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Ground Water Forum Issue Paper

# Ground Water Technical Considerations during the Five-Year Review Process

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## 1. INTRODUCTION

This issue paper has been developed to highlight technical considerations as well as technical resources available to Remedial Project Managers (RPMs) in conducting Five-Year Reviews (FYRs) at CERCLA[1] sites with contaminated groundwater. While it has been developed with the needs of the U.S. Environmental Protection Agency's (EPA) RPMs in mind, it may also be helpful to other federal and state agencies that have the lead for conducting FYRs and may assist EPA staff in reviewing those FYRs. In addition, Table 1 provides FYR teams with examples of technical considerations that can be used as a resource for practicing hydrogeologists when reviewing groundwater remedy implementation.

Groundwater is the pathway of concern at many sites, either as a potential water supply source or as the medium for transporting contaminants that then discharge to sediments, surface water, or air. Many of the more challenging CERCLA remedies involve the management of contaminated groundwater, whether the remedial action objectives (RAOs) include restoration or containment. Almost 90 percent of National Priorities List sites with remedy decisions have a remedy that addresses contaminated groundwater (EPA, 2014).

This issue paper is not guidance. Instead, it outlines technical considerations and resources within EPA regions and states to help RPMs consider groundwater concerns in more detail throughout the FYR process. The issue paper also highlights the importance of involving a hydrogeologist[2] early and consistently throughout the FYR process for groundwater sites. It identifies technical information that may benefit from review by and input from hydrogeologists. It also suggests opportunities for identifying groundwater remedy issues and developing recommendations to address them. Finally, it provides a list of references and technical resources for RPMs and technical staff.

1 Comprehensive Environmental Response, Compensation, and Liability Act, also referred to as "Superfund"

2 A hydrogeologist as referred to in this report can be either a hydrologist, environmental scientist, geologist or earth scientist/engineer that is trained to understand the physical and chemical aspects of the groundwater remedy (e.g., the conceptual site model (CSM), groundwater extraction and injection system integrity, and long-term monitoring program)

## 2. FYR TECHNICAL REVIEW TEAM

Conducting FYRs at complex sites may benefit from EPA establishing a multi-disciplinary technical review team (EPA, 2001). The members of the technical review team provide technical expertise and assistance to RPMs.

Many groundwater site conditions are so complex and unique that the GWF recommends that the technical review team include a hydrogeologist. If EPA does not have this expertise available in their regional office, it is recommended that the RPM explore opportunities to leverage other EPA and state technical resources. These resources may include experts in other EPA regions, EPA Technical Support Centers (e.g., the Groundwater Technical Support Center) and EPA Headquarters support (e.g., Environmental Response Team and the Technology Assessment Branch). In addition, some states and other federal agencies (e.g., the U.S. Geological Survey and the U.S. Army Corps of Engineers) have technical experts available to provide valuable input.

At sites where EPA is the lead agency for the FYR, the technical review team may be involved throughout the FYR process. If EPA is not the lead agency, the team's involvement in a FYR may be limited to reviewing relevant site documents and a final or draft final document developed by the lead agency. The remainder of this document is written assuming the participation of a hydrogeologist on the technical review team.

## 3. TECHNICAL CONSIDERATIONS DURING THE SCOPING MEETING

For FYRs where EPA is the lead agency, a scoping meeting with the technical review team is generally conducted early in the FYR process. Below are some recommendations of groundwater topics to be considered and discussed during this meeting:

- Ensure the team understands the decision document requirements (e.g., groundwater RAOs and associated cleanup levels), expected timeframe(s) to achieve RAOs, source control activities and RAOs, and the remedial actions selected.
- Identify available information related to current groundwater conditions and remedy progress (e.g., sampling data, updated conceptual site model (CSM), and groundwater remedy completion strategy[3]).
- Determine if existing groundwater data are sufficient to conduct a meaningful analysis of remedy performance. If not, identify additional monitoring data needed.
- Identify the groundwater concerns expected to take the most time to resolve (e.g., Is the plume behaving as expected? Are there possible new exposure routes?).
- Properly schedule the collection and analysis of any new data needed for the FYR (e.g., installation of additional wells and related sampling and analysis) to ensure proper consideration in the review cycle.
- Ensure that the team is aware of the anticipated timeframe for the FYR process, particularly document review periods.

At sites where EPA is not the lead, it is recommended that the RPM consult with the technical review team to ensure all applicable reports can be reviewed a few months before the draft FYR report is due. This process is already established in some EPA regions and has been very effective for all parties involved.

## 4. VALIDATION OF THE HYDROGEOLOGIC CSM

Validation of the CSM by the technical review team is a critical part of the technical evaluation of groundwater remedies. The CSM requires revision with the expansion of site knowledge and serves as a primary project planning and management tool (EPA, 2011a). New site data and scientific insights into how contaminants migrate in groundwater ensure that the CSM will always be a work in progress.

At sites with contaminated groundwater, the CSM generally includes two major components: 1) the pathway-receptor network diagram, which is mainly used by risk assessors and concentrates on whether receptors exist and whether pathways are complete; and 2) the hydrogeologic CSM, which focuses on the occurrence, fate and specific migration pathways of contaminants in all site media, and aims to include all the factors that control contaminant distribution and

3 For more information on groundwater remedy completion strategies, refer to http://epa.gov/superfund/health/conmedia/gwdocs/pdfs/EPA_Groundwater_Remedy_Completion.pdf

remedy effectiveness. The GWF recommends that both CSM components be reviewed during the FYR process. A hydrogeologic CSM provides a framework for evaluating the groundwater data and information. In some instances, the technical review team may identify early in the FYR process (e.g., during the scoping meeting) that the site does not yet have a hydrogeologic CSM. In such cases, it is suggested that the hydrogeologist work with the RPM using available data to develop a preliminary hydrogeologic CSM. As discussed in the previous section, the hydrogeologist may also identify issues with the completeness of an existing CSM. In this case, the hydrogeologist may recommend the CSM be updated with the collection and evaluation of additional data.

More information about the hydrogeologic CSM is found in the highlight box.

**The Hydrogeologic Conceptual Site Model: What is it and why is it important?**

The hydrogeologic CSM focuses on the occurrence, fate and migration pathways of contaminants in all site media. It is meant to include all the factors that control contaminant distribution and remedy effectiveness. The hydrogeologic CSM should be described well enough to enable the technical review team to evaluate whether the data collected to date, and other new information, are consistent with the contaminant behavior predicted by the existing CSM. If not, elements of the CSM may need updating to reflect any new information. Typically, figures are necessary to ensure that the team can visualize and understand the hydrogeologic CSM (See example CSM figures at the end of this document.). Cross sections, particularly multiple or intersecting cross sections, can be useful for visualizing complex sites in three dimensions. Understanding of complex contaminant sources, in particular, can be improved through use of more sophisticated visualization tools (e.g., three-dimensional geostatistical models), which can provide a variety of visual outputs that show source strength and distribution. With adequate data, visualization tools also can be used to estimate contaminant mass. In addition to facilitating the current review, an updated or newly developed CSM will benefit future remedy assessments.

Scientific understanding of how sources persist and contaminants migrate has advanced greatly since the Superfund program began. Therefore, the GWF recommends considering new science when reviewing or updating the CSM. Site assumptions made years ago may have been based on more limited information or concepts that are more fully or differently understood today. For example, although dense non-aqueous phase liquids (DNAPLs) were recognized as subsurface contaminant sources early in the Superfund program, our understanding of DNAPL sources and the resulting plume architecture has evolved and is still developing today. Our current understanding of contaminant behavior has resulted in significant changes in strategies for characterizing source and plume extent, estimating cleanup timeframes for remedial actions, and assessing whether the remedy is adequate to meet RAOs or whether the RAOs are technically practicable. Understanding of the local hydrogeology also may change over time. For example, an aquitard that was thought to be regionally thick and continuous may subsequently be found to be discontinuous or thin in places, calling into question previous assumptions about the potential for contaminant transport to deeper aquifers.

For more information, consult, *Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model* (EPA, 2011a).

## 5. GROUNDWATER DOCUMENT REVIEW

The GWF recommends that the technical review team review site documents that support the groundwater technical evaluation. It may be helpful to provide these documents electronically in a central location (e.g., Microsoft™ OneDrive) for the technical review team to review.

The following documents may assist the technical review team in the FYR process. More detail is provided for information of particular interest to the hydrogeologist team member.

1. Remedial investigation and feasibility study (RI/FS) reports that describe the CSM (including site hydrogeology and the nature and extent of contamination) and evaluate the selected remedial alternative.

2. Baseline human health (and ecological, if appropriate) risk assessments conducted as part of the RI/FS.
3. Decision documents, including all the figures and tables, which are not always available in the online versions, especially older records of decision (RODs). The ROD generally establishes RAOs and selects remedial actions that either contain sources or portions of plumes, reduce concentrations, restore contaminated groundwater, prevent exposure, or require improvements to drinking water. It is important for the technical review team to understand the groundwater restoration and associated cleanup timeframe, and containment remedy elements in the ROD.
4. Remedial design and remedial action (RD/RA) work plan, including the monitoring strategy and design (i.e., the operations and maintenance (O&M) plan or compliance monitoring plan).
5. Remedial design investigation reports.
6. Any document that presents an updated CSM.
7. Any document that presents a performance evaluation of a remedy component (e.g., pump and treat capture zone analysis or groundwater modeling report).
8. All previous FYRs for the site.
9. Current monitoring plans (including standard operating procedures), quality assurance project plan, or other documents that set forth the required locations, methodologies, and frequency of sampling for all media being remediated.
10. Historical site data including water-quality and water-level data along with well construction information, ideally compiled in an electronic format (spreadsheet or database) that can be manipulated; a complete set of well logs; any changes that have occurred to the monitoring well network since the previous FYR (e.g., new, modified or decommissioned wells); and O&M reports, which may be separate from the annual monitoring reports.

## 6. GROUNDWATER DATA REVIEW

The hydrogeologist reviews contaminant concentration data to identify trends, anomalies and data gaps. A major element of the technical review at contaminated groundwater sites is the comparison of contaminant concentrations in each well to: 1) the plume behavior anticipated based on the hydrogeologic CSM; and 2) remedy expectations established in the site decision documents. This comparison typically includes performing or reviewing statistical trend analyses of data for individual wells and evaluation of overall plume behavior, either through plume map comparisons over time or through statistical analyses that describe changes in plume characteristics over time (e.g., MAROS package analyses[4]). In particular, the team needs to confirm that the plume is not expanding or behaving in an unanticipated way, and that timely progress is being made toward meeting RAOs and associated cleanup levels.

Ideally, the data should be made available to the technical review team to review in enough time for this evaluation. The hydrogeologist needs time to evaluate the validity of the groundwater monitoring data and the associated trends (including the appropriateness of the statistical approach) in the monitoring reports. If monitoring reports do not include a robust data analysis, the hydrogeologist may need time to develop statistical trends to include in the FYR report.

## 7. GROUNDWATER CONSIDERATIONS FOR THE SITE INSPECTION

The GWF recommends that members of the technical review team visit the site to evaluate current conditions, including those related to the groundwater remedy. The inspection allows the team to identify changes in site conditions (e.g., new construction and exposure pathways), confirm reported site conditions, and evaluate the condition of existing remediation facilities and monitoring networks. If any team member cannot accompany the RPM on the site inspection or visit the site separately, the RPM may consider documenting these site conditions photographically.

If the RPM uses a site inspection checklist, the GWF recommends that the hydrogeologist review the checklist to ensure it includes an adequate evaluation of the condition and functionality of the groundwater remediation facilities and monitoring networks.

Examples of issues related to groundwater remedies that may be encountered during the FYR site inspection include excessive vegetation that blocks access to

4 MAROS 3.0 is available at: http://old.gsi-net.com/en/software/free-software/maros-30.html

monitoring wells and the loss of monitoring wells as a result of site redevelopment or maintenance.

In addition, if previous evaluation of analytical data identified possible problems with sampling procedures or data quality, the GWF recommends, if possible, that the hydrogeologist and RPM schedule the site visit to coincide with a sampling event.

## 8. GROUNDWATER TECHNICAL ASSESSMENT

Beyond the document review, data review, and site inspection, the technical review team may assist the RPM in answering the three technical assessment questions in the 2001 *Comprehensive Five-Year Review Guidance*:

- ***Question A*** – Is the remedy functioning as intended by the decision documents?
- ***Question B*** – Are the exposure assumptions, toxicity data, cleanup levels, and RAOs used at the time of the remedy selection still valid?
- ***Question C*** – Has any other information come to light that could call into question the protectiveness of the remedy?

This GWF issue paper outlines recommended concepts, particularly those related to groundwater, that may be evaluated by the hydrogeologist to assist the RPM in developing answers to these questions. It also identifies possible issues that may arise for groundwater remedies, and provides some examples of recommendations that may be considered.

1. *CSM validation*: Site characterization efforts conducted to date should generally be reflected in the current CSM. In some cases, data may be insufficient to develop or maintain a robust hydrogeologic CSM. If the hydrogeologist cannot validate the CSM, this may lead to questions regarding the performance of the remedy. If time allows, it may be appropriate to conduct additional sampling activities to support the FYR process. If not, it may be appropriate to identify the data needs and recommend additional sampling activities.
2. *Long-term monitoring program and groundwater remedy completion strategy*: The hydrogeologist evaluates the data to ensure that the current long-term monitoring program effectively characterizes the plume and allows the evaluation of progress toward RAOs and associated cleanup levels. This evaluation includes a review of monitoring well placement and construction, as well as the quality of data obtained from monitoring wells, to ensure that both hydrogeologic and water quality data are representative and reliable. Because sampling protocols and equipment have improved over time, as has our understanding of what a given groundwater sample represents, it is suggested that sampling protocols be reviewed to confirm that they are sufficient for obtaining representative samples. Data evaluation may also include a review of the site-specific groundwater remedy completion strategy documentation to ensure that monitoring data are being evaluated against appropriate performance metrics and remedy evaluation decisions. Following review of the monitoring plan, the hydrogeologist may suggest including a recommendation to conduct spatial and/or temporal long-term monitoring optimization (LTMO) to verify and continually improve the effectiveness and efficiency of groundwater remedies. For example, evaluation of the frequency and spatial density of sampling can help determine if monitoring can be scaled back. Conversely, analysis of the monitoring program may identify apparent monitoring gaps and indicate the need for a geospatial analysis of the monitoring well network. Some LTMO software packages include geospatial analysis modules for this purpose (EPA, 2005); however, such analyses do not take groundwater gradients into account and generally cannot identify when plumes are unbounded unless contaminant trends are increasing in a network boundary well. Based on a review of the groundwater remedy completion strategy documentation, the hydrogeologist may also suggest including a recommendation to either modify the strategy components (i.e., performance metrics and/or remedy evaluations). In the event that the groundwater remedy completion strategy is not clearly documented, the hydrogeologist may also suggest including a recommendation to develop a more robust groundwater remedy completion strategy document.
3. *Monitoring well integrity*: The hydrogeologist evaluates well conditions to determine if redevelopment or replacement of any monitoring wells is necessary. Over time, degradation of a monitoring well's performance can occur through sedimentation, corrosion, or biofouling. The GWF recommends that a desktop review of the sampling records be conducted to identify possible degradation of well integrity. Sampling field notes may

reveal red flags such as changes in measured well depth, changes in drawdown behavior during well purging, or changes in indicator parameters such as turbidity.

During the site inspection, the technical review team visually inspects all wells for any damage, inside and outside. If damage is found that affects performance of the well, or could cause the well itself to become a potential contaminant migration pathway, the hydrogeologist may recommend the well be repaired, replaced or decommissioned. For example, a well left uncapped can be vulnerable to surface contamination or vandalism. If exterior damage that may alter wellhead elevations is found, the hydrogeologist may identify this as an issue and provide a recommendation to resurvey any affected wells to ensure that groundwater flow gradients are not mischaracterized.

4. *Groundwater extraction/injection/re-infiltration system integrity*: The GWF recommends that the technical review team assess the integrity of any site pumping wells, re-injection wells, or re-infiltration galleries. The hydrogeologist identifies any issues with the system's performance and recommends corrective activities (e.g., redevelopment or replacement). Likewise, if some portion of the system is not functioning optimally, the hydrogeologist evaluates the effects on the overall system to ensure that any pump and treat remedy is operating effectively. If the hydrogeologist determines that the system is not functioning optimally or if plume capture could be compromised, the hydrogeologist may identify a data need and recommend a formal capture zone analysis (EPA, 2008a).

5. *Assessment of new information*: As part of the FYR process, the technical review team reviews site documentation, current site conditions, and contaminant-specific information to check for changes regarding exposure assumptions, contaminant toxicity, cleanup levels, new contaminants, and standards. While a risk assessor will typically provide guidance on changes in toxicity and cleanup levels, a hydrogeologist may provide input on changes in exposure assumptions or new contaminants identified in groundwater sampling activities. In addition, there may be new information that changes our understanding of site hydrogeology or new site features that might affect groundwater flow or exposure to site contaminants. These features could include new ponds, new public supply or other large capacity pumping wells, or newly paved or unpaved surfaces. Hydrogeologic impacts of these features might include changes in water recharge rates, groundwater flow directions or velocity, groundwater contaminant vapor migration into ambient or indoor air (EPA, 2012a), or groundwater discharge to surface water. Changes in land use may also indicate the potential for new exposure pathways. If new information suggests a change to assumptions made at the time of remedy selection, this may be identified as an issue.

6. *Institutional controls*: The adequacy of and compliance with implemented institutional controls (ICs) limiting groundwater use for the site are generally evaluated during the FYR process. The GWF reccommends that the technical review team identify and evaluate any changes in land use that may create the potential for exposure to groundwater. Changes may include the installation of new wells or new construction over shallow plumes. In addition, if a review of monitoring data indicates that a plume is expanding, the team may recommend that the existing groundwater ICs be modified and operational updates be implemented to address plume expansion.

Table 1 provides this list of topics and related questions that hydrogeologists commonly evaluate at groundwater sites.

## 9. GROUNDWATER REMEDY PERFORMANCE

The FYR evaluates remedy performance to determine if the remedy is functioning as intended. The FYR also presents a good opportunity to evaluate the groundwater remedy components to ensure they function well together and are effective and cost efficient. In addition, the FYR provides an opportunity to review existing data, performance metrics and remedy evaluation decisions to evaluate whether the estimated remedial timeframe is achievable with the implemented remedy (EPA, 2012b). If the technical review team identifies issues with system performance, it may recommend characterization activities such as determining plume stability, containment or plume hydraulic capture. In some cases, an evaluation of remedy performance may result in recommendations to consider a remedy change. For example, the hydrogeologist may recommend evaluating a transition to more passive treatment technologies (e.g., monitored natural attenuation) as part of the groundwater treatment train. Conversely, poor remedy performance may be attributed to remaining groundwater contaminant sources that require additional characterization. Based on the remedy-specific characteristics, the technical review team may suggest that the RPM either consider enhancements to the existing remedy (e.g., more aggressive source treatment or in situ plume treatments) or recommend evaluating an alternative remedial strategy (e.g., a technical impracticability or "TI" waiver (EPA, 1993)[5]). Table 2 lists some specific issues to consider for common remedial technologies for contaminant sources and associated groundwater plumes.

## 10. EXAMPLE GROUNDWATER ISSUES AND RECOMMENDATIONS

As discussed in the previous sections, when groundwater issues are identified throughout the FYR process, the technical review team works with the RPM to document these issues and develop clear and concise recommendations to address them.

Some common groundwater remedy issues that may be identified include, but are not limited to the following:

- Underestimated source mass, both in the saturated and the unsaturated zones.
- Underestimated source extent, including unidentified source areas.
- Inadequately characterized groundwater plumes in three dimensions, including insufficient information to identify and monitor the most contaminated plume intervals or to recognize the potential for migration of contaminants through presumed aquitards.
- Inadequately documented or unclear groundwater remedy completion strategy.
- Inadequate understanding of the effect of matrix storage on remedial time frames due to back diffusion.
- Inadequate understanding of connections with other exposure media, including surface water, sediment, and soil vapor (and potentially complete exposure pathways associated with vapor intrusion).
- Contaminants not previously identified as a concern. For example 1,4-dioxane may not have been previously identified as a contaminant of concern at the ROD stage because the detection limit may have changed.

In general, recommendations are developed to address the issues raised in the review. These recommendations will be specific to site conditions and reflect specific activities necessary to effectively address the issue.

## 11. CONCLUSIONS

Groundwater sites and remedies have specific technical issues and complexities that are better understood by hydrogeologists and other groundwater experts. EPA, other federal agencies, and states have a significant amount of technical expertise available to assist the RPM in conducting FYRs that include groundwater components. Leveraging these resources, as part of the FYR technical review team, will assist the RPM in reviewing complex groundwater site conditions and remedies. When a technical review team is developed to review groundwater elements of a remedy, the GWF recommends that they are involved early in the FYR process to ensure they have adequate time and resources necessary to conduct data review, document review, and participate in the site inspection. This time frame will depend on the complexity of the site and remedies implemented. Professional judgment is required to properly schedule a FYR.

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## 13. ACKNOWLEDGMENTS

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## 14. NOTICE AND DISCLAIMER

The Ground Water Forum, a component of the U.S. EPA Superfund Technical Support Project, has authored this issue paper. Information and opinions contained in this document were developed by the Ground Water Forum, are technical in nature, and represent professional opinions of the participants. This information has not received formal EPA peer review and does not necessarily reflect the views of EPA or other participating organizations, and no official endorsement should be inferred. The information is not intended, nor can it be relied upon, to create any rights enforceable by any party in litigation with the United States or any other party. Use or mention of trade names does not constitute an endorsement or recommendation for use.

A PDF version of *Ground Water Forum Issue Paper: Groundwater Technical Considerations during the Five-Year Review Process* is available to view or download at http://www.epa.gov/superfund and http://www.cluin.org.

## 15. TABLES

### Table 1. Common Technical Questions at Groundwater Sites

| Topic | Review Needs | Questions |
|---|---|---|
| CSM validation | Review documentation of the site geological and hydrological characterization. This includes the RI/FS reports, along with any supplemental information that was used to develop the findings presented in the ROD and any characterization performed during RD/RA. | • Considering the current state of the practice, have the site characterization efforts conducted to date been sufficient?<br>• Is the CSM adequate and up to date?<br>• Has the three-dimensional nature and extent of contamination been fully delineated?<br>• Has the potential for dense non-aqueous phase liquid (DNAPL) source been adequately considered, including the potential for DNAPL movement through aquitards (Bradbury, et al., 2006)?<br>• Might other contaminants be present that were unknown then or are of greater concern today?<br>• Were contaminant migration pathways to sediment and surface water fully characterized?<br>• Has the potential for vapor intrusion been evaluated? |
| Long-term monitoring program (adequacy of monitoring well network and data quality and quantity) | Review the adequacy of the monitoring well network, including construction details of the existing monitoring wells to develop a technical evaluation of the monitoring well design and construction. This may require review of well logs.<br><br>Review the sampling and analysis plan, including standard operating procedures, and the quality assurance project plan (QAPP). This review may involve both a hydrogeologist and a quality assurance expert. Field oversight of a sampling event may be advisable. | • Have the wells been properly placed, both horizontally and vertically, to define the plume(s), to characterize concentrations throughout the aquifer thickness and to track the rate and extent of plume migration?<br>• Are the screen intervals and lengths appropriate?<br>• Are additional wells needed in response to changes in plume configuration?<br>• If there is a pump-and-treat remedy, are wells appropriately located to provide information for a capture zone analysis?<br>• Are monitoring wells accessible to EPA and its contractors yet protected from likely avenues of accidental damage or vandalism? (Wells with flush mount completions are particularly vulnerable to burial under gravel or pavement.)<br>• Are appropriate chemical constituents being analyzed at appropriate quantitation limits, including parent/daughter (biodegradation) products, indicators of change in geochemical conditions, as well as the site's chemicals of concern?<br>• If new chemicals of potential concern have been identified, have they been included in the analytical program?<br>• Are sampling protocols appropriate and up to date?<br>• Are monitoring wells being sampled at an appropriate frequency to establish and maintain statistically robust contaminant trends at appropriate locations (e.g., source wells, plume centerline wells, boundary wells, and sentinel wells)? |

**Table 1. Common Technical Questions at Groundwater Sites (continued)**

| Topic | Review Needs | Questions |
|---|---|---|
| Monitoring well integrity | Assess the integrity of the site monitoring wells. Parts of this evaluation should be performed in the office by reviewing the sampling records to determine if well integrity has been degrading, and conditions should be confirmed during the field visit. | • Are the monitoring wells functioning as designed and constructed?<br>• Is there a plan for periodic assessment and maintenance?<br>• Is total depth measured periodically to check for sedimentation when water levels are measured?<br>• Are there damaged, out-of-date, or poorly constructed wells (e.g., those with inappropriately long screens) that should be properly decommissioned? |
| Groundwater extraction and injection system | Assess the integrity of any site pumping wells, re-injection wells, or re-infiltration galleries. | • Are all the wells functioning? If not, what are the ramifications for overall plume capture?<br>• Is biofouling or premature pump failure an issue?<br>• Are water levels unexpectedly low in pumping wells or high in re-injection wells?<br>• Are groundwater levels around infiltration galleries consistent with historical operating conditions? |
| Revised and new information | Check for changed or new information regarding remedy assumptions. Check whether site conditions have changed in any way that could alter groundwater flow conditions. | • Have there been changes in contaminant toxicity, cleanup levels, or groundwater standards?<br>• Are there newly identified contaminants of potential concern at the site?<br>• Has enough analytical information been collected to evaluate these questions?<br>• Is there new information to indicate that RAOs may not be achievable with the current remedy?<br>• Are there new scientific insights that call a critical element of the CSM into question?<br>• At or near the site, are there new features (ponds, public supply wells, newly paved or unpaved surfaces, etc.) which may have affected groundwater recharge or discharge or otherwise altered the subsurface hydrogeology (e.g., groundwater flow directions or velocity)?<br>• Have there been land use changes that may lead to exposures in a new population? |
| Institutional controls (ICs) | Review the adequacy of and compliance with implemented groundwater ICs for the site. | • Has land use or zoning changed?<br>• Have any new water wells been installed in or near the plume area?<br>• Has there been new construction above shallow plumes of volatile organic compounds (VOCs)?<br>• Have such changes compromised the effectiveness of groundwater remedies and/or presented new exposures (e.g., vapor intrusion) that did not exist at the time of remedy selection? |

Table 1. Common Technical Questions at Groundwater Sites (continued)

| Topic | Review Needs | Questions |
|---|---|---|
| Environmental indicators | Check to ensure consistency with current understanding of site conditions, including exposure scenarios as confirmed during the field visit. | • Are the indicators for "human exposure under control" and "migration of contaminated groundwater under control" still valid? |
| Remedy optimization | Evaluate whether contaminant concentration data may indicate a need for remediation system evaluation (EPA, 2000) or LTMO (EPA, 2005). | • Is the groundwater remedy effective (and cost effective)<br>• For a pump-and-treat remedy, has a capture zone analysis been conducted recently?<br>• Do the data suggest that there may be a contaminant source that has not been controlled?<br>• If contaminant levels have "tailed" and the plume is stable, could monitored natural attenuation (MNA) play a larger role in the groundwater remedy?<br>• What are the life-cycle energy costs?<br>• Could sampling frequencies be reduced without a significant loss in ability to track contaminant trends?<br>• Are there any redundant monitoring wells? |

**Table 2. Remedial Performance Technical Elements to Evaluate**

| Groundwater Remediation Description/Objectives | Common Groundwater Elements to Evaluate | Internet Resources |
|---|---|---|
| **Extraction Systems**<br>Remove contaminated fluids, treat, and discharge (soil gas or water) to contain contamination and/or to restore groundwater to beneficial use. | | |
| Groundwater Pump and Treat (P&T)<br><br>Actively extract contaminated groundwater and treat | • Have extraction systems captured the entire plume length, width and depth (or the entire target zone if the goal is partial capture)?<br>• Has the source area been remediated or controlled successfully?<br>• Did the site have light or dense non-aqueous phase liquids (LNAPL or DNAPL) besides the dissolved plume, and were these remediated?<br>• Is the system meant to deal with a dissolved plume or also with a NAPL source?<br>• Is any reintroduced treated water having the anticipated effect on site hydraulics or on the plume?<br>• Does the treatment system remove all the contaminants in the groundwater, including newly identified contaminants of concern? | *A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems*. (EPA, 2008a). |
| Soil Vapor Extraction (SVE)<br><br>Actively remove contaminated soil vapor and discharge, or treat and discharge. | • Was the SVE checked for meeting goals of remedial action objectives after it was shut down?<br>• Has there been a rebound of ground-water concentrations since the SVE was turned off?<br>• SVE only addresses unsaturated zone (vadose) contamination. If implemented to protect groundwater, might additional sources exist in the saturated zone (below the water table)? | Soil Vapor Extraction focus area: http://www.clu-in.org/techfocus/default.focus/sec/Soil_Vapor_Extraction/cat/Overview/ |
| **In-Situ Treatment**<br>Contaminants are actively or passively degraded or immobilized in the aquifer. | | |
| Air Sparging<br><br>Introduce air to vadose zone and groundwater to enhance removal from soils and groundwater. Coupled with soil vapor extraction. | Same as for SVE | *A Citizen's Guide to Soil Vapor Extraction and Air Sparging*. (EPA, 2012c). |

**Table 2. Remedial Performance Technical Elements to Evaluate (continued)**

| Groundwater Remediation Description/Objectives | Common Groundwater Elements to Evaluate | Internet Resources |
|---|---|---|
| Bioremediation<br><br>Chemicals of concern are remediated by bacteria. The environment for increased biologic activity can be enhanced by injecting carbon sources (oils, sugars) and/or bacteria. | • Is contaminant breakdown complete or stuck at toxic intermediate forms?<br>• Is breakdown fast enough?<br>• Can injected amendments reach the entire contaminated target zone?<br>• Can necessary conditions be maintained naturally? | *A Citizen's Guide to Bioremediation*. (EPA, 2012d). |
| Phytoremediation<br><br>Chemicals of concern are taken up by the root zones of plants (e.g., poplars and hyper-accumulating ferns) and destroyed through metabolization. | • Are the plants healthy?<br>• Do the roots extend deep enough to intercept a significant portion of the plume mass? | Phytotechnologies focus area: http://www.clu-in.org/techfocus/default.focus/sec/Phytotechnologies/cat/Overview/ |
| Monitored Natural Attenuation (MNA)<br><br>Monitor and confirm that natural processes are remediating plumes in an acceptable timeframe that would be comparable to active remediation. | • Evaluate whether natural attenuation is progressing as expected, if not annually, at least for each FYR. Use concentration trend analyses and possibly plume moment analysis. If progress is inadequate, a more active remedy may be required to meet cleanup objectives.<br>• May also need to evaluate whether additional untreated or uncontained sources exist.<br>• In some cases MNA cannot be sustained over time; in others, site conditions may not have been as favorable as was believed when MNA was chosen.<br>• There may be breakdown products which are as much of a problem as the original contaminant.<br>• Geochemical conditions may vary seasonally in shallow aquifers; The recommendation is that monitoring plans account for this temporal effect on contaminant solubility's and associated transport. | *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water*. (EPA, 1998a).<br><br>*Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 1: Technical Basis for Assessment*. (EPA, 2007a).<br><br>*Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 2: Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper,Lead, Nickel, Nitrate, Perchlorate, and Selenium*. (EPA, 2007b).<br><br>*An Approach for Evaluating the Progress of Natural Attenuation in Groundwater*. (EPA, 2011c). |

**Table 2. Remedial Performance Technical Elements to Evaluate (continued)**

| Groundwater Remediation Description/Objectives | Common Groundwater Elements to Evaluate | Internet Resources |
|---|---|---|
| **Source Zone Remediation**<br>Sources are identified, delineated, and removed or destroyed. "How clean is clean?" is a major question. RAOs may be based on percentage of source mass destroyed or removed, but that is very difficult to determine. Reductions in remaining groundwater concentrations, and/or reductions in mass flux to the groundwater plume may be easier objectives to demonstrate. A treatment train approach may be most effective. | | |
| <u>LNAPL Sources</u><br><br>NAPL sources are only slightly soluble in water and are persistent sources to groundwater contamination that are difficult to remove. LNAPLs are easier to find because they float on the water table. | • Were LNAPLs found or suspected at site?<br>• Were LNAPLs removed or just contained at site?<br>• Have concentrations rebounded at site due to LNAPLs?<br>• Do multiple LNAPLs have different solubilities and thus different transport potentials? | *Ground Water Issue: Light Non-Aqueous Phase Liquids*. (EPA, 1995). |
| <u>DNAPL Sources</u><br><br>DNAPLs are difficult to locate because they are heavier than water and sink through aquifers, potentially until they reach a much less permeable layer. In addition, they may flow in relatively narrow flowpaths, which are easily missed, rather than create a broader pool. They may also pool or flow down dip slope regardless of the groundwater flow direction. | • Were DNAPLs found or suspected at site (groundwater concentrations > 1% to 10% of DNAPL solubility)?<br>• Were DNAPLs monitored at the site? Were wells correctly screened to detect DNAPLs?<br>• Were DNAPLs removed or just contained at site?<br>• Have concentrations rebounded at site due to DNAPLs? | DNAPL Focus Area: www.cluin.org/dnapl<br><br>*Ground Water Issue: Assessment and Delineation of DNAPL Source Zones at Hazardous Waste Sites*. (EPA, 2009a).<br><br>*Frequently Asked Questions Regarding Management of Chlorinated Solvents in Soils and Groundwater* (ESTCP, 2007). |
| <u>Excavation</u><br><br>Sources are dug up and treated ex situ or disposed elsewhere. | • Could the entire source be excavated i.e., Was there contamination deeper than excavation could reach, or was horizontal excavation constrained by infrastructure?<br>• If the water table varies seasonally, was excavation performed when the water table was low?<br>• Were excavations backfilled with hydrogeologically comparable soil to minimize changes in site hydrology?<br>• Was monitoring sufficient to evaluate short-term and long-term effects on downgradient groundwater? | DNAPL Focus Area: Source Area Excavation: http://www.clu-in.org/contaminantfocus/default.focus/sec/Dense_Nonaqueous_Phase_Liquids_(DNAPLs)/cat/Treatment_Technologies/p/10 |

**Table 2. Remedial Performance Technical Elements to Evaluate (continued)**

| Groundwater Remediation Description/Objectives | Common Groundwater Elements to Evaluate | Internet Resources |
|---|---|---|
| <u>Thermal Remediation</u><br><br>Thermal energy (via steam or electricity) is applied to soil to remove and/or destroy contaminants, either in situ or ex situ (applied to excavated material at the surface). Contaminants are recovered from the vapor phase (or vapor and liquid phases, in the case of steam) and treated. | • Is groundwater flow adequately controlled to maintain target temperatures throughout the treatment area?<br>• Can the system be modified to increase removal efficiency?<br>• If the energy is injected via steam, did the energy reach the entire source volume?<br>• After shutdown, have concentrations rebounded? | *Ground Water Issue: How Heat Can Enhance In-situ Soil and Aquifer Remediation: Important Chemical Properties and Guidance on Choosing the Appropriate Technique.* (EPA, 1997).<br><br>*Ground Water Issue: Steam Injection for Soil and Aquifer Remediation.* (EPA, 1998b).<br><br>In Situ Thermal Treatment focus area: http://www.clu-in.org/techfocus/default.focus/sec/Thermal_Treatment%3A_In_Situ/cat/Overview/ |
| <u>In Situ Chemical Treatment</u><br><br>Chemicals are injected into a contaminated area to remove or destroy the environment-contaminating chemicals of concern, usually by manipulating redox conditions. | • Can the chemical conditions required to treat source materials be maintained long enough for complete treatment?<br>• Did injected food or bacteria reach the entire source volume?<br>• Has the chemical treatment been successful? Has the contamination rebounded (come back after being reduced/removed)? | In Situ Chemical Reduction focus area: http://www.clu-in.org/techfocus/default.focus/sec/In_Situ_Chemical_Reduction/cat/Overview/ |
| <u>Bioremediation</u><br><br>Chemicals of concern are remediated by bacteria. This process can be enhanced by enhancing the environment for increased biologic activity. | • Has the bioreaction produced other contaminants of concern? Is the remedial system continuing to operate efficiently?<br>• Did injected food or bacteria reach the entire source volume? | Bioremediation focus area: http://www.clu-in.org/techfocus/default.focus/sec/Bioremediation/cat/Overview/ |
| **Containment Barriers**<br>Containment barriers isolate contaminant sources with engineered structures. The source mass remains in place and the integrity of the remedy is limited by the life of the engineered structure. The potential for leakage in both horizontal and vertical directions should be considered. Long-term monitoring to detect releases through containment failure must continue for as long as the source exists, even after the plume outside the containment unit is cleaned up. | | |
| <u>Surface Engineered Barriers</u><br><br>Surface engineered barriers (caps) reduce infiltration and limit direct exposure. | • Are "chemicals of concern" for a site being observed in downgradient monitoring wells at stable or increasing concentrations?<br>• Is the cap continuing to allow runoff, or has differential settlement caused ponding on the surface?<br>• Has large vegetation become established? Are animals compromising the cap by digging or burrowing? | *A Citizen's Guide to Capping* (EPA, 2012e). |

**Table 2. Remedial Performance Technical Elements to Evaluate (continued)**

| Groundwater Remediation Description/Objectives | Common Groundwater Elements to Evaluate | Internet Resources |
|---|---|---|
| Subsurface Engineered Barriers<br><br>Subsurface engineered barriers (impermeable walls) isolate hazardous wastes from adjacent groundwater and surface water. | • If the containment surrounds a source area, are water levels within the containment area unaffected by external water level changes?<br>• Are "contaminants of concern" for a site being observed in downgradient monitoring wells at stable or increasing concentrations?<br>• Can contamination flow around or under the barrier? | *Evaluation of Subsurface Engineered Barriers at Waste Sites* (EPA, 1998c). |
| Permeable Reactive Barriers (PRBs)<br><br>Reactive barriers are designed to treat the entire plume as it flows through, so understanding and managing groundwater flow is critical. Reaction products may gradually reduce the permeability of the barrier and cause the reactants to become depleted or unavailable. | • Performance monitoring is critically important for PRBs. Are downgradient water concentrations as clean as expected? If not, the wall may not be thick enough to completely treat the plume, especially if the plume is more stratified and has a higher range of concentrations than was anticipated at design.<br>• Can it be demonstrated from sampling and water level data that contamination is not flowing around or beneath the barrier? Is the wall still permeable? If not, groundwater may be diverted around or under the wall, especially if it was not properly oriented relative to (i.e., at right angles to) the local groundwater flow direction. PRB cementation or biofouling can occur surprisingly quickly. | *A Citizen's Guide to Permeable Reactive Barriers* (EPA, 2012f).<br><br>*Evaluation of Permeable Reactive Barrier Performance*. (FRTR 2002). |

**Table 2. Remedial Performance Technical Elements to Evaluate (continued)**

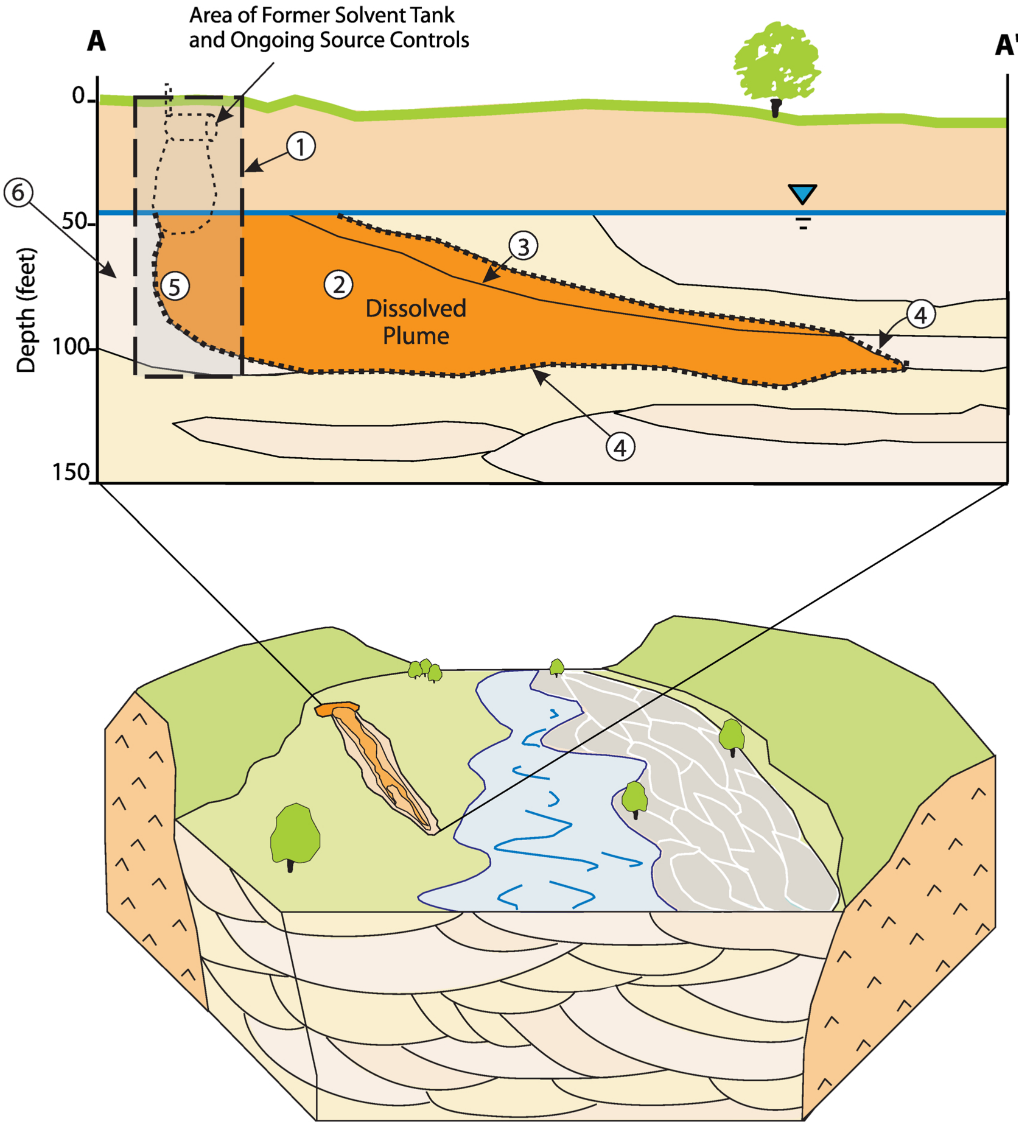
| Groundwater Remediation Description/Objectives | Common Groundwater Elements to Evaluate | Internet Resources |
|---|---|---|
| **Monitoring**<br>Monitoring is an integral element of all groundwater remedies, whether to evaluate the effects of a particular remedial action on nearby groundwater or to evaluate the response of site-wide groundwater plumes. It is also integral to the management of groundwater institutional controls. | | |
| Long-Term Monitoring<br><br>The long-term monitoring plan must provide adequate information to demonstrate effectiveness. | • In general, are wells properly sampled using an acceptable sampling procedure?<br>• Are the QAPP and work plan up to date?<br>• Are plumes bounded on all sides by monitoring wells? If the plume may be advancing, are there enough sentinel wells to evaluate plume migration in a timely fashion, including vertically if appropriate?<br>• Do sampling and water level measurement frequency account for seasonal effects, if present?<br>• Are there enough wells within the plume to evaluate progress toward RAOs? (e.g., If reduction in plume mass is an objective, are there enough centerline wells to track changes in contaminant mass or plume moments statistically?)<br>• Have there been changes in groundwater levels or gradients? Increasing groundwater levels can increase groundwater contamination when contaminants that had been in the vadose zone are now below the water table. Also, different types of strata, such as gravelly layers, may become saturated and allow contaminant plumes to migrate much more quickly. | *Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers*. (EPA, 2002).<br><br>*Final RCRA Comprehensive Ground-Water Monitoring Evaluation (CME) Guidance Document*. (EPA, 1986).<br><br>*Ground Water Sampling for Metals Analysis*. (EPA, 1989).<br><br>*RCRA Ground Water Monitoring: Draft Technical Guidance*. (EPA, 1992).<br><br>Cleanups at Federal Facilities (EPA webpage with several good links): http://www.epa.gov/fedfac/documents/qualityassurance.htm#ufp-qapp |
| Performance Monitoring<br><br>The monitoring program at a site must be appropriately designed to assure that a specific remedial action functions as designed. Once a remedial action is determined to be functional, the long-term monitoring system replaces it. | • Are the wells in the network sufficient and properly placed, both to ensure that groundwater flow is as expected (water level measurements) and to ensure that remedial actions were effective (contaminant reductions where desired) and that they didn't spread contamination (no unanticipated plume spread)?<br>• Were the wells sampled frequently enough to identify changes attributable to the remedial action? | *Performance Monitoring of MNA Remedies for VOCs in Ground Water*. (EPA, 2004a).<br><br>*Methods for Monitoring P&T Performance Parts 1 and 2*. (EPA, 1994). |

**Table 2. Remedial Performance Technical Elements to Evaluate (continued)**

| Groundwater Remediation Description/Objectives | Common Groundwater Elements to Evaluate | Internet Resources |
|---|---|---|
| **Optimization**<br>Remedy optimizations can yield significant operational cost savings and improve remedy effectiveness, either by increasing mass removal rates (thus reducing the length active remediation is required) or by ensuring that the right amount of sampling data is collected. | | |
| Remedial Systems Evaluation / Remedial Process Optimization<br><br>A remediation system may need to be evaluated for cost-efficiency and integrity after it operates for a while. | • Have concentration trends stopped declining, or have they rebounded?<br>• Is the groundwater capture zone well understood?<br>• Is biofouling in pumping wells impacting extraction rates? | *Optimization Strategies for Long-Term Ground Water Remedies*. (EPA, 2007c).<br><br>*Remediation Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation. RPO-1*. (ITRC, 2004)<br><br>*Superfund Reform Strategy Pump and Treat Optimization: Questions and Answers*. http://www.clu-in.org/download/remed/hyopt/questionanswer2.pdf<br><br>*What Is Remediation Process Optimization and How Can It Help Me Identify Opportunities for Enhanced and More Efficient Site Remediation?* (EPA, 2004b) |
| Long-Term Monitoring Optimization<br><br>Long-term monitoring can periodically be optimized both temporally to reduce the frequency of sampling and spatially to ensure that the spacing of wells is sufficient to meet monitoring objectives while eliminating any redundant wells. | • Is groundwater sampling still being conducted at the same frequency (quarterly or semiannually) in all wells?<br>• Are there seasonal variations in contaminant concentrations or in water levels?<br>• Wells which are no longer needed for sampling may still be useful for water level measurements. | *Roadmap to Long-Term Monitoring Optimization*. (EPA, 2005).<br><br>MAROS Overview: http://www.frtr.gov/decisionsupport/DST_Tools/maros.htm (MAROS 2.2)<br><br>MAROS 3.0: http://old.gsi-net.com/en/software/free-software/maros-30.html |

## 16. FIGURES

### Figure 1: Hydrogeologic CSM Example Block Diagram




***Target Monitoring Zones***

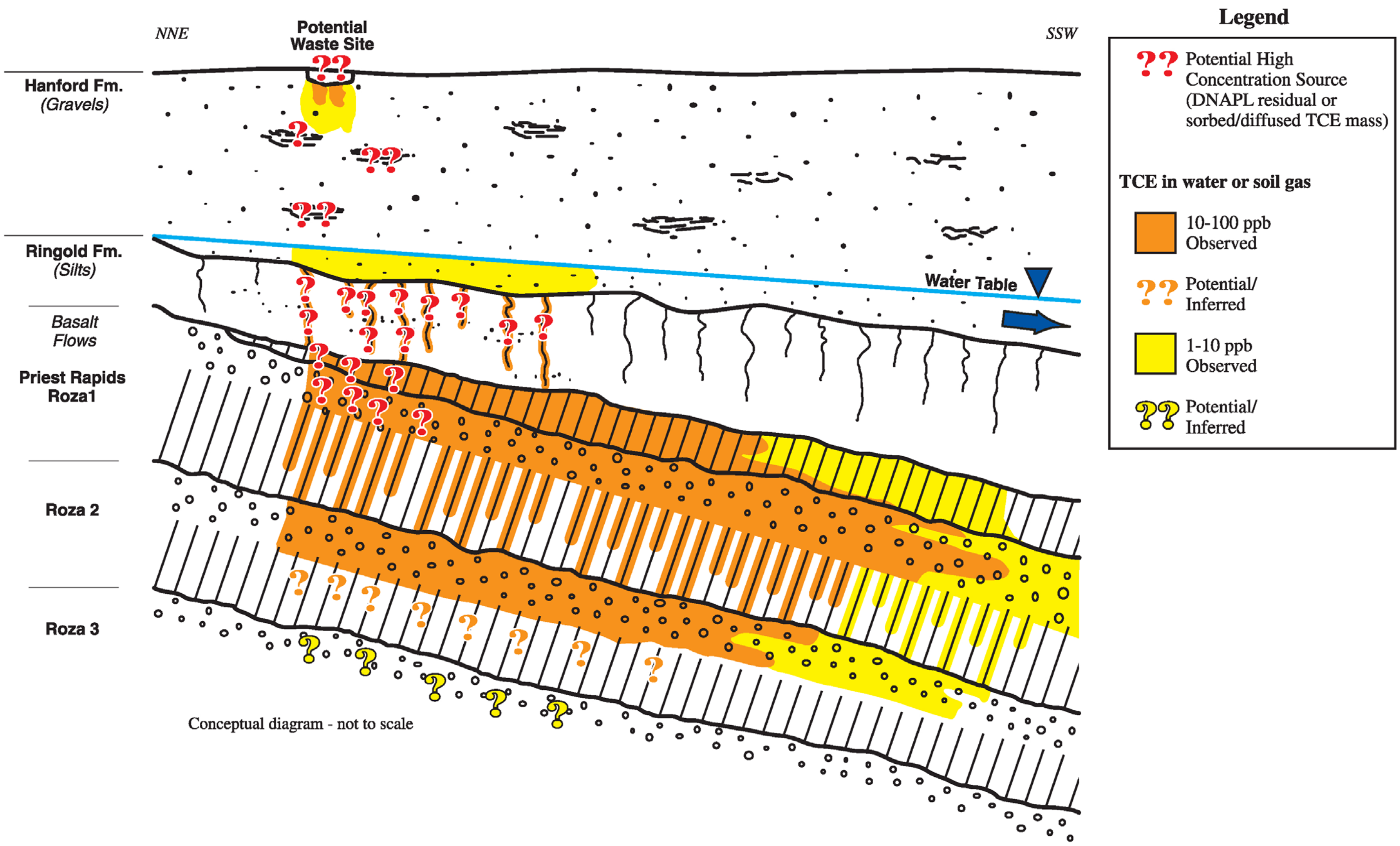
1. Source area
2. Contaminated zones of highest concentrations and mobility
3. Plume fringes exhibiting low contaminant concentrations
4. Plume boundaries
5. Recalcitrant zone determined from historical trends
6. Upgradient locations

***Legend***

- Gravel, gravel-sand mixtures
- Medium to coarse-grained sand
- Fine-grained silty sand
- Bedrock
- Dissolved Plume

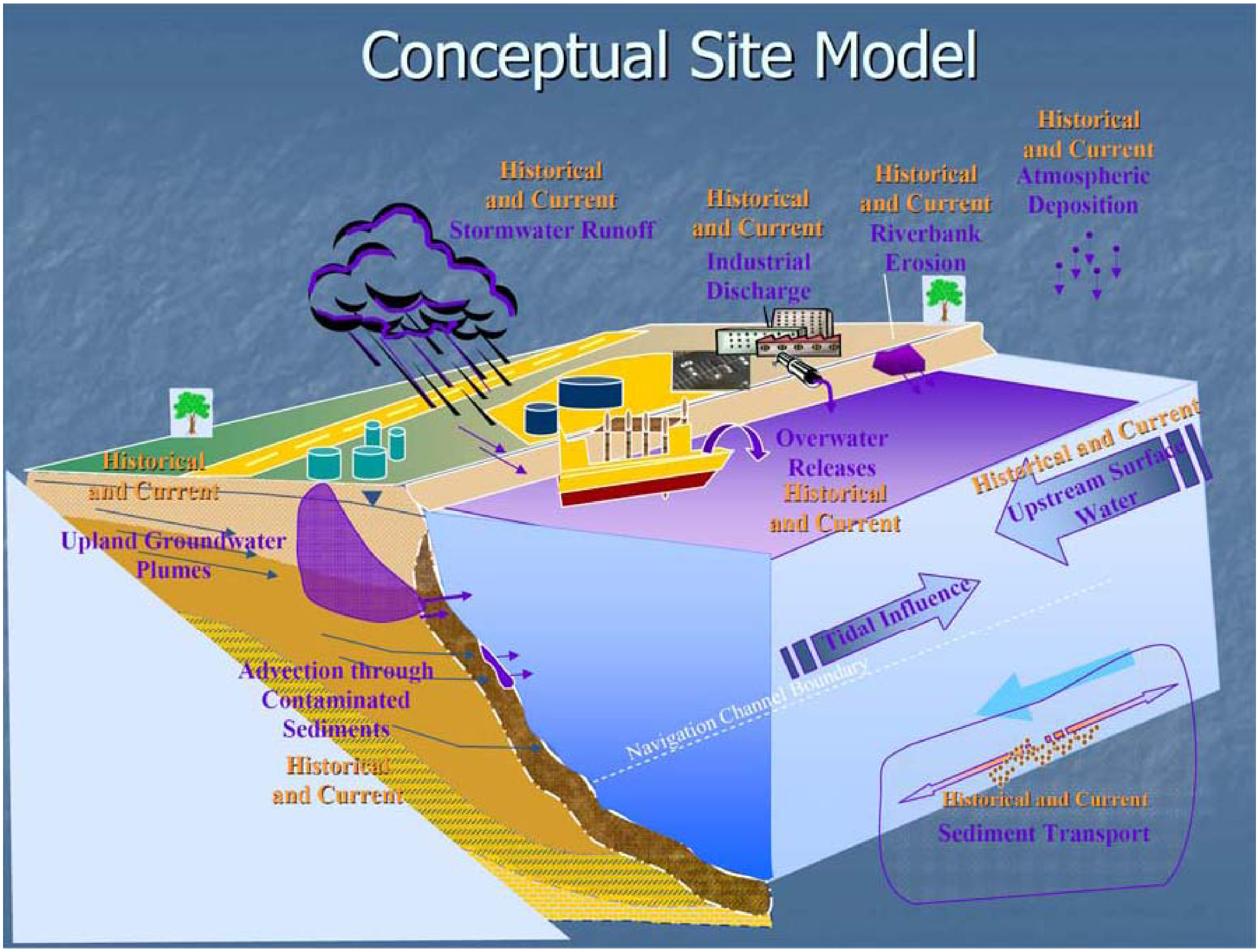
Source: Performance Monitoring of MNA Remedies for VOCs in Ground Water (EPA, 2004a)

## Figure 2: Hydrogeologic CSM Example Cross Section




Source: EPA, 2008b. Interim Record of Decision, Moses Lake Wellfield Superfund Site, Moses Lake, Washington

Figure 3: Groundwater/Surface Water CSM Example




Source: EPA, 2009b. Five-Year Review Report, Third Five-Year Review Report for Commencement Bay Nearshore Tideflats Superfund Site. Tacoma, Washington, December 23, 2009.

## 17. KEY TECHNICAL RESOURCES FOR FYRS AT GROUNDWATER SITES

Because web links tend to change over time, an attempt has been made to include enough information about each document to facilitate web searches.

### 17.1 General Groundwater References

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### 17.2 EPA Five-Year Review Guidance

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### 17.4 Remedy Optimization

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### 17.14 Useful Websites

EPA's Five-Year Reviews web page (links to guidance, supplements, fact sheets, reports to Congress, etc.) http://www.epa.gov/superfund/fiveyearreview/

EPA's Technical Support Project Ground Water Forum http://www.epa.gov/superfund/remedytech/tsp/issue.htm#GWF

Topics Include:

- Groundwater Sample Preservation and In Situ Chemical Oxidation Sites
- Evaluating Ground-Water/Surface-Water Transition Zones in Ecological Risk Assessments
- Fingerprint Analysis of Contaminant Data
- Phytoremediation of Contaminated Soil and Ground Water at Hazardous Waste Sites
- Steam Injection for Soil And Aquifer Remediation
- How Heat Can Enhance In-Situ Soil and Aquifer Remediation
- Natural Attenuation of Hexavalent Chromium in Groundwater and Soils
- Suggested Operating Procedures for Aquifer Pumping Tests
- Chemical Enhancements to Pump-and-Treat Remediation
- In-Situ Bioremediation of Contaminated Ground Water
- Groundwater Sampling Guidelines

CLU-IN: EPA's Hazardous Waste Cleanup Information http://www.clu-in.org/. The DNAPL Contaminant Focus Area on CLU-IN has over a thousand references: http://www.clu-in.org/dnapl

FRTR: Federal Remediation Technologies Roundtable http://www.frtr.gov/

ITRC: Interstate Technology and Regulatory Council http://www.itrc.web.org