United States Environmental Protection Agency

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Groundwater Road Map

Recommended Process for Restoring Contaminated Groundwater at Superfund Sites

Note: All bold-faced words in the text are defined in the glossary at the end of this fact sheet. Cited references and additional references are located at the end of this fact sheet. Cited references include the page number from the reference, as appropriate.

Purpose and Scope

This fact sheet focuses on those groundwater response actions where the decision has been or may be made to restore all or part of the aquifer that are undertaken using cleanup authority under the **Comprehensive Environmental Response, Compensation, and Liability Act** (CERCLA), as amended. Portions of this guidance may also be useful to groundwater remedial actions that do not have restoration as an objective. For purposes of this guidance, "restoration remedies" are remedial actions with the objective of returning all or part of groundwater aquifer to cleanup levels specified in the Record of Decision (ROD) and "restoration" refers to the reduction of contaminant concentrations to cleanup levels that are selected as part of a response action under Superfund.

The fact sheet addresses all types of site leads—fund-lead, potentially responsible party (PRP)-lead, and federal facility lead.

This fact sheet addresses groundwater restoration remedies which may include **pump-and-treat systems,** in situ **treatment systems, monitored natural attenuation** (MNA) or a combination of one or more of these and other remedies. As part of an overall site remediation strategy, groundwater remedies may also be selected in conjunction with in situ source remedies. It is important to note that source control measures and plume containment activities are often critical to the success of aquifer restoration efforts. Although not the focus of this document, these remedy components are generally discussed when evaluating restoration remedies' progress towards their goals.

In addition, institutional controls (ICs), vapor intrusion mitigation measures, alternative water supply, well-head treatment, and Technical Impracticability (TI) ARAR waivers can all be part of a comprehensive groundwater remedy. These components are generally monitored and evaluated throughout the groundwater restoration process; however, these activities are not the focus in this document.

More than half of the RODs through 2008 contain groundwater remedies, many of which are still being implemented (Ref. 1). This fact sheet is intended as a quick reference guide for remedial project managers (RPM) and other site managers of final groundwater **restoration** remedies for all or part of the contaminated plume, and discusses some of the key steps in the groundwater restoration process from remedial investigation to completion. It describes a recommended process (see Figure 1), consistent with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), that can be used for groundwater restoration remedies.

This document does not provide new guidance, but compiles key relevant highlights of previous Superfund law, regulation, policy, and guidance regarding the overall groundwater restoration process; some portions of existing guidance are directly quoted for purposes of easier reference. This recommended road map summarizes the steps and decisions related to:

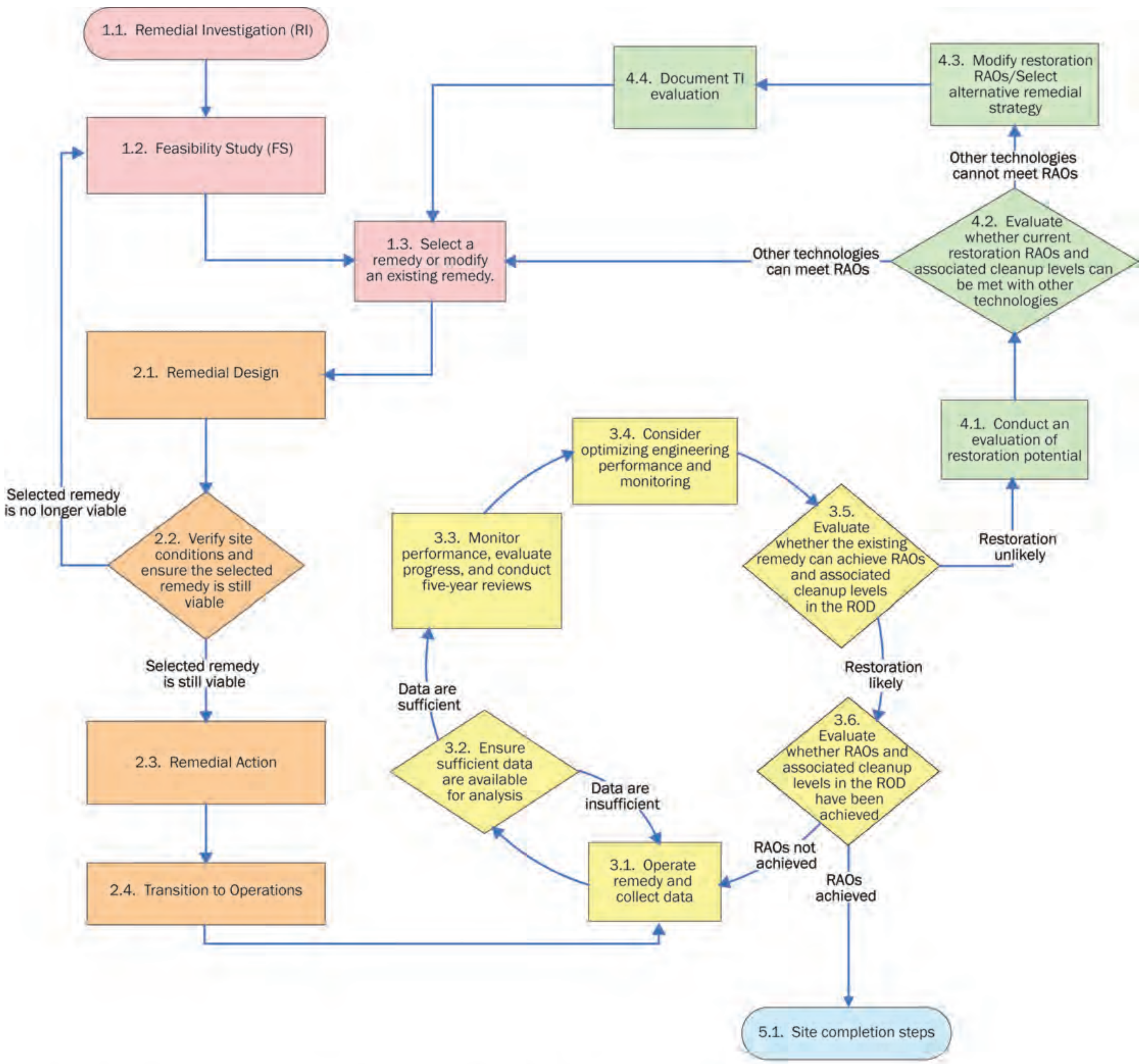


Figure 1: Recommended Process for Restoring Contaminated Groundwater at Superfund Sites

- selecting a groundwater restoration remedy;
- designing, constructing, and initiating the remedy;
- operating, monitoring, evaluating, and optimizing the remedy;
- modifying the remedy, as appropriate; and
- documenting completion of the site response actions.

This fact sheet may be useful at Superfund sites where remedial systems (1) will be selected, designed and operated, or (2) are currently operating as the final remedy to restore all or part of the contaminated groundwater to its beneficial use.

The flow chart in Figure 1 shows a recommended road map of the groundwater evaluation and remediation process. Each section in the document includes a snapshot of this figure highlighting the portion of the process being discussed. Each step in the process is color-coded. The shape of each step indicates whether the step includes activities (rectangle) or factors to consider (diamond). Start and endpoints are indicated by ovals. It should be noted that the steps discussed in this guidance do not represent a comprehensive set of steps or factors to consider when reviewing remedy implementation.

Additional policy and guidance documents in the references section of this fact sheet can be consulted as a source for additional information about each step in the process. Key portions of existing guidance are quoted in this fact sheet for the convenience of the reader.

Background

Under CERCLA 121(d)(2)(A), groundwater response actions are governed in part by the following mandate established by Congress:

> "*…Such remedial action shall require a level or standard of control which at least attains Maximum Contaminant Level Goals established under the Safe Drinking Water Act and water quality criteria established under section 304 or 303 of the Clean Water Act, where such goals or criteria are relevant and appropriate under the circumstances of the release or potential release*" (Ref. 2, p. 2).

Furthermore, the NCP includes general expectations for purposes of groundwater restoration as follows:

> "*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. When restoration of ground water to beneficial uses is not practicable, EPA expects to prevent further migration of the plume, prevent exposure to the contaminated ground water, and evaluate further risk reduction*" (Ref. 3).

OSWER Directive 9283.1, 1-33, *Summary of Key Existing EPA CERCLA Policies for Groundwater Restoration*, summarizes five key principles that stem from the overarching expectations for groundwater restoration. They are:

1. *"If groundwater that is a current or potential source of drinking water is contaminated above protective levels (e.g., for drinking water aquifers, contamination exceeds Federal or State MCLs or non-zero MCLGs), a remedial action under CERCLA should seek to restore that aquifer to beneficial use (e.g., drinking water standards) wherever practicable.*
2. *Groundwater contamination should not be allowed to migrate and further contaminate the aquifer or other media (e.g., vapor intrusion into buildings; sediment; surface water; or wetland).*
3. *Technical impracticability waivers and other waivers may be considered, and under appropriate circumstances granted if the statutory criteria are met, when groundwater cleanup is impracticable; the*

waiver decision should be scientifically supported and clearly documented.

4. *Early actions (such as source removal, plume containment, or provision of an alternative water supply) should be considered as soon as possible. ICs related to groundwater use or even surface use, may be useful to protect the public in the short-term, as well as in the long-term.*
5. *ICs should not be relied upon as the only response to contaminated groundwater or as a justification for not taking action under CERCLA. To ensure protective remedies, CERCLA response action cleanup levels for contaminated groundwater should generally address all pathways of exposure that pose an actual or potential risk to human health and the environment"* (Ref. 2, p. 3-4).

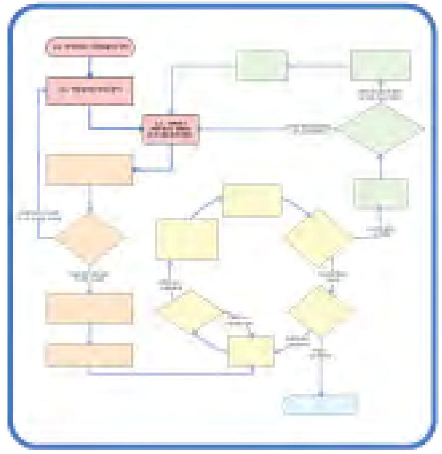
To address the principles discussed above, EPA may use a phased approach for remediating contaminated groundwater. *"In a phased response approach, site response activities are implemented in a sequence of steps, or phases, such that information gained from earlier phases is used to refine subsequent investigations, objectives or actions"* (Ref. 4, p. 5). Implementing investigations and actions in phases can be advantageous for several reasons, including:

- *"Data from earlier response actions are used to further characterize the site and assess restoration potential;*
- *Attainable objectives can be set for each response phase;*
- *Flexibility is provided to adjust the remedy in response to unexpected site conditions;*
- *Remedy performance is increased, decreasing remediation timeframe and cost; and*
- *Likely remedy refinements are built into the selected remedy, better defining the potential scope and minimizing the need for additional decision documents" (*Ref. 4, p. 6).

Phased remedy approaches may include the implementation of early and interim actions. For early actions, "*early refers to the timing of the start of an action with respect to other response actions at a given site. For Superfund sites, early actions could include removal actions, interim remedial actions, or early final remedial actions*" (Ref. 4, p. 6). *"An interim action is limited in scope and only addresses areas/media that also will be addressed by a final site/operable unit Record of Decision*" (Ref. 5, p. 8-2). Both source and groundwater actions may be implemented as either early or interim actions. These actions generally may address exposure to contaminated groundwater, or prevent further migration of groundwater, or prevent further migration of contaminants from sources.

Generally, groundwater restoration is considered a final action; however, "*site characterization and performance data from early or interim groundwater actions should be used to assess the likelihood of restoring groundwater to ARAR or risk-based cleanup levels*" (Ref. 4, p. 7). In addition, "*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*" (Ref. 6, p. 4).

1. Remedy Selection for Groundwater Restoration



Three important steps in the typical groundwater remedy selection process include: (1.1) remedial investigation, (1.2) feasibility study, and (1.3) selection of a remedy. As part of the remedy selection process, a **remedial investigation** and **feasibility study** (RI/FS) should be conducted to characterize site conditions, evaluate risks posed by the site, and identify and evaluate remedial alternatives; after the RI/FS, a proposed plan with the preferred remedy is published to provide an opportunity for public comment, and then a remedy is selected in the ROD.

1.1 Remedial investigation (RI)

The remedial investigation generally has four major components: conducting a field investigation, defining the nature and extent of contamination, identifying federal/state chemical- and location-specific **applicable or relevant and appropriate requirements** (ARARs) and conducting baseline human health and ecological **risk assessments**.

"*Data* [obtained during the field investigation] *on the physical characteristics of the site and surrounding areas should be collected to the extent necessary to define potential transport pathways and receptor populations and to provide sufficient engineering data for development and screening of remedial action alternatives*" (Ref. 7, p. 3-5). Particular to groundwater, it is recommended that the following information be collected:

> The remedial project manager is encouraged to assemble a multi-disciplinary technical review team who, throughout the remedial process outlined in this document, provides technical assistance. This assistance may include the review of important deliverables and monitoring of progress. Technical review team members may include, but are not limited to, the State RPM, Geologist/ Hydrogeologist, Human Health and Ecological Risk Assessors, Chemist, Geochemist, Environmental Engineer, Cost Engineer, EPA Technical Support Project Forums and Centers, and Community Involvement Coordinator.

- *"Nature and extent of groundwater contamination including source(s) of contamination, contaminants of concern (COCs), estimated extent and volume of contaminated plume and the potential for migration of the contaminant plume.*
- *Geology and hydrogeology of the site and surroundings (in addition to the topography and geography), including the following:*
  - *Aquifer(s) affected or threatened by site contamination, types of geologic materials, approximate depths, whether aquifer is confined or unconfined.*
  - *Groundwater flow directions within each aquifer and between aquifers and groundwater discharge locations (e.g.,*

> Community involvement generally is an important aspect of the Superfund program. Community involvement typically is the vehicle EPA uses to get community concerns and interests to the decision-making table. The active involvement of the project manager should help promote public participation among all team members and should ensure the integration of community involvement in the cleanup process (Ref. 8, p. 3).

surface waters, wetlands, other aquifers).

- *Interconnection between surface contamination (e.g., soils) and groundwater contamination*
- *Confirmed or suspected presence and location of NAPLs*" (Ref. 5, p. 9-5, 9-6).

From information collected at the site, it may be determined that MNA or other in situ technologies may be considered as a remedial approach. If this is the case, certain aspects of site characterization may require more detail or additional information gathering during the remedial investigation (as compared to the items referenced above), such as biological and geochemical data.

The information gathered generally is used to develop a **conceptual site model** (CSM). "*Analyses of the data collected should focus on the development or refinement of the conceptual site model by presenting and analyzing data on source characteristics, the nature and extent of contamination, the contaminated transport pathways and fate, and the effects on human health and the environment*" (Ref 7, p. 3-19). To support the CSM, three dimensional visualization platforms are also available to RPMs to assist in evaluating the data collected during the remedial investigation. The CSM may also serve as a guide to the decision-making throughout the remedial process discussed in this document.

In order to determine if groundwater restoration is appropriate, the groundwater use for the impacted aquifers is generally evaluated in accordance with the NCP which states that the lead agency should assess the "*characteristics or classification of air, surface water, and ground water*" as part of the RI (Ref. 9). Designation of groundwater classification should be based on the following: "*While a State's designation of groundwater use will be considered for establishing remediation goals, EPA's classification scheme (EPA Guidelines/or Ground-Water Classification [Final Draft, December 1986]) will generally be used if a state's classification would lead to a less stringent solution. In 1997, EPA initiated a policy of deferring to a State's determination of current and future groundwater uses, when based on criteria or methodology that are specified in an EPA endorsed CSGWPP* [Comprehensive State Groundwater Protection Program], *and can be applied at specific sites or facilities*" (Ref. 2, p. 7).

The CSM is a three-dimensional "picture" of site conditions that illustrates contaminant sources, release mechanisms, exposure pathways, migration routes, and potential human and ecological receptors. The CSM documents current and potential future site conditions and is supported by maps, cross sections, and site diagrams that illustrate what is known about human and environmental exposure through contaminant release and migration to potential receptors (Ref. 5, p. 6-10).

Based upon the identified exposure pathways, baseline human health and ecological risk assessments normally are conducted. "*CERCLA response actions that clean up contaminated groundwater generally address all pathways of exposures that pose an actual or potential risk to human health and the environment. For example, groundwater response actions should generally address the actual or potential direct contact risk posed by contaminated groundwater (e.g., human consumption, dermal contact, or inhalation), and also should consider the potential for the contaminated groundwater to serve as a source of contamination into other media (e.g., for vapor intrusion into buildings; sediment; surface water; or wetlands)*" (Ref. 2, p. 3).

"*Under existing Agency policy, groundwaters that are current or potential sources of drinking water that exceed risk-based standards (e.g., Maximum Concentration Limits [MCLs]) or pose an unacceptable risk generally warrant action under CERCLA*" (Ref. 2, p. 5).

During the RI, EPA generally identifies potential ARARs. "*The lead and support agency shall identify their respective potential ARARs related to the location of and contaminants at the site in a timely manner. The lead and support agencies may also, as appropriate, identify other pertinent advisories, criteria, or guidance in a timely manner*" (Ref. 10). *"CERCLA 121(d) specifically identifies Safe Drinking Water Act MCLs and nonzero MCLGs, as well as Clean Water Act Water Quality Criteria as potentially relevant and appropriate standards to be attained by the remedial action*" (Ref. 2, p. 8). These ARARs are used in developing the appropriate cleanup levels for the remedial action.

The results of the RI will be used in developing remedial alternatives in the feasibility study.

1.2 Feasibility study (FS)

The FS generally serves as the mechanism for the development, screening, and detailed evaluation of alternative remedial actions. "*For groundwater response actions, the lead agency shall develop a limited number of remedial alternatives that attain site-specific remediation levels within different restoration time periods utilizing one or more different technologies*" (Ref. 11). The FS normally includes several steps: developing remedial action objectives (RAOs); determining cleanup levels; identifying potential treatment and containment technologies or natural processes that will satisfy these RAOs; screening the technologies based on their effectiveness, implementability, and cost; and assembling technologies and their associated containment or disposal requirements into alternatives for the contaminated media (Ref. 7, chapter 4).

"*RAOs provide a general description of what the cleanup will accomplish (e.g., restoration of groundwater to drinking water levels)*" (Ref. 5, p. 6-26). "*A range of RAOs may be applicable to groundwater remedy decisions. Some of these objectives may be achievable in a relatively short time frame (e.g., exposure control, plume containment), while other objectives may require a much longer time frame (e.g., plume restoration)*" (Ref. 5, p. 9-6). The RAOs should clearly indicate which objectives are to be achieved over which portion of the plume and in what timeframes these objectives are expected to be achieved. Basic groundwater RAOs generally include one or more of the following:

- *"Prevent exposure to contaminated groundwater, above acceptable risk levels.*
- *Prevent or minimize further migration of the contaminant plume (source control).*
- *Prevent or minimize further migration of contaminants from source materials to groundwater (source control).*
- *Return groundwater to its expected beneficial uses wherever practicable (aquifer restoration)"* (Ref. 5, p. 9-6).

The basic RAOs above are generally used as a starting point for RAO development and should be modified to include site-specific exposure scenarios and more specificity.

Once RAOs are established, "*the preliminary remediation goals are developed on the basis of chemical-specific ARARs, when available, other available information (e.g., Rfds), and site-specific risk-related factors*" (Ref. 7, p. 4-3). Preliminary remediation goals are generally finalized in the remedy decision document as cleanup levels. "*Groundwater cleanup levels are established based on promulgated standards (e.g., Federal or State MCLs or non-zero MCLGs, or other standards found to be ARARs), or risk-based levels (e.g., for contaminants when there are no standards that define protectiveness). Where ARARs are not available or are not sufficiently protective, EPA generally sets site-specific remediation levels for: 1) carcinogens at a level that represents an excess upper bound lifetime cancer risk to an individual of between 10-4 to 10-6; and for 2) non-carcinogens such that the cumulative risks from exposure will not result in adverse effects to human* *populations (including sensitive sub-populations) that may be exposed during a lifetime or part of a lifetime, incorporating an adequate margin of safety*" (Ref. 2, p. 8-9).

After developing preliminary remediation goals, a remediation timeframe is typically developed as a baseline to reach these levels. This timeframe depends on a number of site specific factors, including the current and future use of the aquifer, complexity of site contamination and hydrogeology, and available remediation strategies. "*More rapid restoration of groundwater is favored in situations where a future demand for drinking water from groundwater is likely and other potential sources are not sufficient. Rapid restoration may also be appropriate where the institutional controls to prevent the utilization of contaminated groundwater for drinking water purposes are not clearly effective or reliable*" (Ref. 12, p. 171).

As discussed in existing guidance, "*in cases where there is a high degree of certainty that cleanup levels cannot be achieved, a final ROD that invokes a TI waiver and establishes an alternative remedial strategy may be the most appropriate option*" (Ref. 13, p. 5). "*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*" (Ref. 13, p. 11).

Typically, during the FS, different remedial alternatives for restoration of the groundwater, containment of the plume and source remediation, and restoration timeframes are compared. If MNA is being evaluated as a remedial alternative, the results of the RI should have "*site-specific data sufficient to estimate with an acceptable level of confidence both the rate of attenuation processes and the anticipated time required to achieve remediation objectives*" (Ref. 6, p. 15). Typically, multiple lines of evidence will be used to determine that MNA is occurring and provides a remedy that is protective of human health and the environment (Ref. 6, p. 15 -16). "*The decision to implement MNA should include a comprehensive site characterization, risk assessment where appropriate, and measures to control sources. In addition, the progress of natural attenuation towards a site's remediation objectives should be carefully monitored and compared with expectations to ensure that it will meet site remediation objectives within a timeframe that is reasonable compared to timeframes associated with other methods. Where MNA's ability to meet these expectations is uncertain and based predominantly on predictive analyses, decision-makers should incorporate contingency measures into the remedy*" (Ref. 13, p. 25).

Typically, all alternatives are initially screened for implementability, effectiveness, and cost. Once this screening is done, a detailed analysis is generally done using the nine evaluation criteria specified in the NCP. This detailed evaluation is the basis for the remedy decision (Ref. 7, Chapters 5 and 6).

1.3 Select a remedy or modify an existing remedy

"*The Preferred Alternative for a site is presented to the public in a Proposed Plan. The Proposed Plan briefly summarizes the alternatives studied in the detailed analysis phase of the RI/FS, highlighting the key factors that led to identifying the Preferred Alternative. The Proposed Plan, as well as the RI/FS and the other information that forms the basis for the lead agency's response selection, is made available for public comment in the Administrative Record file. Following receipt of public comments and final comments from the support agency, the lead agency selects and documents the remedy selection decision in a record of decision (ROD)*" (Ref. 5, p. 1-5).

"*To support the selection of a remedial action, all facts, analyses of facts, and site-specific policy determinations considered in the course of carrying out activities . . . shall be documented, as appropriate, in a record of decision, in a level of detail appropriate to the site situation. . .*" (Ref. 14).

The ROD should include RAOs that clearly describe the intended results of the remedial action. In addition, the selected remedy section in a ROD should include: "*a brief discussion of the monitoring program necessary to ensure remedy effectiveness as well as the entity responsible for maintaining the monitoring program (especially important for remedies with long durations such as natural attenuation); and provisions for groundwater monitoring once the system is shut off to ensure cleanup levels are maintained*" (Ref. 5, p. 9-7).

- The expected outcome of the groundwater remedy should be discussed, including the following: "*Available uses of groundwater upon achieving cleanup levels. Note time frame to achieve available use; and*
- *Final cleanup levels for each medium (i.e., contaminant-specific remediation goals), basis for cleanup level, and risk at cleanup levels (if appropriate)*" (Ref. 5, p. 6-45).

A post-ROD change to a selected remedy is a site-specific determination and generally should be consistent with Section 300.435(c)(2) of the NCP, as summarized below:

Scope. Does the change alter the scope of the remedy (for example, type of treatment technology, remediation goals to be achieved, type of waste to be addressed, amount of waste to be addressed)?

Performance. Would the change alter the performance (for example, treatment levels to be attained, long-term reliability of the remedy)?

Cost. Are there significant changes in costs from estimates in the ROD, taking into account the recognized uncertainties associated with the hazardous waste engineering process selected? "*Feasibility cost estimates generally are expected to provide an accuracy of +50% to -30%*" (Ref. 5, p. 7-1).

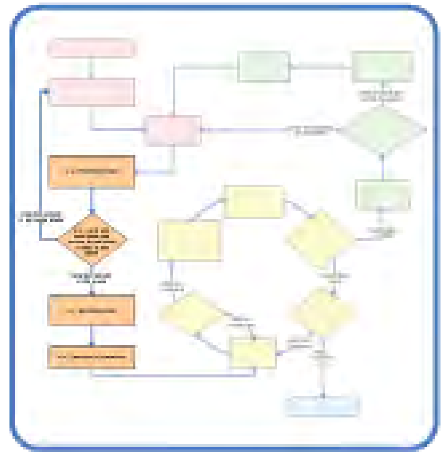
"*Based on this evaluation, and depending on the extent or scope of modification being considered, the lead agency must make a determination as to the type of change involved (i.e., nonsignificant or minor, significant, or fundamental change). Remedy changes should fall along a continuum from minor to fundamental. Similarly, an aggregate of nonsignificant or significant changes could result in a fundamental change*" (Ref. 5, p. 7-1). Examples of the potential types of changes identified and associated documentation modifications are summarized below:

Nonsignificant or Minor Change. This change typically arises during design and construction, when modifications are made to the functional specifications of the remedy to address issues such as performance optimization, new technical information, support agency/community concerns and/or cost minimization (e.g., value engineering process). Such changes may affect things such as the type or cost of materials, equipment, facilities, services, and supplies used to implement the remedy. The change should not have a significant impact on the scope, performance or cost of the remedy. This change should be documented with a brief memorandum to the site file.

Significant change. This change generally involves a change to a component of the remedy that does not fundamentally alter the overall cleanup approach. For example, changing to the contingency remedy selected in the ROD or a large increase of contaminant volume being remediated, would generally be considered a significant change. Significant changes are documented with an Explanation of Significant Differences (ESD) post-ROD document.

Fundamental Change. This change typically involves an appreciable change or changes in the scope, performance, and/or cost—or may be composed of a number of significant changes that together have the effect of a fundamental change. An example of a fundamental change is one that results in a reconsideration of the overall waste management approach selected in the original ROD. For example, change from restoration to containment, or a decision to invoke a technical impracticability waiver would generally be a fundamental change. Fundamental changes are documented with a ROD amendment (ROD-A). (Ref. 5, p. 7-1, 7-2)

2. Remedial Design and Remedial Action



The remedial design and remedial action process typically involve four elements: (2.1) **remedial design (RD)**, (2.2) verify the site conditions and ensure the remedy is still viable, (2.3) **remedial action (RA)**, and (2.4) transition to operations. Each of these steps is discussed below.

2.1 Remedial design

"*The purpose of data collection during the RD is not to recharacterize the site but to obtain data to support the design effort*" (Ref. 15, p. 48). "*If the CSM does not adequately identify or explain (1) historical and continuing sources of groundwater contamination, both above ground and below the surface, (2) historical growth and/or retreat of the groundwater plume, (3) groundwater flow velocity (horizontal and vertical) and other parameters controlling contaminant fate and transport, (4) potential human and ecological receptors, and (5) anticipated results of remedial actions, the data gaps should be addressed with a focused investigation*" (Ref. 16, p. 2). As a result, "*new information may be received or generated that will modify the CSM and could affect implementation of the remedy selected in the ROD, or could prompt a reassessment of that remedy*" (Ref. 5, p. 7-1). "*Because capital costs for installation and annual costs for operation and maintenance are significantly higher than the costs of designing a system, it is often appropriate to request a design review from a third party*" (Ref. 17, p. 1)." *The* [Federal Acquisition Regulation] *FAR has two types of Value Engineering requirements. The first type of requirement is for the RD phase of a project*" (Ref. 18, p. 1). "*Value Engineering (VE) is a highly beneficial technique used to reduce nonessential procurement and program costs. VE uses systematic and creative methods to reduce costs without sacrificing the reliability, efficiency, or original objectives of the project*" (Ref. 19, p. 1). All Superfund RDs that will lead to Fund-lead RAs should undergo the VE process (Ref. 18, p. 2). Although not required, **optimization** approaches may also be employed during design in accordance with EPA's goal to integrate optimization into the overall Superfund cleanup process (Ref. 20, p. 1). During remedial design, new information should be evaluated and may result in a re-evaluation of the selected remedial action (see 2.2).

2.2 Verify the site conditions and ensure the selected remedy is still viable

The information and data collected during remedial design is typically evaluated against the CSM and the assumptions made at the time of remedy selection to ensure the selected remedy is still viable. Where appropriate, changes to these assumptions made at the time of remedy selection are generally documented and incorporated into an updated CSM.

Possible results include:

Selected remedy is still viable: If the collected data and information indicate that the selected remedy does not need to be changed fundamentally, the design is finalized, and non-significant and significant changes to the remedy are documented if necessary (documentation is discussed in 1.3), and remedial action begins as described in 2.3.

Selected remedy is no longer viable: In some instances, data and information collected during the RD may determine that the selected remedy is no longer viable. In this case, the remedy generally needs to be changed fundamentally; the processes described in 1.2 and 1.3 usually are conducted. The following are common examples of changes in site conditions that may necessitate a fundamental change in the remedy:

- Changed or newly discovered hydrogeologic conditions
- Change in surrounding use of the aquifer
- Newly discovered constituents
- Newly identified sources

2.3 Remedial action

Typically, after all final design criteria have been approved, and all detailed system specifications have been selected, the engineering remedy components are constructed. Remedy construction can be phased, which involves implementing certain groundwater remedy elements as their designs are completed. The construction phase may include building the remedial system and installing the monitoring network. In some cases, the need for changes to the selected remedy becomes evident during the remedial action. Any remedy modifications are generally carried out in accordance with CERCLA, the NCP, and existing guidance and policy regarding ROD modifications and the Administrative Record. These changes are typically analyzed and documented in the appropriate decision document before they are implemented (see step 1.3). As part of the RA, an **operation and maintenance** (O&M) plan typically is finalized. The O&M plan generally "documents" the monitoring plan for groundwater restoration which should include, at a minimum, the components selected in the ROD.

For purposes of this guidance, "*monitoring is [defined as] the collection and analysis of data over a sufficient period of time and frequency to determine the status and/or trend in one or more environmental parameters or characteristics. Monitoring should not produce a 'snapshot in time' measurement, but rather should involve repeated sampling over time in order to define site-wide remedy performance and the trends in the parameters of interest relative to clearly defined management objectives*" (Ref. 19, p. Intro-3). In this case, these objectives are typically aquifer restoration in the long-term and plume containment in the short-term.

In order to evaluate these management objectives, "*several types of monitoring may be conducted at a site, such as detection monitoring (to detect changes in ambient conditions), compliance monitoring (to evaluate compliance with regulatory requirements), and remedial* [performance] *monitoring (to evaluate remedy effectiveness)*" (Ref. 19, p. Intro-3).

"*The predicted time frame for operation and completion of the groundwater remedial action is critical to monitoring plan development because it identifies and provides parameters for the monitoring objectives and subsequent monitoring studies*" (Ref. 19, p. 1-2).

These monitoring parameters generally determine the following data collection characteristics (Ref. 19, p. 4-2, 4-4):

- What data are needed?
- How should samples be collected?
- Where should samples be collected?
- When should samples be collected?
- How long should sampling continue?
- How often should sampling occur?

The monitoring plan generally addresses how the data will be analyzed to discern contaminant distribution changes, remedy performance, and, as appropriate, plume capture efficacy based on the established objectives and monitoring parameters. The monitoring plan at a site should be considered a dynamic document; the types of data collected and the sampling frequency may change as both restoration progresses and based on additional information collected during the operation and maintenance of the remedy. Capture zone analysis is generally performed to assess if the short-term RAO of plume containment is being achieved. EPA has developed technical guidance to help evaluate capture zones for groundwater P&T systems and to help determine appropriate frequency for capture zone analysis. The basis for evaluating capture usually includes a lines of evidence approach considering concentration trends and water level data, among other factors (Ref. 21). "*In cases where monitoring is being conducted to identify individual exceedance of some critical environmental conditions, statistical analysis may not be necessary. Use of an appropriate statistical method can help support or refute the monitoring hypotheses and thus help answer the monitoring questions*" (Ref. 19, p. 4-5).

If the groundwater remedy is the last remedy to be implemented at the site, completion of physical construction normally would signify achievement of **construction completion**, and a **preliminary close out report** (PCOR) should be prepared to document this milestone (Ref. 22, p. 3-2 – 3-3). Completion of physical construction of typical groundwater remedies is generally documented in a remedial action (RA) report, which is typically prepared when all construction activities are complete (including site restoration and demobilization), and a successful contract final inspection or equivalent has been conducted (Ref. 22, p. 2-4 – 2-6).

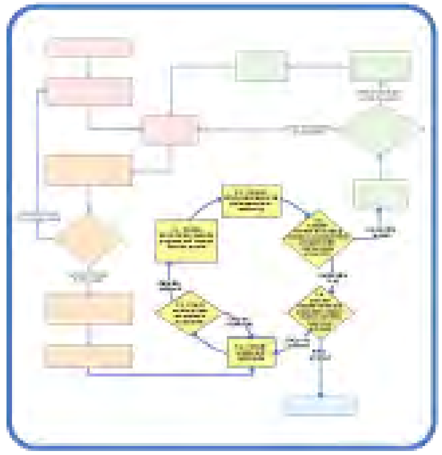
2.4 Transition to operations

"*The phase following construction of the remedy and before* [the] *Operational & Functional (O&F)* [determination] *is often referred to as the shakedown, where the constructor makes minor modifications as necessary to ensure the remedy is operating as designed*" (Ref. 22, p. 2-8).

O&F Determination: "*A remedy becomes O&F either one year after construction is complete, or when the remedy is determined concurrently by EPA and the State to be functioning properly and performing as designed, whichever is earlier. EPA may grant extensions to the one-year period in writing, as appropriate*" (Ref. 22, p. 2-8). Typically, the attainment of O&F is documented in a letter to the interested parties.

As discussed in the NCP section 300.435, for fund-lead groundwater restoration actions, once EPA and the State make the O&F determination, the remedy enters the **long-term response action** (LTRA) phase that involves operation, monitoring, optimization, and evaluation of the remedy. LTRA typically is conducted by EPA for up to 10 years with a 10% cost share by the State (Ref. 3). After 10 years, the remedy normally enters the O&M phase, which is conducted by the State. For groundwater remedies that do not include a restoration objective, once EPA and the State make the O&F determination the remedy generally should enter the operation and maintenance (O&M) phase. Consistent with CERCLA section 104(c), O&M is funded 100% by the State. For PRP-lead sites, the O&F determination normally triggers the **long-term response** (LR) phase. The PRPs generally conduct all activities during the LR and O&M phases. For federal facility-lead sites, groundwater restoration remedies normally enter the O&M phase when determined to be **operating properly and successfully** (OPS). Under Section 120(h) of CERCLA, the OPS determination is a required part of transfers of federal property (Ref. 22, p. 2-3). The federal facility conducts all O&M activities unless otherwise specified in facility transfer documentation.

3. Operate, Monitor and Evaluate Remedy



The operate, monitor and evaluate remedy stage typically involves six steps: (3.1) operate remedy and collect data, (3.2) ensure sufficient data are available for analysis, (3.3) monitor performance, evaluate progress, and conduct **five-year reviews**, (3.4) consider optimizing remedy (engineering) performance and monitoring, (3.5) evaluate whether the existing remedy can achieve RAOs and associated cleanup levels in the ROD, and (3.6) evaluate whether RAOs and associated cleanup levels established in the ROD are met. Once the groundwater restoration remedy is determined to be O&F, the remedy typically enters the operations stage.

During a long-term monitoring effort, groundwater sampling and monitoring data typically are collected to evaluate contaminant migration and changes in chemical suites and concentrations through time at appropriate locations. The site technical review team may use this information to verify that contaminants are not migrating to potential receptors, that remediation is occurring at a rate to achieve the RAOs and associated cleanup levels in a reasonable timeframe, and all sources have been identified (Ref. 23, p. 6). Data collected are also evaluated to determine if the remedy either has achieved the RAOs and associated cleanup levels or is likely to achieve these under current conditions. Data may also be used to determine if both the treatment system and monitoring network are operating efficiently. Not all steps discussed in this section need to be conducted in sequence; they can be conducted and considered at any point throughout the long-term operation of the remedy.

For purposes of this guidance, long-term monitoring is defined as monitoring conducted after some active, passive, or containment remedy has been selected and constructed, and is generally used to evaluate the degree to which the remedial action objectives and associated cleanup levels are being achieved (Ref. 25, p. 1).

3.1 Operate remedy and collect data

Sampling and monitoring data are collected in accordance with the monitoring plan (see 2.3). Sampling and monitoring data are analyzed to fulfill several purposes: (1) to evaluate how the remedy is performing with regard to RAOs and conduct five-year reviews, (2) to optimize the long-term monitoring, and (3) to optimize engineering/remedial components of the remedy.

3.2 Ensure sufficient data are available for analysis

As data are obtained, data assessment occurs and results should be interpreted. Generally, the goal of data collection is to obtain enough data in a usable (typically electronic) format so that trends, if present, may be identified, and progress or lack of progress may be appropriately documented. Several years of data are generally appropriate to identify meaningful trends, patterns, or changes in contaminant reductions and/or to effectively evaluate plume capture. The following items should be considered when making this determination:

- Can an analysis for changes in the groundwater contaminants and extent of the plume be reliably conducted with the methods outlined in the monitoring plan?
- Can a capture zone analysis be conducted with the data that have been collected?
- Are monitoring parameters sufficient to evaluate site conditions illustrated in the CSM?
- Are operational data adequate to evaluate operational performance of engineered remedies?

Possible results include:

Data are insufficient: If data are insufficient to analyze trends or evaluate progress and effectiveness in achieving RAOs and associated cleanup levels, the remedy should continue to be operated and additional data should be collected as described in 3.1.

Data are sufficient: If enough data are available to analyze trends, changes, and patterns and evaluate progress and effectiveness in achieving RAOs and associated cleanup levels, the activities described in 3.3 and 3.4 are recommended.

3.3 Monitor performance, evaluate progress, and conduct five-year reviews

It is important to note that this section discusses discrete activities typically conducted during the long-term operation of the remedy. In addition to the highlighted activities, the RPM and project team should continue to collect and evaluate system performance and monitoring data and make appropriate changes.

Monitor performance and evaluate progress: The data should be used to monitor the effectiveness of the subsurface remedy and evaluate it in relation to the CSM and any site groundwater flow models. "*New data should be interpreted and compared to historical data on a regular basis*" (Ref. 16, p. 8). The progress of remedial systems in achieving RAOs and associated cleanup levels should also be evaluated to determine if actual progress is consistent with progress predicted at the time of remedy decision.

Five-year Reviews: "*The purpose of a five-year review (FYR) is to evaluate the implementation and performance of a remedy in order to determine if the remedy is or will be protective of human health and the environment. Protectiveness is generally defined in the NCP by the risk range and the hazard index (HI). Evaluation of the remedy and the determination of protectiveness should be based on and sufficiently supported by data and observations*" (Ref. 24, p. 1-1).

In general, FYRs are required whenever a remedial action results in hazardous substances, pollutants, or contaminants remaining on site. "*Under the Agency's interpretation contained in the NCP* [40 CFR 300.430(f)(4)(ii)], *the requirement in CERCLA Section 121(c) is triggered when remaining on-site hazardous substances, pollutants, or contaminants are above levels that allow for 'unlimited use and unrestricted exposure*'" (Ref. 24, p. 1-1). "*'Unlimited use and unrestricted exposure' (UU/UE) means that the selected remedy* *will place no restrictions on the potential use of land or other natural resources*" (Ref. 24, p. 1-2). CERCLA requires FYRs if both the following conditions are true:

1. *"Upon completion of the remedial action, hazardous substances, pollutants, or contaminants will remain on site; and*
2. *The ROD of the site was signed on or after October 17, 1986 and the remedial action was selected under CERCLA §121"* (Ref. 24, p. 1-2).

The five-year review guidance addresses remedy assessment through site inspections, monitoring data review, and document review. Five-year reviews generally are conducted in conjunction with and supported by the continuous, effective monitoring of groundwater remedies. To evaluate remedy protectiveness, the guidance recommends three technical assessment questions.

> **Question A:** Is the remedy functioning as intended by the decision documents? When answering this question, site inspection and O&M data are examined to assess if (1) the remedy continues to operate and function as designed, (2) if the remedy has attained, or is expected to attain, cleanup levels, (3) O&M is being implemented (e.g. monitoring activities designed to ensure the effectiveness of the remedy are being conducted and whether they are adequate), and (4) opportunities for optimization are identified.
>
> **Question B:** Are the exposure assumptions, toxicity data, cleanup levels, and RAOs used at the time of remedy selection still valid? In order to answer this question, Regions should evaluate a number of factors, including any changes to standards and assumptions made since the time of remedy selection. If ARARs have been modified or a new standard has been promulgated, Regions should determine if the cleanup level selected in the ROD remains protective. Review of risk parameters used to support the remedy selection, such as reference doses, cancer potency factors, and exposure pathways of concern should also be evaluated. Furthermore, evaluation of the assumptions regarding current and future groundwater uses and contaminants of concern should be reviewed to ensure that they are still valid. All these factors should be considered when updating the CSM and when evaluating exposure pathways and remedy implementation effectiveness to ensure that the remedial action objectives at the site are still valid and remain protective.
>
> **Question C:** Has any other information come to light that could call into question the protectiveness of the remedy? When answering this question, consider and evaluate any new information that may change the protectiveness of the operating remedy. (Ref. 24, p. 4-1 – 4-9)

The FYR process may identify issues and recommendations that generally address either 1) the performance of the remedy, 2) modifications to the monitoring well network, or 3) modifications to the monitoring plan. Typically, all changes or modifications to the remedy considered significant or fundamental should be appropriately documented in a decision document prior to implementation, as discussed in Step 1.3. However, minor changes to the remedy typically do not require modification of the decision document, which normally allows them to be implemented more quickly, as resources allow.

Recommendations from the five-year review may provide support for the decision made in Step 3.5 described below.

3.4 Consider optimizing engineering performance and monitoring

Optimize remedy (engineering) performance: As discussed in the 2000 Superfund Reform Strategy Implementation Manual, EPA's remedy optimization initiative is "*intended to encourage systematic review and modification to the existing P&T systems to enhance overall remedy effectiveness and cost effectiveness, without compromising protectiveness or other objectives of the Superfund program*" (Ref. 23, p. 1). "*Because site conditions change over time and these changes can have implications on the cost and effectiveness of a remedy, P&T managers should routinely compare design parameters versus actual parameters for treatment process parameters*" (Ref. 16, p. 7). Although this strategy focused on pump-and-treat systems, optimization generally may be applied to groundwater restoration remedial actions. This effort [optimization] "*recognizes that remedial approaches should not remain static, that site conditions change over time, and that better tools and strategies have evolved which allow continuous improvement of remedy performance*" (Ref. 23, p. 1). If the result of optimization is a recommendation for a change in technology or the RAOs, then the recommended procedures in Step 4 below should be considered. Optimization actions for the selected remedy may include the following scenarios:

- Altering remedial system parameters (e.g., flow rate, well locations, hydraulic capacity)
- Enhancing or simplifying existing treatment train components (e.g., removing a metals precipitation unit, modifying off-gas treatment)
- Addressing uncertainties in the CSM
- Ensuring that groundwater migration is under control
- Identifying and providing alternatives for addressing source area contamination
- Changing data evaluation and management practices
- Improving or streamlining project management or oversight
- Adjusting groundwater amendments, delivery mechanisms, and location/depths to enhance in situ treatment efficiency

Optimize monitoring: RPMs generally should consider and revisit the use of **long-term monitoring optimization** (LTMO) throughout the lifetime of the operating system to evaluate whether acquisition and assessment of appropriate remedy data are occurring. Moreover, "*LTMO offers an opportunity to improve cost-effectiveness of the long-term monitoring effort by assuring that monitoring achieves its objectives with an appropriate level of effort*" (Ref. 25, p. 1). LTMOs are routine evaluations of existing monitoring data, frequency and location of data acquisition, and objectives. LTMO recommendations may include the following activities:

- A reduction or increase in effort spatially (number of wells/locations)
- A reduction or increase in effort temporally (sampling frequency)
- Evaluation of areas where the plume is moving or changing
- Information related to remedy efficacy/performance (Ref. 25)

Care should be exercised to ensure that sufficient monitoring wells are in place to allow continued evaluation of the groundwater, even after RAOs and cleanup levels have been achieved. Information from these wells is needed to evaluate remedy performance and protectiveness.

Typically, all changes or modifications to the remedy considered significant or fundamental should be appropriately documented in a decision document prior to implementation, as discussed in Step 1.3. However, minor changes to the remedy typically do not require modification of the decision document, which normally allows them to be implemented more quickly, as resources allow. The results of the engineering and monitoring optimization activities may provide support for the decision made in the next step (3.5).

3.5 Evaluate whether the existing remedy can achieve RAOs and associated cleanup levels in the ROD

The remedy (with any necessary modifications resulting from steps 3.3 and step 3.4) and the data collected during operation are generally analyzed and compared to the CSM. The results from this analysis typically are used to evaluate whether data indicate that attainment of RAOs and associated cleanup levels is likely or attainment of RAOs and associated cleanup levels is unlikely under current conditions.

Possible results include:

Long-term restoration is likely and plume is contained in short-term: Typically, restoration is considered likely when the contaminant reductions and plume capture, as identified through monitoring data and analysis, indicate that RAOs and cleanup levels may be attained in the established timeframe. If concentrations are decreasing in a timely manner, it is likely that the current remedial approach is adequate and is functioning as intended by the decision documents and design documents. If the concentrations are decreasing in a less than timely manner, but restoration of the aquifer is still a feasible goal within a timeframe that supports future intended aquifer uses, review and optimization of the existing remedy may be appropriate (see step 3.3 and 3.4). If it is determined that the existing remedy is likely to achieve RAOs and associated cleanup levels, Regions should then begin to evaluate whether these have been achieved. (see 3.6).

Long-term restoration is not likely and/or plume is not contained: Generally, if monitoring data and analysis, five-year reviews, long term monitoring optimization, or remedy optimization results indicate that contaminant concentrations are not progressing towards success, it is likely that the plume is not contained, hydrogeologic conditions have changed, or a new site condition has emerged; in this situation, the remedy generally should be revisited and the technology or remedy may require modification (see section 4). The following are examples of remedy evaluation outcomes that may indicate that restoration is not likely under current site conditions:

- Data analysis indicates that concentration reductions are not occurring at the rate anticipated
- Data analysis shows that groundwater concentrations are increasing
- Data analysis shows that groundwater concentrations are asymptotic and not decreasing
- Contaminant properties and groundwater data analysis indicate that contaminant mass may be either sorbed (by adsorption or absorption) on or into the soil or rock matrix comprising the aquifer
- Technology selected in the ROD does not adequately address contaminants or hydrogeologic conditions
- Hydrogeologic conditions have changed or are found to be different than previously thought and remedy design is not effective
- A capture zone analysis and monitoring show that plume capture is not sufficient or is uncertain
- Aquifer behavior has changed due to external influences which may affect effectiveness
- New contaminants sources have been identified that may impact remedy effectiveness
- New groundwater pathways have been identified that may need to be addressed

3.6 Evaluate whether RAOs and associated cleanup levels in the ROD have been achieved

If data analysis and evaluation indicate that the remedy is likely to achieve the specified RAOs and associated cleanup levels in step 3.5, the RPM and project team should generally determine whether these levels actually have been attained. Possible results include:

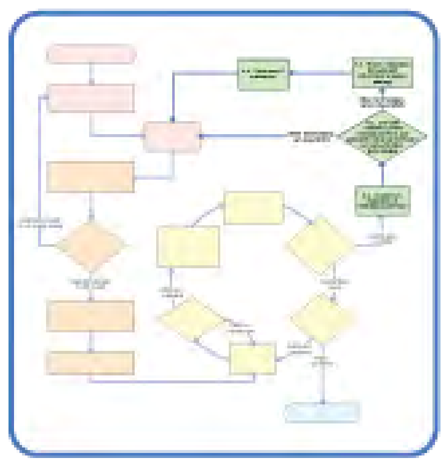
> **RAOs and associated cleanup levels are achieved:** Cleanup levels are generally attained when monitoring throughout the area of attainment or at the point of compliance indicates that contaminant concentrations have met the groundwater cleanup levels established in the decision document (e.g., MCLs) and will not increase in the future. In general, "*the area of attainment/point of compliance for achieving groundwater cleanup levels is generally expected to be throughout the plume or, where there is a waste management area, at the edge of the waste management area*" (Ref. 2, p. 10).

When cleanup levels are attained through implementation of an active treatment system (for example, pump-and-treat and in situ treatment), it may be appropriate to shut down the system and proceed with site completion activities (see section 5), depending on the site-specific facts. Monitoring normally should continue after cleanup levels have been attained since contaminant levels in the aquifer may increase when pumping is terminated (e.g., because contaminants are allowed to re-equilibrate in the groundwater). "*Monitoring programs should therefore ensure that groundwater is sampled until any residual contaminants could have desorbed from the aquifer material*" (Ref. 26, p. 7-4).

If contaminant concentrations rebound and remain above cleanup levels, the recommendations in step 3.5 should be revisited.

> **RAOs and associated cleanup levels are not achieved:** If cleanup levels have not yet been attained, the remedy generally continues to operate; and long-term monitoring data collection and analysis continue (see 3.1 through 3.2).

4. Technology or Remedy Modification



If the data analysis of long-term monitoring and the current CSM indicate that the existing remedy will not achieve the RAOs and associated cleanup levels, either the remedial technology or the comprehensive remedy generally should be modified. In situations where EPA determines it is impracticable to attain the groundwater cleanup levels in the ROD, but no contingency had been previously specified in the ROD, a ROD amendment typically is used to document fundamental changes that are made in the remedy based on the information gained during implementation of the cleanup (Ref. 27). "*It is also generally appropriate to prepare an ESD document when the lead agency decides to exercise a contingency remedy that was previously described in the ROD*" (Ref. 5, p. 7-2).

The recommended remedy modification step may involve the following activities: (4.1) conduct an evaluation of restoration potential, (4.2) evaluate whether current restoration RAOs and associated cleanup levels can be met with other technologies, (4.3) modify restoration RAOs and select an alternative remedial strategy, and (4.4) document **technical impracticability** (TI) evaluation. If restoration is still appropriate with a different technology or if RAOs and associated cleanup levels are modified, then Regions should proceed to select a modified remedy (see step 1.3).

4.1. Conduct an evaluation of restoration potential

Generally, the evaluation of restoration potential includes: evaluation of source control measures, remedial action performance analysis, restoration timeframe analysis, consideration of other applicable technologies, and additional considerations (Ref. 13, p. 13 – 19).

Source control measures are "*critical to the success of aquifer restoration efforts*" (Ref. 13, p. 13). When evaluating restoration potential, there should be a "*demonstration that contamination sources have been, or will be, identified and removed or treated to the extent practicable*" (Ref. 13, p. 13). If additional source material is identified or data indicate that source material is present during the long-term monitoring activities, additional site investigation is generally necessary to characterize the source, and evaluate source removal or source control activities (Ref. 13, p. 19 – 20) (see steps 1.1 and 1.2).

The remedial action performance analysis should:

- *"Demonstrate that the groundwater 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).*
- *Demonstrate that the existing remedy has been effectively operated and adequately maintained.*
- *Describe and evaluate the effectiveness of any remedy modifications (whether variations in operation, physical changes, or augmentations to the system) designed to enhance performance.*
- *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" (*Ref. 13, p. 16).

Timeframes to achieve restoration may be considered in restoration potential 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*" (Ref. 13, p. 16). Lastly, when reviewing restoration potential, other technologies should be reviewed. This should consist of:

- *"A review of the technical literature to identify candidate technologies;*
- *A screening of the candidate technologies based on general site conditions to identify potential applicable technologies; and*
- *An analysis, using site hydrogeologic and chemical data, of the capability of any of the applicable technologies to achieve the required cleanup standards" (*Ref. 13, p. 18).

If source control measures are necessary, the restoration potential evaluation may analyze whether the current groundwater remedial approach being employed at the site is expected to remain effective in restoring all or part of the aquifer after these source controls are implemented.

If, after reviewing restoration potential, it is determined that the "*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, the EPA generally will require that the existing remedy be enhanced, augmented, or replaced by a different technology*" (Ref. 13, p. 16).

The data collected and analyzed and remedial options evaluated during the evaluation of restoration potential should support the decision made in the next step (4.2).

4.2 Evaluate whether current restoration RAOs and associated cleanup levels can be met with other technologies

Based on the results of the evaluation of restoration potential discussed in step 4.1, the RPM should determine if the current restoration RAOs and associated cleanup levels can be met with other actions.

Possible options include:

Other actions can achieve current restoration RAOs and associated cleanup levels: If the assessment indicates that other source control or groundwater actions can achieve current restoration RAOs and associated cleanup levels, it may be appropriate to modify an existing remedy or select a new remedy (see step 1.3) and implement these actions (see section 2).

Other actions cannot achieve current restoration RAOs and associated cleanup levels: If the assessment indicates that no actions can achieve current restoration RAOs and associated cleanup levels throughout the area of attainment where groundwater restoration is the goal, it may be appropriate to modify the restoration RAOs/select alternative remedial strategy (see step 4.3).

4.3 Modify restoration RAOs/Select alternative remedial strategy

If monitoring trends or the evaluation of restoration potential indicate that current RAOs and cleanup levels in the ROD will not likely be achieved, it may be appropriate to modify the restoration RAOs. "*EPA's goal of restoring contaminated groundwater within a reasonable timeframe at Superfund 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 Superfund*" (Ref. 13, p. 19).

"*ARARs may be waived by EPA for any of the six reasons specified by CERCLA and the NCP, 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 groundwater quality criteria*" (Ref. 13, p. 9). If data indicate that restoration RAOs require modification (e.g., MCL cannot be met throughout the plume), it may be appropriate to consider a technical impracticability waiver for the specific ARAR that cannot be met.

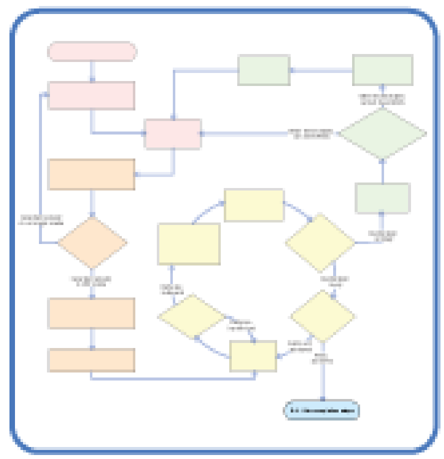
An alternative remedial strategy typically will address (1) the prevention of exposure to contaminated groundwater through institutional controls, (2) source remediation and controls through treatment and containment, and (3) aqueous plume remediation through treatment, containment, and natural attenuation. Alternative remedial strategies may include combinations of two or more options (Ref. 13, p. 19, 20, 21).

For those portions of the aquifer where restoration is technically practicable, a remedial technology considered in the evaluation of restoration potential should be selected or the current groundwater remedy should continue to be operated. For additional source materials that may have been identified, a source removal or source control measure should be evaluated and implemented. The basis for determining that restoration is technically impracticable should be documented in a TI evaluation discussed in step 4.4.

4.4 Document TI evaluation

Determinations of technical impracticability are made by EPA based on site-specific information evaluated when reviewing restoration potential (see step 4.1). The TI evaluation documents the results of this evaluation. The TI evaluation generally should include the following components: (1) specific ARARs (e.g., media cleanup levels) for which TI waiver determinations are sought, (2) spatial area over which the TI waiver decision will apply, (3) current CSM, (4) the results of the evaluation of restoration potential of the site, (5) estimates of the costs of the existing remedy and proposed alternative remedial strategy, and (6) any additional information EPA deems necessary. "*A TI decision* [including the alternative remedial strategy], *must be incorporated into a Superfund ROD or be incorporated into a modification or amendment to an original document*" (Ref. 13, p. 23). A modification to a signed ROD invoking a TI ARAR waiver generally is accomplished through a ROD amendment, since an ARAR waiver usually constitutes a fundamental change in the remedy. In addition to the TI waiver, the decision document should incorporate all components of the alternative remedial strategy (see step 1.3).

5. Site Completion



Site completion activities are typically initiated when RAOs (either the original restoration RAOs or modified RAOs) and associated cleanup levels have been attained. The site completion step typically involves: (5.1) site completion activities.

5.1 Site completion steps

The site typically is eligible for site completion when all remedial actions have been implemented and all site completion criteria are met. Generally, this means that "*all remedial decision documents have been completed and selected remedy is consistent with CERCLA, the NCP, and EPA policy and guidance; all response actions have been completed and appropriately documented in the site file; and all institutional controls are in place*" (Ref. 22, p. 4-1). Site completion typically is documented through a **final close out report** (FCOR) (Ref. 22, p. 4-5 – 4-6).

The site may also be deleted from the NPL either in whole or in part after site completion. Deletion from the NPL is accomplished through EPA notice and rule-making; the proposed deletion notice is published in the Federal Register for public comment, public comment is addressed, and if appropriate, a final notice of deletion is published in the Federal Register (Ref. 22, p. 5-1 – 5-7).

Conclusion

This groundwater road map fact sheet summarizes some of the key recommended steps and factors to consider when selecting a groundwater restoration remedy; designing, constructing, and initiating the remedy; operating, monitoring, evaluating, and optimizing the remedy; modifying the remedy, as appropriate; and documenting completion of the site response actions. The road map is intended to be a quick reference for RPMs and other site managers of groundwater restoration remedies, and provides a broad overview of the recommended Superfund cleanup process; it does not modify or supersede any existing

Agency guidance. The laws, regulations, policy documents, and technical guidance cited in the fact sheet and listed below should be consulted to obtain additional information and details about each step and factors to consider in the process.

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EPA. Recommended Annual O&M/Remedy Evaluation Checklist. April 2008. OSWER Directive No. 9355.0-87. www.epa.gov/superfund/cleanup/postconstruction/operate.htm.

Five Year Reviews

EPA. Five-Year Review Process in the Superfund Program. April 2003. OSWER Directive No. 9355.7-08FS. www.epa.gov/superfund/cleanup/postconstruction/5yr.htm.

EPA. Five-Year Review – Questions & Answers. September 2009. www.epa.gov/superfund/cleanup/postconstruction/5yr.htm.

Helpful Web Sites

EPA TSP Issue Papers: www.epa.gov/tio/tsp/issue.htm

Cleanup Information: www.clu-in.org

EPA Ground Water and Ecosystems Restoration Research: www.epa.gov/ada

Triad: www.triadcentral.org

Green Remediation: www.clu-in.org/greenremediation

Glossary

The following definitions are used for purposes of this guidance:

Applicable or relevant and appropriate requirements (ARAR): An ARAR is a requirement under other environmental laws that is either applicable or relevant and appropriate to the remedial action under CERCLA. Applicable requirements are those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site. Only those state standards that are identified by a state in a timely manner and that are more stringent than federal requirements may be applicable. Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site. Only those state standards that are identified by a state in a timely manner and that are more stringent than federal requirements may be relevant and appropriate. ARARs must be attained (or waived) for hazardous substances, pollutants, or contaminants remaining on-site at the completion of the remedial action [NCP, 40 CFR 300.5].

Area of attainment/point of compliance: The area of attainment/point of compliance for achieving groundwater cleanup levels is generally expected throughout the contaminated plume or, at and beyond the edge of the waste management area, when waste is left in place [55 FR 8753 (March 8, 1990)].

Beneficial future uses: Beneficial future uses of groundwater are determined based on EPA's groundwater classification system or on an EPA-approved Comprehensive State Groundwater Protection Program. Beneficial use is defined by the groundwater's actual use, potential use, vulnerability, ability to be replaced, ecological value, yield, and total dissolved solids levels [EPA, Guidelines for Ground-Water Classification, 1986 Draft Federal Guidelines]. In accordance with the NCP, EPA expects to return usable groundwaters to their beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site [NCP, 40 CFR 300.430(a)(1)(iii)(F)].

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended by the Superfund Amendments and Reauthorization Act of 1986 (several other times thereafter) that authorizes the assessment and cleanup of hazardous substances, pollutants, or contaminants that have been released into the environment.

Cleanup Levels: Final cleanup levels establish acceptable contaminant-specific exposure levels that are protective of human health and the environment. They are not formally determined until the site remedy is ready to be selected and are established in the ROD. In the ROD, it is preferable to use the term "remediation level" or "cleanup level" rather than "remediation goal" in order to make clear that the Selected Remedy establishes binding requirements [EPA, A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents, July 1999].

Conceptual site model (CSM): a three-dimensional "picture" of site conditions that illustrates contaminant sources, release mechanisms, exposure pathways, migration routes, and potential human and ecological receptors. The CSM documents current and potential future site conditions and is supported by text, tables, maps, cross sections, 3D visualizations, and site diagrams that illustrate what is known about human and environmental exposure through contaminant release and migration to potential receptors. The CSM is initially developed during the scoping phase of the RI/FS and should be modified as additional information becomes available. A graphical depiction of the CSM may be appropriate to include in the ROD as it provides a good presentation of the overall site conditions and basis for taking an action, and can be referenced when discussing the overall site management strategy and the specific remedial action objectives addressed by the Selected Remedy. [EPA, A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents, July 1999].

Construction completion: A Superfund program milestone that indicates that all physical construction of all cleanup actions for a site are complete, including actions to address all immediate threats and to bring all long-term threats under control [EPA, Closeout Procedures for National Priorities List Sites, May 2011].

Deletion from the NPL: The removal of a site from the NPL, in accordance with NCP Section 300.425(e), where it is determined that no response or no further response is appropriate [EPA, Closeout Procedures for National Priorities List Sites, May 2011].

Explanation of Significant Differences (ESD): The ESD documents significant changes to a component of a remedy. The ESD must comply with CERCLA Section 117(c) and NCP Sections 300.435(c)(2)(i) and 300.825(a)(2). An ESD must describe to the public the nature of the significant changes, summarize the information that led to making the changes, and affirm that the revised remedy complies with the NCP and the statutory requirements of CERCLA. It is recommended that the ESD provide a side-by-side comparison of the original and proposed remedy components to clearly display the significant differences [EPA, A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents, July 1999].

Feasibility study (FS): FS means a study undertaken by the lead agency to develop and evaluate options for remedial action. The FS emphasizes data analysis and is generally performed concurrently and in an interactive fashion with the remedial investigation (RI), using data gathered during the RI. The RI data are used to define the objectives of the response action, to develop remedial action alternatives, and to undertake an initial screening and detailed analysis of the alternatives. The term also refers to a report that describes the results of the study [NCP, 40 CFR 300.5].

Final close out report (FCOR): The FCOR documents site completion. The FCOR documents compliance with statutory requirements and provides a consolidated record of all removal and remedial activities for the entire site. [EPA, Closeout Procedures for National Priorities List Sites, May 2011].

Five-year reviews: Five-year reviews generally are required by CERCLA or program policy when hazardous substances remain on site above levels which allow for unrestricted use and unlimited exposure. Five-year reviews provide an opportunity to evaluate the implementation and performance of a remedy to determine whether it remains protective of human health and the environment. Generally, reviews are performed five years following the initiation of a CERCLA response action, and are repeated every five years so long as future uses remain restricted. Five-year reviews can be performed by EPA or the lead agency for a site, but EPA retains responsibility for determining the protectiveness of the remedy [EPA, Superfund Post Construction Completion Activities, June 2001].

In situ treatment systems: In situ treatment remedies for groundwater restoration could include chemical oxidation, other types of chemical treatment, biological treatment, thermal treatment (using steam or other heating methods), air sparging, permeable reactive barriers and other similar technologies. In situ treatment remedies for groundwater typically involve adding treatment agents to the subsurface. Treatment agents could include chemical agents (e.g., oxidants or surfactants); agents to facilitate microbiological activity; heating agents (e.g., steam, or electric current); physical reactants (such as zero valent iron, oxygen or air); or other agents [EPA, Closeout Procedures for National Priorities List Sites, May 2011].

Long-term monitoring optimization (LTMO): LTMO refers to efforts to improve the cost-effectiveness of long-term monitoring by assuring that monitoring achieves its objectives with an appropriate level of effort [USACE, Roadmap to Long-Term Monitoring Optimization, May 2005].

Long-term response (LR): LR is the name for the specific type of O&M performed by PRPs for groundwater or surface water restoration remedies. EPA uses the term “PRP LR” for tracking and reporting purposes [EPA, Closeout Procedures for National Priorities List Sites, May 2011].

Long-term response action (LTRA): LTRA is the Fund-financed operation of groundwater and surface water restoration measures, including monitored natural attenuation, for first 10 years of operation following the O&F determination or until cleanup levels are achieved, whichever is earlier [EPA, Closeout Procedures for National Priorities List Sites, May 2011].

Maximum Contaminant Level: MCLs are enforceable standards established under the Safe Drinking Water Act which apply to specified contaminants which EPA has determined have an adverse effect on human health. MCLs are set at levels that are protective of human health, and are set as close to MCLGs as is feasible taking into account available treatment technologies and the costs to large public water systems. CERCLA and the NCP establish MCLs as relevant and appropriate to contaminated groundwater that is or may be used as drinking water [EPA, CERCLA Compliance with Other Laws Manual, August 1988].

Maximum Contaminant Level Goals: MCLGs are strictly health-based levels established under the Safe Drinking Water Act and do not take cost or feasibility into account. MCLGs for carcinogenic compounds are always established at zero, which is an unachievable cleanup level. Therefore, in accordance with

CERCLA and the NCP, only non-zero MCLGs are considered relevant and appropriate to contaminated groundwater that is or may be used as drinking water. When both an MCL and non-zero MCLG exist for a contaminant, generally the lower of the two levels is used as the groundwater ARAR [EPA, CERCLA Compliance with Other Laws Manual, August 1988].

Monitored natural attenuation (MNA): Physical or biological processes (unassisted by human intervention) that effectively reduce contaminant concentrations such that remedial objectives in the contaminant plume (or certain portions of the plume) may be achieved in a reasonable timeframe without active remediation [EPA, Guidance for Evaluating Technical Impracticability of Ground-Water Restoration, September 1993].

National Oil and Hazardous Substances Pollution Contingency Plan (NCP): The NCP is applicable to response actions taken pursuant to the authorities under CERCLA and section 311 of the Clean Water Act. It provides the organization structure and procedures for preparing for and responding to discharges of oil and releases of hazardous substances, pollutants, and contaminants [NCP, 40 CFR 300.1 and 300.2].

National Priorities List (NPL): The NPL means the list, compiled by EPA pursuant to CERCLA section 105, of uncontrolled hazardous substance releases in the United States that are priorities for long-term remedial evaluation and response [NCP, 40 CFR 300.5].

Operable unit (OU): Operable unit means a discrete action that comprises an incremental step toward comprehensively addressing site problems. This discrete portion of a remedial response manages migration, or eliminates or mitigates a release, threat of a release, or pathway of exposure. The cleanup of a site can be divided into a number of operable units, depending on the complexity of the problems associated with the site. Operable units may address geographical portions of a site, specific site problems, or initial phases of an action, or may consist of any set of actions performed over time or any actions that are concurrent but located in different parts of a site [NCP, 40 CFR 300.5] .

Operating properly and successfully (OPS): OPS is a determination, similar to O&F, that is sometimes made at federal facility projects for purposes of property transfer under CERCLA Section 120(h)3(B) [EPA, Closeout Procedures for National Priorities List Sites, May 2011].

Operation and functional (O&F): O&F activities are generally conducted after physical construction of the remedy is complete to ensure that it is functioning properly and operating as designed. O&F determinations are generally made for containment remedies (all media), as well as groundwater and surface water restoration remedies (including monitored natural attenuation). A remedy becomes O&F either one year after construction is complete, or when the remedy is determined to be functioning properly and is performing as designed, whichever is earlier. For groundwater P&T systems, the O&F determination marks the beginning of the LTRA period [EPA, Closeout Procedures for National Priorities List Sites, May 2011].

Operation and maintenance (O&M): O&M means measures required to maintain the effectiveness of response actions. O&M are the activities required to maintain the effectiveness and integrity of the remedy, and, in the case of Fund-financed measures to restore groundwater or surface water, continued operation of such measures beyond the LTRA period until cleanup levels are achieved [EPA, Closeout Procedures for National Priorities List Sites, May 2011].

Optimize: Efforts to improve the performance and/or reduce the annual operating cost of groundwater remediation systems [EPA, Superfund Post Construction Completion Activities, June 2001].

Preliminary Close Out Report (PCOR): The report that documents that construction completion has been achieved. It is prepared when the final operable unit for a site achieves construction completion but final cleanup goals have not yet been achieved [EPA, Closeout Procedures for National Priorities List Sites, May 2011].

Pump-and-treat systems (P&T systems): Groundwater remedies consisting of groundwater extraction, above ground treatment, disposal of treated water, groundwater monitoring in the subsurface to determine if cleanup levels are decreasing or have been achieved, and process monitoring of the treatment plant [EPA, Elements for Effective Management of Operating Pump and Treats Systems. December 2002].

Reasonable timeframe: A reasonable timeframe for restoring groundwater to beneficial use depends on the particular circumstances of the site and the restoration method employed. The most appropriate timeframe generally is determined through an analysis of alternatives. The NCP also specifies that: "For groundwater response actions, the lead agency shall develop a limited number of remedial alternatives that attain site-specific remediation levels within different restoration periods utilizing one or more different technologies." Thus, a comparison of restoration alternatives from most aggressive to passive (i.e., natural attenuation) will provide information concerning the approximate range of time periods needed to attain groundwater cleanup levels. Although restoration timeframe is an important consideration, no single time period can be specified which would be considered excessively long for all site conditions [EPA, Guidance for Evaluating Technical Impracticability of Ground-Water Restoration, September 1993].

Record of Decision (ROD): The ROD is the decision document issued by the lead agency that selects a remedial action and documents the basis for that selection. The ROD documents the remedial action plan for a site or operable unit and serves the following three basic functions: (1) it certifies that the remedy selection process was carried out in accordance with CERCLA and, to the extent practicable, with the NCP; (2) it describes the technical parameters of the remedy, specifying the methods selected to protect human health and the environment including treatment, engineering, and institutional controls components, as well as cleanup levels; and (3) it provides the public with a consolidated summary of information about the site and the chosen remedy, including the rationale behind the selection [EPA, A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents, July 1999].

Remedial action (RA): RA means those actions consistent with permanent remedy taken instead of, or in addition to, removal action in the event of a release or threatened release of a hazardous substance into the environment, to prevent or minimize the release of hazardous substances so that they do not migrate to cause substantial danger to present or future public health and welfare, or the environment [NCP, 40 CFR 300.5].

Remedial action objectives (RAO): RAOs provide a general description of what the cleanup will accomplish (e.g., restoration of groundwater to drinking water levels). [EPA, A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents, July 1999].

Remedial design (RD): RD means the technical analysis and procedures which follow the selection of remedy for a site and result in a detailed set of plans and specifications for implementation of the remedial action [NCP, 40 CFR 300.5].

Remedial investigation (RI): The RI is a process undertaken by the lead agency to determine the nature and extent of the problem presented by the release. The RI emphasizes data collection and site characterization, and is generally performed concurrently and in an interactive fashion with the feasibility study. The RI includes sampling and monitoring, as necessary, and includes the gathering of sufficient information to determine the necessity for remedial action and to support the evaluation of remedial alternatives [NCP, 40 CFR 300.5].

Restoration: Reduction of contaminant concentrations to levels required under Superfund or RCRA Corrective Action programs. For groundwater currently or potentially used for drinking water purposes, these levels may be MCLs or non-zero MCLGs established under the SDWA; State MCLs or other cleanup requirements; or risk-based levels for compounds not covered by specific State of Federal MCLs or MCLGs. Other cleanup levels may be appropriate for groundwaters used for non-drinking purposes [EPA, Guidance for Evaluating Technical Impracticability of Ground-Water Restoration, September 1993].

Risk assessment: The risk assessment is the evaluation of the human health and environmental risks presented by the release and potential release of hazardous substances from a site. The risk assessment (1) provides an analysis of baseline risks and helps determine the need for action; (2) provides a basis for determining levels of chemicals that can remain on site and still be adequately protective of public health and the environment; (3) provides a basis for comparing potential health and environmental impacts of various remedial alternatives; and (4) provides a consistent process for evaluating and documenting public health and environmental threats [EPA, Risk Assessment Guidance For Superfund, Volume I, Part A: Human Health Evaluation Manual, Interim Final, March 1989].

Technical impracticability (TI): TI refers to an ARAR waiver authorized under CERCLA. The TI waiver is used when an ARAR specified in a ROD cannot be met because achieving the ARAR is technically impracticable from an engineering perspective. The TI waiver can be used to waive meeting groundwater restoration ARARs such as MCLs and non-zero MCLGs. 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 preamble to the March 8, 1990 NCP 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." [EPA, Guidance for Evaluating Technical Impracticability of Ground-Water Restoration, September 1993].