to the wall and, therefore, restoration timeframes depend on rates of natural flushing;

- Thermal technologies for in-situ treatment such as steam injection or electrical heating which increase the mobility of in-place DNAPL can induce downward contaminant migration within poorly understood saturated zones, and this limitation must be carefully evaluated.

Given these considerations and the low cleanup goals associated with many contaminants, particularly those associated with DNAPLs, aquifer restoration will remain a difficult goal at many Army sites. More often than not, the answer to Question 1 will be "no", and subsequent decision questions will need to be addressed as discussed below.

In those occasions that restoration is considered to be practicable, standard site remediation procedures should be followed. As noted in **Figure 4.1**, once the appropriate remedial response has been implemented, additional analysis is required to verify that aquifer restoration is indeed "practicable". This may represent the most common situation at Army sites, namely, remedial responses have been in place for several years, and sufficient data are not available to determine if the remedy is effective, and whether restoration in a reasonable timeframe is likely. The EPA required five year reviews at NPL sites provide the type of opportunity to revisit this question. Effectiveness reviews could occur at any time when it is concluded that sufficient data are available to predict more accurately the effectiveness of the existing remedial system.

4.3 LIMITING PLUME GROWTH AND CONTAMINANT MIGRATION

If aquifer restoration is technically impracticable, and alternative source control technologies are deemed insufficient to reduce the timeframe for restoration significantly, then consideration of plume containment should begin thereby minimizing the volume of aquifer subsequently contaminated by plume expansion due to contaminant migration. This issue is addressed by Questions 2, 3 and 4 in the decision framework in **Figure 4.1**. Containment is often achieved hydraulically through the implementation of pump-and-treat systems with pumping rates set to match or exceed the flow rate of contaminated water[1]. Containment may also be accomplished using physical barriers (e.g., permeable reactive barriers) designed with sufficient thickness to provide the contact time needed to degrade contaminants to desired concentrations. Less frequently, impermeable barriers (e.g., slurry walls) are utilized but only in concert with extraction systems to prevent the build-up of excess water. As discussed in more detail below, aggressive mass reduction in the higher concentration or source areas of a plume may help contain plume growth and may also offer the additional benefit of promoting more rapid restoration of the affected aquifer.

In older and relatively more mature plumes, plume growth may already be constrained as a result of one of the following: (1) attenuation mechanisms exceed the contaminant mass discharge at some defined perimeter in the aquifer such that the individual isopleths are static or receding with time (see Question 3, in **Figure 4.1**) or (2) the groundwater discharges into surface waters with sufficient flow volume to dilute contaminants below detection or to background levels in the surface water (see Question 4, in **Figure 4.1**). In the first situation, the plume is at equilibrium and, thus, monitored natural attenuation (MNA) may be the preferred alternative provided that MNA mass reduction mechanisms are sustainable (NRC, 2000). In the second case, if access to contaminated groundwater can be controlled, the site may be managed through an alternate concentration limit approach under CERCLA (EPA, OSWER Directive 9283.1-2) as was discussed in **Section 2.3.2**.

If contaminants are still moving, project managers need to determine if engineered barriers are needed, or whether mass extraction/contaminant destruction in the higher concentration areas of the plume is more appropriate. If calculations show that stasis can be attained relatively quickly using a mass removal approach, and if no significant risk concerns exist in the interim, mass removal may be implemented in lieu of engineered barriers.

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[1] Treated water may be re-injected to create mounding at the perimeter as a way to enhance capture.

The decision between no action, additional mass removal, or installation of an engineered barrier should be determined by applying the standard NCP selection criteria, assuming that alternative cleanup levels have been negotiated for at least a specific zone in the aquifer. It is important to note that any containment alternative must be shown to be effective and reliable over the long-term. For most containment alternatives, particularly the permeable reactive barriers, the lifespan of these technologies under field conditions is still uncertain. The adequacy of any long-term institutional controls would need to be evaluated as a key component of any containment alternative.

While containment is often more readily accomplished than restoration, it is not assured. In aquifer matrices with poor connectivity such as fractured bedrock and karst environments, or in sites with poorly mapped preferential conduits, it may not be practicable to capture all of the contaminated groundwater. In other settings, flow in conduits such as solution channels may be so large as to render containment infeasible. If a plume is not static, it is important to determine if capture/containment can be achieved. If it cannot be contained, or if mass reduction will increase the effectiveness of natural attenuation processes, then the focus of remediation shifts to source control.

4.4 SOURCE CONTROL

The issue of source control for risk reduction comprises Question 5 in the decision framework depicted in **Figure 4.1**. In general, source materials represent the highest concentration of contaminants in the environment. Remedies aimed at removing these materials from subsurface environments generally offer the greatest value in terms of amount of contaminant addressed per unit of expenditure. As a consequence, source control measures may be a cost effective step in most groundwater restoration programs. However, caution is still required in the implementation of source control actions for reasons noted below. Sources of groundwater contamination come in many different forms from pure chemical, either contained (e.g., drums) or uncontained (e.g., DNAPL), to films adsorbed onto soil particles. The concentration, form and location of sources are important determinants of the cost effectiveness of source control options. Because the aquifer media may serve as a source for any contaminant which partitions between solids and water, complete source control would be synonymous to aquifer restoration for these chemicals. In recognition of this, source control is directed to “active” sources that are contributing a greater amount of more mobile contaminants into a plume over a given period of time than would be removed by natural attenuation processes.

The intent of source control is to reduce the mass of the contaminant being released to the aquifer and to achieve quantifiable benefits to the resource. For example, removal of mass can be shown to reduce the time required for restoration of the aquifer due to a substantial decrease in the rate of contaminant mass leaving the source area. Alternatively, mass removal can be shown to increase the area and volume within which restoration can be achieved in a reasonable timeframe. These conditions represent a risk reduction in terms of time and location, respectively. The question of the effectiveness of mass reduction should be addressed in the pilot test phase. Additional information on conducting pilot tests at complex sites is presented in **Appendix E**. Pilot tests conducted to evaluate mass removal technologies are often evaluated in terms of the degree of mass removal achieved. This approach rarely addresses whether the technology, if successful, will provide a reduction in risk or lifecycle costs. In practice, pilot test designs should include pre-test and post-test mass flux analyses to provide an estimate of the effect mass removal may have on the contaminant plume outside the test zone. At complex DNAPL sites, a detailed characterization of the spatial variation of groundwater velocity and DNAPL occurrence is needed for estimating mass flux. **Appendix F** presents additional information on the level of site characterization needed to estimate mass flux at complex DNAPL sites. Evaluation of pilot test results must include an assessment of the scale-up to full-scale application and must ask the question whether pilot test results be extrapolated to other regions of the source area. In the case of DNAPL-contaminated sites, pilot studies may be required to verify technical impracticability.

Achieving quantifiable resource benefits can be difficult in many situations. At sites where DNAPL is present, removal of more than 99% of the DNAPL may not result in any reduction in the dissolved contaminant concentration in groundwater in the source area. For example, in flushing DNAPL zones with water or reactive solutions, the flushing medium reaches local equilibrium with the DNAPL during contact with the upstream side of the source area. In the short-term, further contact with DNAPL located deeper within the source zone may remove little or no additional DNAPL. Hence, aqueous phase concentrations within the source area are sustained (Sale and McWhorter, 2001). Even if the reduction in aqueous concentration was directly proportional to percent mass removal, concentrations on the order of 1,000 mg/L require more than 99.9% removal from the source area to achieve MCLs. DNAPL removal efficiencies at or above 90% have been only rarely reported, and in most of these cases, the sites were small in size. Further information on the difficulties of mass removal in DNAPL source areas is presented in **Appendix C**. In the case of DNAPL-contaminated karst and bedrock sites, pilot studies may be utilized to demonstrate technical impracticability.

In a similar manner, after implementation at diffusion-limited sites, rebound from contaminants trapped in the matrix may return groundwater to pre-remediation levels. The effects of matrix diffusion and dissolution in source areas result in a continued “bleeding” of source mass from the matrix into advective pathways. Even when long-term concentration reductions can be achieved, if the resulting concentration is above the MCL, the aquifer cannot be used as a drinking water resource without treatment. Hence, use restrictions will remain in place and the net risk reduction will still be dependent on eliminating the exposure pathway by treatment rather than through the active source removal remedy.

In some geologic settings, however, modest levels of source removal (less than 50% removal) may result in sufficient reduction of mass discharge to the aquifer from the source area such that alternative remedial strategies can be employed. This approach requires performance of a baseline mass flux analysis and an estimate of the aquifer attenuation capacity (in flux units) prior to implementing source removal. Source removal is continued until subsequent mass flux analyses show sufficient mass flux reduction to sustain contaminant levels favorable to monitored natural attenuation, or to extend the life of permeable reactive barriers. Thus, the appropriate goal of source removal will be mass flux reduction rather than source zone restoration (Rao, 2001). **Appendix F** summarizes the difficulties in performing mass flux analyses at fractured bedrock, deep complex alluvium and karst sites.

The potential effectiveness of source control technologies appears to be highly dependent on the geologic conditions in the source areas and on the volumetric distribution of the DNAPL. In strongly heterogeneous media, the high permeability zones may contribute most of the contaminant flux off site. The amount of mass removal needed for substantial flux reduction depends on DNAPL distribution relative to the high permeability zones (Falta, 2001). These factors will need to be evaluated in assessing whether source removal will significantly reduce the risk at a site with DNAPL source areas.

Given the challenges DNAPL and diffusion-limited sites pose, a key focus of the source control evaluation should be on whether the response being considered will significantly change the timeframe over which water use restrictions must be kept in place. If a mass removal action will reduce the time to restoration from the distant future to the near term, or if mass removal can decrease lifecycle site costs due to the use of an alternative remedial strategy, then the costs of a particular source removal technology may be appropriate. Reductions of years or even tens of years from estimated timeframes that are many hundreds of years long probably do not[2].

Irrespective of the decision as to which response action objective can be achieved at a reasonable cost and within a reasonable time, any selected response must protect human health and the environment. As a consequence, some form of exposure control will be necessary in order to ensure that on-post receptors are not exposed to the groundwater and off-post residents do not consume that groundwater. It is highly likely that institutional

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[2] When restoration will require more than 100 years, it generally will be better to revisit the remedy as part of the CERCLA 5-year review process to determine whether a technology not available at the time the remedy was selected could cost effectively achieve restoration.

controls will be a component of the final remedy at complex sites. Although the use of on-post groundwater can be controlled fairly easily by placing access restrictions in the Master Plan for active installations, implementing land use controls to prevent off-post groundwater consumption is likely to prove more difficult. Possible mechanisms to control exposure to off-site contaminated groundwater include the use of state law or local ordinances that prohibit use of groundwater for residential or potable uses, and require permits for well construction; notices and advisories regarding use of the water; purchase of water rights; and establishment of an alternate water supply. Institutional controls will likely be required for many plumes over extended time periods to eliminate any unacceptable exposure pathway. In order to mitigate the risk of potential institutional neglect, the USEPA may require Land Use Controls Assurance Plans (LUCAPs) as described in **Appendix B**.

4.5 TRANSITION STRATEGY TO SITE CLOSURE

In many respects, the final phase of groundwater restoration will in most cases be monitored natural attenuation (MNA). Even if MNA is not selected as the primary response, the final confirmation monitoring for all other remedies generally is a brief period of monitoring while attenuation processes drive concentrations below their respective MCLs or to background levels.

When viewed in this light, the phases of a groundwater restoration strategy can be considered analogous to the favorable conditions required to utilize MNA as a remedial option. In other words, the transitions between phases of a response occur as each precondition for application of MNA is met. The first phase, source control, is complete when no active source remains. The second phase, or containment, is complete when the plume is brought to equilibrium. Finally, the MNA phase is implemented when sufficient mass removal has occurred to be able to demonstrate that natural attenuation mechanisms will be able to restore the groundwater within a timeframe that is compatible with future use and reasonable as compared to more active measures (the final condition for determining the appropriateness of utilizing an MNA approach).

If no active source is present, the first phase is avoided. If the second phase is highly effective, the third phase is limited to a brief period of post-remedy monitoring. If the second phase is less effective (i.e., site conditions or the type of contaminants limit the performance efficiencies of available technologies), a longer period of MNA will be required. Transitions between phases are dictated by arrival at a point where an MNA precondition is met and implementation of the next phase is deemed more cost effective than continued application of the previous phase.

4.6 RECOMMENDED DATA NEEDS

Ultimately, it will be the results from site characterization/alternative assessment activities that provide the necessary information to make informed cleanup decisions. Specific data needs are identified through the data quality objectives process and, thus, should be tied directly to the objectives identified in the groundwater restoration strategy. The investigations required to support the various groundwater decisions discussed in this document are outlined in **Table 4.1**.

Table 4.1. Examples of Information Needs for Establishing Appropriate Groundwater Remedial Action Objectives in Complex Karst and/or Fractured Bedrock Sites

a. **Highest Beneficial Use**

- Determine yield through conduct of extended pump tests, if needed. If feasible, assess aquifer yield based on local experience with aquifer development.
- Sample and analyze salinity and the presence of naturally occurring toxins (e.g., arsenic and chromium).
- Determine regulatory statutes to be applied at the state level.

b. **Practicability of Aquifer Restoration**

Are contamination concentrations a product of matrix limitations?

- Collect and evaluate boring logs and/or geophysical data relative to the presence of solution channels, fracture flow, preferential conduits and heterogeneities in excess of two orders of magnitude differences in permeability.
- Evaluate spatial distribution of contamination, patterns of use and direct observations to determine likelihood of pure phase solid or liquid (DNAPL) sources in the saturated zone.

Is contamination amenable to available restoration technologies?

- Calculate the number of pore volumes that must be removed to achieve target MCL for a contaminant (requires estimate of partition coefficient and ratio of concentration to MCL) and determine if said requirement can be accomplished in less than 100 years based on feasible extraction rates from pump testing.

c. **Practicability of Containment**

Can the plume be captured effectively using hydraulic or physical barriers

- Determine connectivity in the saturated zone through draw down test using observation wells at staggered distances and directions.
- Determine extraction rate requirements and the potential for essentially infinite source from surface water bodies.
- Determine existence of impermeable layer for anchoring physical barriers.

Table 4.1. Recommended Information Needs for Establishing Appropriate Groundwater Remedial Action Objectives in Complex Karst and/or Fractured Bedrock Sites

Continued from previous page

c. Practicability of Containment *(Continued)*

Is the plume already contained?

- Evaluate temporal trends in groundwater concentrations during wet and dry periods to determine if plume is static.
- Apply MNA protocols to determine if attenuation mechanisms are present and operative at a level that would achieve stasis.

Is stasis due to discharge to a surface water body?

- Determine dilution/dispersion characteristics during both wet and dry periods and calculate if they will sustain concentrations below water quality criteria.
- Determine if access to groundwater between the source and the surface water body is and can continue to be restricted.

d. Efficacy of Mass Removal

Will source removal result in significant risk reduction?

- Measure leaching potential of vadose zone sources and calculate mass discharge contributed by source in the saturated and unsaturated zones.
- Model the time/concentration relationship with and without the expected mass reduction efficiency.
- Evaluate the influence of mass discharge reduction on plume containment.

Will mass reduction within the plume result in significant risk reduction?

- Review data on proposed mass reduction technologies and identify probable levels of effectiveness that can be achieved at this site.
- Model the time/concentration relationship with and without the expected mass reduction efficiency.

5.0 INTERACTION WITH STAKEHOLDERS

In general, for any groundwater restoration strategy to be successful, it must be acceptable to the affected stakeholders. Given that many sites will ultimately rely on MNA at some point in their groundwater response strategies, project and site managers need to be cognizant of the current state of public apprehension with respect to MNA as a remedy. The rationale for the strategy must be well documented and effectively communicated. Key elements of effective communication include the following:

- Credible comparison of alternatives with respect to cost and risk reduction achieved;
- Credible evaluation of the ability of a remedial action to achieve the risk reduction objective; and
- Explicit identification of uncertainties and the means by which they will be managed for all alternatives.

5.1 ALTERNATIVES COMPARISON

While the EPA has developed a hierarchy of programmatic expectations in recognition that aquifer restoration may not be practicable at many sites, many stakeholders do not share this recognition. Years of miscommunication and misunderstandings have left many stakeholders skeptical that emerging alternatives such as MNA are nothing more than a way to avoid spending the resources necessary to right a wrong.

In order to counter such skepticism, it is essential to characterize alternatives accurately and to present their respective costs and degrees of effectiveness clearly to the stakeholders. Each remedy must be assigned an expected performance profile that reflects the likely effects on risk reduction over time so that the differences in cost can be compared with the differences in risk reduction. Moreover, the ramifications of reduced concentrations must be identified and discussed. If it is technically impracticable to reduce concentrations below MCLs, it must be clearly stated that the aquifer will still be restricted for use and that protection will arise from use restrictions or long-term treatment, not mass removal.

5.2 RISK REDUCTION EVALUATION

It is also important that proposed remedies be assigned risk reduction levels objectively. Although an objective evaluation of available remedies may identify the potential for significant risk reduction, there is often a default assumption that a proposed remedy will be effective without drawing on past experience and without considering how performance may be impacted by residual uncertainties. This is particularly true for complex karst and fractured bedrock sites where residual uncertainties are of a significant magnitude. Without objective estimates, remedies of little or no value to the resource may be implemented because of the potentially false assumption that an action of any kind must be beneficial when in fact the opposite may sometimes be true. In some circumstances, active remedies can trigger unintentional movement of the contaminants or work to negate the effects of natural attenuation mechanisms (e.g., pump-and-treat system lowers water table and promotes aeration thus reversing anaerobic mechanisms that may otherwise be responsible for the biotransformation of chlorinated solvents in groundwater).

For complex karst and fractured bedrock DNAPL sites, when the true cost and associated resource benefit/risk reduction of the individual response options being considered are objectively compared, the actual value of many common groundwater remedies is more apparent, and response strategies incorporating alternate approaches such as MNA become more acceptable.

5.3 UNCERTAINTY MANAGEMENT

It is impossible to eliminate all the uncertainty associated with environmental restoration prior to the selection of a remedy. As a consequence, there will always be a need to manage uncertainties by blending uncertainty reduction (data collection) with uncertainty impact mitigation (use of contingencies).[3] For the most part, the significant uncertainties associated with groundwater restoration are closely related to remedy effectiveness. In order to provide assurance that protectiveness will be maintained, it is necessary to implement a monitoring structure that will provide ample warning of conditions that are no longer protective. It is also important to have a contingency plan that will mitigate any adverse impacts before there are significant consequences.

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[3] Uncertainty Management: Expediting Cleanup through Contingency Planning, (DOE/EPA, February, 1997).

6.0 RECOMMENDATIONS

6.1 ROADBLOCKS TO GROUNDWATER STRATEGY IMPLEMENTATION

In general, there has been some reluctance on the part of the regulatory community and the Army to explicitly acknowledge the technical infeasibility of aquifer restoration at many sites. This reluctance may stem from public concerns over perceived risks to human health and the environment of leaving contaminants in the subsurface, even if risk assessments indicate that risks are below regulatory levels. Additionally, there are real concerns on the part of the regulatory community as well as the Army that institutional controls won't work, that the public will not accept alternative water supplies and that the Army will not be able to provide effective long-term management options for contaminated groundwater.

The Army is not alone in experiencing difficulties in implementing alternative remedial strategies at sites where aquifer restoration is technically infeasible. In response to an apparent reluctance of EPA's regional offices to consider TI issues, EPA's Office of Solid Waste and Emergency Response sent a memorandum to Regional Administrators directing that Records of Decision addressing sites where it may be technically impracticable to restore the aquifer, especially DNAPL sites, must employ a waiver of Federal and/or State cleanup standards or provide written justification for a departure from standard policies. This memo could serve as the basis for initiating high-level dialogues between the DOD, the EPA and state regulatory agencies on how to manage complex sites and how to ultimately ensure the protection of human health and the environment without inappropriate use of financial resources. Until the impacts of technical feasibility constraints are considered and explicitly acknowledged in the Army's restoration program, the long-term costs for receptor protection and management of contaminated groundwater may far exceed the commensurate benefits associated with risk reduction as a result of the restoration program.

6.2 RECOMMENDATIONS

Based on the discussion presented in **Section 1** through **Section 5**, the following recommendations for Army installation site managers are made for sites with contaminated groundwater and/or DNAPL in complex karst, fractured rock and deep alluvial hydrogeologic systems:

- Develop and modify as appropriate a conceptual site model for purposes of (1) guiding site characterization efforts, (2) identifying potential receptors, (3) evaluating alternative remedial objectives and (4) selection remedies.
  Detailed information on conceptual models is provided in **Appendix A**.

- When appropriate, ensure that potential receptors are protected by providing alternative water supplies.

- Develop and evaluate institutional control options early in the restoration program.
  Detailed information on institutional controls is provided in **Appendix B**.

- Acknowledge the likely technical infeasibility of delineating and remediating DNAPL sources in karst, fractured bedrock, and deep alluvial aquifers.
  Detailed information on NAPL characterization is provided in **Appendix C**.

- Explicitly acknowledge the technical impracticability of aquifer restoration where source zones cannot be located and remediated due to complex hydrogeologic conditions.
  Additional information on technical impracticability is provided in **Appendix D**.

- Obtain an ARAR waiver or an ACL where appropriate.
  Information on ARAR waivers and State technical impracticability policies is provided in **Appendix G** and **Appendix H**, respectively.

- Develop remedial action objectives that are consistent with an assessment of the technical feasibility of aquifer restoration.

- Provide comparisons of the cost of all actions, including groundwater containment and source remediation actions using innovative technologies, against a realistic assessment of their ability to achieve the alternative remedial goals. Pilot studies are usually needed to assess the potential effectiveness of any source control technology. Guidance on conducting pilot studies is provided in **Appendix E**.

- Provide comparisons of the cost and risk reduction potential of any source removal action against natural attenuation or natural gradient flushing. Conduct an assessment of the impact of any source removal action on the mass discharge to the aquifer of contaminants of concern.
  Information on natural attenuation and mass discharge analysis is provided in **Appendix F**.

- Develop an exit strategy that provides for receptor protection and effective long-term management of contaminated groundwater.

6.3 PANEL MEMBERS

In order to guarantee that the discussion provided in this document is technically defensible, the Army Environmental Center convened a panel of experts to assist in the development of this document. The biosketches of the panel members are provided in **Appendix I**.

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APPENDIX A

CONCEPTUAL SITE MODELS FOR DNAPL-CONTAMINATED FRACTURED ROCK AND KARST SITES

APPENDIX A
CONCEPTUAL SITE MODELS FOR DNAPL-CONTAMINATED FRACTURED ROCK AND KARST SITES

A.1 INTRODUCTION

The overall goal of this section is to provide guidance for Army site managers on the preparation of conceptual site models (CSMs) for Army facilities with groundwater contamination in fractured bedrock or karst aquifers. The objectives of developing a CSM at any site are to address site investigation and remediation in the most cost effective manner, to facilitate a common understanding of site conditions among all stakeholders, and, where appropriate, to focus the regulatory process, as early as possible, on risk reduction rather than on aquifer restoration.

The characterization of groundwater contamination in fractured bedrock and karst aquifers poses unique difficulties, which most often generate uncertainties in risk evaluation, risk reduction, and aquifer cleanup. The CSM is a site management tool that can highlight the assumptions used for risk evaluations, as well as focus investigation resources on verifying such assumptions. Guidance on the development of CSMs often precedes many discussions on the occurrence and migration of environmental contaminants (e.g., Pankow and Cherry, 1996). ASTM (1995) presents specific guidance on the development of a CSM.

A.2 ELEMENTS OF CONCEPTUAL SITE MODELS

Conceptual site models are idealized, written or graphical representations of the environmental systems and the processes that control the transport of chemicals to receptors. In the development of a CSM, the site is formulated as a series of elements that constitute the model. All CSMs include a description of the release mechanism, the source area, migration pathways, exposure pathways, and receptors. The elements of a CSM, and some types of information considered within each element, are summarized in **Table A.1**.

When using CSMs, each of the above elements is evaluated with respect to what is known, what is reasonably expected to be accurate, and what is uncertain or unknown. Site investigation is then planned to verify assumptions and resolve uncertainties in order to better understand the situation being evaluated. The CSM generally evolves from a generic model to a site-specific model in iterative stages with modifications occurring as a result of each phase of investigation. **Table A.2** describes the iterative stages a CSM may go through and the decision making influenced at each stage.

In order to be an effective management tool, the CSM should include a description of the spatial characteristics of the contamination, and identification of the operative processes influencing potential aquifer restoration. At groundwater contamination sites, a thorough CSM requires a description of the hydrogeologic units and their hydraulic properties, hydraulic heads, and hydrologic boundaries at a scale thought to be large enough to include potential receptors or other features relevant to the particular site under study. Given a clear understanding of the geology and hydrogeology, the CSM should describe the distribution of the contaminants of concern (COCs), and rates of contaminant migration in both the vadose zone and in underlying groundwater zone(s). Fractured bedrock and karst aquifers pose unique difficulties in the development of an effective CSM. The primary difficulties posed by fractured bedrock and karst aquifers are discussed below.

A.3 DEVELOPING CSMS IN FRACTURED OR KARST MEDIA

Fractured bedrock aquifers can be dual porosity systems with groundwater flow mostly occurring in fractures and rock matrices. The variance in porosity between different types of rock has a significant impact on whether a fractured system can be simulated with a dual porosity or single porosity model.

Karst aquifers have solution-enlarged fractures and a wider range of porosities than fractured rock aquifers. In karst aquifers, groundwater flow can occur in conduits, fractures and rock matrices. Relatively rapid and possibly turbulent flows can be expected in conduits and in relatively open fractures. Segments of contaminant migration pathways in nearly all karst systems can be characterized by pipe flow in subsurface conduits. The equations of flow in porous media, generally based on Darcy's Law, usually require that the groundwater flow be laminar and of low velocity. Special considerations that apply to fractured rock and karst aquifers are discussed in the next two sections.

A.4 FRACTURED ROCK AQUIFERS

Characteristics of fractured bedrock sites (and the fractured zones of karst sites) that impact site investigation and remediation includes, but are not limited to, the following:

- **Non-Darcian flow:** A significant portion of the groundwater flow occurs in fractures thus limiting the accuracy of the Darcian flow equation. A model of the fractures as an equivalent porous media (EPM) remains applicable in some cases depending upon the scale of fractures and contaminant distribution. Applicability of the EPM should be verified by various means including pumping well responses, hydraulic head distribution, comparisons of scale of fracture spacing to scale of the site, hydraulic conductivity distributions, or water quality variations.

- **Fracture distribution:** Fracture connectivity cannot always be assumed. A small fraction of fractures often transmits a large fraction of the water flow.

- **Contaminant distribution:** The distribution of contaminants is often difficult to define in these environments and does not necessarily correlate with significant water bearing fractures. In fractured porous bedrock, residual contamination occurs as a sorbed phase, which diffuses into the porous matrix adjacent to fractures. Diffusion of the contaminants into the porous matrix serves both as a retardation mechanism for NAPL, and as a long-term source of dissolved phase organics not exposed to flushing. In fractured nonporous bedrock, residual NAPL can occupy a comparatively large proportion of the saturated porosity and can migrate to significant depths.

Elements of an acceptable conceptual site model for fractured rock aquifers should include information on the following items:

- Conventional geologic/hydrogeologic data including vadose zone and aquifer thickness; values of porosity, hydraulic conductivity, transmissivity and storage coefficients; and recharge and discharge areas;
- Fracture distribution, mean aperture, and spacing in addition to significant changes across the area of interest;
- The distribution of contaminants (e.g., DNAPL in fractures or in matrix porosity, or dissolved phase primarily in fractures);
- Fracture related controls on groundwater flow directions;
- An estimate of the scale for which the equivalent porous media model is valid.

A.5 KARST AQUIFERS

Karstic aquifers are distinguished by a number of characteristics that have a significant impact on site investigation and remediation. These include the following:

- **Non-Darcian flow:** A significant portion of the groundwater flow may occur in conduits thus eliminating the accuracy of the Darcian flow equation. Differential velocities and three-dimensional conduit flow lead to non-Gaussian contaminant distributions that may not be easily conceptualized as plumes in the traditional sense.

- **Watershed perspective:** The inability to detect and trace individual conduits could necessitate an evaluation of the system on a watershed basis, a scale that is generally too large to yield representative data from individual wells, and generally increases the need for off-site investigations. Conduit flow generally daylights in springs or discharges to surface water bodies as opposed to transitions into a porous media flow dominated aquifer. Representation of groundwater flow in terms of equipotential lines and flow lines (flow nets) requires basin-wide data from recharge, discharge and conduit flow zones. This forces a groundwater basin perspective on the identification of potential receptors. Due to the influence of conduit flow, dye-tracing studies are essential investigative tools for establishing hydraulic connections between the contaminated site and potential receptors.

- **Types of flow:** Karst aquifers can be classified as unconfined (conduit or free-flow), confined, or diffuse flow karst aquifers. Conduit flow aquifers behave hydraulically as a system of pipes with flow velocities similar to those of surface water streams. Due to rapid discharge, the water table usually does not conform to topography. Subsurface water flow responds rapidly to recharge events. Such conditions are the most susceptible to contamination. In confined karst aquifers, solution-enlarged fractures are typically deep and are not directly connected to recharge zones. Flow zones are bounded by low permeability stratigraphic or structural features. Finally, diffuse flow karst aquifers contain solution-enlarged fractures that are relatively small and generally transmit water under laminar flow conditions. This is generally similar to fractured rock aquifers that may conform to the equivalent porous media model.

- **Contaminant Distribution**: Conceptual models of contaminant distribution in karst aquifers suggest that residual contaminant storage may occur in the regolith, in the epikarst, in diffuse rock fractures, and in conduits. In many karst sites, the epikarst has a high potential to trap residual DNAPL due to its highly weathered, irregular surface. Residual contamination may also occur in conduit sediments. Flow channels include in-filled pockets and zones where porous media flow on a micro scale dominates transport thus fostering a slow dissolution and desorption of contaminants so that secondary sources persist in spite of high flow rates in channels.

Because of the uncertainties that arise from the inherent characteristics of karst aquifers, a good CSM for such sites should include sufficient information to describe the following:

- Traditional geologic/hydrogeologic data including vadose zone and aquifer thickness; estimates of porosity, hydraulic conductivity, transmissivity and storage coefficients; and recharge and discharge areas;
- The type of karst aquifer (e.g., diffuse flow, free flow, or confined flow);
- Recharge and discharge zones illustrating, at least qualitatively, the relationship between subsurface flow, and recharge and discharge points;
- The flow path associated with each monitoring well. If applicable, the CSM should clearly depict the potential for conduit flow paths to short circuit contaminants away from a monitoring location;
- Portions of the watershed that contain potential receptors;
- The potential for contaminated sediments to accumulate in flow conduits when applicable.

Table A.1. Site Conceptual Model Elements

CSM Element	Description	Examples (not comprehensive)
Causative Source	▪ Known or potential release mechanism ▪ Known or potential points of release and magnitude ▪ Contaminants of Concern (COCs)	Pipeline, leaking tank, unlined lagoon, dry well
Source Areas	▪ Environmental media contaminated at or near the release point(s)	Contaminated soil or sediments, zones containing NAPL
Migration Pathways	▪ Environmental media along which COCs migrate from the source area ▪ Processes that influence COC concentrations along the migration pathway	Surface soil: volatilization, overland flow Subsurface soil: leaching Sediment: resuspension Groundwater: advection, sorption, NAPL dissolution
Exposure Pathways	▪ Modes of contaminant uptake by receptors	Ingestion, inhalation
Receptors	▪ Human or ecological environments exposed to the contaminants	Users of drinking water wells or reservoirs

Table A.2. Site Conceptual Model Iterations

CSM Version	Timeline	Function
1.0	▪ Following site reconnaissance ▪ Preliminary data review ▪ Limited site characterization	Basis for RI planning
2.0	▪ Based on RI data ▪ Considers receptors ▪ Includes quantitative characterization	Basis for FS
3.0	▪ Incorporates pilot studies ▪ Guides remedy selection	Basis for final remedy selection and contingency plans
4.0	▪ Remedy performance monitoring	Basis for remedy performance evaluation

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APPENDIX B

INSTITUTIONAL CONTROLS

APPENDIX B
INSTITUTIONAL CONTROLS

B.1 INTRODUCTION

Even if some form of treatment and/or removal is selected as a groundwater remedy for complex karst and fractured bedrock sites, it is doubtful that any such remedy will achieve remedial objectives or goals within a reasonable timeframe or fully protect potential receptors. Therefore, some form of exposure control will be necessary in order to ensure that on-post receptors are not exposed to the groundwater and off-post residents are not exposed to that groundwater. Consequently, it is highly likely that institutional controls will be a component of the final remedy. Although the use of on-post groundwater can be controlled fairly easily by placing access restrictions in the Master Plan for active installations, implementing institutional controls to prevent off-post groundwater consumption, as discussed below, is likely to prove more difficult.

An institutional control is considered a remedy under the NCP and must be selected in accordance with the procedures therein. As such, institutional controls should neither be accepted without analysis as to their enforceability and protectiveness, nor summarily rejected simply because they involve no treatment of the groundwater. The nine criteria in the NCP must be applied to an institutional control remedy in the same manner as remedies involving treatment or removal. In order to properly and fairly evaluate institutional controls for groundwater, the exact control proposed for use should be described and legal research should be conducted up front to support an assessment of the potential effectiveness of different forms of institutional controls in the Feasibility Study. The ability to enforce any controls should be evaluated, and the party responsible for enforcing such controls should be identified

Institutional controls fall into two general categories - proprietary controls, and government controls. Proprietary controls are private contractual mechanisms contained in property transfer documents such as deeds. Proprietary controls involve the placement of some form of restriction on the land through the use of easements, covenants, and reversionary interests. Unless it is anticipated that installation property will be transferred in the foreseeable future, institutional controls of this nature are not an immediate means of safeguarding off-post residents from groundwater that may be contaminated above safe levels. If, however, the Installation transfers property in the future, proprietary controls may well prove to be an appropriate institutional control to protect future receptors from exposure to unsafe groundwater.

Government controls are restrictions that are within the traditional police powers of state and local governments to impose and enforce. Examples of these types of controls include permit programs, and planning and zoning restrictions. Zoning and use restrictions are typically imposed by local governments such as cities or counties and restrict, limit, or prohibit land uses. Examples of zoning restrictions would be the prohibition of industrial development in a particular area, or minimal lot sizes in residential areas. Permit restrictions are those that require the issuance of a permit prior to the authorization of a particular activity or land use. An example of such a restriction would be the requirement to obtain a permit prior to the construction of a well.

Government controls are another type of institutional control that can be used to protect off-post residents from contaminated groundwater emanating from an installation. Unfortunately there can be obstacles to implementing such controls. In some states, the property surrounding an installation may be county property. Counties in some states, for example Alabama, have limited home rule or police powers. Absent such authority, the county lacks the ability to impose zoning restrictions on land development or create, impose, or enforce a well permitting program. Consequently, the only effective means of imposing effective land use controls is through the state legislature. While securing such legislative restrictions may prove difficult, it may be necessary, in conjunction with the local and county government officials, to pursue this course of action. Without such legislation, it would not be possible to control or enforce institutional controls or land use restrictions in off-post areas.

As to institutional/land use controls to restrict access to groundwater underlying the Installation, such controls are easily within the Installation's power to implement and enforce. Such controls can be implemented by: (1) amending the Installation Master Plan to prohibit the construction of on post wells; (2) developing standard operating procedures to ensure that such restrictions are operating properly; and, (3) developing excavation clearance request forms and procedures to safeguard against accidental exposure to groundwater.

Because institutional control will be an integral part of an approved remedy at complex karst and fractured bedrock sites and other sites where restoration is technically infeasible, implementation should include the means to monitor effectiveness, report violations, and enforce the control measures[4]. USEPA Region IV has developed a policy to ensure the long-term effectiveness of institutional controls. Similar approaches are recommended for posts located in other EPA Regions in accordance with USEPA OSWER policy. EPA Region IV requires that as a precondition to concurrence on any remedial action relying on one or more land use controls (LUCs), that the lead federal agency commit itself to implementing a detailed written LUC Assurance Plan (LUCAP). The purpose of the LUCAP is to ensure that the proposed LUCs are effective and will remain reliable for as long as they are required. Land use controls are defined by EPA Region IV as, "… any restriction or control, arising from the need to protect human health and the environment, that limits use of/or exposure to any portion of the property, including water resources[5]". LUCs encompass both institutional controls and engineering controls designed to deny or restrict access to property posing an unacceptable risk to human health. A LUCAP is defined as, "… a written installation-wide plan that sets out the procedures to assure LUCs remain effective over the long-term for all areas at the particular installation where they are required[6]". The specific components that comprise a LUCAP differ based on site-specific conditions, but the minimum elements that must be contained are outlined in the LUC Policy.

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[4] .Institutional Controls and Transfer of Real Property Under CERCLA 120(h)(3)(A), (B) and (C). USEPA OSWER (FFRRO), January 2000.

[5] Memorandum from John D. Johnson, Chief Federal Facilities Branch, EPA Region IV, subject: Assuring Land Use Controls at Federal Facilities, dated April 13, 1998, page 2.

[6] Id., page 3

Institutional controls on groundwater use may expose the Army to liabilities for Natural Resource Damage claims, unless specific language protecting the Army is included in the decision document that implements the restrictions.

In summary, the Installation or MACOM ELS should research requirements under State law and local ordinances to make zoning changes to the allowable groundwater use or to require well construction permits. One element that should be explored is the willingness of the local government to work with the Installation to adopt these measures. For BRAC parcels, the Installation or MACOM ELS should research state property law in order to determine the appropriate language to be used in drafting restrictive deed covenants against groundwater use in order to ensure that they run with the land.

Possible mechanisms that could be evaluated for use as institutional controls include the following:

Off-post groundwater

- State law and local ordinances that allow for zoning against use of groundwater for particular uses, such as residential or potable;
- State law and local ordinances that require permits for well construction;
- Notices and advisories regarding use of the water;
- Purchase of water rights;
- Establishment of an alternate water supply.

BRAC property groundwater

- State law and local ordinances that allow for zoning against use of groundwater for particular uses, such as residential or potable;
- State law and local ordinances that require permits for well construction;
- Notices and advisories regarding use of the water;
- State property law relating to restrictive deed covenants;
- Retention of water rights upon transfer of property.

Retained property groundwater

- Amendment to installation master plan;
- Development of standard operating procedures to ensure land use controls remain in effect, including designation of Installation personnel who are responsible for inspecting land use;
- Incorporation of controls into contracting procedures;
- Development of excavation clearance request forms and procedures.

B.2 EPA REGION IV LUC POLICY FOR FEDERAL FACILITIES

B.2.1 Purpose and Applicability

This memorandum establishes EPA Region IV Federal Facilities Branch policy on measures to be taken to assure the long-term effectiveness of land use controls (LUCs) being relied upon to protect human health and the environment at contaminated federal facilities undergoing remediation pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and/or the Resource Conservation and Recovery Act (RCRA). The purpose of this policy is to establish uniform requirements for efficient oversight of LUC remedy components at federal facilities and to clarify our expectations and criteria for concurring on remedies including LUCs. This policy should not be interpreted as altering the Region's preference for active and permanent remedies consistent with CERCLA and RCRA remedy selection criteria. We continue to regard LUCs primarily as components of, or enhancements to, remedies which employ treatment that reduces toxicity, mobility, or volume as a principal element.

Effective with issuance of this memorandum, it is Federal Facilities Branch policy to require -- as a precondition to concurrence on any remedial and/or corrective action involving any reliance on one or more LUCs for the protectiveness of that action -- that the lead federal agency seeking EPA's concurrence commit itself to implementing a detailed written LUC Assurance Plan (LUCAP) designed to assure the effectiveness and reliability of the required

LUC(s) for as long as any LUC continues to be required in order for the remedial/corrective action to remain protective.[7] Such a requirement is consistent with this Agency's obligation, for example under CERCLA remedy-selection criteria established in the National Contingency Plan at 40 C.F.R. §300.430(e)(9)(iii), to assess the long-term reliability of ongoing remedial measures as part of evaluating a remedy's effectiveness in protecting public health and the environment. This policy applies with respect to federal facilities that are expected to remain in the control of the federal agency for the foreseeable future. Because of significant differences in the kinds of measures which may be required to assure the effectiveness of LUCs after property passes out of direct federal agency control, this policy is not specifically applicable to situations involving imminent transfer of the facility to a private party; however, the objectives of this policy -- to assure long-term effectiveness of LUCs -- and the approach this policy utilizes for such assurances may be utilized for some situations involving a property transfer. This policy is applicable to Region IV federal facility: 1) CERCLA actions at NPL sites; and 2) HSWA corrective actions within non-HSWA authorized states. For their consideration as guidance, the policy will be provided to HSWA-authorized states and to those federal facilities taking CERCLA actions on non-NPL sites.

B.2.2 Applicable Definitions

As used in this policy, the term *"Land Use Control"* or *"LUC"* in regard to real property on federal facilities should be broadly interpreted to mean any restriction or control, arising from the need to protect human health and the environment, that limits use of and/or exposure to any portion of that property, including water resources. This term encompasses "institutional controls," such as those involving real estate interests, governmental permitting, zoning, public advisories, deed notices, and other "legal" restrictions. The term may also include restrictions on access, whether achieved by means of engineered barriers such as a fence or concrete pad, or by "human" means, such as the presence of security guards. Additionally, the term may involve both affirmative measures to achieve the desired restriction (e.g., night

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[7] During the initial ninety (90) days after this policy is issued, the requirement for a federal agency to commit to a LUCAP may be waived as a precondition to EPA's concurrence on any action, which, in the opinion of the Federal Facilities Branch Chief, might be unduly delayed if this precondition were applied.

lighting of an area) and prohibitive directives (no drilling of drinking water wells). Considered altogether, the "LUCs" for a facility, in conjunction with the base master plan, will provide a blueprint for how its property should be used in order to maintain the level of protectiveness which one or more remedial/corrective actions were designed to achieve.

The term *"Land Use Control Assurance Plan"* or *"LUCAP"* is a written installation-wide plan that sets out the procedure to assure LUCs remain effective over the long-term for all areas at the particular installation where they are required. Because of its procedural nature, there will normally be only one LUCAP per installation (although a number of "substantive" LUC Implementation Plans may be appended to it). Minimum contents of a LUCAP are listed below in Part A of Section IV.

The term *"LUC Implementation Plan"*, as used in this policy, refers to a written plan, normally developed after a decision document has required one or more LUCs for some particular area (operable unit, contaminated unit, and/or solid waste management unit) which (1) identifies each LUC objective for that area (e.g., to restrict public access to the area for recreational use) and (2) specifies those actions required to achieve each identified objective (e.g., install/maintain a fence, post warning signs, record notice in deed records). LUC Implementation Plans specify what must be done to impose and maintain the required LUCs, and are therefore analogous to design and/or operation and maintenance plans developed for active remedies.

The term *"decision document,"* as used in this policy, refers to CERCLA Records of Decision (RODs), RCRA Statements of Basis/ Notices of Decision, and RCRA Permit Modifications.

As used in this policy, the term *"facility"* refers to a military base or other entire federal installation, whereas the term "site" refers to a particular area (such as an "operable unit") making up only a portion of the facility.

The term *"monitoring"* is used in this policy to indicate a variety of investigative activities, ranging from mere "drive-by" visual observations to detailed scientific sampling and testing. The nature of the particular Land Use Controls being implemented will determine the type(s) and extent of any "monitoring" activities provided for under this policy.

B.2.3 Background

CERCLA and RCRA require cleanup of hazardous substances which have been released into the environment to a degree which is determined to be "protective of human health and the environment." How a piece of land is anticipated to be used in the future is frequently an important consideration in determining the extent of remediation necessary to achieve the required protectiveness. For example, assumptions about whether a piece of land is likely to be used in the future for residential or industrial activities may influence the evaluation of exposure pathways made during the baseline risk assessment, thereby affecting the likely exposure scenario, the resultant risk determined to be present, and consequently how much (if any) cleanup is needed to lower that risk to "protective" levels. Similarly, one or more aspects of a remedy chosen as the means of lowering the risk to "protective" levels may involve deliberate efforts to maintain or impose some limitation on future use of the property, such as limiting physical contacts with contaminated soil through engineered barriers or limiting legal rights to use groundwater resources by recorded deed restrictions, covenants or "institutional controls." In such circumstances, uncertainties about the future use assumptions and/or the ongoing effectiveness of the use limitations imposed are directly related to achievement of the central objective of the entire remediation process -- protection of human health and the environment. In light of EPA experience in this Region and elsewhere, that land use control and environmental protection programs have not been adequately coordinated to ensure adherence to LUCs, we believe that it is essential to adopt new, more reliable means for assuring that necessary LUCs are maintained. Because we regard inadvertent violations as the most probable reason why LUCs might not be maintained on federally-controlled property, we think that it is important for each federal facility relying on LUCs to commit to implementing an active LUC-monitoring process, and to raise the visibility of its LUCs through periodic reporting/certification by each such facility's base commander or top civilian manager reaffirming the ongoing integrity of LUCs to EPA and state environmental regulators. As described below, this process should be embodied in a facility-specific Land Use Control Assurance Plan (LUCAP).

B.2.4 Implementation

B.2.4.1 Land Use Control Assurance Plan: A LUCAP may be documented in a number of different ways, for example, in a Memorandum of Agreement (MOA) or a Federal Facility Agreement (FFA) between EPA, the State and the federal installation or service. The LUCAP should also be referenced in the base master plan. The LUCAP may be developed and signed prior to the next planned decision document in anticipation of its need, or its development within a specified time may be required by the next decision document, as a condition of EPA's concurrence. In the absence of an approved LUCAP or some specific, time-bound requirement for the development of one, the provisions of a LUCAP, as described below, shall be incorporated into any decision document that requires LUCs. Once the installation-wide LUCAP is in place, additional site-specific LUC Implementation Plans will be appended to it as final cleanup decisions are made.

All LUCAPs will include, at a minimum, the following:

1) A requirement that, after each decision document selecting any LUC, a LUC Implementation Plan must be developed and approved for the subject site (operable unit, corrective action unit and/or solid waste management unit). The LUC Implementation Plan must identify the land area under restriction (e.g., by a certified survey plat) and the LUC objectives for that area, and must specify the particular controls and mechanisms which will be used to achieve each identified LUC objective. Each site-specific LUC Implementation Plan will be attached to the LUCAP as it is approved so that the LUCAP will serve as a single facility-wide source documenting all LUCs.

2) Identification of the federal facility program and point-of-contact designated responsible for monitoring, maintaining and enforcing site-specific LUC Implementation Plans and site-wide LUCAP.

3) A commitment by the facility to request funds for maintaining LUCs in budget allocation requests.

4) A requirement for quarterly on-site monitoring by the facility for compliance with the LUC Implementation Plans throughout the remediation period, unless another monitoring frequency is approved in the LUC Implementation Plan.

5) A requirement for the facility to provide notification to EPA and state regulators and obtain their written concurrence whenever the facility anticipates any "major changes in land use" (defined below) for the sites subject to LUCs. The facility should notify the regulatory agencies as soon as a major land use change is anticipated in order to allow sufficient time for regulatory review and amendments to remedy selection decision documents. Such notifications should be made to the regulatory agencies at least 60 days prior to a major change in land use and should include:

    a) An evaluation of whether the anticipated land use change will pose unacceptable risks to human health and the environment or negatively impact the effectiveness of the remedy;

    b) An evaluation of the need for any additional remedial action resulting from the anticipated land use changes;

    c) A proposal for any necessary changes to the selected remedial action, and identification of procedural requirements (e.g., ROD amendment/RCRA permit modification) for the proposed changes.

The regulatory agencies should provide a written response in a timely manner after the facility's notification and request for review, taking into account the need to minimize any adverse impact upon facility operations.

The following are considered "major changes in land use":

a) A change in land use that is inconsistent with the exposure assumptions in the risk assessment that was the basis for the LUCs (either human health or ecological risk assessment). For example, the human health risk assessment assumed that a site is in "caretaker" status with a worker visiting the site once a week for 2 hours, and the proposed change in land use would have the worker at the site for 8 hours a day, 5 days a week. Any change from industrial, commercial or recreational land use to a more sensitive land use, such as housing, schools, hospitals, and/or day-care centers is a major land use change. Similarly, any change from industrial or commercial land use to recreational land use is also considered "major changes in land use." Further, any change in a land use that has been prohibited in order to protect the environment is also a major land use change. For example, an area with residual contamination may be prohibited from being used for creation of wetland habitat and the land use change would result in the creation of a wetland.

b) Any action that may disrupt the effectiveness of the remedial action. For example, excavation at a landfill, groundwater pumping that may impact a groundwater pump-and-treat system, or a construction project that may result in unacceptable exposure to an ecological habitat protected by the remedy.

c) Any other action that might alter or negate the need for the LUC. For example, any plan to actively remediate a site subject to LUCs in order to allow for unrestricted use.

6) A requirement for the facility to conduct field inspections at least annually to assess the conditions of all sites subject to LUCs. These inspections shall determine whether the current land use remains protective and consistent with all remedial action/corrective measures objectives outlined in the decision document.

7) A requirement for the designated official responsible for the facility operations (e.g., DOD Base Commander, DOE Site Manager) to certify the continued compliance with all site-specific LUC Implementation Plans described in an annual report to specified EPA and State officials. The annual report shall also serve to notify agencies of a change in designated officials or of land use changes that are not considered major under subparagraph 5 above.

8) A requirement for the facility to notify EPA and the State immediately upon discovery of any unauthorized "major change in land use" or any activity inconsistent with any LUC Implementation Plan and to describe what actions will be taken to ensure protectiveness.

9) A requirement for advance notification to EPA and the State in the event of that the facility contemplates any transfer, by sale or lease, of sites subject to LUCs in order to ensure adoption of such additional measures as may be needed to assure continued compliance with LUCs on the transferred property.

B.2.4.2 Decision Documents: All decision documents for sites at which the remedy involves LUCs will require reasonable assurances that LUCs will be effectively maintained and monitored. Compliance with a LUCAP which includes the minimum provisions listed above in Part A of this section is one method for satisfying this requirement. Decision documents establishing LUCs shall specify the general land use designation, the associated land use exposure assumptions and the general LUC objectives. The following information should be specified in any decision document requiring LUCs:

1) Assumptions made concerning current and expected future land use designation/exposure scenarios. The land use scenario(s) used in risk assessment upon which the risk management and remedy decisions are premised should be stated. Identify the Lead Agency's Current and Future Land Use Designation, how such designations were developed, and the human health/ecological exposure scenarios which may not be protective under less restrictive land uses. Specify the time period necessary for remediation/corrective measures and LUCs.

2) Identification of the LUC objectives that are necessary to ensure the protectiveness of the remedy decision. Specific means to achieve the LUC objectives may be included in the decision document on a case-specific basis. In general, the specific means of achieving the LUC objectives will be included in the site-specific LUC implementation plan.

3) A requirement to develop a site-specific LUC Implementation Plan, which will include site-specific controls and controls necessary to assure the protectiveness of the selected remedy. The LUC Implementation Plan may include, for example, site access controls, site security, operation and maintenance activities necessary to maintain any physical access control features, drilling controls, groundwater use controls, signs, etc.

B.2.4.3 Existing Decision Documents with LUCs: At some federal facilities one or more previously completed decision documents containing LUCs are currently in place. EPA intends to address these issues as a part of the 5-Year Review and/or as a part of the HSWA permit review. The review process should include an analysis of the effectiveness of LUCs, with emphasis on those LUCs not subject to a LUCAP. This policy is not intended to imply automatic reopening of previously completed decision documents. As needs are identified, EPA, in coordination with the state, will negotiate a schedule for developing LUC Implementation Plans with the affected facility. These LUC Implementation Plans will then be appended to the facility-wide

LUCAP. If a facility-wide LUCAP has not been developed, EPA will require submission of a LUCAP at the time the site-specific LUC implementation plans are due, in accordance with the negotiated schedule.

B.2.5 DISCLAIMER

This memorandum is intended solely to guide employees of the Federal Facilities Branch, EPA Region IV, in carrying out their responsibilities with respect to federal facility actions to which the guidance is expressly made applicable. It is also being distributed to HSWA-authorized Region IV states and to certain federal facilities taking CERCLA actions at non-NPL sites within Region IV for their consideration as guidance. This policy does not constitute rulemaking by EPA and does not create legal rights or obligations in any person or entity.

APPENDIX C

CHARACTERIZATION AND REMOVAL OF NAPLS AT KARST AND FRACTURED BEDROCK SITES

APPENDIX C
CHARACTERIZATION AND REMOVAL OF NAPLS AT KARST AND FRACTURED BEDROCK SITES

C.1 INTRODUCTION

Remediation of contaminated groundwater at military bases continues to demand a significant percentage of available military resources allocated for site remediation, and is likely to do so into the foreseeable future. Remedial actions for groundwater are dominated by pump-and-treat systems, which in many cases may need to operate for very long periods, i.e., greater than 100 years. At those sites where non-aqueous phase liquids (NAPLs) are known or presumed to be present, providing a continuing source of contamination to the groundwater, characterization of the extent of contamination, and removal of the contamination is a central technical challenge to achieve remedial action objectives. In addition to defining a cleanup level and point of compliance for the contaminants of concern (COCs), site remediation objectives will usually include a requirement that the NAPL be removed “to the extent practicable”. The definition of “practicable” must then be negotiated between the responsible party and the lead regulatory agency. Thus, considerable effort is now being directed at the characterization of the extent of NAPL contamination, and on removal of the NAPL. Both of these desirable technical goals, however, represent significant technical challenges. This is particularly the case for karst and fractured bedrock saturated zones contaminated with NAPLs. The following discussion addresses those technical issues that should be addressed at various stages of site remediation regarding source characterization and removal at karst and fractured bedrock sites.

Both source characterization and removal for NAPL sites are appealing technical goals. In the best of scenarios, the nature and extent of the NAPL in the subsurface can be characterized and complete source removal can be achieved. The degree of source removal should be sufficient to reduce the risk to receptors to an acceptable level, and should reduce the lifecycle costs of alternative remedies. These alternatives will usually include containment technologies (such as a permeable reactive barrier); slow mass removal technologies (such as pump-and-treat) and monitored natural attenuation, alone on in combination with other technologies. It is also important to note that the arsenal of source removal technologies that have progressed past the proof of concept stage is growing. Thus, alternatives to barrier or natural attenuation options are growing, with the potential for significant lifecycle savings at some sites while meeting the risk reduction goals inherent in the remedial action objectives. Unfortunately, at many sites, the potential for significant source removal is thwarted by the geologic realities of the subsurface, a situation that is especially acute at karst and fractured bedrock sites. Thus, the remediation team must assess carefully several key technical issues associated with source characterization and source removal at these sites before undertaking what is likely to be an expensive strategy. The following key questions must be addressed during certain stages of site remediation:

- Does the site conceptual model suggest that NAPL is likely to be present in the saturated zone?

- If NAPL is likely present, what source characterization efforts will be required to locate and quantify the amount of NAPL present? Moreover, what is the level of accuracy required, and can this level be achieved by current site characterization tools?

- If the amount and spatial distribution of NAPL can be adequately characterized, what level of source removal will be required to reduce the risks to human health and the environment associated with the groundwater contamination? Can this level of NAPL removal be achieved with currently available technologies?

- If the amount and spatial distribution of NAPL can be adequately characterized, what impact will source removal have on the time required to meet the remedial action objectives for the groundwater? Is the potential reduction in mass discharge from the source area sufficient to reduce the lifecycle costs of the remedial action?

- Do the benefits in reducing the duration of groundwater cleanup or the reduction in mass discharge outweigh the expected costs of the source removal action, taking the risk of failure into account?

Addressing these questions requires fundamental understanding of the fate and transport of NAPLs in the subsurface. Sufficient experience is now available, however, to provide an adequate assessment of these questions.

C.2 DNAPL CHARACTERIZATION

Field, laboratory, and modeling experience in North America and Europe indicate that DNAPL distributes itself in the subsurface in very complicated and unpredictable ways. The DNAPL is believed to exist in the subsurface in the form of disconnected pools and globules, the locations and geometries of which are dictated by a number of factors. Probably the most influential factor is soil/rock heterogeneity. It is virtually impossible to locate all such DNAPL bodies within the overall source zone. It follows that sampling to estimate DNAPL mass, either before or after remediation, is fraught with large uncertainties.

C.3 DNAPL DISSOLUTION

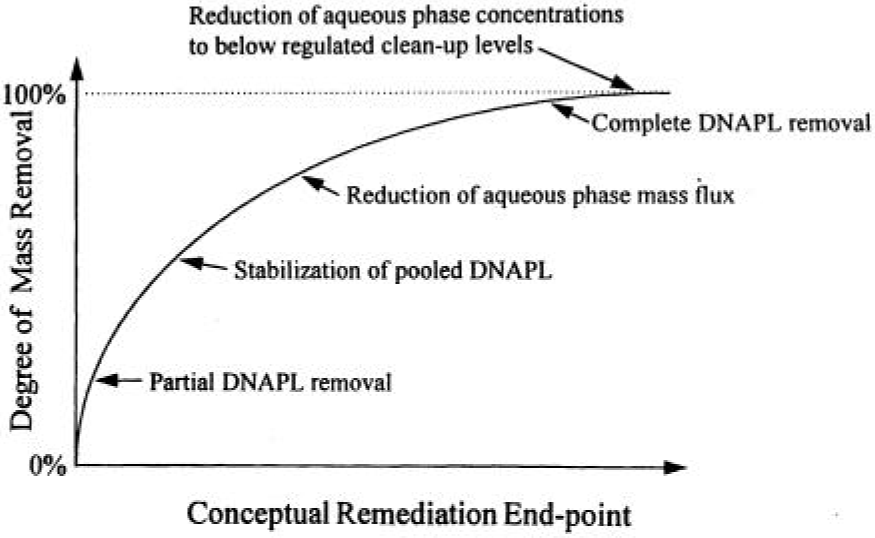
More important, perhaps, is a consideration of the physics that govern the process of groundwater contamination from a DNAPL source zone. The chemicals that comprise the DNAPL dissolve into groundwater that contacts a DNAPL pool or globule. At the interface between the DNAPL and the water, the aqueous concentrations of chemicals reach values dictated by the mole fractions of the various constituents of the DNAPL. Because the volume of water that actually contacts DNAPL is usually a small fraction of the total volume of water passing through the source zone, the average concentration in source-zone effluent is well below the concentrations that one would expect based on solubility considerations alone. This dilution effect makes it appear as if the dissolution process was kinetically controlled.

Dissolved phase contaminant concentrations passing through a DNAPL source zone typically reach their effective solubility levels near the upgradient side of the source. As the groundwater continues to pass through the source zone, the concentrations do not increase any further. Therefore, the dissolution of the DNAPL occurs almost entirely on the upstream side of the source zone, and the volume of DNAPL in the source zone downgradient of the maximum dissolution zone has little or no effect on the dissolved phase concentrations in the rest of the plume. The practical implications of this phenomenon are as follows. Suppose all DNAPL were removed except a small region near the upstream limit of the source zone. Such removal would have no short-term effects on the concentration in the source-zone effluent because influent waters would still contact the DNAPL on the upstream side and attain the same concentrations as before removal. The same conclusion is reached if the DNAPL is removed from the downstream side.

If source removal occurs so as to remove DNAPL uniformly over the source zone, then there is less probability that water will contact the small amount of DNAPL that is left, and concentrations in the source-zone effluent will be reduced. But by how much? The effect of the percent reduction in the dissolved phase plume will be proportional to the percent reduction in the cross sectional area of the source zone along the groundwater flow path. Therefore, if 90% of the DNAPL is removed from the source zone, approximately a 90% reduction in the dissolved phase plume can be expected. The question, then, is whether this level of removal is adequate.

From the perspective of meeting MCLs at individual monitoring points, source removal appears futile at sites contaminated with NAPLs. Supposing that contaminant concentrations within the dissolved phase plume are approximately 1,000 mg/L prior to remediation, a 90% reduction in concentration following remediation would result in a concentration of 100 mg/L. This level exceeds MCLs for most organic constituents by orders of magnitude. A removal of 99.9 percent would still leave about 1 mg/l in the source-zone effluent, and this is still well above most MCLs. The relationship between mass removal and remediation end point is illustrated conceptually in **Figure C.1**.

Figure C.1. Conceptual graphical representation of degree of mass removal required achieving certain remediation end-points



Of the thousands of sites that are contaminated with DNAPLs in the United States, very few have been remediated to the point where MCLs have been reached.

At some sites, however, a reduction in the mass of DNAPL in the source area may reduce the mass discharge of the contaminant leaving the source area. Whether this reduction in mass discharge is sufficient to reduce lifecycle costs while meeting risk reduction goals must be determined on a site-specific basis.

C.4 MATRIX DIFFUSION

Another factor that makes complete removal of DNAPL from fractured and karst media extremely difficult is DNAPL disappearance or matrix diffusion. The phenomenon of matrix diffusion is driven by a DNAPL concentration gradient between the high concentrations in fracture apertures and the lower concentrations in the rock matrix. Through this process, it is possible for a large percentage of the source to be present in the matrix of the bedrock and not “easily” accessible in the bedrock fractures. An added complicating factor when trying to remediate a source zone with a large mass of contaminants in the matrix is reverse dissolution. Because matrix diffusion and dissolution is driven by a concentration differential, the rate of dissolution out of the matrix is orders of magnitude slower than diffusion into the matrix. This is due to the concentration differential between the matrix and the fracture that is lower than between the DNAPL and the clean matrix pore waters. The effects of matrix diffusion and dissolution on source removal result in a continued “bleeding” of contaminants from the matrix into the fractures thereby increasing the timeframe required to meet contaminant regulatory limits. On the other hand, such matrix diffusion will reduce the mass discharge from the source area. In some cases, this reduction may be sufficient to shift the remedial action to natural attenuation (Reynolds and Kueper, 2002).

C.5 CLEANUP DURATION

Consideration should also be given to the effects of source removal on the duration of the cleanup of the dissolved phase plume. When evaluating the removal of a source, an evaluation should be made as to the expected time reduction in the long-term remedial solution for the plume. The question being posed here involves a clarification of whether source removal will significantly reduce the time required to meet remedial objectives for the contaminant plume. If it is determined that there is a significant reduction in time to reach the end point, then a cost benefit analysis should be conducted which utilizes a net present value approach for source removal. The resulting analysis will aid in determining whether there is economic value in removing the source versus a strategy of long-term plume containment through a pump-and-treat technology or by using an alternative remedial approach such as a reactive barrier wall. The risks associated with long-term institutional management of the remedial action must also be accounted for, including replacement costs, and possible system failure or institutional neglect.

C.6 RISK REDUCTION

An important consideration when completing a source removal benefit analysis is the element of risk reduction. Typically, an evaluation of risk from the source area and the resulting plume is conducted prior to the process of determining the need for a source removal action. This evaluation of risk should take into account the mass flux impacting the receptor. If there is no significant risk from a source as indicated by a mass flux calculation, then source removal may be unnecessary, for achieving site closure. On the other hand, a reduction of the mass in the source area may sufficiently reduce dissolved concentrations in the plume causing a decrease of mass flux from the source area, resulting in reduction of risks at a receptor to below the regulatory limit.

C.7 SOURCE CONTAINMENT

If source removal is not technically possible or warranted as indicated by the calculation of mass flux and risk, source zone containment should be considered. In such cases, selected technologies such as reactive barrier walls or hydraulic containment, should be pilot-tested to determine the lifetime of the selected technology versus the required time for containment. Thus, the operations and maintenance costs associated with the selected technology can then be calculated. Other factors such as the long-term reliability of barrier technologies, and the reliability of long-term institutional management must also be considered in this analysis.

C.8 CONCLUSIONS

In the case of DNAPL source areas, there is no one proven technology for the restoration of groundwater to MCLs at karst and bedrock environments and other sites where restoration may be unfeasible mostly as a result of the geologic complexities associated with these types of terrain. As was discussed earlier, to have any possibility of reaching MCLs at many sites, the mass of contaminants in the source zone must be reduced by at least two orders of magnitude. In most cases, such reductions in contaminant masses at karst and bedrock sites are not currently achievable using available technologies. On the other hand, lower levels of source removal (e.g., less than 50 percent mass reduction) may be sufficient at some sites to reduce mass discharge from the source area to levels supporting the use of monitored natural attenuation or no further action if risks at receptors can be reduced below regulatory levels.

At bedrock and karst sites, source characterization and source removal represent significant technical challenges as noted. A balance must be achieved between risk reduction and lifecycle costs of any remedial action, taking into account technical infeasibility of complete restoration at the majority of such sites. The earlier these technical limitations are noted, the more effective will be site remediation strategy to meet the needs of all stakeholders.

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APPENDIX D

TECHNICAL IMPRACTICABILITY OF GROUND-WATER RESTORATION

APPENDIX D
TECHNICAL IMPRACTICABILITY OF GROUNDWATER RESTORATION

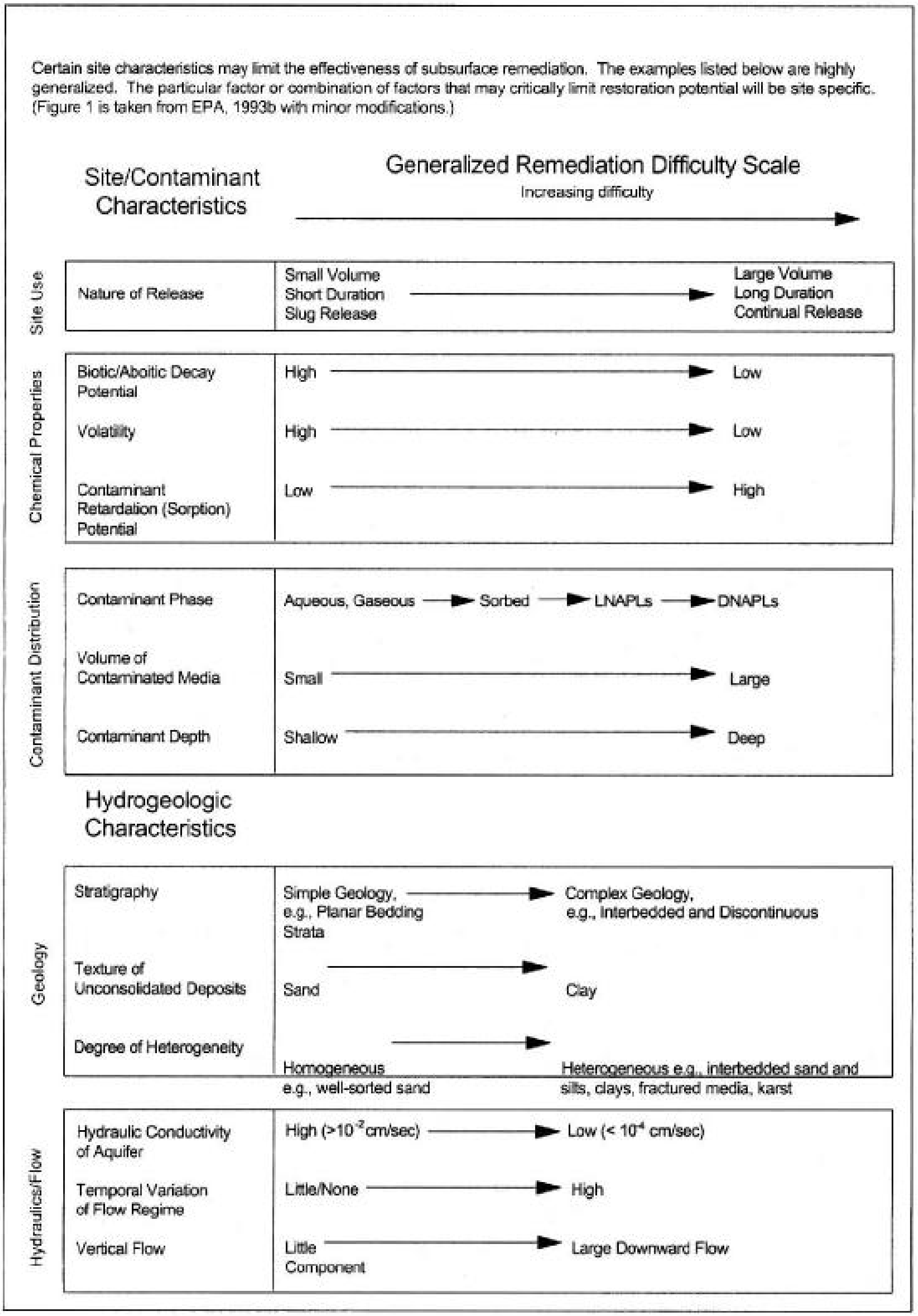
D.1 TECHNICAL IMPRACTICABILITY OF GROUNDWATER RESTORATION

Recent scientific literature and regulatory guidance documents suggest that the remediation of groundwater in the presence of DNAPL sources in a complex geologic setting may be technically impracticable. As stated in the EPA Guidelines for Evaluating the Technical Impracticability of Ground-Water Restoration (1993), “EPA recognizes that locating and remediating subsurface sources can be difficult. For example, locating DNAPLs in certain complex geologic environments may be impracticable. Delineation of the extent of the DNAPL zone may be difficult at certain sites due to complex geology or waste disposal practices.” The report goes on to state “EPA recognizes that there are technical limitations to ground-water remediation technologies unrelated to the presence of a DNAPL source zone. These limitations, which include contaminant-related factors (e.g., slow desorption of contaminants from aquifer materials) and hydrogeologic factors (e.g., heterogeneity of soil or rock properties), should be considered when evaluating the technical practicability of restoring the aqueous plume.” **Figure D.1** from the TI guidelines illustrates the factors affecting the potential for groundwater restoration.

The EPA’s Rules of Thumb for Superfund Remedy Selection (1997) also states “The presence of DNAPLs can significantly impact the restoration potential of the site. Where DNAPLs (or other persistent contamination sources) are present in the subsurface and cannot be practicably removed, containment of such sources may be the most appropriate remediation goal. In such cases, a TI waiver should be invoked for the DNAPL zone.

The National Research Council (NRC, 1994) categorized sites according to their technical infeasibility, as can be seen in **Table D.1** from their book.

Figure D.1. Examples of Factors Affecting Groundwater Restoration Potential



Certain site characteristics may limit the effectiveness of subsurface remediation. The examples listed below are highly generalized. The particular factor or combination of factors that may critically limit restoration potential will be site specific. (Figure 1 is taken from EPA, 1993b with minor modifications.)

Site/Contaminant Characteristics

Generalized Remediation Difficulty Scale

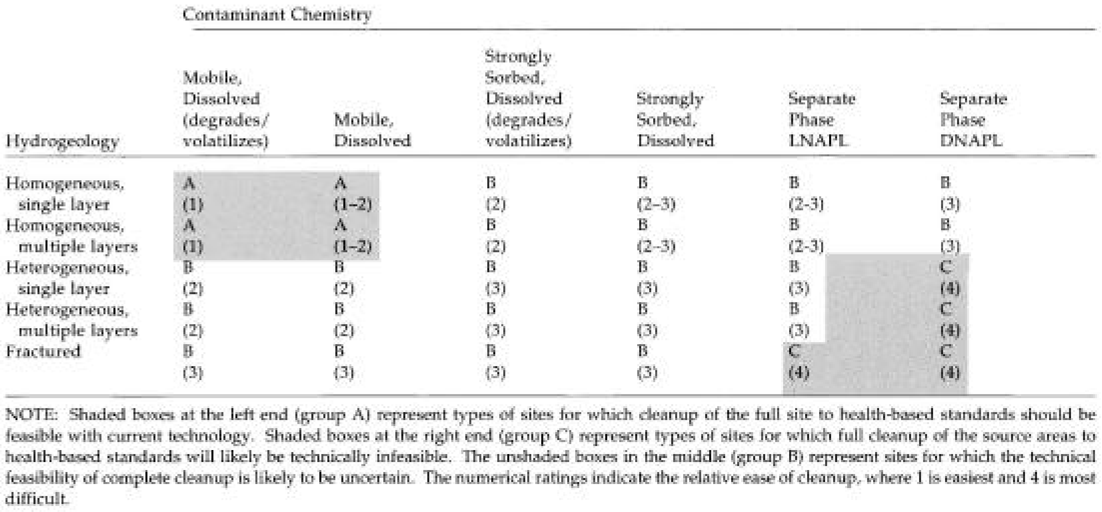
Increasing difficulty →

Site Use	Nature of Release	Small Volume Short Duration Slug Release	→ Large Volume Long Duration Continual Release
Chemical Properties	Biotic/Aboitic Decay Potential	High	→ Low
	Volatility	High	→ Low
	Contaminant Retardation (Sorption) Potential	Low	→ High
Contaminant Distribution	Contaminant Phase	Aqueous, Gaseous → Sorbed → LNAPLs	→ DNAPLs
	Volume of Contaminated Media	Small	→ Large
	Contaminant Depth	Shallow	→ Deep

Hydrogeologic Characteristics

Geology	Stratigraphy	Simple Geology, e.g., Planar Bedding Strata	→ Complex Geology, e.g., Interbedded and Discontinuous
	Texture of Unconsolidated Deposits	Sand	→ Clay
	Degree of Heterogeneity	Homogeneous e.g., well-sorted sand	→ Heterogeneous e.g., interbedded sand and silts, clays, fractured media, karst
Hydraulics/Flow	Hydraulic Conductivity of Aquifer	High (>10^{-2} cm/sec)	→ Low (< 10^{-4} cm/sec)
	Temporal Variation of Flow Regime	Little/None	→ High
	Vertical Flow	Little Component	→ Large Downward Flow

Table D.1. Categories of Sites for Technical Infeasibility Studies



	Contaminant Chemistry					
Hydrogeology	Mobile, Dissolved (degrades/ volatilizes)	Mobile, Dissolved	Strongly Sorbed, Dissolved (degrades/ volatilizes)	Strongly Sorbed, Dissolved	Separate Phase LNAPL	Separate Phase DNAPL
Homogeneous, single layer	A (1)	A (1–2)	B (2)	B (2–3)	B (2-3)	B (3)
Homogeneous, multiple layers	A (1)	A (1–2)	B (2)	B (2–3)	B (2-3)	B (3)
Heterogeneous, single layer	B (2)	B (2)	B (3)	B (3)	B (3)	C (4)
Heterogeneous, multiple layers	B (2)	B (2)	B (3)	B (3)	B (3)	C (4)
Fractured	B (3)	B (3)	B (3)	B (3)	C (4)	C (4)

NOTE: Shaded boxes at the left end (group A) represent types of sites for which cleanup of the full site to health-based standards should be feasible with current technology. Shaded boxes at the right end (group C) represent types of sites for which full cleanup of the source areas to health-based standards will likely be technically infeasible. The unshaded boxes in the middle (group B) represent sites for which the technical feasibility of complete cleanup is likely to be uncertain. The numerical ratings indicate the relative ease of cleanup, where 1 is easiest and 4 is most difficult.

***Source**: NRC, 1994.*

When planning an approach for remediating a site, it is extremely important to recognize from the outset the presence of complexities such as those indicated in Category 4. Failure to account for these complex conditions can result in the establishment of unrealistic cleanup goals." As an example, at 18 of the 77 sites reviewed for this study, the remedial actions failed to contain the groundwater contamination. The likely reason for this failure was the inaccurate characterization of the horizontal and vertical extent of contamination. Recognition of the difficulty in characterizing this type of site and the technical impracticability of groundwater restoration could prevent the establishment of unrealistic cleanup goals.

To further illustrate the difficulty of cleaning up Category 4 sites, the report presents case study statistics and states that "cleanup of sites in Category 4 to health-based standards is extremely unlikely, although in most cases containing the contamination and shrinking the contaminated area is possible. Sites in Category 4 have either LNAPLs in fractured rock aquifers or DNAPLs in heterogeneous or fractured rock aquifers. Removing NAPLs from fractured rock and heterogeneous regions poses the most extreme of technical challenges because of the difficulty of circulating water through these regions and the difficulty of dissolving NAPLs. Of the 34 sites in Category 4 and the 8 sites on the borderline between categories 3 and 4 in **Figure D.1**, none have been fully cleaned up."

D.2 REFERENCES

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APPENDIX E

GUIDANCE FOR CONDUCTING PILOT STUDIES AT KARST AND FRACTURED ROCK SITES

APPENDIX E
GUIDANCE FOR CONDUCTING PILOT STUDIES AT KARST AND FRACTURED ROCK SITES

E.1 INTRODUCTION

Typically, pilot studies are conducted for the purpose of evaluating the technical and economic feasibility and applicability of a technology or a combination of technologies at a given site. At CERCLA sites, feasibility evaluations are made to satisfy criteria established in the National Contingency Plan (NCP) including overall protection of human health and the environment, compliance with ARARs, long-term effectiveness, short-term effectiveness, implementability, cost, and reduction of toxicity, mobility, or volume through treatment. Similar analyses can be made for RCRA, state, or local-lead sites. Pilot studies can also be used to initiate source control or site remediation activities especially at smaller sites.

It is often impracticable to meet ARARs at karst or fractured rock sites when DNAPL is present. Within the context of overall performance, technology evaluations through pilot studies should focus on effectiveness of contaminant mass removal, contaminant mass discharge reduction (i.e. reduction in the mass of contaminant per unit time migrating from the expected source area), and determination of mass removal rates and boundary mass discharge rates if aquifer restoration is not practicable.

Several key steps are necessary to perform an effective pilot study. Once the decision has been made to conduct such a study (go/no go decision), the key steps include definition of study objectives, technology selection, study design, and pilot study performance and data analysis. Each of these steps is discussed below:

E.2 GO NO-GO DECISION MAKING

Before initiating a pilot study project, careful consideration should be given to determine if a pilot study is appropriate. General guidance for technical project planning can be found in

EM-200-1-2. Although there is a wide range of costs for performing pilot studies, such studies at karst and fractured rock sites are at the higher end of the cost spectrum. Cost-benefit comparisons should be made between the costs of performing a pilot study versus the potential benefits of the information from the tests.. For example, in the case of NAPL removal at karst and bedrock sites, residual NAPL could still cause a significant dissolved contaminant plume and a mass discharge equivalent to that prior to NAPL source removal. Thus, source removal under these conditions may have little impact on lifecycle costs, based on present worth comparisons. The value of the pilot test should also be considered with respect to addressing stakeholder concerns about mass removal and the issue of technical impracticability.

At karst or fractured bedrock sites where active remediation is planned either to achieve project objectives or as required by regulatory authorities, a pilot study is strongly recommended. Due to the intricacy of subsurface geology and the complexity of contaminant fate and transport processes in consolidated media, it could be difficult to design a full-scale remediation system based only literature reviews, bench and laboratory scale studies, or modeling.

If performed correctly, the data obtained from pilot studies can be used to provide an essential understanding of NAPL or contaminant plume response to a given technology configuration. Specifically, the ability of such a technology to reduce contaminant mass, mass discharge, and the rate of mass discharge reduction can be assessed by pilot studies. In practice, pilot test designs should include pre-test and post-test mass flux analyses to provide an estimate of the effect mass removal may have on the contaminant plume outside the test zone. At complex DNAPL sites, a detailed characterization of the spatial variation of groundwater velocity and the DNAPL occurrence is needed for estimating mass flux. **Appendix F** presents additional information on the level of site characterization needed to estimate mass flux at complex DNAPL sites. This increased understanding of mass reduction can be used to determine if the technology will in fact reduce risks at the site or provide significant reductions in lifecycle costs.

Thorough site investigations are recommended prior to proceeding with pilot studies. However, it is possible to perform a pilot study in a well-characterized portion of the site (e.g., source area) without complete understanding of contaminant distribution, subsurface geology, and transport mechanisms throughout the entire site. If a pilot study is performed to evaluate NAPL remediation, location of some of the NAPL is essential. This location can often be inferred from water quality sampling results if no DNAPL is actually observed, which commonly occurs.

E.3 DEFINING STUDY OBJECTIVES

The definition of study objectives is critical for the effective design and implementation of a pilot study. Typical objectives may include determination of process feasibility, collection of relevant design and cost data, performance of additional site characterization, or interim site remediation. Specific data quality objectives are discussed in more detail in the section titled "Study Design". Inherent in the need to assess the influence of a technology on risk reduction or lifecycle costs is an assessment of not only the degree of mass removal, but also the impact of mass removal on the aqueous plume.

E.4 TECHNOLOGY SELECTION

Many technologies that are typically considered for shallow aquifer systems or unconsolidated saturated deposits can be eliminated from further consideration for karst and fractured rock sites. On a programmatic level, for multiple sites or source areas, a presumptive list of applicable technologies can be developed for karst and fractured rock sites through preliminary technology screening. Several technologies presented in **Table E.1** have shown promise at karst and fractured rocks sites. Many of these technologies continue to be demonstrated at the pilot scale and in some cases at the full scale. Innovative technologies continue to be developed and demonstrated and may also merit consideration. Advantages and disadvantages of these technologies in karst and fractured bedrock sites are summarized.

Table E.1. Remedial Technologies Applicable to Karst and Fractured Rock Sites

Technology	Key Advantage(s)	Key Disadvantage(s)
In-Situ Air Sparging	▪ Transfer of contaminant from aqueous phase	▪ Not applicable for NAPL ▪ Channeling prevalent in fractured media
In-Situ Chemical Oxidation	▪ Contaminant destruction ▪ Can be applied to NAPL	▪ Chemical handling ▪ Proprietary chemical or delivery system costs ▪ Potential geochemical interactions
Multiphase Extraction	▪ NAPL recovery ▪ Vapor phase recovery	▪ Slow rate of mass removal for dissolved phase ▪ Ex-situ treatment required
Hydraulic Control (Pump & Treat)	▪ Common and readily available technology	▪ Slow or ineffective rate of mass removal ▪ Ex-situ treatment required ▪ Treated water disposal ▪ Long term O&M
Waterflooding	▪ NAPL recovery ▪ Increased advective rates	▪ Slow rate of mass removal for dissolved phase ▪ Ex-situ treatment required
Surfactant Enhancement	▪ Can improve P&T performance	▪ Increased mobility can cause uncontrolled contaminant migration
Biostimulation or Bioaugmentation	▪ Contaminant destruction ▪ Enhances natural physical and chemical process	▪ Limited ability of rock formation to sustain biomass ▪ Formation of toxic daughter products (typically under anaerobic conditions
Natural Attenuation	▪ Low capital costs ▪ Utilizes available physical, chemical, and biological mechanisms	▪ Extensive data collection requirements ▪ Little to no control over performance
Thermal Destruction	▪ Contaminant destruction ▪ Matrix penetration	▪ High energy requirements
Physical Barriers	▪ Site boundary control	▪ No control of vertical migration ▪ No treatment ▪ Depth limitations
Treatment Barriers	▪ Site boundary control ▪ Contaminant destruction or mass transfer to other phase	▪ No control of vertical migration

A thorough literature review is recommended prior to selecting pilot study technologies. This preliminary effort can be complemented by bench scale testing and modeling as predecessors to a pilot study.

E.5 PILOT STUDY DESIGN

Once a decision has been made regarding the performance of a pilot study, and following the determination of study objectives and technology selection, a detailed design of the pilot study is recommended. Design guidance exists for most of the technologies presented in **Table E.1**. However, the focus of such guidance documents or design manuals is generally of most use for overburdened aquifer systems. When designing a pilot or full-scale system for bedrock site remediation, there is no substitute for experience. Qualified and experienced personnel should be made available to participate in the design effort.

Pilot design considerations include, but are not limited to the following:

- Data needs, expectations and collection methodologies;
- Tests variations, including tracer studies;
- System configuration and scale of the system (e.g., numbers of wellpoints, injection points, or trenches);
- Site layout;
- System operation, and degree of automation and instrumentation;
- Weather-guarding and weather-proofing;
- Redundancy and flexibility integration, and backup systems and components;
- Effective study duration for each phase of the study;
- Health and safety considerations;
- Permitting considerations;
- Documentation of startup and operation and maintenance (O&M) procedures.

Guidance for development of sampling and analysis plans for pilot studies can be found in EM 200-1-3. Data quality objectives may include determination of mass reduction rates, radius of influence of extraction technologies, treatment response to system operation variation (i.e., system operation optimization), effect of enhancements, and changes in system efficiency with time (e.g., clogging or fouling of well screens or pumps with time).

E.6 PILOT STUDY PERFORMANCE/DATA ANALYSIS

The pilot system should be designed to allow for flexibility, such that interim data review and analysis can be conducted periodically during the study to assess the performance of the system. Modifications to operational parameters (e.g., flow rates, pressures) and system configuration (e.g., treatment points, monitoring points, or system equipment) should be made to demonstrate system performance under stressed conditions to verify system reliability.

Upon completion of the study, an assessment of the adequacy of the information collected compared to study objectives should be completed. Judgment is required to determine if the data quality objectives have been satisfied. Additional data gaps or need for additional studies should be identified and prioritized.

E.7 SCALE-UP ISSUES

Evaluation of the pilot test results must include an assessment of the scale-up to full-scale application. Can the pilot test results be extrapolated to other regions of the source area? Given the degree of site anisotropy, understanding of fracture network, and knowledge of active flow and transport zones; the results from a pilot study in one area of the site may not be applicable to other areas of the site and additional pilot studies may be necessary. Pilot tests are often performed in comparatively homogeneous and well characterized portions of the source area in order to simplify interpretation of the test results. Full-scale application of the technology often encounters heterogeneities in geology and contaminant distribution not present in the pilot test area.

The ultimate goal of the study is to determine whether implementation of the technology tested will provide reduction in risks, and reduction in lifecycle costs for site remediation. The decision to implement the technology following completion of the pilot study rests on a determination of technical and economic feasibility to achieve the remediation goals established for the site. In the case of karst and bedrock sites contaminated with DNAPL, pilot studies may be needed to verify that it is technically impractical to achieve complete aquifer restoration. Thus, pilot studies serve multiple uses. They are essential for determining the technical and economic feasibility of a technology for site remediation and they provide the basis for verifying whether or not aquifer restoration can be achieved taking into account cost and risk reduction.

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APPENDIX F

NATURAL ATTENUATION/FLUX ANALYSIS

APPENDIX F
NATURAL ATTENUATION/FLUX ANALYSIS

F.1 INTRODUCTION

Flux analysis is a technical term that is finding growing use in site remediation efforts. The term is defined as a calculation of the mass of a contaminant of concern (COC) in the saturated zone passing through some hypothetical vertical boundary per unit cross sectional area per unit time. Thus, the mass flux at any given point in space and time is simply a product of the discharge velocity or Darcy velocity at that point and the concentration of the COC in appropriate units.

The estimate of mass flux is critical to both the feasibility and design analyses of in-situ remediation technologies relying on physical, chemical or microbial transformations of the COCs needed to meet remedial action objectives at the site (e.g., achieving MCLs throughout the contaminated aquifer or achieving MCLs at a property boundary). Mass flux becomes an important design parameter that significantly controls the scale of the in-situ technology. The mass flux will determine the amount of electron acceptors or donors that must be added to the aquifer to support an in-situ bioremediation option, such as aerobic degradation of BTEX compounds, or anaerobic dehalogenation of chlorinated solvents. Design of other in-situ technologies such as air sparging, monitored natural attenuation, or permeable reactive barriers also depends in part on accurate estimates of the mass flux of COCs. Finally, mass flux calculations permit an estimate of the time required to remove a NAPL source from the saturated zone. A second, but less frequently observed, application of mass flux analysis is the use of this parameter to establish alternative remedial action objectives in lieu of concentration limits, such as MCLs. In this context, mass flux estimates at a selected cross sectional boundary in the saturated zone can be established such that concentrations of the COCs at receptors downgradient from the source area are maintained within agreed upon limits. These limits could be MCLs or they could be risked-based targets established using appropriate risk analysis calculations for human health or ecological risks. It is thus conceptually possible to establish mass flux limits at the selected boundary and to use these limits as the end points of the remediation strategy. That is, the active or passive remediation technologies will be considered successful if the mass flux of the COC at the selected boundary meets the mass flux limit established.

Conceptually, a mass flux analysis provides a methodology to evaluate the benefits of source removal. Prior to source removal, the mass flux emanating from a source area plane and the mass flux at a downgradient plane of compliance is estimated. The difference between the two flux measurements provides an estimate of the natural attenuation rate downgradient of the source area. The efficacy of a proposed source removal or source containment can be evaluated by assuming a percent reduction in flux at the source area plane, applying the attenuation rate, and estimating the resulting flux at the plane of compliance. The progress of a source removal or containment remedy can be measured by performing periodic flux analyses after implementation.

The critical question is whether this approach to design and to setting RAOs can replace or simply compliment current RAOs established on the basis of concentration limits. The latter approach is usually designed to restore the aquifer to a condition where no treatment would be required if the aquifer were to be used as a source of drinking water, beyond what would have been required before the aquifer became contaminated by site releases. The mass flux approach is particularly useful when it is technically impractical to achieve aquifer restoration. This is most often the case at sites where the geologic and chemical conditions make restoration impractical, such as karst and fractured bedrock sites contaminated with DNAPLs. The following discussion provides a brief overview of the technical considerations that must be addressed when mass flux analyses are used for establishing RAOs.

F.2 TECHNICAL CONSIDERATIONS

Conceptually, calculation of the mass flux at any point in time and space is simple. However, in the context of highly heterogeneous geologic environments, these calculations become problematic. If the saturated zone is relatively homogeneous, with no preferential pathways, the mass flux becomes primarily a function of time, and can be considered a two dimensional problem. That is, the mass flux at the selected boundary is independent of location in the two-dimensional space. Thus, the technical challenge is to estimate the existing mass flux at the moment that the groundwater samples were collected, and to predict the mass flux at the boundary over time with or without remedial actions.

If the aquifer is sufficiently heterogeneous such that preferential pathways or active flow zones exist and dominate the advective flow regime (i.e., flow through these zones or pathways represents greater than 90 percent of the horizontal flow), then the flow through these zones and the concentration of the COC within these zones must be calculated. Sufficiently accurate characterization of these zones thus becomes essential for accurate estimates of the mass flux. In many instances, the saturated zone can be considered as an equivalent volume of porous media (EPM), and Darcy's law can be applied along with the concentrations measured using the groundwater monitoring network.

For karst and bedrock sites, however, the assumption that the saturated zone can be modeled as an equivalent porous media may not be valid. This approach remains valid for fractured, and karst media when the fractured and solution channel spacing is sufficiently dense such that the medium acts as an equivalent porous media. When the fracture and solution channel spacing have low densities in the system, flux calculations should be conducted on an individual fracture or solution channel basis. Through experimentation, it has been shown that Darcy's Law can be used in fractured or Karst media if the Reynolds number is between 1 and 10. In Karst formations, flow rates typically exceed the upper limits of Darcy's Law thus necessitating that the calculation of flux be based on an individual cavern or solution channel basis rather than on a discharge face where a large volume of rock does not contribute significantly to the over-all flux of groundwater and or contaminants. The site conceptual model must address this problem through appropriate site characterization techniques and a careful analysis of preferential pathways such as fracture or solution channels.

F.3 CHARACTERIZATION

Numerous investigation techniques exist to characterize fractured media and karst settings to access the appropriateness of the equivalent porous media model. At complex fractured rock and karst sites the investigation objectives should include determination of the spacing and hydraulic characteristics of preferred pathways, which can range from joints and bedding planes in fractured rock to water bearing caverns in karst. The necessary investigative approach includes surface investigations, combined with integrated borehole geophysical logging and hydraulic testing. The following is a brief summary of some of the available techniques:

- **Site-wide/Regional Methods**
  - Fault Trace Lineaments and geologic mapping;
  - Aerial and surface geophysical mapping;
  - Aerial thermal infrared mapping to locate spring discharges in karst;
  - Dye tracing in karst to determine recharge and discharge areas of conduit flow zones.

  The need for these investigative methods depends upon the hydrogeologic setting of the site and the scale of the preferred pathway. Groundwater tracing using dyes is an essential technique used for determining recharge and discharge zones, general directions of groundwater flow, and residence times for groundwater in high flow rate conduits.

- **Bedrock Coring and Borehole Geophysics**

  At present, bedrock coring is one of the simplest tools available for determining fracture frequency and orientation. Data gathered during the coring process includes fracture spacing, fracture roughness and mineral precipitation within the fractures. However, the usefulness of coring data can be limited by incomplete core recovery, and should be supplemented with borehole geophysical data.

Numerous borehole geophysical methods for fracture/solution cavity identification are currently available and range from the traditional caliper logs to the more sophisticated acoustic televiewers and Borehole Image Processing (BIPs) tools. Both acoustics televiewer systems and BIPs are capable of determining fracture orientation and apertures in a three dimensional image. An open hole logging suite should also include normal resistivity logs, natural gamma ray log, flow meter and water quality logs.

- **Borehole Flow Logging**

  Hydraulically active fracture zones can be identified using high-resolution heat-pulse or electromagnetic flow meters. This data can tie the geophysical borehole data to borehole hydraulics. Hydraulically active fractures and solution openings identified in boreholes are connected between boreholes to form flow systems. Cross-borehole aquifer tests are capable of determining the degree of anisotropy and the hydraulic conductivity of fractured media. Through the use of straddle packer injection tests in individual open hole wells, or flow meter logging in adjacent wells, it is possible to determine the transient response to pumping, and estimate fracture transmissivity.

- **Tracer tests**

  The use of these tests allows for the collection of information on the effective porosity of fractured media and matrix diffusion rates associated with the media. Both of these parameters are used in the flux calculations as discussed below..

While each of the tests discussed above have their individual advantages and disadvantages, they are best used in conjunction with one or more of the remaining tests so that each successive method builds on the data collected with the previous method.

F.4 DISCUSSION ON MATRIX DIFFUSION

Another parameter that must be taken into consideration when determining contaminant flux from a site is the effect of matrix diffusion. Matrix diffusion can significantly influence the flux of contaminants discharging from a system especially if the furthest down gradient monitoring point is not directly adjacent to the discharge boundary. In addition, matrix diffusion can extensively retard the advance of a contaminant front as well as drastically reduce the potential of risk at a discharge point down gradient of the site. The matrix diffusion rate is proportional to the concentration gradient between the fracture and the adjacent bedrock matrix with contaminants moving from areas of high concentration to those with lower concentrations. This process is generally described using Fick's First Law:

$$J_D = -\phi \bullet D_e \bullet \delta C_w / \delta x$$

where:

J_D = diffusive flux (mass/area/time)
ϕ = matrix porosity
D_e = effective diffusion coefficient in the porous media
C_w = dissolved aqueous phase contaminant concentration
x = distance

Many of the above parameters can be approximated either using the field investigation methods described above or by laboratory scale testing. While diffusive flux into the matrix can effectively reduce concentrations at a discharge boundary to below acceptable risk levels, it should be noted that a reversal of the concentration gradient could occur thus allowing elevated concentrations in the matrix to diffuse back into the fracture thereby increasing the concentrations once again in the formation (Reynolds and Kueper, 2002)

F.5 REFERENCES

Reynolds, D. and Kueper, B. 2002. Numerical examination of the factors controlling DNAPL migration through a single fracture. Ground Water 40(4):368-377.

APPENDIX G

ARAR WAIVERS

If the Army plans to waive any groundwater cleanup standards at this site, it is especially important to clearly identify alternative remedial strategies that are protective of human health and the environment. Alternatives to prevent exposure to contamination using institutional controls, and reduction of contaminant concentrations to levels consistent with CERCLA risk management goals should be explored.

ARAR Waiver Guidance: In the ARAR waiver guidance, EPA provides an example where a technical impracticability waiver was considered appropriate: "Ground water located in bedrock fractures and deep bedrock contained highly contaminated pockets of liquid waste along the fractures. MCLs were waived because their attainment was technically impracticable for several reasons, including: (1) difficulty in predicting the extent and location of fractures; (2) the inability to locate and extract all pockets of liquid waste; (3) excessive timeframes for cleanup; and (4) the irregular nature of the fractures that made effective placement of extraction wells difficult." See OSWER Fact Sheet - Overview of ARARs - Focus on ARAR Waivers, Publication No. 9234.2-03, December 1989.

While not focused specifically on ARAR waivers, EPA has also provided guidance on the technical impracticability of groundwater restoration, which outlines the components to be included in a technical impracticability determination. See OSWER Directive 9234.2-25, Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration, Interim Final, September, 1993. According to EPA, the following components should be included in technical impracticability determinations:

1. Specific ARARs or media cleanup standards for which TI determinations are made;
2. Spatial area over which TI decision will apply;
3. Conceptual model that describes site geology, hydrology, ground-water contamination sources, transport, and fate;

4. Evaluation of restoration potential of the site, including data and analyses that support any assertion that attainment of ARARs or media cleanup standards is technically impracticable from an engineering perspective; this should include:
    a. A demonstration that contamination sources have been identified and have been, or will be removed and contained to the extent practicable;
    b. An analysis of the performance of any ongoing or completed remedial actions;
    c. Predictive analyses of the timeframes to attain required cleanup levels using available technologies;
    d. A demonstration that no other remedial technologies (conventional or innovative) could reliably, logically, or feasibly attain the cleanup levels at the site within a reasonable timeframe.
5. Estimates of the cost of the existing or proposed remedy options, including construction, operation, and maintenance costs;
6. Any additional information deemed necessary for the TI determination.

Data collection, data analysis and technology studies should be focused on these components, in order to provide the documentation needed for a TI determination. Many installations already have a significant amount of information that will support this determination.

Installations should seek guidance regarding ARAR waivers from Headquarters, Department of the Army (HQDA), including information on examples where the Army has previously waived ARARs (e.g., Schofield Barracks).

APPENDIX H

STATE POLICES ON TECHNICAL IMPRACTICABILITY

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A preliminary review of available information indicates that at a minimum of seven states (Missouri, Texas, Georgia, North Carolina, Wyoming, Illinois, and Mississippi) and the District of Columbia consider technical impracticability in their corrective action policies. In addition, California has a “Containment Zone Policy” that is essentially a technical impracticability policy. The following are details for each of these states.

H.1 MISSOURI

Missouri's Voluntary Cleanup Program is administered by the Department of Natural Resources (DNR). A cleanup guidance document, "How Clean is Clean?" developed by the DNR has been adopted as a guide for site remediation. The document defines two tiers of remediation goals. In general, meeting the Tier 1 standard requires groundwater to be remediated to meet the most conservative of the maximum contaminant levels (MCLs) in the Missouri Water Quality Standards (10CSR 20-7). If meeting the Tier 1 cleanup standards is proven to be technically impracticable or site conditions render the uniform cleanup standards inappropriate, the second tier alternate cleanup standards may be used. The cleanup party must propose the alternate cleanup standards and support them with a site-specific risk-based assessment. Alternate cleanup standards may be used if the Missouri DNR does not have an established cleanup standard for a particular contaminant or if the participant can demonstrate the technical impracticability of achieving an established cleanup standard. Missouri is presently revising its cleanup guidance. The result may be greater access to alternative cleanup standards.

Source*: Northeast Midwest Institute (www.nemw.org/cmclea4a.htm).*

H.2 TEXAS

As outlined in 30 TAC Sec 350.33(f)(3)(A) through (F), technical impracticability may be used for affected Class 1, 2, and 3 groundwaters under Remedy Standard B, and a technical impracticability demonstration must be submitted in a Remedial Action Plan (RAP) that meets the criteria established in the rule for Texas National Resource Conservation Commission (TNRCC) approval. To use this approach, the owner/operator must demonstrate that it is not feasible from a physical perspective using currently available remediation technologies due either to hydrogeologic or chemical-specific factors to reduce the concentration of contaminants of concern (COCs) throughout all or a portion of the groundwater Protective Concentration Levels Exceedance (PCLE) zone to the applicable critical groundwater Protective Concentration Levels (PCLs) within a reasonable timeframe. The owner/operator is required to restore groundwater to PCLs to the extent possible, and establish a Plume Management Zone (PMZ) for the portion that cannot be restored. However, an owner/operator is not allowed to take advantage of any of the flexibility that would normally be afforded with a PMZ in accordance with 30 TAC Section 350.37(l)(4) or Section 350.37(m) for expansion of the PCLE Zone. The existing limits of the PCLE Zone must not be allowed to increase. In addition, Class 1 groundwater must be restored except where Waste Control Unit (WCU) exclusions apply or where technical impracticability has been demonstrated. And, landowner consent is required for the filing of institutional controls to be accepted by TNRCC unless technical impracticability has been demonstrated.

Source*: Texas National Resource Conservation Commission (TNRCC) Regulatory Guidance, Application of Remedy Standards A and B. RG-366/TRRP-28. April 2001.*

H.3 GEORGIA

Potential responsible parties (PRPs) are allowed to use institutional controls as part of an overall cleanup strategy when contamination cannot be removed due to technical impracticability.
***Source**: ASTSWMO Survey of State Institutional Control Mechanisms. December 1997. Association of State and Territorial Solid Waste Management Officials.*

H.4 NORTH CAROLINA

PRPs may elect to place property use restrictions on his property and limit cleanup to levels which correspond to the restricted use in cases including where the technical impracticability of active groundwater remediation can be shown.
***Source**: ASTSWMO Survey of State Institutional Control Mechanisms. December 1997. Association of State and Territorial Solid Waste Management Officials.*

H.5 WYOMING

PRPs may elect to use institutional controls whenever a remedy will not be safe for unrestricted use and when other remedies are prohibitively costly. Generally, except in the technical impracticability of groundwater remediation, use of institutional controls is appropriate only to prevent exposure to contaminated soils pending attainment of “walk-away” cleanup levels. Technical impracticability is a component of Wyoming’s “Brownfields Bill” (Senate File 147), passed in March 1999.
***Source**: ASTSWMO Survey of State Institutional Control Mechanisms. December 1997. Association of State and Territorial Solid Waste Management Officials.*

H.6 ILLINOIS

The Illinois Environmental Protection Agency (IEPA) incorporate consideration of TI through its RBCA policies contained in 35 Illinois Administrative Code Part 742, which applies to nearly all remedial programs implemented by the IEPA. There are five different approaches to developing remedial objectives under Part 742. One of them is Tier 3 of the tiered approach. This allows a wide variety of tools to evaluate and address site risks which include the consideration of technical impracticability.
***Source**: http://aec.army.mil/prod/usaec/ro/northern/newsltrs/illinois.htm*.

H.7 MISSISSIPPI

The EPA's OSWER Directive 9234.2-25 on TI (September 1993) may be utilized in developing a demonstration of TI with regard to groundwater and soil remediation, free product removal, and other site-specific conditions approved by Mississippi Department of Environmental Quality (MDEQ).
***Source**: Final Regulations Governing Brownfields Voluntary Cleanup and Redevelopment in Mississippi. Mississippi Commission on Environmental Quality. May 27, 1999.*

H.8 DISTRICT OF COLUMBIA

The Department of Consumer & Regulatory Affairs, UST Branch, allows Remediation by Natural Attenuation (RNA) as a possible remedial measure if TI can be demonstrated.
***Source**: www.gsi-net.com/RBCAPOL/StateInfo/Update1a/DC.htm.*

H.9 CALIFORNIA

A containment zone (CZ) may be considered by the California Regional Water Quality Control Boards (RWQCBs) for a site or a portion of a site where cleanup of contamination to levels that comply with applicable water quality objectives (WQOs) is technologically and/or economically infeasible. California's CZ Policy is contained within amendments to the State Water Resources Control Board (SWRCB) Resolution 92-49 which provides enforceable policies and procedures to address sites where wastes have been discharged that cause or threaten to cause contamination of waters of the State. The CZ Policy was adopted after two years of contentious hearings and workshops. The controversy was caused by the Policy's recognition that some groundwater bodies are so contaminated that otherwise applicable Water Quality Objectives (WQOs) cannot reasonably be achieved as part of their cleanup.

The CZ Policy requires dischargers to cleanup groundwater and soils which threaten to impact groundwater to the extent that beneficial uses of that water resource are restored and protected. The amendment containing the CZ policy does not permit dischargers to avoid their responsibilities for site cleanup, but instead recognizes that in some cases, compliance with WQOs for groundwater cannot reasonably be achieved within a reasonable period of time. Technical Impracticability (TI) Waivers by the USEPA or the State of California Department of Toxic Substances Control (DTSC) are deemed equivalent to a CZ if substantive requirements of the CZ policy are met. Local agencies supervising cleanup pursuant to a UST program may propose CZs for RWQCB consideration.

For a CZ to be approved, the owner/operator must show that timely compliance with WQOs is not technologically and/or economically feasible. In support, the owner/operator must provide information on the amount of contaminant reduction that *is* technologically and economically achievable, whether such reduction will significantly reduce the concentration of contaminants, the volume of the CZ or the level of maintenance required, and the availability of funds to manage the CZ for as long as contamination remains at the site. The owner/operator must also develop a management plan to contain the remaining plume of groundwater contamination, to monitor containment, and to provide contingency actions should containment fail.

APPENDIX I

PANEL MEMBER BIOSKETCHES

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PANEL MEMBER BIOSKETCHES

In order to guarantee that the discussion provided in this document is technically defensible, the Army Environmental Center convened a panel of experts to assist in the development of this document. Brief biosketches of the panel members (presented in alphabetical order) are provided below.

I.1 EDWARD J. BOUWER, Ph.D.

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Edward J. Bouwer is a professor of environmental engineering in the Department of Geography and Environmental Engineering at the Johns Hopkins University. His research interests include the biodegradation of hazardous organic chemicals in subsurface environments, biofilm kinetics, water and wastewater treatment processes, and transport and fate of bacteria in porous media. He is on the Research Advisory Council for the American Water Works Association Research Foundation, the editorial boards of the Journal of Contaminant Hydrogeology and Environmental Engineering Science, and the managing editorial board for Biodegradation. He received a Ph.D. in environmental engineering and science from Stanford University in 1982. Dr. Bouwer has served on several National Research Council committees, including the U.S. National Committee for SCOPE, the Steering Committee on Building Environmental Management Science Programs, and the Committee on Groundwater Cleanup Alternatives.

I.2 GAYNOR DAWSON, P.E., DEE

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Mr. Dawson is a chemical engineer with 28+ years of experience in environmental industry. He spent 16 years at Battelle, Pacific Northwest Laboratories, performing R&D on wastewater and hazardous waste problems. During that time, he managed the investigation of the Kepone incident in Hopewell, VA and prepared background documents for reports to Congress on spills of hazardous polluting substances and hazardous waste management. He was also among the early arrivals at Love Canal, and pioneered application of modeling, risk assessment, and geophysical surveys to waste site remediation. Mr. Dawson then spent eight years at ICF Kaiser Engineers, where he managed the Northwest Operations and Technical Services for the Environmental Practice. It was there that he helped develop streamlined approaches to site restoration at DOE facilities, and served as an expert witness for hazardous waste site litigation around the United States. During his four years as President of EG&G Environmental Mr. Dawson spearheaded the development and commercialization of the NoVOCs recirculating well technology.

Currently, Mr. Dawson is vice president of Project Performance Corporation, where he continues his expert witness work, manages a technology commercialization practice, and instructs DOE/EPA sponsored training courses on environmental restoration. Mr. Dawson is a registered PE and a Diplomate in the American Academy of Environmental Engineers.

I.3 THOMAS D. GILLESPIE. P.G.

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Mr. Gillespie is a licensed professional geologist in Pennsylvania, Virginia and Kentucky, with 15 years of experience in hydrogeology and engineering geology. He has directed projects involving environmental contamination, water supply and water resource management, natural resource evaluation and management, and geologic hazards. He specializes in the geology and hydrogeology of bedrock aquifer systems, with particular experience in karst terrains. Mr. Gillespie has represented clients involved in environmental projects regulated at the federal level (CERCLA and RCRA), in over 20 states, and in Canada and Puerto Rico. He has also published original research and case study papers on the movement and behavior of non-aqueous phase liquids in karst bedrock aquifers, the fate and transport of dissolved contamination in various bedrock flow systems with an emphasis on the geologic controls on contaminant movement and remediation, and on sinkhole hazards in karst terrains. Since 1988 Mr. Gillespie has also been an adjunct professor of geology at The College of New Jersey (formerly Trenton State College). Mr. Gillespie holds a M.S. in structural geology/hydrogeology from Rutgers University.

Currently, Mr. Gillespie is the principal hydrogeologist and a Senior Manager at Environmental Liability Management, Inc., where he provides technical consultation and project management to private and public clients, including the direction of investigations and remedial actions, representation at public meetings, regulatory negotiations, litigation support and expert witness services. He also currently serves as an independent technical review consultant to several Superfund PRP groups.

I.4 MICHAEL C. KAVANAUGH, Ph.D., P.E., DEE

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Dr. Kavanaugh is a Vice President and currently the National Science and Technology Leader for Malcolm Pirnie, Inc. He is a chemical and environmental engineer with over 27 years of consulting experience, providing a broad range of environmental and chemical engineering services to private and public sector clients. His areas of expertise include hazardous waste management, site remediation with particular focus on groundwater remediation, risk and decision analysis, water quality, water treatment, potable and non-potable water reuse, industrial and municipal wastewater treatment, strategic environmental management, and technology evaluations including patent reviews on environmental technologies. Dr. Kavanaugh has extensive litigation experience, both as a testifying expert and a fact witness on engineering and hydrogeologic issues related to hazardous waste sites as well as on other issues related to his areas of expertise. He also has broad experience with alternative dispute resolution for settling environ-mental disputes and has participated on several mediation and arbitration panels as a neutral technical expert. Dr. Kavanaugh has been project engineer, project manager, principal-in-charge, technical director or technical reviewer on over 175 projects covering a broad range of environmental problems. Dr. Kavanaugh has prepared over 35 peer reviewed technical publications, two books, and has made over 100 presentations to technical audiences as well as public groups including testimony before congressional and legislative committees. Dr. Kavanaugh was elected into the National Academy of Engineering in 1998.

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Dr. McWhorter's specialty is transport phenomena in sand and gravel aquifers and in fractured porous rocks. He has taught and conducted research into a variety of transport phenomena for more than 25 years and has received several awards for his contributions to teaching and research. He is co-founder, with Dr. John Cherry of the University of Waterloo, of the University Consortium for Research of Solvents in Groundwater and, until his recent retirement from Colorado State University, held a research chair funded by the Boeing Company. He is regarded as an expert in multi-fluid flow in porous and fractured rocks, soils and aquifers and is a regular consultant to industry and government on problems of groundwater contamination by non-aqueous liquids such as chlorinated solvents and petroleum products. Much of Dr. McWhorter's current consulting activity consists of participating on expert advisory panels established by companies such as Union Pacific Railroad, Eastman Kodak, Boeing, BP-Amoco and others. Also, he has been involved in the allocation of responsibility and costs for groundwater contamination and remediation, both as a member of an allocation panel and as a court-appointed expert. He has testified in depositions and at trial on matters related to groundwater contamination by chlorinated solvents, petroleum products, and mine/mill wastes. He has advised the United Nations/FAO and the governments of Kuwait and Brazil on special problems of water supply and contamination.

Dr. McWhorter holds degrees in petroleum, civil, and soil-water engineering. He is retired from Colorado State University, where he was Professor of Chemical and Bioresource Engineering for 29 years. He now is an independent consultant on problems of groundwater contamination and supply.