Dense non-aqueous phase liquids: Site remediation and redevelopment

Remedial objectives, remedy selection, and performance monitoring

Purpose

This guidance provides guidance on the processes used to develop an effective strategy to manage sites contaminated with dense non-aqueous phase liquid (DNAPL). The document focuses on remedy selection factors and considerations for site monitoring and treatment technologies.

General remedial objectives and remedy selection

MPCA remedy selection guidance

Minnesota has developed a list of threshold remedial action objectives (RAOs) that are used to evaluate and achieve cleanup. These are:

- Public health, welfare and the environment must be protected.
- Federal, and state regulations, rules, and statutes, must be complied with.
- Remedy(ies) must consider the planned and current use of the property.

Once these factors are evaluated as "passing" or "failing" the threshold criteria, incorporate the following balancing criteria for assessing alternative remedies: long-term effectiveness; implementability; short-term risk; cost effectiveness; and community acceptance (see MPCA's remedy selection guidance, rem9_98).

DNAPL-Specific remedy selection factors

DNAPL remediation technologies are typically only applicable to the source zone and the down gradient aqueous phase. Therefore, DNAPL remediation is typically focused on the following:

- DNAPL that is present within the source zone along with aqueous and sorbed phase contamination on the soil or aquifer materials. This also includes the vapor phase if unsaturated media is involved (see the MPCA Vapor intrusion guidance web page).
- Aqueous phase contamination that is present downstream of the source zone, typically with sorbed phase contamination. This may include the vapor phase in unsaturated media see the MPCA Vapor intrusion guidance web page).

Remedial goals may include one or more of the following:

- In the DNAPL source zone:
  - Source zone restoration (complete removal of DNAPL, aqueous phase, sorbed phase, and vapor phase in source zone)
  - Partial mass removal (sufficient DNAPL mass removal from the source so that the length of the downstream aqueous phase is subject to natural attenuation that stabilizes and reduces the plume)

  - Stabilization of mobile DNAPL (reduce saturated DNAPL pools to residual levels; appropriate where DNAPL is moving or may start moving due to groundwater pumping, excavation, or drilling)
  - Source zone containment (physical and/or hydraulic DNAPL source zone containment such that aqueous phase plumes no longer expand)
  - Implementation of Institutional controls
- Downstream of the DNAPL source zone:
  - Aquifer restoration (complete elimination of the groundwater plume, including sorbed and aqueous contamination)
  - Partial aquifer restoration to reduce concentrations in the groundwater plume. This may lead to monitored natural attenuation (noted below)
  - Plume interception (interception of the groundwater plume using permeable reactive barriers or groundwater extraction wells)
  - Monitored natural attenuation (monitoring of groundwater concentrations and intrinsic processes to ensure a steady state (ideally shrinking) plume
  - Implementation of Institutional controls

Remedial goals that restore the aquifer to the extent practical are preferred; an aquifer that has been restored to the extent practicable has less operation and maintenance associated with it than an aquifer that has a containment or barrier remedy. A robust Feasibility Study should be provided to the MPCA.

Apply and evaluate treatment technologies

A treatment strategy needs to be comprehensive so that it evaluates several factors (e.g. technical, regulatory, stakeholder interests, etc.). This comprehensive approach often involves integrating several technologies that couple spatial and temporal data. Common treatment technologies (descriptions from Clu-In and Environment Agency, 2003) are included in the Remedial Technologies Appendix. Note the following considerations for treatment technologies:

- A single treatment technology is rarely sufficient to treat all phases of a DNAPL release from beginning to end. A sequence of technologies will likely be needed to meet treatment objectives. Site conditions change over time as a result of removals, remediation, and/or natural attenuation.
- DNAPL sites typically have multiple attributes that present remediation challenges compared with "typical" sites (particularly if challenges are not adequately understood and addressed early on). Therefore, adaptive site management should be used to make decisions in response to remedy performance while considering changes in site conditions, the conceptual site model, technology performance, and technological advances over time. See ITRC, 2017 for more information.
- Site conditions are often transient during treatment. Therefore, treatment technologies should be spatially and temporally combined.
  - An original technology can be replaced by a more cost-effective technology after the point of diminishing returns is met for the original treatment
  - Before implementing a remedial technology, check that it is compatible with optimum performance metrics. Also check that it is compatible with by-products of individual technologies and their impacts on the technology(ies). See Table-4-2 in ITRC, 2011

Table 4-2 from ITRC, 2011

Table 4-2. Technology compatibility matrix

<table>
<tr><th colspan="2" rowspan="2">Followed by this technology or in downgradient area →
↓ Apply this technology first or in upgradient area</th><th colspan="3">Physical removal technologies</th><th colspan="4">Chemical/biological technologies</th><th colspan="2">Containment technologies</th></tr>
<tr><th>Surfactant/ cosolvent flushing</th><th>Thermal technologies</th><th>Other extractive technologies</th><th>Chemical oxidation</th><th>Chemical reduction</th><th>Bioremediation</th><th>Monitored natural attenuation</th><th>Permeable reactive walls</th><th>Other containment technologies</th></tr>
<tr><td rowspan="3">Physical removal technologies</td><td>Surfactant/ cosolvent flushing</td><td></td><td colspan="4">Potentially compatible but not an anticipated couple (see Note 1)</td><td colspan="2">Generally compatible (see Note 1)</td><td colspan="2">Potentially compatible but not an anticipated couple (see Note 1)</td></tr>
<tr><td>Thermal technologies</td><td>Potentially compatible but not an anticipated couple (see Note 2)</td><td></td><td colspan="3">Potentially compatible but not an anticipated couple (see Note 2)</td><td colspan="2">Generally compatible (see Note 1)</td><td colspan="2">Potentially compatible but not an anticipated couple (see Note 2)</td></tr>
<tr><td>Other extractive technologies</td><td colspan="2">Potentially compatible but not an anticipated couple (see Note 3)</td><td></td><td colspan="4">Generally compatible (see Note 3)</td><td colspan="2">Potentially compatible but not an anticipated couple (see Note 3)</td></tr>
<tr><td rowspan="4">Chemical/biological technologies</td><td>In situ chemical oxidation</td><td colspan="3">Potentially compatible but not an anticipated couple (see Note 4)</td><td></td><td>Potentially compatible but not an anticipated couple (see Note 4)</td><td colspan="2">Generally compatible but requires consideration of chemical reagents (see Note 4)</td><td>Potentially compatible but not an anticipated couple (see Note 4)</td><td>Generally compatible (see Note 4)</td></tr>
<tr><td>In situ chemical reduction</td><td colspan="3">Potentially compatible but not an anticipated couple (see Note 5)</td><td>Likely incompatible (see Note 5)</td><td></td><td colspan="4">Potentially Compatible (see Note 5)</td></tr>
<tr><td>Engineered bioremediation</td><td colspan="3">Potentially compatible but not an anticipated couple (see Note 6)</td><td>Compatibility varies (see Note 6)</td><td>Potentially compatible but not an anticipated couple (see Note 6)</td><td></td><td>Generally compatible (see Note 6)</td><td colspan="2">Potentially compatible but not an anticipated couple (see Note 6)</td></tr>
<tr><td>Monitored natural attenuation</td><td colspan="6">Potentially compatible but not an anticipated couple (see Note 7)</td><td></td><td colspan="2">Potentially compatible but not an anticipated couple (see Note 7)</td></tr>
<tr><td rowspan="2">Containment technologies</td><td>Permeable reactive barriers</td><td colspan="3">Potentially compatible but not an anticipated couple (see Note 8)</td><td>Likely incompatible (see Note 8)</td><td colspan="3">Potentially compatible but not an anticipated couple (see Note 8)</td><td></td><td>Potentially compatible but not an anticipated couple (see Note 8)</td></tr>
<tr><td>Other containment technologies</td><td colspan="8">Potentially compatible but not an anticipated couple (see Note 9)</td><td></td></tr>
</table>

  - As soon as feasible, initiate implementation of a new technology once it is identified; reaching site objectives may be more successful if a technology is implemented sooner rather than later
- Use site monitoring (discussed below) to determine how and when to transition between technologies. "Triggers" can include:
  - An evaluation of contaminant concentrations indicates a high likelihood of exposure of the contaminant in one or more phases to the public or environment
  - A new site issue occurs after application of a treatment technology (e.g. chemical rebound occurs after chemical oxidation)
  - Data review identifies free phase product
  - Higher contaminant concentrations are identified in a single phase (particularly the percentage of aqueous-phase solubility)
  - Evaluation of parent vs. daughter products identifies a change (e.g. reducing vs. oxidizing conditions)
  - Evaluation of groundwater chemistry (e.g. pH, Eh, contaminant concentrations) during method execution (such as in situ injection) identifies a change
  - The cost per unit contaminant destroyed can be optimized with a different technology
- Useful steps for guiding the transition between technologies (Figure 4-1, Remedy transition flowchart, in ITRC, 2011) include:
  - Step 1: Implement the remedy
  - Step 2: Collect data to assess progress of the remedy towards the remedial objectives
  - Step 3: Collect characterization data and decision-making information (e.g. technology performance, cost, treatment time, risk, etc.)
  - Step 4: Evaluate remedy effectiveness ("Is adequate progress being made towards the functional objectives?" and, "Is the remedy operating as designed?")
  - Step 5: (for a "yes" to Step 4) Continue remedy operation

- Step 6: (for a "no" to Step 4) Evaluate if optimization can (or should) occur with the remedy to improve performance
- Step 7: (for a "yes" to Step 6): Optimize the remedy and continue operation. Periodically return to Step 2 for assessment
- Step 8 (for a "no" to Step 6): Transition to the next remedy. Return to Step 1 for implementation

Figure 4-1 from ITRC, 2011

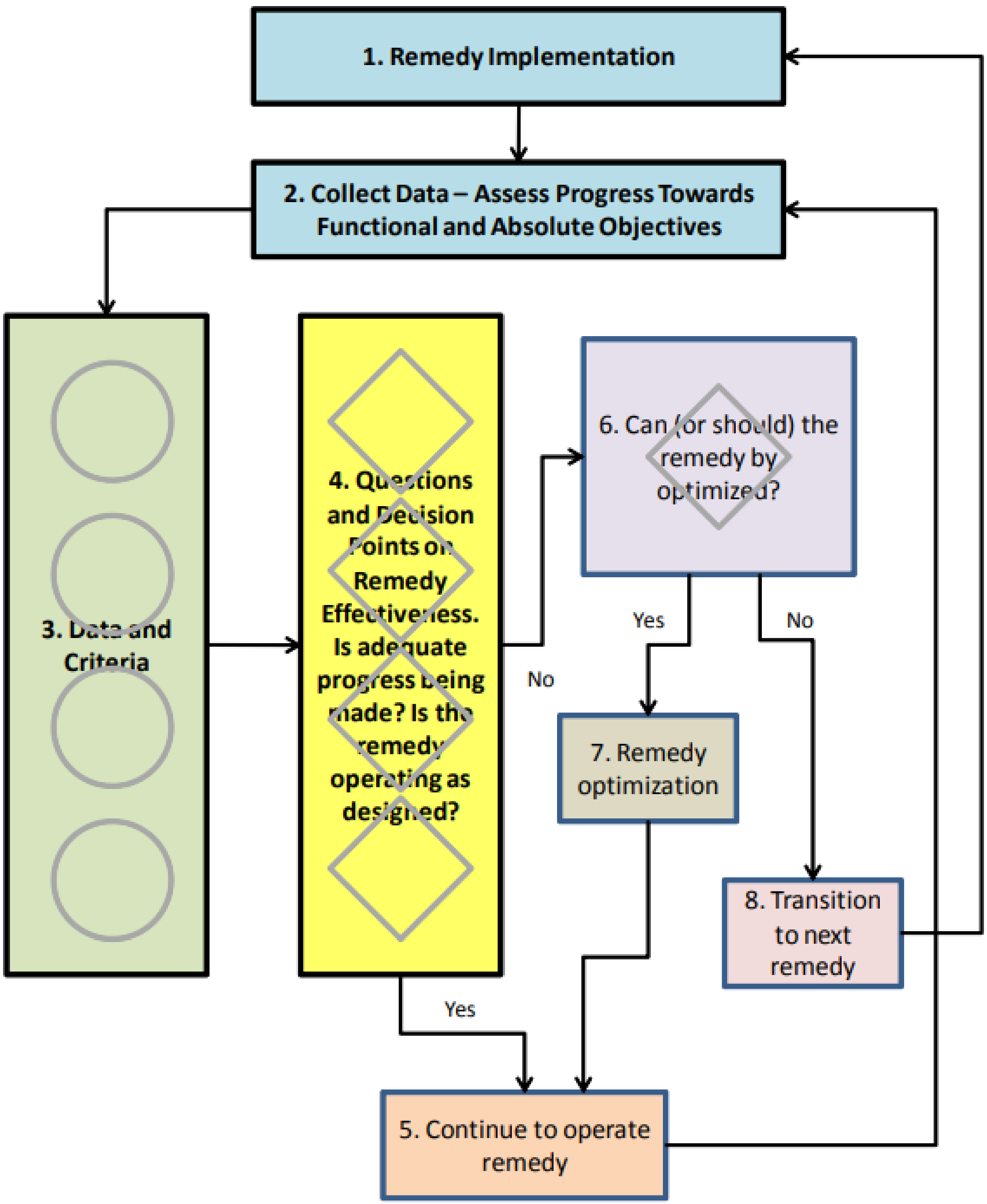

Figure 4-1. Remedy transition flowchart.

Site monitoring

Monitoring is conducted to evaluate progress towards a remedial objective. It consists of:

- Compliance monitoring, which is used throughout the site investigation/remediation to document nature and extent of impacts, to ensure potential exposure pathways are controlled, and to monitor progress towards the remedial goals.
- Process monitoring, which is used to assess whether or not the remediation system is functioning as intended. The data can be used to identify system adjustment needs, as well as modifications to optimize performance.
- Performance monitoring, which is used to assess if the remedial approach is effective at meeting the SMART objectives (see Strategies guidance). Multiple lines of evidence can be used as part of performance monitoring, but the rationale should be provided to MPCA staff prior to implementation.

Details on monitoring plan elements are discussed further in ITRC, 2011. In general, monitoring plans should:

- Provide the type of media (e.g. soil, groundwater, soil-gas, surface water, etc.) to be monitored. The sample type is based on what the remedy objective is, as well as what the exposure pathways are.
- Document what the contaminant(s) of concern (COCs) are, as well as other parameters that may be needed to establish multiple lines of evidence. This is aligned with meeting SMART objectives and establishes what analysis is needed.
- Provide existing information as well as what information will be obtained to establish multiple lines of evidence.
- Denote where monitoring points will be located to ensure appropriate data quality. Not having enough sampling points can result in having a limited understanding of the CSM, as well as an incomplete understanding of spatial changes in contaminant concentrations.
- Establish the sampling frequency, particularly when evaluating treatment technologies. Also note that site conditions (e.g.: precipitation, barometric pressure, remedial system effects, etc.) can cause significant temporal variations in sampling results.
- Provide appropriate monitoring metrics (e.g. the "measureable" component of SMART objectives). Metrics can include:
  - If the chemical concentration is increasing or decreasing
  - What is happening to the contaminant mass (e.g. is it being removed, reduced or destroyed? How much is remaining)
  - What the mass flux/discharge is in order to quantify plume stability and chemical fate/transport, and evaluate technology transition needs and evaluate receptor risk
- Explicit identification of conditions when a remedial technology is no longer effective and needs to be modified or replaced with more effective technologies.
- Opportunities for monitoring optimization in the monitoring plan. This is done to reduce cost while still collecting appropriate data to assess progress and site conditions. Opportunities include:
  - Determining whether or not monitoring network points contribute meaningful data; points that do not contribute worthwhile data should be discontinued
  - Completing a trend analysis (e.g. Mann-Kendall or other modeling/linear regression software) to determine if the sampling frequency can be reduced
  - Evaluating if the constituent monitoring is appropriate; analyte selection may change as site geochemistry changes, or as the remedy moves from active to passive
- A means to evaluate and report whether remedial objectives can be achieved within an acceptable time period. If site objectives are being met at an acceptable rate then monitoring likely does not need modification. If not, the approach will need modification in the form of revisiting the CSM and/or implementing a different treatment technology.

Conclusion: Getting to closure

DSS is an iterative systematic process that begins with developing a CSM using high-resolution characterization methods, setting remedial objectives, application of appropriate treatment technologies, remedy performance monitoring and remedy evaluation. If there is inadequate progress toward meeting the remedial objectives, evaluate alternative technologies, coupling technologies or revisiting the CSM to determine if there are data gaps that may affect remedy performance. After revisiting the CSM, evaluate the functional objectives to determine if they conform to SMART attributes.