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Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration

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Office of Solid Waste and Emergency Response
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1.0 Introduction

1.1 Background

Restoration[1] of contaminated ground waters is one of the primary objectives of both the Superfund and RCRA Corrective Action programs. Ground-water contamination problems are pervasive in both programs; over 85 percent of Superfund National Priorities List (NPL) sites and a substantial portion of RCRA facilities have some degree of ground-water contamination. The Superfund and RCRA Corrective Action programs share the common purposes of protecting human health and the environment from contaminated ground waters and restoring those waters to a quality consistent with their current, or reasonably expected future, uses.

The National Contingency Plan (NCP), which provides the regulatory framework for the Superfund program, states that:

> "EPA expects to return usable ground waters to their beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site" (NCP §300.430(a)(1)(iii)(F)).

Generally, restoration cleanup levels in the Superfund program are established by applicable or relevant and appropriate requirements (ARARs), such as the use of Federal or State standards for drinking water quality. Cleanup levels protective of human health and the environment are identified by EPA where no ARARs for particular contaminants exist (see Section 4.1.1).

The RCRA Corrective Action program for releases from solid waste management facilities (see 40 CFR 264.101)[2] requires a facility owner/operator to:

> "...institute corrective action as necessary to protect human health and the environment for all releases of hazardous waste or constituents from any solid waste management unit..."

The goal of protectiveness is further clarified in the Preamble to the Proposed Subpart S to 40 CFR 264:

> "Potentially drinkable ground water would be cleaned up to levels safe for drinking throughout the contaminated plume, regardless of whether the water was in fact being consumed... Alternative levels protective of the environment and safe for other uses could be established for ground water that is not an actual or reasonably expected source of drinking water."[3]

While both programs have had a great deal of success reducing the immediate threats posed by contaminated ground waters, experience over the past decade has shown that restoration to drinking water quality (or more stringent levels where required) may not always be achievable due to the limitations of available remediation technologies (EPA 1989b, 1992d). EPA, therefore, must evaluate whether ground-water restoration at Superfund and RCRA ground-water cleanup sites is attainable from an engineering perspective. **This document outlines EPA's approach to evaluating the technical impracticability of attaining required ground-water cleanup levels and establishing alternative, protective remedial strategies where restoration is determined to be technically impracticable.**

Many factors can inhibit ground-water restoration. These factors may be grouped under three general categories:

- Hydrogeologic factors;
- Contaminant-related factors; and
- Remediation system design inadequacies.

Hydrogeologic limitations to aquifer remediation include conditions such as complex sedimentary deposits; aquifers of very low permeability; certain types of

1 For this guidance, "restoration" refers to the reduction of contaminant concentrations to levels required under the Superfund or RCRA Corrective Action programs. For ground water currently or potentially used for drinking water purposes, these levels may be Maximum Contaminant Levels (MCLs) or non-zero Maximum Contaminant Levels Goals (MCLGs) established under the Safe Drinking Water Act; State MCLs or other cleanup requirements; or risk-based levels for compounds not covered by specific State or Federal MCLs or MCLGs. Other cleanup levels may be appropriate for ground waters used for non-drinking water purposes.

2 At this time, this guidance is not applicable to corrective actions for releases from Subpart F regulated units that are subject to corrective actions under 40 CFR 264.91-264.100.

3 "Corrective Action for Solid Waste Management Units (SWMUs) at Hazardous Waste Management Facilities," 55 FR 30798-30884, July 27, 1990, Proposed Rules, is currently used as guidance in the RCRA Corrective Action program. When final regulations under Subpart S are promulgated, certain aspects of this guidance pertaining to the RCRA program may need to be revised to reflect new regulatory requirements.

fractured bedrock; and other conditions that presently make extraction or *in situ* treatment of contaminated ground water extremely difficult (Figure 1).

Contaminant-related factors, while not independent of hydrogeologic constraints, are more directly related to contaminant properties that may limit the success of an extraction or *in situ* treatment process. These properties include a contaminant's potential to become either sorbed onto, or lodged within, the soil or rock comprising the aquifer. Nonaqueous phase liquids (NAPLs) are examples of contaminants that may pose such technical limitations to aquifer restoration efforts. NAPLs that are denser than water (DNAPLs) often are particularly difficult to locate and remove from the subsurface; their ability to sink through the water table and penetrate deeper portions of aquifers is one of the properties that makes them very difficult to remediate (Figure 1).

The widespread use of DNAPLs in manufacturing and many other sectors of the economy prior to the advent of safe waste-management practices has led to their similarly widespread occurrence at ground-water contamination sites. Most of the sites where EPA already has determined that ground-water restoration is technically impracticable have DNAPLs present. The potential impact of DNAPL contamination on attainment of remediation goals is so significant that EPA is developing specific recommendations for DNAPL site management; the key elements of this strategy are presented in Section 3.0 below.

The third factor that may limit ground-water restoration is inadequate remediation system design and implementation. Examples of design inadequacies in a ground-water extraction system include an insufficient number of extraction points (e.g., ground water or vapor extraction wells) or wells whose locations, screened intervals, or pumping rates lead to an inability to capture the plume. Design inadequacies may result from incomplete site characterization, such as inaccurate measurement of hydraulic conductivity of the affected aquifer or not considering the presence of NAPL contamination. Poor remediation system operation, such as excessive downtime or failure to modify or enhance the system to improve performance, also may limit the effectiveness of restoration efforts. **Failure to achieve desired cleanup standards resulting from inadequate system design or operation is not considered by EPA to be a sufficient justification for a determination of technical impracticability of ground-water cleanup.**

1.2 Purpose of the Guidance

This guidance clarifies how EPA will determine whether ground-water restoration is technically impracticable and what alternative measures or actions must be undertaken to ensure that the final remedy is protective of human health and the environment. Topics covered include the types of technical data and analyses needed to support EPA's evaluation of a particular site and the criteria used to make a determination. As technical impracticability (TI) decisions are part of the process of site investigation, remedy selection, remedial action, and evaluation of remedy performance, the guidance also briefly discusses the overall framework for decision making during these phases of site cleanup.

This guidance does not signal a scaling back of EPA's efforts to restore contaminated ground waters at Superfund sites and RCRA facilities. Rather, EPA is promoting the careful and realistic assessment of the technical capabilities at hand to manage risks posed by ground-water contamination. This guidance provides consistent guidelines for evaluating technical impracticability and for maintaining protectiveness at sites where ground water cannot be restored within a reasonable timeframe. EPA will continue to conduct, fund, and encourage research and development in the fields of subsurface assessment, remediation, and pollution prevention so that an ever decreasing number of sites will require the analysis described in this document.

2.0 Ground-Water Remedy Decision Framework

2.1 Use of the Phased Approach

At sites with very complex ground-water contamination problems, it may be difficult to determine whether required cleanup levels are achievable at the time a remedy selection decision must be made. This is especially true when such decisions must be based on site data collected prior to implementation and monitoring of pilot or full-scale remediation systems. EPA recognizes this limitation and has recommended several approaches to reduce uncertainty during the site characterization, remedy selection, and remedy implementation processes (EPA 1989a, 1992a).

Determining the restoration potential of a site may be aided by employing a **phased approach** to site characterization and remediation. Each phase of site

Figure 1. Examples of Factors Affecting Ground-Water Restoration

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.

Generalized Remediation Difficulty Scale

Increasing difficulty →

Contaminant Characteristics

Site Use	Nature of Release	Small Volume Short Duration Slug Release →	Large Volume Long Duration Continual Release
Chemical Properties	Biotic/Abiotic 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 →	Complex Geology, e.g., Interbedded and Discontinuous Strata
	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	High ($>10^{-2}$ cm/sec) →	Low ($< 10^{-4}$ cm/sec)
	Temporal Variation	Little/None →	High
	Vertical Flow	Little →	Large Downward Flow Component

characterization should be designed to provide information necessary for the next phase of characterization. Likewise, site remediation activities can be conducted in phases to achieve interim goals at the outset, while developing a more accurate understanding of the restoration potential of the contaminated aquifer. An example of how this approach might be applied at a site is provided below in Section 4.4.3.

The timing of phased cleanup actions (early, interim, final) should reflect the relative urgency of the action and the degree to which the site has been characterized. Early actions should focus on reducing the risk posed by site contamination (e.g., removal of contamination sources) and may be carried out before detailed site characterization studies have been completed. Interim remedial actions may abate the spread of contamination or limit exposure but do not fully address the final cleanup levels for the site. Interim actions generally will require a greater degree of site characterization than early actions. However, implementation of interim actions still may be appropriate prior to completion of site characterization studies, such as the Remedial Investigation/Feasibility Study (RI/FS) or RCRA Facility Investigation (RFI) and Corrective Measures Study (CMS). Final remedial actions must address the cleanup levels and other remediation requirements for the site and, therefore, must be based on completed characterization reports. Information from early and interim actions also should be factored into these reports and final remedy decisions.

Phasing of activities generally should not delay or prolong site characterization or remediation. In fact, such an approach may accelerate the implementation of interim risk reduction actions and lead more quickly to the development of achievable final remediation levels and strategies. A phased approach should be considered when there is uncertainty regarding the ultimate restoration potential of the site but also a need to quickly control risk of exposure to, or limit further migration of, the contamination.

It is critical that the performance of phased remedial actions (e.g., control of plume migration) be monitored carefully as part of the ongoing effort to characterize the site and assess its restoration potential. Data collection activities during such actions not only should be designed to evaluate performance with respect to the action's specific objectives but also contribute to the overall understanding of the site. In this manner, actions implemented early in the site remediation process can achieve significant risk reduction and lead to development of technically sound, final remedy decisions.

2.2 Documenting Ground-Water Remedy Decisions Under CERCLA

The phased approach to site characterization and remediation can be employed using the existing decision document options within the Superfund program.

2.2.1 Removal Actions

Removal authority can be used for early actions as part of a phased approach to ground-water cleanup and decision making and should be considered where early response to ground-water contamination is advantageous or necessary. Within the context of ground-water actions, removals are appropriate where contamination poses an actual or potential threat to drinking water supplies or threatens sensitive ecosystems. Examples of actions that might qualify for use of removal authority include removal of surface sources (e.g., drums or highly contaminated soils), removal of subsurface sources (e.g., NAPL accumulations, highly contaminated soils, or other buried waste), and containment of migrating ground-water contamination "hot spots" (zones of high contaminant concentration) or plumes to protect current or potential drinking water supplies.

Removals of subsurface sources most likely will be non-time-critical actions, although time-critical actions may be appropriate for removal of NAPL accumulations or other sources, depending on the urgency of the threat. Documentation requirements for removal actions include a Removal Action Memorandum and, for non-time critical actions, an Engineering Evaluation/Cost Analysis report.[4]

Removal actions must attain ARARs to the extent practicable, considering the exigencies of the situation. The urgency of the situation and the scope of the removal action may be considered when determining the practicability of attaining ARARs (NCP §300.415(i)). Standards or regulations typically used to establish ground-water cleanup levels for final actions (e.g., MCLs/MCLGs) may not be ARARs, depending on the scope of the removal. Further

4 See "Guidance on Conducting Non-Time Critical Removal Actions under CERCLA," OSWER Publication 9360.0-32, August 1993 (EPA 1993b).

information on removal actions may be found in other EPA guidances (EPA 1990b, 1991d).

2.2.2 Interim RODs

Interim RODs may be appropriate where there is a moderate to high degree of uncertainty regarding attainment of ARARs or other protective cleanup levels. As mentioned before, an interim action may be used to minimize further contaminant migration and reduce the risk of exposure to contaminated ground water. Interim actions include containment of the leading edge of a plume to prevent further contamination of unaffected portions of an aquifer, removal of source material, remediation of ground-water hot spots, and in some cases, installation of physical barriers or caps to contain releases from source materials. Interim actions should be monitored carefully to collect detailed information regarding aquifer response to remediation, which should be used to augment and update previous site characterization efforts. This information then can be used at a later date to develop final remediation goals and cleanup levels that more accurately reflect the particular conditions of the site.

It is important to note that for interim actions, ARARs must be attained only if they are within the scope of that action. For example, where an interim action will manage or contain migration of an aqueous contaminant plume, MCLs and MCLGs would not be ARARs, since the objective of the action is containment, not cleanup (although requirements such as those related to discharge of the treated water still would be ARARs, since they address the disposition of treated waste).

Furthermore, a requirement that is an ARAR for an interim action may be waived under certain circumstances. An "interim action" ARAR waiver may be invoked where an interim action that does not attain an ARAR is part of, or will be followed by, a final action that does (NCP §300.430(f)(1)(ii)(C)). For example, where an interim action seeks to reduce contamination levels in a ground-water hot spot, MCLs/MCLGs may be ARARs since the action is cleaning up a portion of the contaminated ground water. If, however, this interim action is expected to be followed by a final, ARAR-compliant action that addresses the entire contaminated ground-water zone, an interim action ARAR waiver may be invoked.

2.2.3 Final RODs

Where site characterization is very thorough and there is a moderate to high degree of certainty that cleanup levels can be achieved, a final decision document should be developed that adopts those levels. Conversely, in cases where there is a high degree of certainty that cleanup levels cannot be achieved, a final ROD that invokes a TI ARAR waiver and establishes an alternative remedial strategy may be the most appropriate option.[5] Note that for ROD-stage waivers, site characterization generally should be sufficiently detailed to address the data and analysis requirements for TI determinations set forth in this guidance.

2.2.4 ROD Contingency Remedies and Contingency Language

Where a moderate degree of uncertainty exists regarding the ability to achieve cleanup levels, a final ARAR-compliant ROD generally still is appropriate. However, the ROD may include contingency language that addresses actions to be taken in the event the selected remedy is unable to achieve the required cleanup levels (EPA 1990a, 1991a). The contingency language may include requirements to enhance or augment the planned remediation system as well as an alternative remedial technology to be employed if modifications to the planned system fail to significantly improve its performance. Use of language in final remedy decision documents that addresses the uncertainty in achieving required cleanup levels also is appropriate in certain cases. **However, language that identifies a TI decision (e.g., an ARAR waiver) as a future contingency of the remedy should be avoided.** Such language is not necessary, as a TI evaluation may be performed (and a decision made) by EPA at any site regardless of whether such a contingency is provided in the decision document.

Note that in cases of existing RODs that already include a contingency for invoking a TI ARAR waiver, the conditions under which the ARAR may be waived should be consistent with, and as stringent as, those presented in this guidance or a future update.

Furthermore, the fact that such contingency language has been included in an existing ROD does not alter the need to enhance or augment a remedy to improve its ability to attain ARARs before concluding that a waiver can be granted. It also

5 At sites where a TI ARAR waiver is invoked in the ROD, preparation of the pre-referral negotiation package ("mini-lit" package) must include analysis of the model Consent Degree language to ensure that appropriate consideration of the waiver's impact is incorporated.

should be noted that remediation must be conducted for a sufficient period of time before its ability to restore contaminated ground water can be evaluated. This minimum time period will be determined by EPA on a site-specific basis.

2.3 Documenting Ground-Water Remedy Decisions under RCRA

The instruments used for implementing the RCRA Corrective Action program (permits and orders) also are amenable to a phased approach to remedy selection and facility remediation. The RCRA program can use permits or orders to compel both interim measures and final remedies.

2.3.1. Permits/Orders Addressing Stabilization
RCRA permits or orders can require the stabilization of releases from solid waste management units (SWMUs) at the facility. The Stabilization Initiative focuses on taking interim actions to prevent the further spread of existing contamination and reduce risks. Examples of measures used for stabilization include capping, excavation, and plume containment. Since the long-term or final cleanup of the facility is not the objective of stabilization (although stabilization should be consistent with the final remedy), TI decisions are not applicable at this early stage. Information gained during stabilization should be used to help determine the restoration potential of the facility and the objectives of the final remedy.

2.3.2. Permits/Orders Addressing Final Remedies
Where achieving ground-water cleanup standards is determined by EPA to be technically impracticable, the permit or order addressing final remedies should include practicable and protective alternative remedial measures. EPA's decision to make a TI determination will be based on clear and convincing information provided by the owner/operator. EPA generally will seek public comment on TI determinations prior to implementation. EPA's preliminary TI determinations and justification for these determinations should be documented in a Statement of Basis. As discussed above, uncertainty in the ability to restore an aquifer should be reduced through phased characterization and the use of interim remedial measures, where appropriate.

Permits and orders that address "final" remedies should specify the remediation cleanup levels selected by the implementing Agency. Such permits and orders, however, generally should not incorporate contingency TI language. The permit or order will need to be modified to document the TI determination and to specify, as appropriate, alternative cleanup levels and alternative remedial measures that have been determined to be technically practicable and protective of human health and the environment.

3.0 Remedial Strategy for DNAPL Sites

Many of the subsurface contaminants present at Superfund sites and RCRA facilities are organic compounds that are either lighter-than-water NAPLs (LNAPLs) or DNAPLs. As mentioned in Section 1.1, the presence of NAPL contamination, and in particular DNAPL contamination, may have a significant impact on site investigations and the ability to restore contaminated portions of the subsurface to required cleanup levels. Furthermore, DNAPL contamination may be a relatively widespread problem. A recent EPA study (EPA 1993a) concluded that up to 60 percent of National Priorities List (NPL) sites may have DNAPL contamination in the subsurface; a significant percentage of RCRA Corrective Action facilities also are thought to be affected by DNAPLs. As proven technologies for the removal of certain types of DNAPL contamination do not exist yet, DNAPL sites are more likely to require TI evaluations than sites with other types of contamination. Although this guidance pertains to TI evaluations at all site types, EPA believes the significance of the DNAPL contamination problem warrants the following brief discussion of DNAPL contamination and recommended site management strategies.

DNAPLs comprise a broad class of compounds, including creosote and coal tars, polychlorinated biphenyls (PCBs), certain pesticides, and chlorinated organic solvents such as trichloroethylene (TCE) and tetrachloroethylene (PCE). The term "DNAPL" refers only to liquids immiscible in, and denser than, water and **not** to chemicals that are dissolved in water that originally may have been derived from a DNAPL source. DNAPLs may occur as "free-phase" or "residual" contamination. **Free-phase** DNAPL is an immiscible liquid in the subsurface that is under positive pressure; that is, the DNAPL is capable of flowing into a well or migrating laterally or vertically through an aquifer. Where vertically migrating free-phase DNAPL encounters a rock or soil layer of relatively low permeability (e.g., clay or other fine-grained layer), a DNAPL accumulation or "pool" may form. **Residual** DNAPL is immiscible liquid held by capillary forces within the pores or fractures in soil or rock layers; residual DNAPL, therefore, generally is not capable of migrating or being displaced by normal ground-water flow. Both free-phase and residual DNAPL, however, can slowly dissolve in ground water and produce "plumes" of aqueous-phase contamination. DNAPLs also can produce subsurface vapors capable of migrating through the unsaturated zone and contaminating ground water (EPA 1992c). Figure 2 depicts the various types of contamination that may be encountered at a DNAPL site.

The three areas that should be delineated at a DNAPL site are the DNAPL entry location, the DNAPL zone, and the aqueous contaminant plume. The **entry locations** are those areas where DNAPL was released and likely is present in the subsurface. Entry locations include waste disposal lagoons, drum burial sites, or any other area where DNAPL was allowed to infiltrate into the subsurface. The **DNAPL zone** is defined by that portion of the subsurface containing free-phase or residual DNAPL. Thus, the DNAPL zone includes all portions of the subsurface where the immiscible-phase contamination has come to be located. The DNAPL zone may occur within both the saturated zone (below the water table) and the unsaturated zone (above the water table). The DNAPL zone also may contain vapor and aqueous-phase contamination derived from the DNAPL. The DNAPL zone may include areas at relatively great depths and lateral distances from the entry locations, depending on the subsurface geology and the volume of DNAPL released. The **aqueous contaminant plume** contains organic chemicals in the dissolved phase. The plume originates from the DNAPL zone and may extend hundreds or thousands of feet downgradient (in the direction of ground-water flow). Figure 3 illustrates the various components of a DNAPL site.

Since each DNAPL site component may require a different remediation strategy, it is important to characterize these components to the extent practicable. Thus, the properties and behavior of DNAPL contamination require consideration when planning and conducting both site investigation and remediation. The potential for DNAPL occurrence at the site should be evaluated as early as possible in the site investigation. Recent publications such as "Estimating Potential for DNAPL Occurrence at Superfund Sites" (EPA 1992c) and "DNAPL Site Evaluation" (Cohen and Mercer, 1993) provide detailed guidance on these topics. At sites where DNAPL disposal is known or suspected to have occurred, likely DNAPL entry locations should be identified from available historical waste-management information and subsurface chemistry data. This information can assist in the delineation of the DNAPL zone.

Characterization and delineation of the DNAPL zone is critical for remedy design and evaluation of the restoration potential of the site. At many sites, a subsurface investigation strategy that begins outside of the suspected DNAPL zone may be appropriate ("outside-in" strategy), in part to minimize the possibility of inadvertent mobilization of DNAPLs to

Figure 2. Types of Contamination and Contaminant Zones at DNAPL Sites (Cross-sectional view)

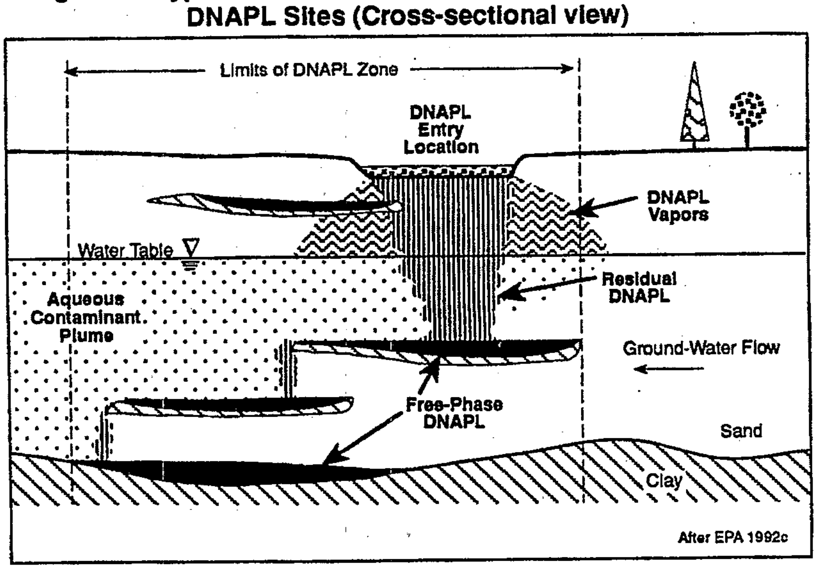
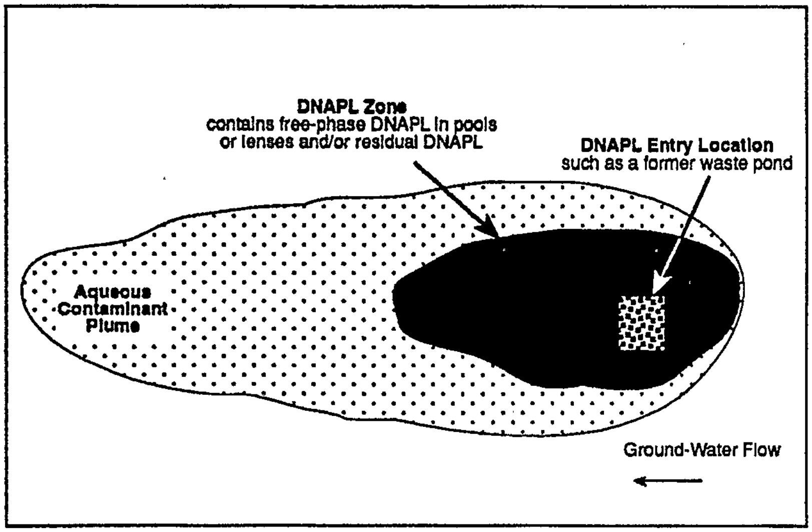


Figure 3. Components of DNAPL Sites



lower aquifers. Delineation of the extent of the DNAPL zone may be difficult at certain sites due to complex geology or waste disposal practices. In such cases, the extent of the DNAPL zone may need to be inferred from geologic information (e.g., thickness, extent, structure, and permeability of soil or rock units) or from interpretation of the aqueous concentration of contaminants derived from DNAPL sources. At some sites, however, geologic complexity and inadequate information on waste disposal may make the delineation of the DNAPL zone difficult.

A phased approach, as discussed in Section 2.1, is recommended for DNAPL sites; such an approach may facilitate identification of appropriate short- and long-term site remediation objectives. Note also that technical approaches appropriate for the DNAPL zone (e.g., free-phase DNAPL removal, vapor extraction, excavation, and slurry walls aided by limited pump-and-treat) may differ significantly from those appropriate for the aqueous contaminant plume (typically pump-and-treat).

Short-term remediation objectives generally should include prevention of exposure to contaminated ground water and containment of the aqueous contaminant plume. Where sufficient information is available, early removal of DNAPL sources also is recommended. Information gathered during these actions should be used to help characterize the site and identify practicable options for further remediation.

The long-term remediation objectives for a DNAPL zone should be to remove the free-phase, residual, and vapor phase DNAPL to the extent practicable and contain DNAPL sources that cannot be removed. EPA recognizes that it may be difficult to locate and remove all of the subsurface DNAPL within a DNAPL zone. Removal of DNAPL mass should be pursued wherever practicable and, in general, where significant reduction of current or future risk will result.[6] Where it is technically impracticable to remove subsurface DNAPLs, EPA expects to contain the DNAPL zone to minimize further release of contaminants to the surrounding ground water, wherever practicable.[7]

Where it is technically practicable to contain the long-term sources of contamination, such as the DNAPL zone, EPA expects to restore the aqueous contaminant plume outside the DNAPL zone to required cleanup levels. Effective containment of the DNAPL zone generally will be required to achieve this long-term objective because ground-water extraction remedies (e.g., pump-and-treat) or *in situ* treatment technologies are effective for plume restoration only where source areas have been contained or removed.

6 DNAPL mass removal also must satisfy the Superfund or RCRA Corrective Action remedy selection criteria, as appropriate.

7 As DNAPLs may be remobilized during drilling or ground-water pumping, caution should be exercised where such activities are proposed for DNAPL zone characterization, remediation, or containment.

Monitoring and assessing the performance of DNAPL zone containment and aquifer restoration systems, therefore, are critical to maintaining remedy protectiveness and evaluating the need for remedy enhancements or application of new technologies.

EPA recognizes, however, 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.

EPA encourages consideration of innovative technologies at DNAPL sites, particularly where containment of a DNAPL zone may require costly periodic maintenance (and perhaps replacement). Innovative technologies, therefore, should be considered where DNAPL zone containment could be enhanced or where such a technology could clean up the DNAPL zone.

4.0 TI Decisions and Supporting Information

4.1 Regulatory Framework for TI Decisions

The bases for TI decisions discussed in this guidance are provided in CERCLA and the NCP for the Superfund program and in the Proposed Subpart S rule for the RCRA program. While the processes the two programs use to establish cleanup levels differ (e.g., the ARAR concept is not used in RCRA), the primary considerations for determining the technical impracticability of achieving those levels are identical:

- **Engineering feasibility; and**
- **Reliability.**

A brief summary of the regulatory basis for establishing cleanup levels and making TI determinations at Superfund and RCRA sites is provided below.

4.1.1 Superfund

Remedial alternatives at Superfund sites must satisfy two "threshold" criteria specified in the NCP to be eligible for selection: 1) the remedy must be protective of human health and the environment; and 2) the remedy must meet (or provide the basis for waiving) the ARARs identified for the action.[8] There generally are several different types of ARARs associated with ground-water remedies at Superfund sites, such as requirements for discharge of treated water to surface water bodies or other receptors, limitations on reinjection of treated water into the subsurface, and cleanup levels for contaminants in the ground water. ARARs used to establish cleanup levels for current or potentially drinkable ground water typically are MCLs or non-zero MCLGs established under the Federal Safe Drinking Water Act, or in some cases, more stringent State requirements. For compounds for which there are no ARARs, cleanup levels generally are chosen to protect users or receptors from unacceptable cancer and non-cancer health risks or adverse environmental effects. Such levels generally are established to fall within the range of 10^{-4} to 10^{-6} lifetime cancer risk or below a hazard index of one for non-carcinogens, as appropriate.

ARARs may be waived by EPA for any of the six reasons specified by CERCLA and the NCP (Highlight 1), including **technical impracticability from an engineering perspective.** TI waivers generally will be applicable only for ARARs that are used to establish cleanup performance standards or levels, such as chemical-specific MCLs or State ground-water quality criteria.

Highlight 1.
CERCLA ARAR Waivers

The six ARAR waivers provided by CERCLA §121(d)(4) are:

1. Interim Action Waiver;
2. Equivalent Standard of Performance Waiver;
3. Greater Risk to Health and the Environment Waiver;
4. Technical Impracticability Waiver;
5. Inconsistent Application of State Standard Waiver; and
6. Fund Balancing Waiver.

8 NCP §300.430(f)(1)(i). For a detailed discussion of the Superfund remedy selection process, see also EPA 1988a and 1988b.

Use of the term "engineering perspective" implies that a TI determination should primarily focus on the technical capability of achieving the cleanup level, with cost playing a subordinate role. The NCP Preamble states that TI determinations should be based on:

> "...engineering feasibility and reliability, with cost generally not a major factor unless compliance would be inordinately costly."[9]

4.1.2 RCRA

The Proposed Subpart S rule specifies that the corrective action for contaminated ground water include attainment of "media cleanup standards," which generally are Federal or State MCLs, contaminant levels within the range of 10^{-4} to 10^{-6} lifetime cancer risk, or hazard index of less than one for non-carcinogens, as appropriate. The proposed rule also specifies three conditions under which attainment of media cleanup standards may not be required: 1) remediation of the release would provide no significant reduction in risks to actual or potential receptors; 2) the release does not occur in, or threaten, ground waters that are current or potential sources of drinking water; and 3) **remediation of the release to media cleanup standards is technically impracticable.**[10]

Further clarification of TI determinations is provided in the preamble to the proposed rule. The determination involves a consideration of the "**engineering feasibility and reliability**" of attaining media cleanup standards, as well as situations where remediation may be "technically possible," but the "scale of the operations required might be of such a **magnitude and complexity** that the alternative would be impracticable" (emphasis added).[11]

The basis for a RCRA Subpart S TI decision (engineering feasibility, reliability, and the magnitude and complexity of the action) therefore is consistent with that provided for the Superfund program in the NCP. In the context of remedy selection, both programs consider the notion of technical feasibility along with reliability and economic considerations; however, **the role of cost (or scale) of the action is subordinate to the goal of remedy protectiveness.**

4.2 Timing of TI Decisions

TI decisions may be made either when a final site decision document is being developed (e.g., RCRA Statement of Basis and Response to Comments or Superfund ROD) or after the remedy has been implemented and monitored for a period of time. EPA believes that, in many cases, TI decisions should be made only after interim or full-scale aquifer remediation systems are implemented because often it is difficult to predict the effectiveness of remedies based on limited site characterization data alone. However, in some cases, TI decisions may be made prior to remedy implementation. These pre-implementation or "front-end" TI decisions must be supported adequately by detailed site characterization and data analysis. Front-end TI evaluations should focus on those data and analyses that define the most critical limitations to ground-water restoration.

Data and analysis requirements for front-end decisions should be considered carefully. Generally, information regarding the nature and extent of contamination sources is more critical to assessing restoration potential than are other types of characterization data. This often is the case, as currently available technologies generally are more effective for remediating and restoring contaminated aquifers affected only by dissolved, or aqueous, contamination. However, certain types of source contamination are resistant to extraction by these technologies and can continue to dissolve slowly into ground water for indefinite periods of time. Examples of this type of source constraint include certain occurrences of NAPLs, such as where the quantity, distribution, or properties of the NAPL render its removal from, or destruction within, the subsurface infeasible or inordinately costly (See Section 3.0).

Geologic constraints, such as aquifer heterogeneity (e.g., interlayering of coarse and fine-grained strata), also may critically limit the ability to restore an aquifer. However, it generally is more difficult to accurately determine the impact of such constraints prior to implementation and monitoring of partial or full-scale aquifer remediation efforts. Some geologic constraints, however, may be defined sufficiently during site characterization so that their impacts on restoration potential are known with a relatively high degree of certainty. An example of this type of constraint includes complex fracturing of bedrock aquifers, which makes recovery of contaminated ground water or DNAPLs extremely difficult.

It should be noted, however, that the presence of known remediation constraints, such as DNAPL,

9 See NCP Preamble, 55 FR 8748, March 8, 1990.

10 Technical impracticability is discussed in Sections 264.525(d)(2) and 264.531 of the Proposed Subpart S rule.

11 Proposed Subpart S; 55 FR 30830, July 27, 1990.

fractured bedrock, or other condition, are not by themselves sufficient to justify a TI determination. Adequate site characterization data must be presented to demonstrate, not only that the constraint exists, but that the effect of the constraint on contaminant distribution and recovery potential poses a critical limitation to the effectiveness of available technologies.

4.3 TI Evaluation Components[12]

Determinations of technical impracticability will be made by EPA based on site-specific characterization and, where appropriate, remedy performance data. These data should be collected, analyzed, and presented so that the engineering feasibility and reliability of ground-water restoration are fully addressed in a concise and logical manner.

The TI evaluation may be prepared by the owner/operator of a RCRA facility, by a PRP at an enforcement-lead Superfund site, or by EPA or the State at Fund- or State-lead sites, as appropriate. **The evaluation generally should include the following components, based on site-specific information and analyses:**

1. Specific ARARs or media cleanup standards for which TI determinations are sought (See Section 4.4.1).

2. Spatial area over which the TI decision will apply (See Section 4.4.2).

3. Conceptual model that describes site geology, hydrology, ground-water contamination sources, transport, and fate (See Section 4.4.3).

4. An evaluation of the 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 (See Section 4.4.4). At a minimum, this generally 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; and
   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 (See Section 4.4.5).

6. Any additional information or analyses that EPA deems necessary for the TI evaluation.

The data and analyses needed to address each of these components of a TI evaluation should be determined on a site-specific basis. Where outside parties are preparing the TI evaluation, its contents generally should be identified and discussed prior to submittal of the evaluation to EPA. Early agreement between EPA and PRPs or owner/operators on the type and quantity of data and analyses required for TI decisions will promote efficient review of TI evaluations.

References to other documents in the administrative record, such as the RI/FS and RFI, likely will be necessary to produce a concise evaluation; however, these references should be as explicit as possible (e.g., cite specific page or table numbers). Technical discussions and conclusions should be supported by data compilations, statistical analyses, or other types of data reduction included in the evaluation.

4.4 Supporting Information for TI Evaluations

Most, if not all, of the information needed to evaluate TI could be obtained during a thorough site investigation and, where appropriate, remedy performance monitoring efforts. At some sites, however, additional analysis of existing data or new information may be required before EPA can determine accurately the technical practicability of the restoration goals. Not all of the data or analyses outlined in this guidance will be required at all sites; specific information needs will depend on site conditions and any ongoing remediation efforts.

12 For this guidance a "TI evaluation" comprises the data and analyses necessary to make a TI determination. The TI evaluation may be performed by PRPs at enforcement-lead Superfund sites, or by State or other Federal agencies, where appropriate. Similarly, owner/operators at RCRA facilities may perform TI evaluations. However, the actual TI "determination," or "decision," will be made by EPA (or other lead agency, as appropriate).

The data and analyses identified and discussed below address the TI evaluation components provided in Section 4.3.

4.4.1. Specific ARARs or Media Cleanup Standards

The TI evaluation should identify the specific ARARs or media cleanup standards (i.e., the specific contaminants) for which the determination is sought. Such contaminants generally should include only those for which attainment of the required cleanup levels is technically impracticable. Factors EPA will consider when evaluating contaminants that may be included in the TI decision include: 1) the technical feasibility of restoring some of the contaminants present in the ground water; and 2) the potential advantages of attaining cleanup levels for some of the contaminants.

For example, consider a Superfund site with a DNAPL contamination problem (e.g., TCE), including a widespread subsurface DNAPL source area for which containment or restoration are technically impracticable. The aqueous plume also contains inorganic contamination (e.g., chromium) from on-site sources. Although it would be feasible to reduce chromium concentrations to the required cleanup level within a reasonable timeframe, TCE concentrations would remain above cleanup levels much longer due to the continued presence of the DNAPL or slow desorption of TCE from aquifer materials. However, in such cases, EPA may choose to limit the TI ARAR waiver to TCE alone, while requiring cleanup of the chromium.[13]

Two situations would favor use of this approach. The first would be where attaining chromium cleanup levels in the ground water will make future *ex situ* treatment of the (TCE-contaminated) ground water less complex and less expensive. This may be advantageous where a community wishes to extract the TCE-contaminated water, perform *ex situ* treatment, and put the treated water to beneficial use. A related consideration is whether removal of the chromium will facilitate future subsurface remediation using a newly developed technology. The second situation favoring this approach is where one of the contaminants (e.g., TCE) is being naturally biodegraded and the other (e.g., chromium) is not. Therefore, cleanup of the chromium may result in more rapid attainment of the long-term cleanup goals at the site.

Where the balance of conditions at such a site do not indicate that it is practicable to attain the cleanup levels for only some of the contaminants present, EPA may conclude that cleanup levels for the remaining contaminants need not be attained, depending on the circumstances of the site. As discussed further in Section 5.0, however, this decision does not preclude EPA from selecting (or continuing operation of) a remedy that includes active measures (e.g., pump-and-treat) along with measures to prevent exposure (e.g., institutional controls) needed to address site risks.

4.4.2 Spatial Extent of TI Decisions

The TI evaluation should specify the horizontal and vertical extent of the area for which the TI determination is sought. Where EPA determines that ground-water restoration is technically impracticable, the area over which the decision applies (the "TI zone") generally will include all portions of the contaminated ground water that do not meet the required cleanup levels (contaminated ground-water zone), unless the TI zone is otherwise defined by EPA.

In certain cases, EPA may restrict the extent of the TI zone to a portion or subarea within the contaminated ground-water zone. For example, consider a DNAPL site where it is technically impracticable to remove the residual DNAPLs from the subsurface but it is feasible and practicable to: 1) limit further migration of contaminated ground-water using a containment system; and 2) restore that portion of the aqueous plume outside of the containment area. The TI zone in this case should be restricted to that portion of the site that lies within the containment area. Outside of the TI zone, ARARs or media cleanup standards still would apply. The potential to spatially restrict the TI zone, therefore, will depend on the ability to delineate and contain non-removable subsurface contamination sources and restore those portions of the aqueous plume outside of the containment area. The spatial extent of the TI zone should be limited to as small an area as possible, given the circumstances of the site.

A TI zone should be delineated spatially, both in area and depth. Depth of a TI zone may be defined in absolute terms (e.g., feet above mean sea level) or in relative terms (e.g., with respect to various aquifers within multi-aquifer systems), as appropriate. Where

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13 The extracted ground water would likely need to be treated for both TCE and chromium to satisfy treatment and waste disposal ARARs.

the TI zone will be restricted to a portion of the contaminated ground-water zone, the limits of the TI zone should be delineated clearly on site maps and geologic cross-sections. Delineation of the TI zone based on the location of a particular mapped contaminant concentration contour interval (e.g., the 200 part per billion isoconcentration line) generally should be avoided. This is because the location of such mapped contours often is highly interpretive, and their position may change with time. While concentration data may be appropriate to consider when determining the size of a containment area or the extent of a TI zone, the limits of that TI zone should be fixed in space, both horizontally and vertically.

4.4.3 Development and Purpose of the Site Conceptual Model

Decisions regarding the technical practicability of ground-water restoration must be based on a thorough characterization of the physical and chemical aspects of the site. Characterization data should describe site geology and hydrology; contamination sources, properties, and distribution; release mechanisms and rates; fate and transport processes; current or potential receptors; and other elements that define the contamination problem and facilitate analysis of site restoration potential. While the elements of such a model may vary from site to site, some generalizations can be made about what such a model would contain. Examples of these elements are provided in Figure 4. The site conceptual model synthesizes data acquired from historical research, site characterization, and remediation system operation.

The site conceptual model typically is presented as a summary or specific component of a site investigation report. The model is based on, and should be supported by, interpretive graphics, reduced and analyzed data, subsurface investigation logs, and other pertinent characterization information. The site conceptual model is not a mathematical or computer model, although these may be used to assist in developing and testing the validity of a conceptual model or evaluating the restoration potential of the site. The conceptual model, like any theory or hypothesis, is a dynamic tool that should be tested and refined throughout the life of the project. As illustrated in Figure 5, the model should evolve in stages as information is gathered during the various phases of site remediation. This iterative process allows data collection efforts to be designed so that key model hypotheses may be tested and revised to reflect new information.

The conceptual model serves as the foundation for evaluating the restoration potential of the site and, thereby, technical impracticability as well. The TI determination must consider how site conditions impact the potential for achieving remediation goals and whether remediation performance, cost-effectiveness, and timeframe meet EPA requirements or expectations. As these determinations rely on professional judgment, the clarity of the conceptual model (and supporting information) is critical to the decision-making process.

4.4.4 Evaluation of Restoration Potential

4.4.4.1 Source Control Measures. Remediation of contamination sources is critical to the success of aquifer restoration efforts. Continued releases of contamination from source materials to ground water can greatly reduce the effectiveness of aquifer restoration technologies, such as pump-and-treat, which generally are effective only for removing dissolved contaminants (EPA 1989b; 1992d). EPA considers subsurface NAPLs to be source materials because they are capable of releasing significant quantities of dissolved contamination to ground water over long periods of time.

A demonstration that ground-water restoration is technically impracticable generally should be accompanied by a demonstration that contamination sources have been, or will be, identified and removed or treated to the extent practicable. EPA recognizes that locating and remediating subsurface sources can be difficult. For example, locating DNAPLs in certain complex geologic environments may be impracticable. EPA expects, however, that all reasonable efforts will be made to identify the location of source areas through historical information searches and site characterization efforts.

Source removal and remediation may be difficult, even where source locations are known. The appropriate level of effort for source removal and remediation must be evaluated on a site-specific basis, considering the degree of risk reduction and any other potential benefits that would result from such an action. Even partial removal of contamination sources can greatly reduce the long-term reliance on both active and passive ground-water remediation.

Where complete source removal or treatment is impracticable, use of migration control or containment measures should be considered. Physical and hydraulic barriers are proven technologies that are capable of limiting or preventing further contaminant

Figure 4. Elements of Site Conceptual Model

The data and analysis required for TI evaluations will be determined by EPA on a site-specific basis. This information should be presented in formats conducive to analysis and in sufficient detail to define the key site conditions and mechanisms that limit restoration potential. Types of information and analysis that may be needed for conceptual model development are illustrated below.

Background Information

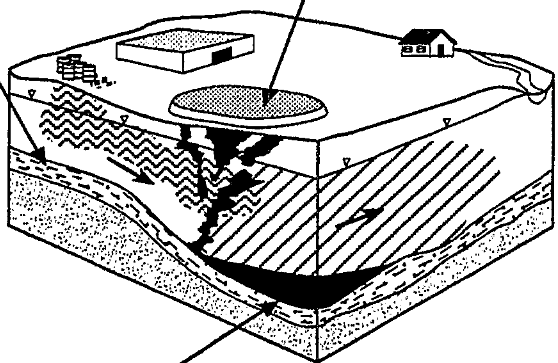
- Location of water supply wells.
- Ground-water Classification.
- Nearby wellhead protection areas or sole-source aquifers.
- Location of potential environmental receptors.

Geologic and Hydrologic Information

- Description of regional and site geology.
- Physical properties of subsurface materials (e.g., texture, porosity, bulk density).
- Stratigraphy, including thickness, lateral extent, continuity of units, and presence of depositional features, such as channel deposits, that may provide preferential pathways for, or barriers to, contaminant transport.
- Geologic structures that may form preferential pathways for NAPL migration or zones of accumulation.
- Depth to ground water.
- Hydraulic gradients (horizontal and vertical).
- Hydraulic properties of subsurface materials (e.g., hydraulic conductivity, storage coefficient, effective porosity) and their directional variability (anisotropy).
- Spatial distribution of soil or bedrock physical/hydraulic properties (degree of heterogeneity).
- Characterization of secondary porosity features (e.g., fractures, karst features) to the extent practicable.
- Temporal variability in hydrologic conditions.
- Ground-water recharge and discharge information.
- Ground-water/surface water interactions.

Contaminant Source and Release Information

- Location, nature, and history of previous contaminant releases or sources.
- Locations and characterizations of continuing releases or sources.
- Locations of subsurface sources (e.g., NAPLs).

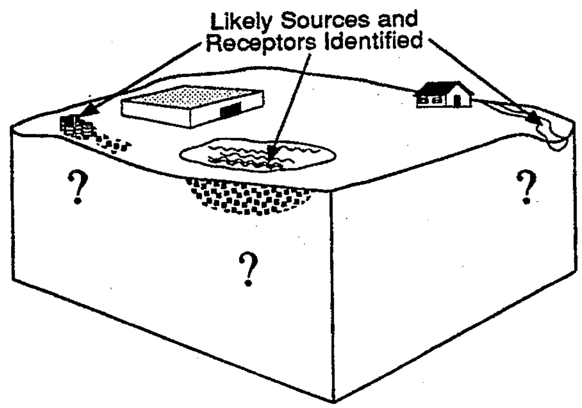


Contaminant Distribution, Transport, and Fate Parameters

- Phase distribution of each contaminant (gaseous, aqueous, sorbed, free-phase NAPL, or residual NAPL) in the unsaturated and saturated zones.
- Spatial distribution of subsurface contaminants in each phase in the unsaturated and saturated zones.
- Estimates of subsurface contaminant mass.
- Temporal trends in contaminant concentrations in each phase.
- Sorption information, including contaminant retardation factors.
- Contaminant transformation processes and rate estimates.
- Contaminant migration rates.
- Assessment of facilitated transport mechanisms (e.g., colloidal transport).
- Properties of NAPLs that affect transport (e.g., composition, effective constituent solubilities, density, viscosity).
- Geochemical characteristics of subsurface media that affect contaminant transport and fate.
- Other characteristics that affect distribution, transport, and fate (e.g., vapor transport properties).

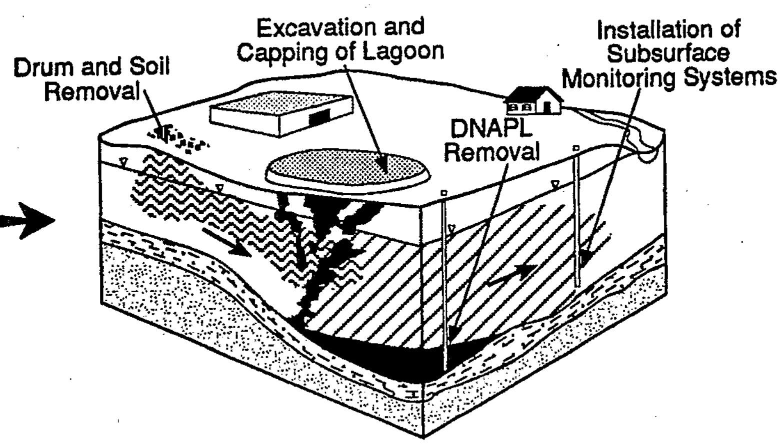
Figure 5. Evolution of the Site Conceptual Model

- Site Background and History
- Preliminary Site Investigations



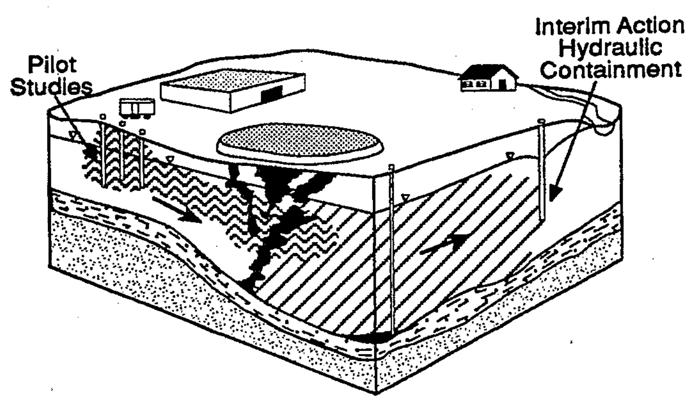
Conceptual Model Provides Basis for:

- Early Action/Removal of Near-Surface Materials
- Site Characterization Studies (RI/FS, RFI)
- Removal of Subsurface Sources (e.g., free-phase NAPLs)



Conceptual Model Provides Basis for:

- Pilot Studies
- Interim Ground-Water Actions



Conceptual Model Provides Basis for:

- Evaluation of Restoration Potential (or TI)
- Full-Scale Treatment System Design and Implementation
- Performance Monitoring and Evaluations
- Enhancement or Augmentation of Remediation System, if Required
- Future Evaluation of TI, if Required (See Figure 6)

migration from a source area under the right circumstances. While these containment measures are not capable of restoring source areas to required cleanup levels (i.e., a TI decision may be necessary for the source area), they may enable restoration of portions of the aquifer outside the containment zone.

4.4.4.2 Remedial Action Performance Analysis. The suitability and performance of any completed or ongoing ground-water remedial actions should be evaluated with respect to the objectives of those actions. Examples of remedy performance data are provided in Figure 6. The performance analysis should:

1. Demonstrate that the ground-water monitoring program within and outside of the aqueous contaminant plume is of sufficient quality and detail to fully evaluate remedial action performance (e.g., to analyze plume migration or containment and identify concentration trends within the remediation zone).[14]

2. Demonstrate that the existing remedy has been effectively operated and adequately maintained.

3. Describe and evaluate the effectiveness of any remedy modifications (whether variations in operation, physical changes, or augmentations to the system) designed to enhance its performance.

4. Evaluate trends in subsurface contaminant concentrations. Consider such factors as whether the aqueous plume has been contained, whether the areal extent of the plume is being reduced, and the rates of contaminant concentration decline and contaminant mass removal. Further considerations include whether aqueous-phase concentrations rebound when the system is shut down, whether dilution or other natural attenuation processes are responsible for observed trends, and whether contaminated soils on site are contaminating the ground water.

Analysis of aqueous-phase concentration data should be performed with caution. Contaminant concentrations plotted as a function of time, pore volumes of flushed fluids, or other appropriate variables may be useful in evaluating dominant contaminant fate and transport processes, evaluating remedial system design, and predicting future remedial system performance. Sampling methodologies, locations, and strategies, however, should be analyzed to determine the impact they may have had on observed concentration trends. For example, studies of ground-water extraction systems indicate that some systems show rapid initial decreases in aquifer concentration, followed by less dramatic decreases that eventually approach an asymptotic concentration level (EPA 1989b, 1992d). This "leveling off" effect may represent either a physical limitation to further remediation (e.g., contaminant diffusion from low permeability units) or an artifact of the system design or monitoring program. Professional judgment must be applied carefully when drawing conclusions concerning restoration potential from this information.

In certain cases, EPA may determine that lack of progress in achieving the required cleanup levels has resulted from system design inadequacies, poor system operation, or unsuitability of the technology for site conditions. Such system-related constraints are not sufficient grounds for determining that ground-water restoration is technically impracticable. In such instances, EPA generally will require that the existing remedy be enhanced, augmented, or replaced by a different technology. Furthermore, EPA may require modification or replacement of an existing remedy to ensure protectiveness, regardless of whether or not attainment of required cleanup levels is technically impracticable.

4.4.4.3 Restoration Timeframe Analysis. Estimates of the timeframe required to achieve ground-water restoration may be considered in TI evaluations. While restoration timeframes may be an important consideration in remedy selection, no single timeframe can be specified during which restoration must be achieved to be considered technically practicable. However, very long restoration timeframes (e.g., longer than 100 years) may be indicative of hydrogeologic or contaminant-related constraints to remediation. While predictions of restoration timeframes may be useful in illustrating the effects of such constraints, EPA will base TI decisions on an overall demonstration of the extent of such physical constraints at a site, not on restoration timeframe analyses alone. Such demonstrations should be based on detailed and accurate site conceptual models that also can provide the bases for meaningful predictions of restoration timeframes.

14 Further guidance on design of performance monitoring for remedial actions at ground-water sites is provided in "General Methods for Remedial Operations Performance Evaluations," EPA Office of Research and Development Publication EPA/600/R-92/002, January 1992 (EPA 1992e).

Figure 6. Remedy Performance Analysis

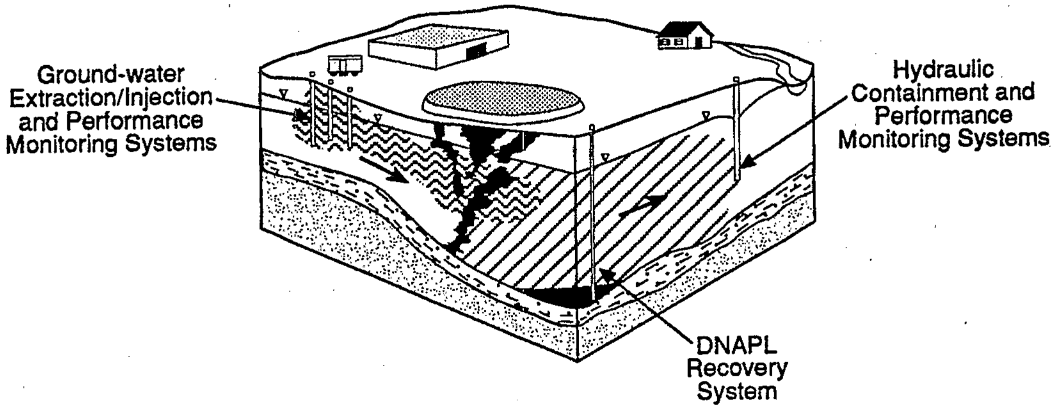
Remedy design and performance data requirements should be specific to technologies employed and site conditions. The categories of required information normally necessary to evaluate performance are provided below with some examples of specific data elements. These data should be reported to EPA in formats conducive to analysis and interpretation. Simple data compilations are insufficient for this purpose.

Remedy Design and Operational Information

- Design and as-built construction information, including locations of extraction or *in situ* treatment points with respect to the contamination.
- Supporting design calculations (e.g., calculation of well spacing).
- Operating information pertinent to remedy (e.g., records of the quantity and quality of extracted or injected fluids).
- Percent downtime and other maintenance problems.

Enhancements to Original Remedial Design

- Information concerning operational modifications, such as variations in pumping, injection rates, or locations.
- Rationale, design, and as-built construction information for system enhancements.
- Monitoring data and analyses that illustrate the effect these modifications have had on system performance.



Source Removal or Control

- Source removal information (e.g., results of soil excavations, removal of lagoon sediments, NAPL removal activities).
- Source control information (e.g., results of NAPL containment, capping of former waste management units).

Performance Monitoring Information

- Design and as-built construction information for performance monitoring systems.
- Hydraulic gradients and other information demonstrating plume containment or changes in areal extent or volume.
- Trends in subsurface contaminant concentrations determined at several/many appropriate locations in the subsurface. Trends should be displayed as a function of time, a function of pore volumes of flushed fluids, or other appropriate measures.
- Information on types and quantities of contaminant mass removed and removal rates.

A further consideration regarding the usefulness of restoration timeframe predictions in TI evaluations is the uncertainty inherent in such analyses. Restoration timeframes generally are estimated using mathematical models that simulate the behavior of subsurface hydrologic processes. Models range from those with relatively limited input data requirements that perform basic simulations of ground-water flow only, to those with extensive data requirements that are capable of simulating multi-phase flow (e.g., water, NAPL, vapor) or other processes such as contaminant adsorption to, and desorption from, aquifer materials. Model input parameters generally are a combination of values measured during site characterization studies and values assumed based on scientific literature or professional judgment. The input parameter selection process, as well as the simplifying assumptions of the mathematical model itself, result in uncertainty of the accuracy of the output. Restoration timeframes predicted using even the most sophisticated modeling tools and data, therefore, will have some degree of uncertainty associated with them.

Restoration timeframe analyses, therefore, generally are well suited for comparing two or more remediation design alternatives to determine the most appropriate strategy for a particular site. Where employed for such purposes, restoration timeframe analyses should be accompanied by a thorough discussion of all assumptions, including a list of measured or assumed parameters and a quantitative analysis, where appropriate, of the degree of uncertainty in those parameters and in the resulting timeframe predictions. The uncertainty in the predictions should be factored into the weight they are given in the remedy decision process.

4.4.4.4 Other Applicable Technologies. The TI evaluation should include a demonstration that no other remedial technologies or strategies would be capable of achieving ground-water restoration at the site.[15] The type of demonstration required will depend on the circumstances of the site and the state of ground-water remediation science at the time such an evaluation is made. In general, EPA expects that such a demonstration should consist of: 1) a review of the technical literature to identify candidate technologies; 2) a screening of the candidate technologies based on general site conditions to identify potentially applicable technologies; and 3) an analysis, using site hydrogeologic and chemical data, of the capability of any of the applicable technologies to achieve the required cleanup standards. Analysis of the potentially applicable technologies generally can be performed as a "paper study." EPA, however, may reserve the right to require treatability or pilot testing demonstrations to determine the actual effectiveness of a technology at a particular site.

Treatability and pilot testing should be conducted with rigorous controls and mass balance constraints. Information required by EPA for evaluation of pilot tests will be similar to that required for evaluation of existing remediation systems (e.g., detailed design and performance data).

4.4.4.5 Additional Considerations. Techniques used for evaluation of ground-water restoration potential are still evolving. The results of such evaluations generally will have some level of uncertainty associated with them. Interpretation of the results of restoration potential evaluations, therefore, will require the use of professional judgment. The use of mathematical models and calculations of mass removal rates are two examples of techniques that require particular caution.

Ground-water Flow and Contaminant Transport/Fate Modeling. Simulation of subsurface systems through mathematical modeling can be useful for designing remediation systems or predicting design performance. However, the limitations of predictive modeling must be considered when evaluating site restoration potential. As discussed in Section 4.4.4.3, ground-water models are sensitive to initial assumptions and the choice of parameters, such as contaminant source locations, leachability, and hydraulic conductivity. Predictions such as the magnitude and distribution of subsurface contaminant concentrations, therefore, will involve uncertainty. The source and degree of this uncertainty should be described, quantified, and evaluated wherever possible so the reviewer understands the level of confidence that should be placed in the predicted concentration values or other outputs. Predictive modeling may be most valuable in providing insight into processes that dominate contaminant transport and fate at the site and evaluating the relative effectiveness of different remedial alternatives. Further guidance and information on the use of ground-water models is provided in Anderson and Woessner (1992), EPA (1992f), and EPA (1992g).

Contaminant Mass Removal Estimates. Evaluation of contaminant mass removal may be useful at some sites

15 See discussions in the NCP (55 FR 8748, March 8, 1990) and Subpart S (55 FR 30838, July 27, 1990).

with existing remediation systems. These measures may include evaluation of mass removal rates, comparison of removal rates to *in situ* mass estimates, changes in the size of the contaminated area, comparison of mass removal rates with pumping rates, and comparison of such measures with associated costs. Mass removal and balance estimates should be used with caution, as there often is a high degree of uncertainty associated with estimates of the initial mass released and the mass remaining *in situ*. This uncertainty results from inaccuracy of historical site waste-management records, subsurface heterogeneities, and the difficulty in delineating the severity and extent of subsurface contamination.

4.4.5 Cost Estimate

Estimates of the cost of remedy alternatives should be provided in the TI evaluation. The estimates should include the present worth of construction, operation, and maintenance costs. Estimates should be provided for the continued operation of the existing remedy (if the evaluation is conducted following implementation of the remedy) or for any proposed alternative remedial strategies.

As discussed in Section 4.4.1, a Superfund remedy alternative may be determined to be technically impracticable if the cost of attaining ARARs would be inordinately high. The role of cost, however, is subordinate to that of ensuring protectiveness. The point at which the cost of ARAR compliance becomes inordinate must be determined based on the particular circumstances of the site. As with long restoration timeframes, relatively high restoration costs may be appropriate in certain cases, depending on the nature of the contamination problem and considerations such as the current and likely future use of the ground water. Compliance with ARARs is not subject to a cost-benefit analysis, however.[16]

5.0 Alternative Remedial Strategies

5.1 Options and Objectives for Alternative Strategies[17]

EPA's goal of restoring contaminated ground water within a reasonable timeframe at Superfund or RCRA sites will be modified where complete restoration is found to be technically impracticable. In such cases, EPA will select an alternative remedial strategy that is technically practicable, protective of human health and the environment, and satisfies the statutory and regulatory requirements of the Superfund or RCRA programs, as appropriate.[18]

Where a TI decision is made at the "front end" of the site remediation process (before a final remedy has been identified and implemented), the alternative strategy should be incorporated into a final remedy decision document, such as a Superfund ROD or RCRA permit or enforcement order. Where the TI decision is made after the final decision document has been signed (i.e., after a remedy has been implemented and its performance evaluated), the alternative remedial strategy should be incorporated in a modified final remedy decision document, such as a ROD amendment or RCRA permit/order modification (see Section 6.0).

Alternative remedial strategies typically will address three types of problems at contaminated ground-water sites: prevention of exposure to contaminated ground water; remediation of contamination sources; and remediation of aqueous contaminant plumes. Recommended objectives and options for addressing these three problems are discussed below. Note that combinations of two or more options may be appropriate at any given site, depending on the size and complexity of the contamination problem or other site circumstances.

5.1.1 Exposure Control

Since the primary objective of any remedial strategy is overall protectiveness, exposure prevention may play a significant role in an alternative remedial strategy. Exposure control may be provided using institutional controls, such as deed notifications and restrictions on water-supply well construction and use. The remedy should provide assurance that these measures are enforceable and consistent with State or local laws and ordinances.

5.1.2 Source Control

Source remediation and control should be considered when developing an alternative remedial strategy.

16 A Fund-Balancing ARAR waiver may be invoked at Fund-lead Superfund sites where meeting an ARAR would entail such cost in relation to the added degree of protection or reduction of risk that remedial actions at other sites would be jeopardized (EPA 1989c).

17 These recommendations are consistent with those made in Section 3.0 concerning DNAPL sites, but are applicable for any site where restoration is technically impracticable.

18 PRPs or owner/operators may propose and analyze alternative remedial strategies. However, only EPA (or designated lead agency, where appropriate) has remedy selection authority.

Sources should be located and treated or removed where feasible and where significant risk reduction will result, regardless of whether EPA has determined that ground-water restoration is technically impracticable.

In some cases, however, the inability to remove or treat sources will be a major factor in a TI decision. Where sources cannot be completely treated or removed, effective source containment may be critical to the long-term effectiveness and reliability of an alternative ground-water remedy. Options currently available for source containment usually involve either a physical barrier system (such as a slurry wall) or a hydraulic containment system (typically a pump-and-treat system) (EPA 1992b).

Applicability and effectiveness of containment systems are influenced by several hydrogeologic factors, however. For example, the effectiveness of a slurry wall generally depends on whether a continuous, low permeability layer exists at a relatively shallow depth beneath the site.

Source containment has several benefits. First, source containment will contribute to the long-term management of contaminant migration by limiting the further contamination of ground water and spread of potentially mobile sources, such as NAPLs. Second, effective source containment may permit restoration of that portion of the aqueous plume that lies outside of the containment area. Third, effective containment may facilitate the future use of new source removal technologies, as some of these technologies (e.g., surfactants, steam injection, radio frequency heating) may increase the mobility of residual and free-phase NAPLs. Remobilization of NAPLs, particularly DNAPLs, often presents a significant risk unless the source area can be reliably contained.

5.1.3 Aqueous Plume Remediation

Remediation of the aqueous plume is the third major technical concern of an alternative remedial strategy. Where the technical constraints to restoration include the inability to remove contamination sources, the ability to effectively contain those sources will be critical to establishing the objectives of plume remediation. Where sources can be effectively contained, the portion of the aqueous plume outside of the containment area generally should be restored to the required cleanup levels.

Inability to contain the sources, or other technical constraints, may render plume restoration technically impracticable. There are several options for alternative remedial strategies in such cases. These include hydraulic containment of the leading edge of the aqueous plume, establishing a less-stringent cleanup level that would be actively sought throughout the plume (at Superfund sites), and natural attenuation or natural gradient flushing of the plume.

Containment of the aqueous plume usually requires the pumping and treating of contaminated ground water, but usually involves fewer wells and smaller quantities of water than does a full plume restoration effort. Plume containment offers the potential advantages of preventing further spreading of the contaminated ground water, thereby limiting the size of the plume, and preventing the plume from encroaching on water-supply wells or discharging to ecologically sensitive areas.

At certain Superfund sites, it may be feasible to restore the contaminated plume (outside of any source containment area) to a site-specific cleanup level that is less stringent than that originally identified. EPA may establish such a level as the cleanup level within the TI zone, where appropriate. The site-specific level may consider the targeted risk level for site cleanup and other factors. Site-specific cleanup levels offer the advantage of providing a clear goal against which to measure the progress of the alternative remedial strategy. However, where site-specific cleanup levels exceed the acceptable risk range for human or environmental exposure, the remedy generally must include other measures (e.g., institutional controls) to ensure protectiveness.

At some Superfund sites, a less-stringent ARAR than the one determined to be unattainable may have to be complied with. For example, it may be technically impracticable to attain the most stringent ARAR at a site (e.g., a State requirement to restore ground water to background concentration levels). However, the next most stringent ARAR (e.g., Federal MCL) for the same compound may be attainable. In such cases, the next most stringent ARAR generally must be attained.

In certain situations where restoration is technically impracticable, EPA may choose natural attenuation as a component of the remedy for the aqueous plume.[19] Natural attenuation generally will result in

19 Technical impracticability of restoration is not a precondition for the use of natural attenuation in a ground-water remedy, however.

attainment of the desired cleanup levels, but may take longer to meet them than active remediation. This approach is most likely to be appropriate where the affected ground water is not a current or reasonably expected future source of drinking water, and ground-water discharge does not significantly impact surface water or ecologic resources. Sufficient technical information and supporting data must be presented to demonstrate the effectiveness of this strategy, along with assurances that any institutional controls required to prevent exposure will be reliable and enforceable. Contingencies for additional or more active remediation also should be incorporated into the remedy, to be triggered by specific contaminant concentration levels in the site ground-water monitoring network, or other criteria as appropriate.

5.2 Alternative Remedy Selection

The alternative remedial strategy options discussed above represent a range of responses for addressing the various aspects of a ground-water contamination site. Selection of the options appropriate for a particular site must not only consider the desired remediation objectives, as discussed above, but also the statutory and regulatory requirements applicable to the program under which the action is being taken. These requirements are discussed briefly below. Further information and guidance on these requirements can be obtained from publications referenced in this section.

5.2.1. Superfund

The selection of an alternative remedy at a Superfund site should follow the remedy selection process provided in NCP §300.430(f). Regardless of whether ARARs are waived at the site, the alternative remedy still must satisfy the two threshold remedy selection criteria (protect human health and the environment and comply with all ARARs that have not been waived); be cost effective; and utilize permanent solutions and treatment to the maximum extent practicable. This last finding is satisfied by identifying the alternative that best balances the trade-offs with respect to the remaining balancing and modifying criteria, taking into account the demonstrated technical limitations (see Highlight 2).[20]

Where ground-water ARARs are waived at a Superfund site due to technical impracticability, EPA's general expectations are to prevent further migration of the contaminated ground-water plume, prevent exposure to the contaminated ground water, and evaluate further risk reduction measures as appropriate. (NCP §300.430(a)(1)(iii)(F)). These expectations should be evaluated along with the nine remedy selection criteria to determine the most appropriate remedial strategy for the site.

Highlight 2.
Superfund Remedy Selection Criteria

Threshold Criteria
- Overall protection of human health and the environment
- Compliance with (or justification for a waiver of) ARARs

Balancing Criteria
- Long-term effectiveness and permanence
- Reduction of mobility, toxicity, or volume
- Short-term effectiveness
- Implementability
- Cost

Modifying Criteria
- State acceptance
- Community acceptance

5.2.2 RCRA

At RCRA facilities where ground-water restoration is technically impracticable, the permit or order schedule of compliance may be modified by establishing: 1) further measures that may be required of the permittee to control exposure to residual contamination, as necessary to protect human health and the environment; and 2) alternate levels or measures for cleaning up contaminated media.[21]

Criteria for establishing an alternative remedial strategy under RCRA are presented in Highlight 3. In addition to satisfying the general standards for remedies, the alternative remedial strategy at a RCRA facility also should provide the best balance of trade-offs among the five remedy selection decision factors.[22]

20 For further guidance on the Superfund remedy selection process, see NCP §300.430(f) and "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA," (EPA 1988a).

21 Proposed Subpart S Rule, §264.531(b).

22 Further guidance on remedy selection at RCRA facilities is provided in the proposed Subpart S Rule (55 FR 30823-30824, July 27, 1990).

Highlight 3.
RCRA Remedy Standards and Selection Factors

General Standards for Remedies
1. Overall protection of human health and the environment
2. Attainment of media cleanup standards
3. Source control
4. Compliance with waste management standards

Remedy Selection Decision Factors
1. Long-term effectiveness
2. Reduction of waste toxicity, mobility, or volume
3. Short-term effectiveness
4. Implementability
5. Cost

5.2.3 Additional Remedy Selection Considerations

The choice among available remedial strategy options may involve a consideration of the aggressiveness of the remedy, a concept that includes both the choice of remedial technologies as well as the relative intensity of how that technology is applied at the site. For example, consider a site where source area restoration is technically impracticable but source containment is both feasible and practicable. With the contaminant source contained, restoration of the portion of the plume outside of the containment area may be feasible. However, as discussed earlier, there are several options for attaining cleanup levels within the aqueous plume: active pump-and-treat throughout the aqueous plume; natural gradient flushing of the plume towards a pump-and-treat capture system located at the leading edge of the plume; and natural attenuation (dilution, dispersion, and any natural degradation processes active within the affected aquifer). Each alternative will attain the required cleanup levels, but the choice involves a trade-off among several factors, including: 1) remediation timeframe (longer with less aggressive strategies); 2) cost (lower with less aggressive strategies); and 3) potential risk of exposure (may increase with less aggressive strategies).[23]

Conditions favoring more aggressive strategies (i.e., active pump-and-treat throughout the aqueous plume) include the following:

1) **The aggressive strategy clearly will result in a significantly shorter restoration timeframe than other available options.** This will depend on site hydrogeologic and contaminant-related factors, including the complexity of the aquifer system, natural rate of ground-water flow, quantity of sorbed contaminant mass in the aquifer (and its rate of desorption), and other factors.

2) **A shorter remediation timeframe is desired to reduce the potential for human exposure.** This generally is the case where there is current or reasonably expected near-term future use of the ground water. Factors that may be useful in evaluating the likelihood of exposure include the State (or Federal, as appropriate) classification of the ground water; availability of alternate supplies, such as municipal hookups or other water supply aquifers; interconnections of the contaminated aquifer with other surface or ground waters; and the ability of institutional controls to limit exposure.

3) **A shorter remediation timeframe is desired to reduce ongoing or potential impacts to environmental receptors.** Such impacts may be caused by discharges to surface waters, sensitive ecologic areas (e.g., wetlands), or sole-source aquifers.

EPA will evaluate and determine the objectives and relative aggressiveness of the alternative remedy on a site-specific basis, based on the applicable regulatory requirements and considering the factors discussed throughout this section. Where conditions favoring more aggressive strategies do not exist, EPA is more likely to choose a less aggressive strategy to achieve the desired remediation objectives. EPA recognizes that, at some sites, remedies may need to be in operation for very long time periods. Adequate monitoring and periodic evaluation of remedy performance should be conducted to ensure protectiveness and to evaluate the need for remedy enhancements or the use of new or different remediation technologies.

5.2.4 Relation to Alternate Concentration Limits

Site-specific cleanup levels established as part of an alternative remedial strategy at a Superfund site should not be confused with CERCLA Alternate Concentration Limits (ACLs). To qualify for use of a CERCLA ACL, the site must meet the following three requirements: 1) there are known points of entry of the contaminated ground water into surface water; 2) there

23 The long-term reliability of a remedy also is an important consideration for alternative remedial strategy selection. In this example, long-term reliability is primarily a function of the design and integrity of the source containment system.

will be no statistically significant increases of the contaminant concentrations in the surface water or contaminant accumulations in downstream sediments; and 3) enforceable measures can be put into place to prevent exposure to the contaminated ground water (see CERCLA §121(d)(2)(B)(ii)). In addition, EPA generally considers ACLs appropriate only where cleanup to ARARs is impracticable, based on an analysis using the Superfund remedy selection "balancing" and "modifying" criteria shown in Highlight 2. 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 a CERCLA ACL. For further guidance on CERCLA ACLs, refer to the NCP Preamble (55 FR 8754, March 1990).

Site-specific cleanup levels established in response to a TI determination at a RCRA facility also should not be confused with ACLs established as part of the ground-water monitoring program for regulated units under 40 CFR 264.94. ACLs established under §264.94(a)(3) represent concentrations that EPA determines will not pose a substantial hazard to human or environmental receptors. (If the ACL is exceeded, then corrective action responsibilities for the regulated unit are triggered.) A TI determination generally will not satisfy the criteria for an ACL under this authority.

6.0 Administrative Issues

6.1 TI Review and Decision Process

A TI decision must be incorporated into a site decision document (Superfund ROD or RCRA permit or enforcement order) or be incorporated into a modification or amendment to an original document. Information and analyses supporting the TI decision must be incorporated into the site administrative record, either as part of a Feasibility Study or Corrective Measures Study (for a "front-end" TI determination) or remedy performance evaluation or other technical report or evaluation (for a post-remedy implementation determination).

The first step in EPA's review process for a TI determination will be to assess the completeness and adequacy of the TI evaluation. TI evaluations that do not adequately address the considerations identified in this guidance likely will have to be revised or augmented to address the inadequacies identified by EPA or the responsible agency. Early consultation with EPA by PRPs or owner/operators is encouraged to help identify appropriate data and analysis for the evaluation. While a TI evaluation is underway, remediation efforts underway at a site shall continue until the State or Federal official responsible for the decision determines that the existing remedy should be altered. Requirements specific to the Superfund and RCRA programs are discussed further below.

6.1.1 Superfund

As discussed in Section 4.2, TI decisions may be made either in the ROD (front-end decisions) or after the remedy has been implemented and monitored (post-implementation decisions), depending on the circumstances of the site.

TI decisions at Superfund sites generally will be made by the EPA Regional Administrator who, upon review of a TI evaluation, will determine whether ground-water restoration is technically impracticable and will identify further remedial actions to be taken at the site. TI determinations at Superfund sites may require consultation with headquarters program management. Regional personnel should refer to the most recent OERR Remedy Delegation Memorandum for current consultation requirements.[24]

Where a Superfund ROD will invoke a TI ARAR waiver (front-end decision), EPA (or the lead agency) must provide notice of its intent to waive the ARAR in the Proposed Plan for the site and respond to any State (or Federal) agency or public comments concerning the waiver. The requirements for State and community involvement are provided in NCP §300.500-515 and §300.430, respectively. In general, State and community involvement in the decision to waive an ARAR based on technical impracticability will be the same as for other site remedy decisions. Since TI decisions may affect the potential future uses of ground water, interest in TI ARAR waivers may be high. Therefore, it is EPA's intent to coordinate and consult with States and the public regarding TI ARAR waiver issues as early as possible in the remedy decision process.

24 The types of Superfund site remedy decisions that require consultation with headquarters program management are identified in the periodically updated OERR Remedy Delegation Memorandum. The most recent version available at the time of publication of this guidance was the "Twenty Fourth Remedy Delegation Report - FY 1993," dated February 18, 1993.

State concurrence should be sought, but is not required, for all remedy decisions in which EPA invokes an ARAR waiver. Where the ARAR to be waived is a State ARAR, EPA must notify the State of this when submitting the RI/FS to the State or when responding to a State-lead RI/FS (NCP §300.515(d)(3)). EPA must provide the State with an explanation of any waiver of a State standard (CERCLA §121(f)(1)(G)).

For remedial actions under CERCLA §106 that will waive an ARAR, the State must be notified at least 30 days prior to the date on which any Consent Decree will be entered. If the State wishes the action to conform to (and not waive) those standards, the State may intervene in the action before the Consent Decree is entered (see §121(f)(2) and (f)(3)).

At certain State-lead sites, the State may make the final remedy decision, including a decision to invoke an ARAR waiver. This situation is restricted to sites where the State has been assigned the lead role for the response action, the action is being taken under State law, and the State is not receiving funding for the action from the Trust Fund. In such situations, the State may seek, but is not required to obtain, EPA concurrence on the remedy decision. For further guidance on this and other issues regarding the State role in remedy selection, see "Questions and Answers About the State Role in Remedy Selection at Non-Fund-Financed Enforcement Sites" (EPA 1991c).

Post-remedy-implementation TI decisions may be made in cases where an outside party or agency submits comments requesting a TI determination or EPA determines on its own initiative that a waiver is warranted. The information considered in making such decisions should include the same types of information and analyses discussed for front-end determinations, except that remedy performance data and analysis also should be provided. This information must be entered into the site administrative record before the TI decision can be made and an ARAR waiver invoked. There are limitations, however, to the requirement that EPA open the administrative record to new comments, such as an outside party's request for a TI determination. EPA is not required to consider comments on the selected remedy unless the comments contain "significant information not contained elsewhere in the administrative record file which substantially supports the need to significantly alter the response action" (see NCP §300.825). The type and amount of information necessary to meet this requirement (e.g., the length of time a remedy must be operated prior to a TI evaluation) will be determined by EPA on a site-specific basis.

A modification to a signed ROD invoking a TI ARAR waiver generally will require a ROD amendment, since a waiver usually will constitute a fundamental change in the remedy. A public comment period of 30 days is required for an amendment to a ROD; this period may be extended to 60 days upon request.[25] A public meeting also should be granted if requested. In the exceptional case where an ESD is used to invoke a TI ARAR waiver, public notice and opportunity for comment also should be provided. Further guidance on ROD amendments is provided in "Guide to Addressing Pre-ROD and Post-ROD Changes" (EPA 1991b) and upcoming revisions to "Guidance on Preparing Superfund Decision Documents" (expected Fall 1993).

6.1.2 RCRA

TI decisions at RCRA Corrective Action facilities will be made either by the EPA Regional Administrator or by the appropriate State agency, depending on the RCRA program authorization status of the State. EPA's goal in the RCRA corrective action program is to work cooperatively with individual States, regardless of their authorization status, to promote consistent TI decisions. As in the Superfund program, it is recommended that the State and EPA notify and consult each other as early as possible regarding sites where TI determinations may be made. This notification and consultation process may be outlined in the State/EPA Memorandum of Understanding.

For States authorized for Hazardous and Solid Waste Amendments (HSWA) Corrective Action, the State will have primary authority for remedy decisions, including TI decisions. EPA will retain authority for TI determinations in States that are not authorized for HSWA corrective action.

At RCRA permitted facilities, implementation of a TI determination generally would require a Class 3 permit modification for the purpose of specifying (alternative) corrective measures. This process requires a 45-day notice and comment period, response to comments, and

25 Public notice and opportunity for comment should be provided before an ARAR waiver is granted, regardless of whether an Explanation of Significant Differences (ESD) or ROD amendment is used to invoke the waiver.

public hearing, if requested. At RCRA facilities conducting corrective action under an order, TI determinations generally are implemented through the negotiation of a new order or an amendment to an existing order. This process generally includes a 30- to 45-day pubic comment period and public hearing, if requested.

6.1.3 Technical Review and Support

Technical support for the TI evaluation should be sought as early in the process as possible, preferably during the initial scoping of the content of the TI evaluation. TI determinations usually will require expertise from several disciplines, including hydrogeology, engineering, and risk assessment. Technical staff within the Regions representing these disciplines should be part of the TI review team. EPA's Office of Research and Development (ORD) technical liaisons and scientists based in the Regions also may provide assistance to program staff. Further assistance and review may be obtained from the ORD laboratories involved in the Technical Support Project, including the R.S. Kerr Environmental Research Laboratory (Ada, OK), the Risk Reduction and Engineering Laboratory (Cincinnati, OH), the Environmental Research Laboratory (Athens, GA), and the Environmental Monitoring Systems Laboratory (Las Vegas, NV). The directory of ORD technical services may be consulted for further information (EPA 1993c).

General assistance and site-specific consultation on technical impracticability issues also is available from EPA headquarters staff. Inquiries should be directed to the appropriate OSWER program office.

6.2 Duration of TI Decisions

A determination that ground-water restoration is technically impracticable and the subsequent selection of an alternative remedial strategy will be subject to future review by EPA.

At Superfund sites, an alternative remedial strategy implemented under a CERCLA TI waiver remains in effect so long as that strategy remains protective of human health and the environment. Protectiveness in this context encompasses long-term reliability of the remedy. If the conditions of protectiveness or reliability conditions cease to be met, EPA will determine what additional remedial actions must be implemented to enhance or augment the existing remedy. EPA shall conduct a full assessment of the protectiveness of the alternative remedy at least every five years at any site where contamination remains above levels that allow for unrestricted use, as required under NCP §300.430(f)(4)(ii).

RCRA TI decisions will be incorporated into facility permits or enforcement orders and therefore will be subject to continual oversight and review. Conditions of the permit or order involving the TI decision or the alternative strategy may be revisited on a periodic basis to ensure protectiveness. It may be necessary to modify permits or orders to reflect new information that becomes available during the remedy implementation and monitoring period.[26] Additional measures may be required by EPA to ensure the ongoing protectiveness and reliability of the remedy. Further, owner/operators of RCRA facilities may be required by EPA to undertake additional remedial measures in the future if subsequent advances in remediation technology make attainment of media cleanup standards technically practicable.

The protectiveness of an alternative remedial strategy at a Superfund site or RCRA facility must be ensured through a monitoring program designed to detect releases from containment areas, migration of contaminants to water supply wells, or other releases that would indicate a possible failure of one of the remedy components. EPA may decide to take any further response actions necessary to ensure protectiveness at any time based upon whether the alternative remedy is achieving its required performance standards. Monitoring data, therefore, must be provided to EPA on a regular basis to ensure adequate performance of the alternative remedy. The format, content, and reporting schedule of the monitoring program will be determined by EPA as part of the TI determination and alternative remedy selection process.

26 RCRA Corrective Action Orders that incorporate TI decisions should contain language that retains EPA's authority to review these decisions and complete additional site remediation, as necessary.

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Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration

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Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration

Interim Final

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Notice

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Contents

1.0 Introduction

1.1 Background

Restoration[1] of contaminated ground waters is one of the primary objectives of both the Superfund and RCRA Corrective Action programs. Ground-water contamination problems are pervasive in both programs; over 85 percent of Superfund National Priorities List (NPL) sites and a substantial portion of RCRA facilities have some degree of ground-water contamination. The Superfund and RCRA Corrective Action programs share the common purposes of protecting human health and the environment from contaminated ground waters and restoring those waters to a quality consistent with their current, or reasonably expected future, uses.

The National Contingency Plan (NCP), which provides the regulatory framework for the Superfund program, states that:

> "EPA expects to return usable ground waters to their beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site" (NCP §300.430(a)(1)(iii)(F)).

Generally, restoration cleanup levels in the Superfund program are established by applicable or relevant and appropriate requirements (ARARs), such as the use of Federal or State standards for drinking water quality. Cleanup levels protective of human health and the environment are identified by EPA where no ARARs for particular contaminants exist (see Section 4.1.1).

The RCRA Corrective Action program for releases from solid waste management facilities (see 40 CFR 264.101)[2] requires a facility owner/operator to:

> "...institute corrective action as necessary to protect human health and the environment for all releases of hazardous waste or constituents from any solid waste management unit..."

The goal of protectiveness is further clarified in the Preamble to the Proposed Subpart S to 40 CFR 264:

> "Potentially drinkable ground water would be cleaned up to levels safe for drinking throughout the contaminated plume, regardless of whether the water was in fact being consumed... Alternative levels protective of the environment and safe for other uses could be established for ground water that is not an actual or reasonably expected source of drinking water."[3]

While both programs have had a great deal of success reducing the immediate threats posed by contaminated ground waters, experience over the past decade has shown that restoration to drinking water quality (or more stringent levels where required) may not always be achievable due to the limitations of available remediation technologies (EPA 1989b, 1992d). EPA, therefore, must evaluate whether ground-water restoration at Superfund and RCRA ground-water cleanup sites is attainable from an engineering perspective. **This document outlines EPA's approach to evaluating the technical impracticability of attaining required ground-water cleanup levels and establishing alternative, protective remedial strategies where restoration is determined to be technically impracticable.**

Many factors can inhibit ground-water restoration. These factors may be grouped under three general categories:

- Hydrogeologic factors;
- Contaminant-related factors; and
- Remediation system design inadequacies.

Hydrogeologic limitations to aquifer remediation include conditions such as complex sedimentary deposits; aquifers of very low permeability; certain types of

1 For this guidance, "restoration" refers to the reduction of contaminant concentrations to levels required under the Superfund or RCRA Corrective Action programs. For ground water currently or potentially used for drinking water purposes, these levels may be Maximum Contaminant Levels (MCLs) or non-zero Maximum Contaminant Levels Goals (MCLGs) established under the Safe Drinking Water Act; State MCLs or other cleanup requirements; or risk-based levels for compounds not covered by specific State or Federal MCLs or MCLGs. Other cleanup levels may be appropriate for ground waters used for non-drinking water purposes.

2 At this time, this guidance is not applicable to corrective actions for releases from Subpart F regulated units that are subject to corrective actions under 40 CFR 264.91-264.100.

3 "Corrective Action for Solid Waste Management Units (SWMUs) at Hazardous Waste Management Facilities," 55 FR 30798-30884, July 27, 1990, Proposed Rules, is currently used as guidance in the RCRA Corrective Action program. When final regulations under Subpart S are promulgated, certain aspects of this guidance pertaining to the RCRA program may need to be revised to reflect new regulatory requirements.

fractured bedrock; and other conditions that presently make extraction or *in situ* treatment of contaminated ground water extremely difficult (Figure 1).

Contaminant-related factors, while not independent of hydrogeologic constraints, are more directly related to contaminant properties that may limit the success of an extraction or *in situ* treatment process. These properties include a contaminant's potential to become either sorbed onto, or lodged within, the soil or rock comprising the aquifer. Nonaqueous phase liquids (NAPLs) are examples of contaminants that may pose such technical limitations to aquifer restoration efforts. NAPLs that are denser than water (DNAPLs) often are particularly difficult to locate and remove from the subsurface; their ability to sink through the water table and penetrate deeper portions of aquifers is one of the properties that makes them very difficult to remediate (Figure 1).

The widespread use of DNAPLs in manufacturing and many other sectors of the economy prior to the advent of safe waste-management practices has led to their similarly widespread occurrence at ground-water contamination sites. Most of the sites where EPA already has determined that ground-water restoration is technically impracticable have DNAPLs present. The potential impact of DNAPL contamination on attainment of remediation goals is so significant that EPA is developing specific recommendations for DNAPL site management; the key elements of this strategy are presented in Section 3.0 below.

The third factor that may limit ground-water restoration is inadequate remediation system design and implementation. Examples of design inadequacies in a ground-water extraction system include an insufficient number of extraction points (e.g., ground water or vapor extraction wells) or wells whose locations, screened intervals, or pumping rates lead to an inability to capture the plume. Design inadequacies may result from incomplete site characterization, such as inaccurate measurement of hydraulic conductivity of the affected aquifer or not considering the presence of NAPL contamination. Poor remediation system operation, such as excessive downtime or failure to modify or enhance the system to improve performance, also may limit the effectiveness of restoration efforts. **Failure to achieve desired cleanup standards resulting from inadequate system design or operation is not considered by EPA to be a sufficient justification for a determination of technical impracticability of ground-water cleanup.**

1.2 Purpose of the Guidance

This guidance clarifies how EPA will determine whether ground-water restoration is technically impracticable and what alternative measures or actions must be undertaken to ensure that the final remedy is protective of human health and the environment. Topics covered include the types of technical data and analyses needed to support EPA's evaluation of a particular site and the criteria used to make a determination. As technical impracticability (TI) decisions are part of the process of site investigation, remedy selection, remedial action, and evaluation of remedy performance, the guidance also briefly discusses the overall framework for decision making during these phases of site cleanup.

This guidance does not signal a scaling back of EPA's efforts to restore contaminated ground waters at Superfund sites and RCRA facilities. Rather, EPA is promoting the careful and realistic assessment of the technical capabilities at hand to manage risks posed by ground-water contamination. This guidance provides consistent guidelines for evaluating technical impracticability and for maintaining protectiveness at sites where ground water cannot be restored within a reasonable timeframe. EPA will continue to conduct, fund, and encourage research and development in the fields of subsurface assessment, remediation, and pollution prevention so that an ever decreasing number of sites will require the analysis described in this document.

2.0 Ground-Water Remedy Decision Framework

2.1 Use of the Phased Approach

At sites with very complex ground-water contamination problems, it may be difficult to determine whether required cleanup levels are achievable at the time a remedy selection decision must be made. This is especially true when such decisions must be based on site data collected prior to implementation and monitoring of pilot or full-scale remediation systems. EPA recognizes this limitation and has recommended several approaches to reduce uncertainty during the site characterization, remedy selection, and remedy implementation processes (EPA 1989a, 1992a).

Determining the restoration potential of a site may be aided by employing a **phased approach** to site characterization and remediation. Each phase of site

Figure 1. Examples of Factors Affecting Ground-Water Restoration

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.

Generalized Remediation Difficulty Scale

Increasing difficulty →

Contaminant Characteristics

	Factor	Generalized Remediation Difficulty Scale
Site Use	Nature of Release	Small Volume, Short Duration, Slug Release → Large Volume, Long Duration, Continual Release
Chemical Properties	Biotic/Abiotic 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

	Factor	Generalized Remediation Difficulty Scale
Geology	Stratigraphy	Simple Geology, e.g., Planar Bedding → Complex Geology, e.g., Interbedded and Discontinuous Strata
	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	High (>10^{-2} cm/sec) → Low (< 10^{-4} cm/sec)
	Temporal Variation	Little/None → High
	Vertical Flow	Little → Large Downward Flow Component

characterization should be designed to provide information necessary for the next phase of characterization. Likewise, site remediation activities can be conducted in phases to achieve interim goals at the outset, while developing a more accurate understanding of the restoration potential of the contaminated aquifer. An example of how this approach might be applied at a site is provided below in Section 4.4.3.

The timing of phased cleanup actions (early, interim, final) should reflect the relative urgency of the action and the degree to which the site has been characterized. Early actions should focus on reducing the risk posed by site contamination (e.g., removal of contamination sources) and may be carried out before detailed site characterization studies have been completed. Interim remedial actions may abate the spread of contamination or limit exposure but do not fully address the final cleanup levels for the site. Interim actions generally will require a greater degree of site characterization than early actions. However, implementation of interim actions still may be appropriate prior to completion of site characterization studies, such as the Remedial Investigation/Feasibility Study (RI/FS) or RCRA Facility Investigation (RFI) and Corrective Measures Study (CMS). Final remedial actions must address the cleanup levels and other remediation requirements for the site and, therefore, must be based on completed characterization reports. Information from early and interim actions also should be factored into these reports and final remedy decisions.

Phasing of activities generally should not delay or prolong site characterization or remediation. In fact, such an approach may accelerate the implementation of interim risk reduction actions and lead more quickly to the development of achievable final remediation levels and strategies. A phased approach should be considered when there is uncertainty regarding the ultimate restoration potential of the site but also a need to quickly control risk of exposure to, or limit further migration of, the contamination.

It is critical that the performance of phased remedial actions (e.g., control of plume migration) be monitored carefully as part of the ongoing effort to characterize the site and assess its restoration potential. Data collection activities during such actions not only should be designed to evaluate performance with respect to the action's specific objectives but also contribute to the overall understanding of the site. In this manner, actions implemented early in the site remediation process can achieve significant risk reduction and lead to development of technically sound, final remedy decisions.

2.2 Documenting Ground-Water Remedy Decisions Under CERCLA

The phased approach to site characterization and remediation can be employed using the existing decision document options within the Superfund program.

2.2.1 Removal Actions

Removal authority can be used for early actions as part of a phased approach to ground-water cleanup and decision making and should be considered where early response to ground-water contamination is advantageous or necessary. Within the context of ground-water actions, removals are appropriate where contamination poses an actual or potential threat to drinking water supplies or threatens sensitive ecosystems. Examples of actions that might qualify for use of removal authority include removal of surface sources (e.g., drums or highly contaminated soils), removal of subsurface sources (e.g., NAPL accumulations, highly contaminated soils, or other buried waste), and containment of migrating ground-water contamination "hot spots" (zones of high contaminant concentration) or plumes to protect current or potential drinking water supplies.

Removals of subsurface sources most likely will be non-time-critical actions, although time-critical actions may be appropriate for removal of NAPL accumulations or other sources, depending on the urgency of the threat. Documentation requirements for removal actions include a Removal Action Memorandum and, for non-time critical actions, an Engineering Evaluation/Cost Analysis report.[4]

Removal actions must attain ARARs to the extent practicable, considering the exigencies of the situation. The urgency of the situation and the scope of the removal action may be considered when determining the practicability of attaining ARARs (NCP §300.415(i)). Standards or regulations typically used to establish ground-water cleanup levels for final actions (e.g., MCLs/MCLGs) may not be ARARs, depending on the scope of the removal. Further

4 See "Guidance on Conducting Non-Time Critical Removal Actions under CERCLA," OSWER Publication 9360.0-32, August 1993 (EPA 1993b).

information on removal actions may be found in other EPA guidances (EPA 1990b, 1991d).

2.2.2 Interim RODs

Interim RODs may be appropriate where there is a moderate to high degree of uncertainty regarding attainment of ARARs or other protective cleanup levels. As mentioned before, an interim action may be used to minimize further contaminant migration and reduce the risk of exposure to contaminated ground water. Interim actions include containment of the leading edge of a plume to prevent further contamination of unaffected portions of an aquifer, removal of source material, remediation of ground-water hot spots, and in some cases, installation of physical barriers or caps to contain releases from source materials. Interim actions should be monitored carefully to collect detailed information regarding aquifer response to remediation, which should be used to augment and update previous site characterization efforts. This information then can be used at a later date to develop final remediation goals and cleanup levels that more accurately reflect the particular conditions of the site.

It is important to note that for interim actions, ARARs must be attained only if they are within the scope of that action. For example, where an interim action will manage or contain migration of an aqueous contaminant plume, MCLs and MCLGs would not be ARARs, since the objective of the action is containment, not cleanup (although requirements such as those related to discharge of the treated water still would be ARARs, since they address the disposition of treated waste).

Furthermore, a requirement that is an ARAR for an interim action may be waived under certain circumstances. An "interim action" ARAR waiver may be invoked where an interim action that does not attain an ARAR is part of, or will be followed by, a final action that does (NCP §300.430(f)(1)(ii)(C)). For example, where an interim action seeks to reduce contamination levels in a ground-water hot spot, MCLs/MCLGs may be ARARs since the action is cleaning up a portion of the contaminated ground water. If, however, this interim action is expected to be followed by a final, ARAR-compliant action that addresses the entire contaminated ground-water zone, an interim action ARAR waiver may be invoked.

2.2.3 Final RODs

Where site characterization is very thorough and there is a moderate to high degree of certainty that cleanup levels can be achieved, a final decision document should be developed that adopts those levels. Conversely, in cases where there is a high degree of certainty that cleanup levels cannot be achieved, a final ROD that invokes a TI ARAR waiver and establishes an alternative remedial strategy may be the most appropriate option.[5] Note that for ROD-stage waivers, site characterization generally should be sufficiently detailed to address the data and analysis requirements for TI determinations set forth in this guidance.

2.2.4 ROD Contingency Remedies and Contingency Language

Where a moderate degree of uncertainty exists regarding the ability to achieve cleanup levels, a final ARAR-compliant ROD generally still is appropriate. However, the ROD may include contingency language that addresses actions to be taken in the event the selected remedy is unable to achieve the required cleanup levels (EPA 1990a, 1991a). The contingency language may include requirements to enhance or augment the planned remediation system as well as an alternative remedial technology to be employed if modifications to the planned system fail to significantly improve its performance. Use of language in final remedy decision documents that addresses the uncertainty in achieving required cleanup levels also is appropriate in certain cases. **However, language that identifies a TI decision (e.g., an ARAR waiver) as a future contingency of the remedy should be avoided.** Such language is not necessary, as a TI evaluation may be performed (and a decision made) by EPA at any site regardless of whether such a contingency is provided in the decision document.

Note that in cases of existing RODs that already include a contingency for invoking a TI ARAR waiver, the conditions under which the ARAR may be waived should be consistent with, and as stringent as, those presented in this guidance or a future update.

Furthermore, the fact that such contingency language has been included in an existing ROD does not alter the need to enhance or augment a remedy to improve its ability to attain ARARs before concluding that a waiver can be granted. It also

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5 At sites where a TI ARAR waiver is invoked in the ROD, preparation of the pre-referral negotiation package ("mini-lit" package) must include analysis of the model Consent Degree language to ensure that appropriate consideration of the waiver's impact is incorporated.

should be noted that remediation must be conducted for a sufficient period of time before its ability to restore contaminated ground water can be evaluated. This minimum time period will be determined by EPA on a site-specific basis.

2.3 Documenting Ground-Water Remedy Decisions under RCRA

The instruments used for implementing the RCRA Corrective Action program (permits and orders) also are amenable to a phased approach to remedy selection and facility remediation. The RCRA program can use permits or orders to compel both interim measures and final remedies.

2.3.1. Permits/Orders Addressing Stabilization

RCRA permits or orders can require the stabilization of releases from solid waste management units (SWMUs) at the facility. The Stabilization Initiative focuses on taking interim actions to prevent the further spread of existing contamination and reduce risks. Examples of measures used for stabilization include capping, excavation, and plume containment. Since the long-term or final cleanup of the facility is not the objective of stabilization (although stabilization should be consistent with the final remedy), TI decisions are not applicable at this early stage. Information gained during stabilization should be used to help determine the restoration potential of the facility and the objectives of the final remedy.

2.3.2. Permits/Orders Addressing Final Remedies

Where achieving ground-water cleanup standards is determined by EPA to be technically impracticable, the permit or order addressing final remedies should include practicable and protective alternative remedial measures. EPA's decision to make a TI determination will be based on clear and convincing information provided by the owner/operator. EPA generally will seek public comment on TI determinations prior to implementation. EPA's preliminary TI determinations and justification for these determinations should be documented in a Statement of Basis. As discussed above, uncertainty in the ability to restore an aquifer should be reduced through phased characterization and the use of interim remedial measures, where appropriate.

Permits and orders that address "final" remedies should specify the remediation cleanup levels selected by the implementing Agency. Such permits and orders, however, generally should not incorporate contingency TI language. The permit or order will need to be modified to document the TI determination and to specify, as appropriate, alternative cleanup levels and alternative remedial measures that have been determined to be technically practicable and protective of human health and the environment.

3.0 Remedial Strategy for DNAPL Sites

Many of the subsurface contaminants present at Superfund sites and RCRA facilities are organic compounds that are either lighter-than-water NAPLs (LNAPLs) or DNAPLs. As mentioned in Section 1.1, the presence of NAPL contamination, and in particular DNAPL contamination, may have a significant impact on site investigations and the ability to restore contaminated portions of the subsurface to required cleanup levels. Furthermore, DNAPL contamination may be a relatively widespread problem. A recent EPA study (EPA 1993a) concluded that up to 60 percent of National Priorities List (NPL) sites may have DNAPL contamination in the subsurface; a significant percentage of RCRA Corrective Action facilities also are thought to be affected by DNAPLs. As proven technologies for the removal of certain types of DNAPL contamination do not exist yet, DNAPL sites are more likely to require TI evaluations than sites with other types of contamination. Although this guidance pertains to TI evaluations at all site types, EPA believes the significance of the DNAPL contamination problem warrants the following brief discussion of DNAPL contamination and recommended site management strategies.

DNAPLs comprise a broad class of compounds, including creosote and coal tars, polychlorinated biphenyls (PCBs), certain pesticides, and chlorinated organic solvents such as trichloroethylene (TCE) and tetrachloroethylene (PCE). The term "DNAPL" refers only to liquids immiscible in, and denser than, water and **not** to chemicals that are dissolved in water that originally may have been derived from a DNAPL source. DNAPLs may occur as "free-phase" or "residual" contamination. **Free-phase** DNAPL is an immiscible liquid in the subsurface that is under positive pressure; that is, the DNAPL is capable of flowing into a well or migrating laterally or vertically through an aquifer. Where vertically migrating free-phase DNAPL encounters a rock or soil layer of relatively low permeability (e.g., clay or other fine-grained layer), a DNAPL accumulation or "pool" may form. **Residual** DNAPL is immiscible liquid held by capillary forces within the pores or fractures in soil or rock layers; residual DNAPL, therefore, generally is not capable of migrating or being displaced by normal ground-water flow. Both free-phase and residual DNAPL, however, can slowly dissolve in ground water and produce "plumes" of aqueous-phase contamination. DNAPLs also can produce subsurface vapors capable of migrating through the unsaturated zone and contaminating ground water (EPA 1992c). Figure 2 depicts the various types of contamination that may be encountered at a DNAPL site.

The three areas that should be delineated at a DNAPL site are the DNAPL entry location, the DNAPL zone, and the aqueous contaminant plume. The **entry locations** are those areas where DNAPL was released and likely is present in the subsurface. Entry locations include waste disposal lagoons, drum burial sites, or any other area where DNAPL was allowed to infiltrate into the subsurface. The **DNAPL zone** is defined by that portion of the subsurface containing free-phase or residual DNAPL. Thus, the DNAPL zone includes all portions of the subsurface where the immiscible-phase contamination has come to be located. The DNAPL zone may occur within both the saturated zone (below the water table) and the unsaturated zone (above the water table). The DNAPL zone also may contain vapor and aqueous-phase contamination derived from the DNAPL. The DNAPL zone may include areas at relatively great depths and lateral distances from the entry locations, depending on the subsurface geology and the volume of DNAPL released. The **aqueous contaminant plume** contains organic chemicals in the dissolved phase. The plume originates from the DNAPL zone and may extend hundreds or thousands of feet downgradient (in the direction of ground-water flow). Figure 3 illustrates the various components of a DNAPL site.

Since each DNAPL site component may require a different remediation strategy, it is important to characterize these components to the extent practicable. Thus, the properties and behavior of DNAPL contamination require consideration when planning and conducting both site investigation and remediation. The potential for DNAPL occurrence at the site should be evaluated as early as possible in the site investigation. Recent publications such as "Estimating Potential for DNAPL Occurrence at Superfund Sites" (EPA 1992c) and "DNAPL Site Evaluation" (Cohen and Mercer, 1993) provide detailed guidance on these topics. At sites where DNAPL disposal is known or suspected to have occurred, likely DNAPL entry locations should be identified from available historical waste-management information and subsurface chemistry data. This information can assist in the delineation of the DNAPL zone.

Characterization and delineation of the DNAPL zone is critical for remedy design and evaluation of the restoration potential of the site. At many sites, a subsurface investigation strategy that begins outside of the suspected DNAPL zone may be appropriate ("outside-in" strategy), in part to minimize the possibility of inadvertent mobilization of DNAPLs to

Figure 2. Types of Contamination and Contaminant Zones at DNAPL Sites (Cross-sectional view)

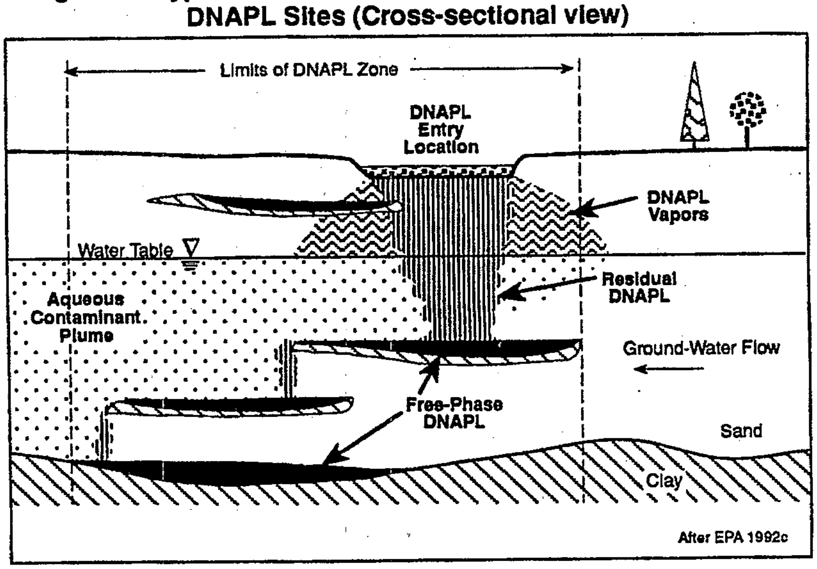
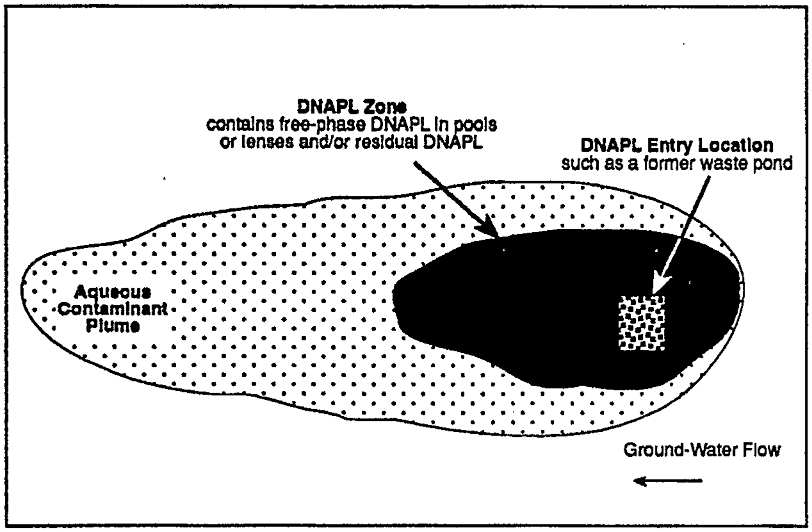


Figure 3. Components of DNAPL Sites



lower aquifers. Delineation of the extent of the DNAPL zone may be difficult at certain sites due to complex geology or waste disposal practices. In such cases, the extent of the DNAPL zone may need to be inferred from geologic information (e.g., thickness, extent, structure, and permeability of soil or rock units) or from interpretation of the aqueous concentration of contaminants derived from DNAPL sources. At some sites, however, geologic complexity and inadequate information on waste disposal may make the delineation of the DNAPL zone difficult.

A phased approach, as discussed in Section 2.1, is recommended for DNAPL sites; such an approach may facilitate identification of appropriate short- and long-term site remediation objectives. Note also that technical approaches appropriate for the DNAPL zone (e.g., free-phase DNAPL removal, vapor extraction, excavation, and slurry walls aided by limited pump-and-treat) may differ significantly from those appropriate for the aqueous contaminant plume (typically pump-and-treat).

Short-term remediation objectives generally should include prevention of exposure to contaminated ground water and containment of the aqueous contaminant plume. Where sufficient information is available, early removal of DNAPL sources also is recommended. Information gathered during these actions should be used to help characterize the site and identify practicable options for further remediation.

The long-term remediation objectives for a DNAPL zone should be to remove the free-phase, residual, and vapor phase DNAPL to the extent practicable and contain DNAPL sources that cannot be removed. EPA recognizes that it may be difficult to locate and remove all of the subsurface DNAPL within a DNAPL zone. Removal of DNAPL mass should be pursued wherever practicable and, in general, where significant reduction of current or future risk will result.[6] Where it is technically impracticable to remove subsurface DNAPLs, EPA expects to contain the DNAPL zone to minimize further release of contaminants to the surrounding ground water, wherever practicable.[7]

Where it is technically practicable to contain the long-term sources of contamination, such as the DNAPL zone, EPA expects to restore the aqueous contaminant plume outside the DNAPL zone to required cleanup levels. Effective containment of the DNAPL zone generally will be required to achieve this long-term objective because ground-water extraction remedies (e.g., pump-and-treat) or *in situ* treatment technologies are effective for plume restoration only where source areas have been contained or removed.

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6 DNAPL mass removal also must satisfy the Superfund or RCRA Corrective Action remedy selection criteria, as appropriate.

7 As DNAPLs may be remobilized during drilling or ground-water pumping, caution should be exercised where such activities are proposed for DNAPL zone characterization, remediation, or containment.

Monitoring and assessing the performance of DNAPL zone containment and aquifer restoration systems, therefore, are critical to maintaining remedy protectiveness and evaluating the need for remedy enhancements or application of new technologies.

EPA recognizes, however, 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.

EPA encourages consideration of innovative technologies at DNAPL sites, particularly where containment of a DNAPL zone may require costly periodic maintenance (and perhaps replacement). Innovative technologies, therefore, should be considered where DNAPL zone containment could be enhanced or where such a technology could clean up the DNAPL zone.

4.0 TI Decisions and Supporting Information

4.1 Regulatory Framework for TI Decisions

The bases for TI decisions discussed in this guidance are provided in CERCLA and the NCP for the Superfund program and in the Proposed Subpart S rule for the RCRA program. While the processes the two programs use to establish cleanup levels differ (e.g., the ARAR concept is not used in RCRA), the primary considerations for determining the technical impracticability of achieving those levels are identical:

- **Engineering feasibility; and**
- **Reliability.**

A brief summary of the regulatory basis for establishing cleanup levels and making TI determinations at Superfund and RCRA sites is provided below.

4.1.1 Superfund

Remedial alternatives at Superfund sites must satisfy two "threshold" criteria specified in the NCP to be eligible for selection: 1) the remedy must be protective of human health and the environment; and 2) the remedy must meet (or provide the basis for waiving) the ARARs identified for the action.[8] There generally are several different types of ARARs associated with ground-water remedies at Superfund sites, such as requirements for discharge of treated water to surface water bodies or other receptors, limitations on reinjection of treated water into the subsurface, and cleanup levels for contaminants in the ground water. ARARs used to establish cleanup levels for current or potentially drinkable ground water typically are MCLs or non-zero MCLGs established under the Federal Safe Drinking Water Act, or in some cases, more stringent State requirements. For compounds for which there are no ARARs, cleanup levels generally are chosen to protect users or receptors from unacceptable cancer and non-cancer health risks or adverse environmental effects. Such levels generally are established to fall within the range of 10^{-4} to 10^{-6} lifetime cancer risk or below a hazard index of one for non-carcinogens, as appropriate.

ARARs may be waived by EPA for any of the six reasons specified by CERCLA and the NCP (Highlight 1), including **technical impracticability from an engineering perspective.** TI waivers generally will be applicable only for ARARs that are used to establish cleanup performance standards or levels, such as chemical-specific MCLs or State ground-water quality criteria.

Highlight 1.
CERCLA ARAR Waivers

The six ARAR waivers provided by CERCLA §121(d)(4) are:

1. Interim Action Waiver;
2. Equivalent Standard of Performance Waiver;
3. Greater Risk to Health and the Environment Waiver;
4. Technical Impracticability Waiver;
5. Inconsistent Application of State Standard Waiver; and
6. Fund Balancing Waiver.

8 NCP §300.430(f)(1)(i). For a detailed discussion of the Superfund remedy selection process, see also EPA 1988a and 1988b.

Use of the term "engineering perspective" implies that a TI determination should primarily focus on the technical capability of achieving the cleanup level, with cost playing a subordinate role. The NCP Preamble states that TI determinations should be based on:

> "...engineering feasibility and reliability, with cost generally not a major factor unless compliance would be inordinately costly."[9]

4.1.2 RCRA

The Proposed Subpart S rule specifies that the corrective action for contaminated ground water include attainment of "media cleanup standards," which generally are Federal or State MCLs, contaminant levels within the range of 10^{-4} to 10^{-6} lifetime cancer risk, or hazard index of less than one for non-carcinogens, as appropriate. The proposed rule also specifies three conditions under which attainment of media cleanup standards may not be required: 1) remediation of the release would provide no significant reduction in risks to actual or potential receptors; 2) the release does not occur in, or threaten, ground waters that are current or potential sources of drinking water; and 3) **remediation of the release to media cleanup standards is technically impracticable.**[10]

Further clarification of TI determinations is provided in the preamble to the proposed rule. The determination involves a consideration of the "**engineering feasibility and reliability**" of attaining media cleanup standards, as well as situations where remediation may be "technically possible," but the "scale of the operations required might be of such a **magnitude and complexity** that the alternative would be impracticable" (emphasis added).[11]

The basis for a RCRA Subpart S TI decision (engineering feasibility, reliability, and the magnitude and complexity of the action) therefore is consistent with that provided for the Superfund program in the NCP. In the context of remedy selection, both programs consider the notion of technical feasibility along with reliability and economic considerations; however, **the role of cost (or scale) of the action is subordinate to the goal of remedy protectiveness.**

4.2 Timing of TI Decisions

TI decisions may be made either when a final site decision document is being developed (e.g., RCRA Statement of Basis and Response to Comments or Superfund ROD) or after the remedy has been implemented and monitored for a period of time. EPA believes that, in many cases, TI decisions should be made only after interim or full-scale aquifer remediation systems are implemented because often it is difficult to predict the effectiveness of remedies based on limited site characterization data alone. However, in some cases, TI decisions may be made prior to remedy implementation. These pre-implementation or "front-end" TI decisions must be supported adequately by detailed site characterization and data analysis. Front-end TI evaluations should focus on those data and analyses that define the most critical limitations to ground-water restoration.

Data and analysis requirements for front-end decisions should be considered carefully. Generally, information regarding the nature and extent of contamination sources is more critical to assessing restoration potential than are other types of characterization data. This often is the case, as currently available technologies generally are more effective for remediating and restoring contaminated aquifers affected only by dissolved, or aqueous, contamination. However, certain types of source contamination are resistant to extraction by these technologies and can continue to dissolve slowly into ground water for indefinite periods of time. Examples of this type of source constraint include certain occurrences of NAPLs, such as where the quantity, distribution, or properties of the NAPL render its removal from, or destruction within, the subsurface infeasible or inordinately costly (See Section 3.0).

Geologic constraints, such as aquifer heterogeneity (e.g., interlayering of coarse and fine-grained strata), also may critically limit the ability to restore an aquifer. However, it generally is more difficult to accurately determine the impact of such constraints prior to implementation and monitoring of partial or full-scale aquifer remediation efforts. Some geologic constraints, however, may be defined sufficiently during site characterization so that their impacts on restoration potential are known with a relatively high degree of certainty. An example of this type of constraint includes complex fracturing of bedrock aquifers, which makes recovery of contaminated ground water or DNAPLs extremely difficult.

It should be noted, however, that the presence of known remediation constraints, such as DNAPL,

9 See NCP Preamble, 55 FR 8748, March 8, 1990.

10 Technical impracticability is discussed in Sections 264.525(d)(2) and 264.531 of the Proposed Subpart S rule.

11 Proposed Subpart S; 55 FR 30830, July 27, 1990.

fractured bedrock, or other condition, are not by themselves sufficient to justify a TI determination. Adequate site characterization data must be presented to demonstrate, not only that the constraint exists, but that the effect of the constraint on contaminant distribution and recovery potential poses a critical limitation to the effectiveness of available technologies.

4.3 TI Evaluation Components[12]

Determinations of technical impracticability will be made by EPA based on site-specific characterization and, where appropriate, remedy performance data. These data should be collected, analyzed, and presented so that the engineering feasibility and reliability of ground-water restoration are fully addressed in a concise and logical manner.

The TI evaluation may be prepared by the owner/operator of a RCRA facility, by a PRP at an enforcement-lead Superfund site, or by EPA or the State at Fund- or State-lead sites, as appropriate. **The evaluation generally should include the following components, based on site-specific information and analyses:**

1. Specific ARARs or media cleanup standards for which TI determinations are sought (See Section 4.4.1).

2. Spatial area over which the TI decision will apply (See Section 4.4.2).

3. Conceptual model that describes site geology, hydrology, ground-water contamination sources, transport, and fate (See Section 4.4.3).

4. An evaluation of the 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 (See Section 4.4.4). At a minimum, this generally 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; and
   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 (See Section 4.4.5).

6. Any additional information or analyses that EPA deems necessary for the TI evaluation.

The data and analyses needed to address each of these components of a TI evaluation should be determined on a site-specific basis. Where outside parties are preparing the TI evaluation, its contents generally should be identified and discussed prior to submittal of the evaluation to EPA. Early agreement between EPA and PRPs or owner/operators on the type and quantity of data and analyses required for TI decisions will promote efficient review of TI evaluations.

References to other documents in the administrative record, such as the RI/FS and RFI, likely will be necessary to produce a concise evaluation; however, these references should be as explicit as possible (e.g., cite specific page or table numbers). Technical discussions and conclusions should be supported by data compilations, statistical analyses, or other types of data reduction included in the evaluation.

4.4 Supporting Information for TI Evaluations

Most, if not all, of the information needed to evaluate TI could be obtained during a thorough site investigation and, where appropriate, remedy performance monitoring efforts. At some sites, however, additional analysis of existing data or new information may be required before EPA can determine accurately the technical practicability of the restoration goals. Not all of the data or analyses outlined in this guidance will be required at all sites; specific information needs will depend on site conditions and any ongoing remediation efforts.

12 For this guidance a "TI evaluation" comprises the data and analyses necessary to make a TI determination. The TI evaluation may be performed by PRPs at enforcement-lead Superfund sites, or by State or other Federal agencies, where appropriate. Similarly, owner/operators at RCRA facilities may perform TI evaluations. However, the actual TI "determination," or "decision," will be made by EPA (or other lead agency, as appropriate).

The data and analyses identified and discussed below address the TI evaluation components provided in Section 4.3.

4.4.1. Specific ARARs or Media Cleanup Standards

The TI evaluation should identify the specific ARARs or media cleanup standards (i.e., the specific contaminants) for which the determination is sought. Such contaminants generally should include only those for which attainment of the required cleanup levels is technically impracticable. Factors EPA will consider when evaluating contaminants that may be included in the TI decision include: 1) the technical feasibility of restoring some of the contaminants present in the ground water; and 2) the potential advantages of attaining cleanup levels for some of the contaminants.

For example, consider a Superfund site with a DNAPL contamination problem (e.g., TCE), including a widespread subsurface DNAPL source area for which containment or restoration are technically impracticable. The aqueous plume also contains inorganic contamination (e.g., chromium) from on-site sources. Although it would be feasible to reduce chromium concentrations to the required cleanup level within a reasonable timeframe, TCE concentrations would remain above cleanup levels much longer due to the continued presence of the DNAPL or slow desorption of TCE from aquifer materials. However, in such cases, EPA may choose to limit the TI ARAR waiver to TCE alone, while requiring cleanup of the chromium.[13]

Two situations would favor use of this approach. The first would be where attaining chromium cleanup levels in the ground water will make future *ex situ* treatment of the (TCE-contaminated) ground water less complex and less expensive. This may be advantageous where a community wishes to extract the TCE-contaminated water, perform *ex situ* treatment, and put the treated water to beneficial use. A related consideration is whether removal of the chromium will facilitate future subsurface remediation using a newly developed technology. The second situation favoring this approach is where one of the contaminants (e.g., TCE) is being naturally biodegraded and the other (e.g., chromium) is not. Therefore, cleanup of the chromium may result in more rapid attainment of the long-term cleanup goals at the site.

Where the balance of conditions at such a site do not indicate that it is practicable to attain the cleanup levels for only some of the contaminants present, EPA may conclude that cleanup levels for the remaining contaminants need not be attained, depending on the circumstances of the site. As discussed further in Section 5.0, however, this decision does not preclude EPA from selecting (or continuing operation of) a remedy that includes active measures (e.g., pump-and-treat) along with measures to prevent exposure (e.g., institutional controls) needed to address site risks.

4.4.2 Spatial Extent of TI Decisions

The TI evaluation should specify the horizontal and vertical extent of the area for which the TI determination is sought. Where EPA determines that ground-water restoration is technically impracticable, the area over which the decision applies (the "TI zone") generally will include all portions of the contaminated ground water that do not meet the required cleanup levels (contaminated ground-water zone), unless the TI zone is otherwise defined by EPA.

In certain cases, EPA may restrict the extent of the TI zone to a portion or subarea within the contaminated ground-water zone. For example, consider a DNAPL site where it is technically impracticable to remove the residual DNAPLs from the subsurface but it is feasible and practicable to: 1) limit further migration of contaminated ground-water using a containment system; and 2) restore that portion of the aqueous plume outside of the containment area. The TI zone in this case should be restricted to that portion of the site that lies within the containment area. Outside of the TI zone, ARARs or media cleanup standards still would apply. The potential to spatially restrict the TI zone, therefore, will depend on the ability to delineate and contain non-removable subsurface contamination sources and restore those portions of the aqueous plume outside of the containment area. The spatial extent of the TI zone should be limited to as small an area as possible, given the circumstances of the site.

A TI zone should be delineated spatially, both in area and depth. Depth of a TI zone may be defined in absolute terms (e.g., feet above mean sea level) or in relative terms (e.g., with respect to various aquifers within multi-aquifer systems), as appropriate. Where

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13 The extracted ground water would likely need to be treated for both TCE and chromium to satisfy treatment and waste disposal ARARs.

the TI zone will be restricted to a portion of the contaminated ground-water zone, the limits of the TI zone should be delineated clearly on site maps and geologic cross-sections. Delineation of the TI zone based on the location of a particular mapped contaminant concentration contour interval (e.g., the 200 part per billion isoconcentration line) generally should be avoided. This is because the location of such mapped contours often is highly interpretive, and their position may change with time. While concentration data may be appropriate to consider when determining the size of a containment area or the extent of a TI zone, the limits of that TI zone should be fixed in space, both horizontally and vertically.

4.4.3 Development and Purpose of the Site Conceptual Model

Decisions regarding the technical practicability of ground-water restoration must be based on a thorough characterization of the physical and chemical aspects of the site. Characterization data should describe site geology and hydrology; contamination sources, properties, and distribution; release mechanisms and rates; fate and transport processes; current or potential receptors; and other elements that define the contamination problem and facilitate analysis of site restoration potential. While the elements of such a model may vary from site to site, some generalizations can be made about what such a model would contain. Examples of these elements are provided in Figure 4. The site conceptual model synthesizes data acquired from historical research, site characterization, and remediation system operation.

The site conceptual model typically is presented as a summary or specific component of a site investigation report. The model is based on, and should be supported by, interpretive graphics, reduced and analyzed data, subsurface investigation logs, and other pertinent characterization information. The site conceptual model is not a mathematical or computer model, although these may be used to assist in developing and testing the validity of a conceptual model or evaluating the restoration potential of the site. The conceptual model, like any theory or hypothesis, is a dynamic tool that should be tested and refined throughout the life of the project. As illustrated in Figure 5, the model should evolve in stages as information is gathered during the various phases of site remediation. This iterative process allows data collection efforts to be designed so that key model hypotheses may be tested and revised to reflect new information.

The conceptual model serves as the foundation for evaluating the restoration potential of the site and, thereby, technical impracticability as well. The TI determination must consider how site conditions impact the potential for achieving remediation goals and whether remediation performance, cost-effectiveness, and timeframe meet EPA requirements or expectations. As these determinations rely on professional judgment, the clarity of the conceptual model (and supporting information) is critical to the decision-making process.

4.4.4 Evaluation of Restoration Potential

4.4.4.1 Source Control Measures. Remediation of contamination sources is critical to the success of aquifer restoration efforts. Continued releases of contamination from source materials to ground water can greatly reduce the effectiveness of aquifer restoration technologies, such as pump-and-treat, which generally are effective only for removing dissolved contaminants (EPA 1989b; 1992d). EPA considers subsurface NAPLs to be source materials because they are capable of releasing significant quantities of dissolved contamination to ground water over long periods of time.

A demonstration that ground-water restoration is technically impracticable generally should be accompanied by a demonstration that contamination sources have been, or will be, identified and removed or treated to the extent practicable. EPA recognizes that locating and remediating subsurface sources can be difficult. For example, locating DNAPLs in certain complex geologic environments may be impracticable. EPA expects, however, that all reasonable efforts will be made to identify the location of source areas through historical information searches and site characterization efforts.

Source removal and remediation may be difficult, even where source locations are known. The appropriate level of effort for source removal and remediation must be evaluated on a site-specific basis, considering the degree of risk reduction and any other potential benefits that would result from such an action. Even partial removal of contamination sources can greatly reduce the long-term reliance on both active and passive ground-water remediation.

Where complete source removal or treatment is impracticable, use of migration control or containment measures should be considered. Physical and hydraulic barriers are proven technologies that are capable of limiting or preventing further contaminant

Figure 4. Elements of Site Conceptual Model

The data and analysis required for TI evaluations will be determined by EPA on a site-specific basis. This information should be presented in formats conducive to analysis and in sufficient detail to define the key site conditions and mechanisms that limit restoration potential. Types of information and analysis that may be needed for conceptual model development are illustrated below.

Background Information

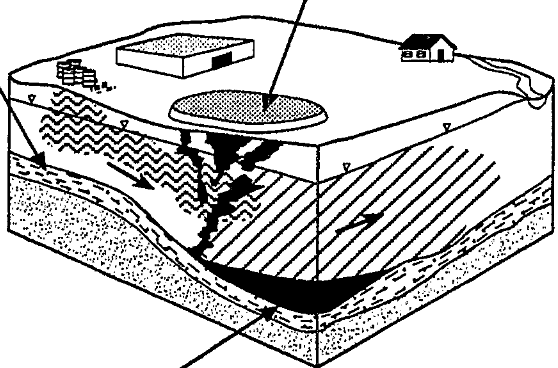
- Location of water supply wells.
- Ground-water Classification.
- Nearby wellhead protection areas or sole-source aquifers.
- Location of potential environmental receptors.

Geologic and Hydrologic Information

- Description of regional and site geology.
- Physical properties of subsurface materials (e.g., texture, porosity, bulk density).
- Stratigraphy, including thickness, lateral extent, continuity of units, and presence of depositional features, such as channel deposits, that may provide preferential pathways for, or barriers to, contaminant transport.
- Geologic structures that may form preferential pathways for NAPL migration or zones of accumulation.
- Depth to ground water.
- Hydraulic gradients (horizontal and vertical).
- Hydraulic properties of subsurface materials (e.g., hydraulic conductivity, storage coefficient, effective porosity) and their directional variability (anisotropy).
- Spatial distribution of soil or bedrock physical/hydraulic properties (degree of heterogeneity).
- Characterization of secondary porosity features (e.g., fractures, karst features) to the extent practicable.
- Temporal variability in hydrologic conditions.
- Ground-water recharge and discharge information.
- Ground-water/surface water interactions.

Contaminant Source and Release Information

- Location, nature, and history of previous contaminant releases or sources.
- Locations and characterizations of continuing releases or sources.
- Locations of subsurface sources (e.g., NAPLs).

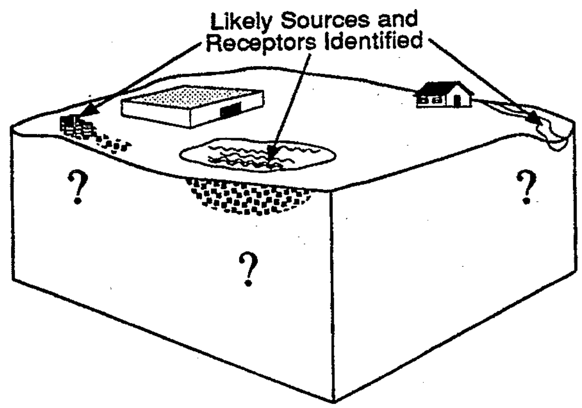


Contaminant Distribution, Transport, and Fate Parameters

- Phase distribution of each contaminant (gaseous, aqueous, sorbed, free-phase NAPL, or residual NAPL) in the unsaturated and saturated zones.
- Spatial distribution of subsurface contaminants in each phase in the unsaturated and saturated zones.
- Estimates of subsurface contaminant mass.
- Temporal trends in contaminant concentrations in each phase.
- Sorption information, including contaminant retardation factors.
- Contaminant transformation processes and rate estimates.
- Contaminant migration rates.
- Assessment of facilitated transport mechanisms (e.g., colloidal transport).
- Properties of NAPLs that affect transport (e.g., composition, effective constituent solubilities, density, viscosity).
- Geochemical characteristics of subsurface media that affect contaminant transport and fate.
- Other characteristics that affect distribution, transport, and fate (e.g., vapor transport properties).

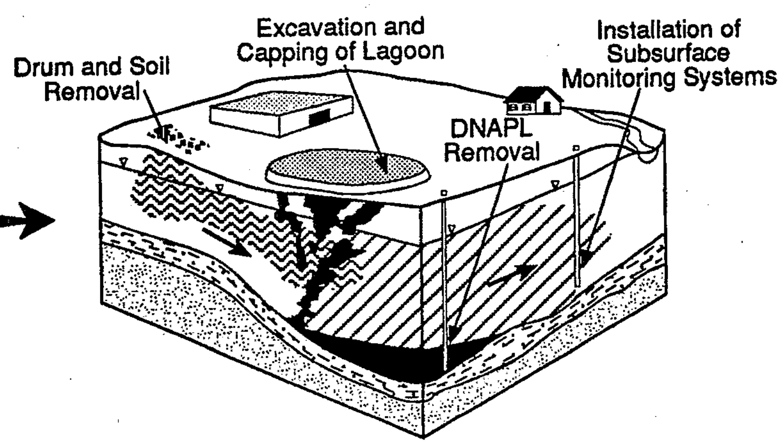
Figure 5. Evolution of the Site Conceptual Model

- Site Background and History
- Preliminary Site Investigations



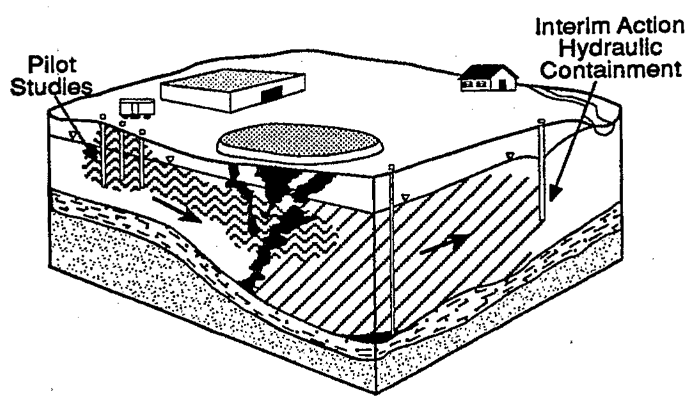
Conceptual Model Provides Basis for:

- Early Action/Removal of Near-Surface Materials
- Site Characterization Studies (RI/FS, RFI)
- Removal of Subsurface Sources (e.g., free-phase NAPLs)



Conceptual Model Provides Basis for:

- Pilot Studies
- Interim Ground-Water Actions



Conceptual Model Provides Basis for:

- Evaluation of Restoration Potential (or TI)
- Full-Scale Treatment System Design and Implementation
- Performance Monitoring and Evaluations
- Enhancement or Augmentation of Remediation System, if Required
- Future Evaluation of TI , if Required (See Figure 6)

migration from a source area under the right circumstances. While these containment measures are not capable of restoring source areas to required cleanup levels (i.e., a TI decision may be necessary for the source area), they may enable restoration of portions of the aquifer outside the containment zone.

4.4.4.2 Remedial Action Performance Analysis. The suitability and performance of any completed or ongoing ground-water remedial actions should be evaluated with respect to the objectives of those actions. Examples of remedy performance data are provided in Figure 6. The performance analysis should:

1. Demonstrate that the ground-water monitoring program within and outside of the aqueous contaminant plume is of sufficient quality and detail to fully evaluate remedial action performance (e.g., to analyze plume migration or containment and identify concentration trends within the remediation zone).[14]

2. Demonstrate that the existing remedy has been effectively operated and adequately maintained.

3. Describe and evaluate the effectiveness of any remedy modifications (whether variations in operation, physical changes, or augmentations to the system) designed to enhance its performance.

4. Evaluate trends in subsurface contaminant concentrations. Consider such factors as whether the aqueous plume has been contained, whether the areal extent of the plume is being reduced, and the rates of contaminant concentration decline and contaminant mass removal. Further considerations include whether aqueous-phase concentrations rebound when the system is shut down, whether dilution or other natural attenuation processes are responsible for observed trends, and whether contaminated soils on site are contaminating the ground water.

Analysis of aqueous-phase concentration data should be performed with caution. Contaminant concentrations plotted as a function of time, pore volumes of flushed fluids, or other appropriate variables may be useful in evaluating dominant contaminant fate and transport processes, evaluating remedial system design, and predicting future remedial system performance. Sampling methodologies, locations, and strategies, however, should be analyzed to determine the impact they may have had on observed concentration trends. For example, studies of ground-water extraction systems indicate that some systems show rapid initial decreases in aquifer concentration, followed by less dramatic decreases that eventually approach an asymptotic concentration level (EPA 1989b, 1992d). This "leveling off" effect may represent either a physical limitation to further remediation (e.g., contaminant diffusion from low permeability units) or an artifact of the system design or monitoring program. Professional judgment must be applied carefully when drawing conclusions concerning restoration potential from this information.

In certain cases, EPA may determine that lack of progress in achieving the required cleanup levels has resulted from system design inadequacies, poor system operation, or unsuitability of the technology for site conditions. Such system-related constraints are not sufficient grounds for determining that ground-water restoration is technically impracticable. In such instances, EPA generally will require that the existing remedy be enhanced, augmented, or replaced by a different technology. Furthermore, EPA may require modification or replacement of an existing remedy to ensure protectiveness, regardless of whether or not attainment of required cleanup levels is technically impracticable.

4.4.4.3 Restoration Timeframe Analysis. Estimates of the timeframe required to achieve ground-water restoration may be considered in TI evaluations. While restoration timeframes may be an important consideration in remedy selection, no single timeframe can be specified during which restoration must be achieved to be considered technically practicable. However, very long restoration timeframes (e.g., longer than 100 years) may be indicative of hydrogeologic or contaminant-related constraints to remediation. While predictions of restoration timeframes may be useful in illustrating the effects of such constraints, EPA will base TI decisions on an overall demonstration of the extent of such physical constraints at a site, not on restoration timeframe analyses alone. Such demonstrations should be based on detailed and accurate site conceptual models that also can provide the bases for meaningful predictions of restoration timeframes.

14 Further guidance on design of performance monitoring for remedial actions at ground-water sites is provided in "General Methods for Remedial Operations Performance Evaluations," EPA Office of Research and Development Publication EPA/600/R-92/002, January 1992 (EPA 1992e).

Figure 6. Remedy Performance Analysis

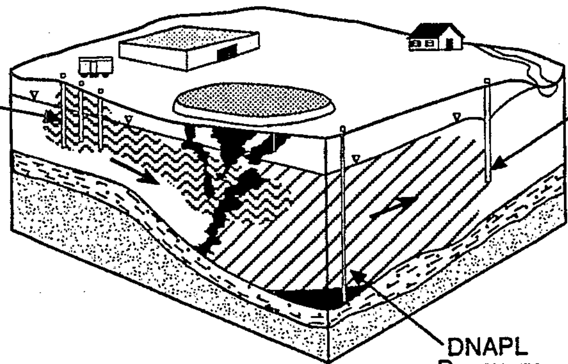
Remedy design and performance data requirements should be specific to technologies employed and site conditions. The categories of required information normally necessary to evaluate performance are provided below with some examples of specific data elements. These data should be reported to EPA in formats conducive to analysis and interpretation. Simple data compilations are insufficient for this purpose.

Remedy Design and Operational Information

- Design and as-built construction information, including locations of extraction or *in situ* treatment points with respect to the contamination.
- Supporting design calculations (e.g., calculation of well spacing).
- Operating information pertinent to remedy (e.g., records of the quantity and quality of extracted or injected fluids).
- Percent downtime and other maintenance problems.

Enhancements to Original Remedial Design

- Information concerning operational modifications, such as variations in pumping, injection rates, or locations.
- Rationale, design, and as-built construction information for system enhancements.
- Monitoring data and analyses that illustrate the effect these modifications have had on system performance.



Source Removal or Control

- Source removal information (e.g., results of soil excavations, removal of lagoon sediments, NAPL removal activities).
- Source control information (e.g., results of NAPL containment, capping of former waste management units).

Performance Monitoring Information

- Design and as-built construction information for performance monitoring systems.
- Hydraulic gradients and other information demonstrating plume containment or changes in areal extent or volume.
- Trends in subsurface contaminant concentrations determined at several/many appropriate locations in the subsurface. Trends should be displayed as a function of time, a function of pore volumes of flushed fluids, or other appropriate measures.
- Information on types and quantities of contaminant mass removed and removal rates.

A further consideration regarding the usefulness of restoration timeframe predictions in TI evaluations is the uncertainty inherent in such analyses. Restoration timeframes generally are estimated using mathematical models that simulate the behavior of subsurface hydrologic processes. Models range from those with relatively limited input data requirements that perform basic simulations of ground-water flow only, to those with extensive data requirements that are capable of simulating multi-phase flow (e.g., water, NAPL, vapor) or other processes such as contaminant adsorption to, and desorption from, aquifer materials. Model input parameters generally are a combination of values measured during site characterization studies and values assumed based on scientific literature or professional judgment. The input parameter selection process, as well as the simplifying assumptions of the mathematical model itself, result in uncertainty of the accuracy of the output. Restoration timeframes predicted using even the most sophisticated modeling tools and data, therefore, will have some degree of uncertainty associated with them.

Restoration timeframe analyses, therefore, generally are well suited for comparing two or more remediation design alternatives to determine the most appropriate strategy for a particular site. Where employed for such purposes, restoration timeframe analyses should be accompanied by a thorough discussion of all assumptions, including a list of measured or assumed parameters and a quantitative analysis, where appropriate, of the degree of uncertainty in those parameters and in the resulting timeframe predictions. The uncertainty in the predictions should be factored into the weight they are given in the remedy decision process.

4.4.4.4 Other Applicable Technologies. The TI evaluation should include a demonstration that no other remedial technologies or strategies would be capable of achieving ground-water restoration at the site.[15] The type of demonstration required will depend on the circumstances of the site and the state of ground-water remediation science at the time such an evaluation is made. In general, EPA expects that such a demonstration should consist of: 1) a review of the technical literature to identify candidate technologies; 2) a screening of the candidate technologies based on general site conditions to identify potentially applicable technologies; and 3) an analysis, using site hydrogeologic and chemical data, of the capability of any of the applicable technologies to achieve the required cleanup standards. Analysis of the potentially applicable technologies generally can be performed as a "paper study." EPA, however, may reserve the right to require treatability or pilot testing demonstrations to determine the actual effectiveness of a technology at a particular site.

Treatability and pilot testing should be conducted with rigorous controls and mass balance constraints. Information required by EPA for evaluation of pilot tests will be similar to that required for evaluation of existing remediation systems (e.g., detailed design and performance data).

4.4.4.5 Additional Considerations. Techniques used for evaluation of ground-water restoration potential are still evolving. The results of such evaluations generally will have some level of uncertainty associated with them. Interpretation of the results of restoration potential evaluations, therefore, will require the use of professional judgment. The use of mathematical models and calculations of mass removal rates are two examples of techniques that require particular caution.

Ground-water Flow and Contaminant Transport/Fate Modeling. Simulation of subsurface systems through mathematical modeling can be useful for designing remediation systems or predicting design performance. However, the limitations of predictive modeling must be considered when evaluating site restoration potential. As discussed in Section 4.4.4.3, ground-water models are sensitive to initial assumptions and the choice of parameters, such as contaminant source locations, leachability, and hydraulic conductivity. Predictions such as the magnitude and distribution of subsurface contaminant concentrations, therefore, will involve uncertainty. The source and degree of this uncertainty should be described, quantified, and evaluated wherever possible so the reviewer understands the level of confidence that should be placed in the predicted concentration values or other outputs. Predictive modeling may be most valuable in providing insight into processes that dominate contaminant transport and fate at the site and evaluating the relative effectiveness of different remedial alternatives. Further guidance and information on the use of ground-water models is provided in Anderson and Woessner (1992), EPA (1992f), and EPA (1992g).

Contaminant Mass Removal Estimates. Evaluation of contaminant mass removal may be useful at some sites

15 See discussions in the NCP (55 FR 8748, March 8, 1990) and Subpart S (55 FR 30838, July 27, 1990).

with existing remediation systems. These measures may include evaluation of mass removal rates, comparison of removal rates to *in situ* mass estimates, changes in the size of the contaminated area, comparison of mass removal rates with pumping rates, and comparison of such measures with associated costs. Mass removal and balance estimates should be used with caution, as there often is a high degree of uncertainty associated with estimates of the initial mass released and the mass remaining *in situ.* This uncertainty results from inaccuracy of historical site waste-management records, subsurface heterogeneities, and the difficulty in delineating the severity and extent of subsurface contamination.

4.4.5 Cost Estimate

Estimates of the cost of remedy alternatives should be provided in the TI evaluation. The estimates should include the present worth of construction, operation, and maintenance costs. Estimates should be provided for the continued operation of the existing remedy (if the evaluation is conducted following implementation of the remedy) or for any proposed alternative remedial strategies.

As discussed in Section 4.4.1, a Superfund remedy alternative may be determined to be technically impracticable if the cost of attaining ARARs would be inordinately high. The role of cost, however, is subordinate to that of ensuring protectiveness. The point at which the cost of ARAR compliance becomes inordinate must be determined based on the particular circumstances of the site. As with long restoration timeframes, relatively high restoration costs may be appropriate in certain cases, depending on the nature of the contamination problem and considerations such as the current and likely future use of the ground water. Compliance with ARARs is not subject to a cost-benefit analysis, however.[16]

5.0 Alternative Remedial Strategies

5.1 Options and Objectives for Alternative Strategies[17]

EPA's goal of restoring contaminated ground water within a reasonable timeframe at Superfund or RCRA sites will be modified where complete restoration is found to be technically impracticable. In such cases, EPA will select an alternative remedial strategy that is technically practicable, protective of human health and the environment, and satisfies the statutory and regulatory requirements of the Superfund or RCRA programs, as appropriate.[18]

Where a TI decision is made at the "front end" of the site remediation process (before a final remedy has been identified and implemented), the alternative strategy should be incorporated into a final remedy decision document, such as a Superfund ROD or RCRA permit or enforcement order. Where the TI decision is made after the final decision document has been signed (i.e., after a remedy has been implemented and its performance evaluated), the alternative remedial strategy should be incorporated in a modified final remedy decision document, such as a ROD amendment or RCRA permit/order modification (see Section 6.0).

Alternative remedial strategies typically will address three types of problems at contaminated ground-water sites: prevention of exposure to contaminated ground water; remediation of contamination sources; and remediation of aqueous contaminant plumes. Recommended objectives and options for addressing these three problems are discussed below. Note that combinations of two or more options may be appropriate at any given site, depending on the size and complexity of the contamination problem or other site circumstances.

5.1.1 Exposure Control

Since the primary objective of any remedial strategy is overall protectiveness, exposure prevention may play a significant role in an alternative remedial strategy. Exposure control may be provided using institutional controls, such as deed notifications and restrictions on water-supply well construction and use. The remedy should provide assurance that these measures are enforceable and consistent with State or local laws and ordinances.

5.1.2 Source Control

Source remediation and control should be considered when developing an alternative remedial strategy.

16 A Fund-Balancing ARAR waiver may be invoked at Fund-lead Superfund sites where meeting an ARAR would entail such cost in relation to the added degree of protection or reduction of risk that remedial actions at other sites would be jeopardized (EPA 1989c).

17 These recommendations are consistent with those made in Section 3.0 concerning DNAPL sites, but are applicable for any site where restoration is technically impracticable.

18 PRPs or owner/operators may propose and analyze alternative remedial strategies. However, only EPA (or designated lead agency, where appropriate) has remedy selection authority.

Sources should be located and treated or removed where feasible and where significant risk reduction will result, regardless of whether EPA has determined that ground-water restoration is technically impracticable.

In some cases, however, the inability to remove or treat sources will be a major factor in a TI decision. Where sources cannot be completely treated or removed, effective source containment may be critical to the long-term effectiveness and reliability of an alternative ground-water remedy. Options currently available for source containment usually involve either a physical barrier system (such as a slurry wall) or a hydraulic containment system (typically a pump-and-treat system) (EPA 1992b).

Applicability and effectiveness of containment systems are influenced by several hydrogeologic factors, however. For example, the effectiveness of a slurry wall generally depends on whether a continuous, low permeability layer exists at a relatively shallow depth beneath the site.

Source containment has several benefits. First, source containment will contribute to the long-term management of contaminant migration by limiting the further contamination of ground water and spread of potentially mobile sources, such as NAPLs. Second, effective source containment may permit restoration of that portion of the aqueous plume that lies outside of the containment area. Third, effective containment may facilitate the future use of new source removal technologies, as some of these technologies (e.g., surfactants, steam injection, radio frequency heating) may increase the mobility of residual and free-phase NAPLs. Remobilization of NAPLs, particularly DNAPLs, often presents a significant risk unless the source area can be reliably contained.

5.1.3 Aqueous Plume Remediation

Remediation of the aqueous plume is the third major technical concern of an alternative remedial strategy. Where the technical constraints to restoration include the inability to remove contamination sources, the ability to effectively contain those sources will be critical to establishing the objectives of plume remediation. Where sources can be effectively contained, the portion of the aqueous plume outside of the containment area generally should be restored to the required cleanup levels.

Inability to contain the sources, or other technical constraints, may render plume restoration technically impracticable. There are several options for alternative remedial strategies in such cases. These include hydraulic containment of the leading edge of the aqueous plume, establishing a less-stringent cleanup level that would be actively sought throughout the plume (at Superfund sites), and natural attenuation or natural gradient flushing of the plume.

Containment of the aqueous plume usually requires the pumping and treating of contaminated ground water, but usually involves fewer wells and smaller quantities of water than does a full plume restoration effort. Plume containment offers the potential advantages of preventing further spreading of the contaminated ground water, thereby limiting the size of the plume, and preventing the plume from encroaching on water-supply wells or discharging to ecologically sensitive areas.

At certain Superfund sites, it may be feasible to restore the contaminated plume (outside of any source containment area) to a site-specific cleanup level that is less stringent than that originally identified. EPA may establish such a level as the cleanup level within the TI zone, where appropriate. The site-specific level may consider the targeted risk level for site cleanup and other factors. Site-specific cleanup levels offer the advantage of providing a clear goal against which to measure the progress of the alternative remedial strategy. However, where site-specific cleanup levels exceed the acceptable risk range for human or environmental exposure, the remedy generally must include other measures (e.g., institutional controls) to ensure protectiveness.

At some Superfund sites, a less-stringent ARAR than the one determined to be unattainable may have to be complied with. For example, it may be technically impracticable to attain the most stringent ARAR at a site (e.g., a State requirement to restore ground water to background concentration levels). However, the next most stringent ARAR (e.g., Federal MCL) for the same compound may be attainable. In such cases, the next most stringent ARAR generally must be attained.

In certain situations where restoration is technically impracticable, EPA may choose natural attenuation as a component of the remedy for the aqueous plume.[19] Natural attenuation generally will result in

19 Technical impracticability of restoration is not a precondition for the use of natural attenuation in a ground-water remedy, however.

attainment of the desired cleanup levels, but may take longer to meet them than active remediation. This approach is most likely to be appropriate where the affected ground water is not a current or reasonably expected future source of drinking water, and ground-water discharge does not significantly impact surface water or ecologic resources. Sufficient technical information and supporting data must be presented to demonstrate the effectiveness of this strategy, along with assurances that any institutional controls required to prevent exposure will be reliable and enforceable. Contingencies for additional or more active remediation also should be incorporated into the remedy, to be triggered by specific contaminant concentration levels in the site ground-water monitoring network, or other criteria as appropriate.

5.2 Alternative Remedy Selection

The alternative remedial strategy options discussed above represent a range of responses for addressing the various aspects of a ground-water contamination site. Selection of the options appropriate for a particular site must not only consider the desired remediation objectives, as discussed above, but also the statutory and regulatory requirements applicable to the program under which the action is being taken. These requirements are discussed briefly below. Further information and guidance on these requirements can be obtained from publications referenced in this section.

5.2.1. Superfund

The selection of an alternative remedy at a Superfund site should follow the remedy selection process provided in NCP §300.430(f). Regardless of whether ARARs are waived at the site, the alternative remedy still must satisfy the two threshold remedy selection criteria (protect human health and the environment and comply with all ARARs that have not been waived); be cost effective; and utilize permanent solutions and treatment to the maximum extent practicable. This last finding is satisfied by identifying the alternative that best balances the trade-offs with respect to the remaining balancing and modifying criteria, taking into account the demonstrated technical limitations (see Highlight 2).[20]

Where ground-water ARARs are waived at a Superfund site due to technical impracticability, EPA's general expectations are to prevent further migration of the contaminated ground-water plume, prevent exposure to the contaminated ground water, and evaluate further risk reduction measures as appropriate. (NCP §300.430(a)(1)(iii)(F)). These expectations should be evaluated along with the nine remedy selection criteria to determine the most appropriate remedial strategy for the site.

Highlight 2.
Superfund Remedy Selection Criteria

Threshold Criteria
- Overall protection of human health and the environment
- Compliance with (or justification for a waiver of) ARARs

Balancing Criteria
- Long-term effectiveness and permanence
- Reduction of mobility, toxicity, or volume
- Short-term effectiveness
- Implementability
- Cost

Modifying Criteria
- State acceptance
- Community acceptance

5.2.2 RCRA

At RCRA facilities where ground-water restoration is technically impracticable, the permit or order schedule of compliance may be modified by establishing: 1) further measures that may be required of the permittee to control exposure to residual contamination, as necessary to protect human health and the environment; and 2) alternate levels or measures for cleaning up contaminated media.[21]

Criteria for establishing an alternative remedial strategy under RCRA are presented in Highlight 3. In addition to satisfying the general standards for remedies, the alternative remedial strategy at a RCRA facility also should provide the best balance of trade-offs among the five remedy selection decision factors.[22]

20 For further guidance on the Superfund remedy selection process, see NCP §300.430(f) and "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA," (EPA 1988a).

21 Proposed Subpart S Rule, §264.531(b).

22 Further guidance on remedy selection at RCRA facilities is provided in the proposed Subpart S Rule (55 FR 30823-30824, July 27, 1990).

Highlight 3.
RCRA Remedy Standards and Selection Factors

General Standards for Remedies
1. Overall protection of human health and the environment
2. Attainment of media cleanup standards
3. Source control
4. Compliance with waste management standards

Remedy Selection Decision Factors
1. Long-term effectiveness
2. Reduction of waste toxicity, mobility, or volume
3. Short-term effectiveness
4. Implementability
5. Cost

5.2.3 Additional Remedy Selection Considerations

The choice among available remedial strategy options may involve a consideration of the aggressiveness of the remedy, a concept that includes both the choice of remedial technologies as well as the relative intensity of how that technology is applied at the site. For example, consider a site where source area restoration is technically impracticable but source containment is both feasible and practicable. With the contaminant source contained, restoration of the portion of the plume outside of the containment area may be feasible. However, as discussed earlier, there are several options for attaining cleanup levels within the aqueous plume: active pump-and-treat throughout the aqueous plume; natural gradient flushing of the plume towards a pump-and-treat capture system located at the leading edge of the plume; and natural attenuation (dilution, dispersion, and any natural degradation processes active within the affected aquifer). Each alternative will attain the required cleanup levels, but the choice involves a trade-off among several factors, including: 1) remediation timeframe (longer with less aggressive strategies); 2) cost (lower with less aggressive strategies); and 3) potential risk of exposure (may increase with less aggressive strategies).[23]

Conditions favoring more aggressive strategies (i.e., active pump-and-treat throughout the aqueous plume) include the following:

1) **The aggressive strategy clearly will result in a significantly shorter restoration timeframe than other available options.** This will depend on site hydrogeologic and contaminant-related factors, including the complexity of the aquifer system, natural rate of ground-water flow, quantity of sorbed contaminant mass in the aquifer (and its rate of desorption), and other factors.

2) **A shorter remediation timeframe is desired to reduce the potential for human exposure.** This generally is the case where there is current or reasonably expected near-term future use of the ground water. Factors that may be useful in evaluating the likelihood of exposure include the State (or Federal, as appropriate) classification of the ground water; availability of alternate supplies, such as municipal hookups or other water supply aquifers; interconnections of the contaminated aquifer with other surface or ground waters; and the ability of institutional controls to limit exposure.

3) **A shorter remediation timeframe is desired to reduce ongoing or potential impacts to environmental receptors.** Such impacts may be caused by discharges to surface waters, sensitive ecologic areas (e.g., wetlands), or sole-source aquifers.

EPA will evaluate and determine the objectives and relative aggressiveness of the alternative remedy on a site-specific basis, based on the applicable regulatory requirements and considering the factors discussed throughout this section. Where conditions favoring more aggressive strategies do not exist, EPA is more likely to choose a less aggressive strategy to achieve the desired remediation objectives. EPA recognizes that, at some sites, remedies may need to be in operation for very long time periods. Adequate monitoring and periodic evaluation of remedy performance should be conducted to ensure protectiveness and to evaluate the need for remedy enhancements or the use of new or different remediation technologies.

5.2.4 Relation to Alternate Concentration Limits

Site-specific cleanup levels established as part of an alternative remedial strategy at a Superfund site should not be confused with CERCLA Alternate Concentration Limits (ACLs). To qualify for use of a CERCLA ACL, the site must meet the following three requirements: 1) there are known points of entry of the contaminated ground water into surface water; 2) there

23 The long-term reliability of a remedy also is an important consideration for alternative remedial strategy selection. In this example, long-term reliability is primarily a function of the design and integrity of the source containment system.

will be no statistically significant increases of the contaminant concentrations in the surface water or contaminant accumulations in downstream sediments; and 3) enforceable measures can be put into place to prevent exposure to the contaminated ground water (see CERCLA §121(d)(2)(B)(ii)). In addition, EPA generally considers ACLs appropriate only where cleanup to ARARs is impracticable, based on an analysis using the Superfund remedy selection "balancing" and "modifying" criteria shown in Highlight 2. 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 a CERCLA ACL. For further guidance on CERCLA ACLs, refer to the NCP Preamble (55 FR 8754, March 1990).

Site-specific cleanup levels established in response to a TI determination at a RCRA facility also should not be confused with ACLs established as part of the ground-water monitoring program for regulated units under 40 CFR 264.94. ACLs established under §264.94(a)(3) represent concentrations that EPA determines will not pose a substantial hazard to human or environmental receptors. (If the ACL is exceeded, then corrective action responsibilities for the regulated unit are triggered.) A TI determination generally will not satisfy the criteria for an ACL under this authority.

6.0 Administrative Issues

6.1 TI Review and Decision Process

A TI decision must be incorporated into a site decision document (Superfund ROD or RCRA permit or enforcement order) or be incorporated into a modification or amendment to an original document. Information and analyses supporting the TI decision must be incorporated into the site administrative record, either as part of a Feasibility Study or Corrective Measures Study (for a "front-end" TI determination) or remedy performance evaluation or other technical report or evaluation (for a post-remedy implementation determination).

The first step in EPA's review process for a TI determination will be to assess the completeness and adequacy of the TI evaluation. TI evaluations that do not adequately address the considerations identified in this guidance likely will have to be revised or augmented to address the inadequacies identified by EPA or the responsible agency. Early consultation with EPA by PRPs or owner/operators is encouraged to help identify appropriate data and analysis for the evaluation. While a TI evaluation is underway, remediation efforts underway at a site shall continue until the State or Federal official responsible for the decision determines that the existing remedy should be altered. Requirements specific to the Superfund and RCRA programs are discussed further below.

6.1.1 Superfund

As discussed in Section 4.2, TI decisions may be made either in the ROD (front-end decisions) or after the remedy has been implemented and monitored (post-implementation decisions), depending on the circumstances of the site.

TI decisions at Superfund sites generally will be made by the EPA Regional Administrator who, upon review of a TI evaluation, will determine whether ground-water restoration is technically impracticable and will identify further remedial actions to be taken at the site. TI determinations at Superfund sites may require consultation with headquarters program management. Regional personnel should refer to the most recent OERR Remedy Delegation Memorandum for current consultation requirements.[24]

Where a Superfund ROD will invoke a TI ARAR waiver (front-end decision), EPA (or the lead agency) must provide notice of its intent to waive the ARAR in the Proposed Plan for the site and respond to any State (or Federal) agency or public comments concerning the waiver. The requirements for State and community involvement are provided in NCP §300.500-515 and §300.430, respectively. In general, State and community involvement in the decision to waive an ARAR based on technical impracticability will be the same as for other site remedy decisions. Since TI decisions may affect the potential future uses of ground water, interest in TI ARAR waivers may be high. Therefore, it is EPA's intent to coordinate and consult with States and the public regarding TI ARAR waiver issues as early as possible in the remedy decision process.

24 The types of Superfund site remedy decisions that require consultation with headquarters program management are identified in the periodically updated OERR Remedy Delegation Memorandum. The most recent version available at the time of publication of this guidance was the "Twenty Fourth Remedy Delegation Report - FY 1993," dated February 18, 1993.

State concurrence should be sought, but is not required, for all remedy decisions in which EPA invokes an ARAR waiver. Where the ARAR to be waived is a State ARAR, EPA must notify the State of this when submitting the RI/FS to the State or when responding to a State-lead RI/FS (NCP §300.515(d)(3)). EPA must provide the State with an explanation of any waiver of a State standard (CERCLA §121(f)(1)(G)).

For remedial actions under CERCLA §106 that will waive an ARAR, the State must be notified at least 30 days prior to the date on which any Consent Decree will be entered. If the State wishes the action to conform to (and not waive) those standards, the State may intervene in the action before the Consent Decree is entered (see §121(f)(2) and (f)(3)).

At certain State-lead sites, the State may make the final remedy decision, including a decision to invoke an ARAR waiver. This situation is restricted to sites where the State has been assigned the lead role for the response action, the action is being taken under State law, and the State is not receiving funding for the action from the Trust Fund. In such situations, the State may seek, but is not required to obtain, EPA concurrence on the remedy decision. For further guidance on this and other issues regarding the State role in remedy selection, see "Questions and Answers About the State Role in Remedy Selection at Non-Fund-Financed Enforcement Sites" (EPA 1991c).

Post-remedy-implementation TI decisions may be made in cases where an outside party or agency submits comments requesting a TI determination or EPA determines on its own initiative that a waiver is warranted. The information considered in making such decisions should include the same types of information and analyses discussed for front-end determinations, except that remedy performance data and analysis also should be provided. This information must be entered into the site administrative record before the TI decision can be made and an ARAR waiver invoked. There are limitations, however, to the requirement that EPA open the administrative record to new comments, such as an outside party's request for a TI determination. EPA is not required to consider comments on the selected remedy unless the comments contain "significant information not contained elsewhere in the administrative record file which substantially supports the need to significantly alter the response action" (see NCP §300.825). The type and amount of information necessary to meet this requirement (e.g., the length of time a remedy must be operated prior to a TI evaluation) will be determined by EPA on a site-specific basis.

A modification to a signed ROD invoking a TI ARAR waiver generally will require a ROD amendment, since a waiver usually will constitute a fundamental change in the remedy. A public comment period of 30 days is required for an amendment to a ROD; this period may be extended to 60 days upon request.[25] A public meeting also should be granted if requested. In the exceptional case where an ESD is used to invoke a TI ARAR waiver, public notice and opportunity for comment also should be provided. Further guidance on ROD amendments is provided in "Guide to Addressing Pre-ROD and Post-ROD Changes" (EPA 1991b) and upcoming revisions to "Guidance on Preparing Superfund Decision Documents" (expected Fall 1993).

6.1.2 RCRA

TI decisions at RCRA Corrective Action facilities will be made either by the EPA Regional Administrator or by the appropriate State agency, depending on the RCRA program authorization status of the State. EPA's goal in the RCRA corrective action program is to work cooperatively with individual States, regardless of their authorization status, to promote consistent TI decisions. As in the Superfund program, it is recommended that the State and EPA notify and consult each other as early as possible regarding sites where TI determinations may be made. This notification and consultation process may be outlined in the State/EPA Memorandum of Understanding.

For States authorized for Hazardous and Solid Waste Amendments (HSWA) Corrective Action, the State will have primary authority for remedy decisions, including TI decisions. EPA will retain authority for TI determinations in States that are not authorized for HSWA corrective action.

At RCRA permitted facilities, implementation of a TI determination generally would require a Class 3 permit modification for the purpose of specifying (alternative) corrective measures. This process requires a 45-day notice and comment period, response to comments, and

25 Public notice and opportunity for comment should be provided before an ARAR waiver is granted, regardless of whether an Explanation of Significant Differences (ESD) or ROD amendment is used to invoke the waiver.

public hearing, if requested. At RCRA facilities conducting corrective action under an order, TI determinations generally are implemented through the negotiation of a new order or an amendment to an existing order. This process generally includes a 30- to 45-day pubic comment period and public hearing, if requested.

6.1.3 Technical Review and Support

Technical support for the TI evaluation should be sought as early in the process as possible, preferably during the initial scoping of the content of the TI evaluation. TI determinations usually will require expertise from several disciplines, including hydrogeology, engineering, and risk assessment. Technical staff within the Regions representing these disciplines should be part of the TI review team. EPA's Office of Research and Development (ORD) technical liaisons and scientists based in the Regions also may provide assistance to program staff. Further assistance and review may be obtained from the ORD laboratories involved in the Technical Support Project, including the R.S. Kerr Environmental Research Laboratory (Ada, OK), the Risk Reduction and Engineering Laboratory (Cincinnati, OH), the Environmental Research Laboratory (Athens, GA), and the Environmental Monitoring Systems Laboratory (Las Vegas, NV). The directory of ORD technical services may be consulted for further information (EPA 1993c).

General assistance and site-specific consultation on technical impracticability issues also is available from EPA headquarters staff. Inquiries should be directed to the appropriate OSWER program office.

6.2 Duration of TI Decisions

A determination that ground-water restoration is technically impracticable and the subsequent selection of an alternative remedial strategy will be subject to future review by EPA.

At Superfund sites, an alternative remedial strategy implemented under a CERCLA TI waiver remains in effect so long as that strategy remains protective of human health and the environment. Protectiveness in this context encompasses long-term reliability of the remedy. If the conditions of protectiveness or reliability conditions cease to be met, EPA will determine what additional remedial actions must be implemented to enhance or augment the existing remedy. EPA shall conduct a full assessment of the protectiveness of the alternative remedy at least every five years at any site where contamination remains above levels that allow for unrestricted use, as required under NCP §300.430(f)(4)(ii).

RCRA TI decisions will be incorporated into facility permits or enforcement orders and therefore will be subject to continual oversight and review. Conditions of the permit or order involving the TI decision or the alternative strategy may be revisited on a periodic basis to ensure protectiveness. It may be necessary to modify permits or orders to reflect new information that becomes available during the remedy implementation and monitoring period.[26] Additional measures may be required by EPA to ensure the ongoing protectiveness and reliability of the remedy. Further, owner/operators of RCRA facilities may be required by EPA to undertake additional remedial measures in the future if subsequent advances in remediation technology make attainment of media cleanup standards technically practicable.

The protectiveness of an alternative remedial strategy at a Superfund site or RCRA facility must be ensured through a monitoring program designed to detect releases from containment areas, migration of contaminants to water supply wells, or other releases that would indicate a possible failure of one of the remedy components. EPA may decide to take any further response actions necessary to ensure protectiveness at any time based upon whether the alternative remedy is achieving its required performance standards. Monitoring data, therefore, must be provided to EPA on a regular basis to ensure adequate performance of the alternative remedy. The format, content, and reporting schedule of the monitoring program will be determined by EPA as part of the TI determination and alternative remedy selection process.

26 RCRA Corrective Action Orders that incorporate TI decisions should contain language that retains EPA's authority to review these decisions and complete additional site remediation, as necessary.

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