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GROUNDWATER REMEDY COMPLETION STRATEGY:
Moving Forward with Completion in Mind

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1. Introduction

1.1 Purpose and Scope

This document presents a recommended strategy for evaluating Superfund groundwater remedy performance and decision making to help facilitate achievement of remedial action objectives and associated cleanup levels. Groundwater remediation is a component of more than 90% of Superfund sites where a remedy has been selected (EPA, 2013b). Groundwater remediation can take from years to decades to meet objectives. To ensure protectiveness of human health and the environment, it is generally important to have defined metrics in place to measure performance and a clear decision making process to determine if the remedy selected in a Record of Decision (ROD) is operating as anticipated or to evaluate whether other remedial actions and/or remedy modifications may be needed.

As used in this document, a "groundwater remedy completion strategy" is a recommended site-specific course of action to achieve groundwater remedial action objectives (RAOs) and associated cleanup levels selected in the site decision documents. The strategy describes a recommended step-wise plan and decision making process for evaluating remedy operation, progress and attainment of RAOs using an updated conceptual site model, performance metrics and data derived from site-specific remedy evaluations. A completion strategy is designed to help the site team focus resources on the information and decisions needed to effectively move a site to completion and ensure protection of human health and the environment. An overview of the recommended groundwater strategy concept is presented in Figure 1.

> A *Groundwater Remedy Completion Strategy* is a recommended site-specific course of action(s) and decision making process(es) to achieve groundwater RAOs and associated cleanup levels using an updated conceptual site model, performance metrics and data derived from site-specific remedy evaluations.

EPA recommends that a completion strategy be developed for all Superfund Fund-lead, potentially responsible party (PRP)-lead and federal facility-lead groundwater remedies. The recommended approach generally should be useful throughout all phases of the cleanup – including remedy selection, remedial design/remedial action, long-term remedial action and operation and maintenance. While this guidance focuses on groundwater restoration remedies, the recommended approach also may be useful for CERCLA[1] remedial actions that do not include a groundwater restoration RAO.

This document is based upon existing Superfund law, regulations, policy and guidance to present a recommended groundwater completion or "exit" strategy reference. This consolidated information is intended to enhance the understanding, development and application of site-specific strategies. The intended audience for this document is EPA technical professionals who analyze groundwater data and EPA managers who either review analyses or make decisions based upon them. Others that may find this document useful include other regulators and technical representatives of states, tribes, other federal agencies, PRPs and community members.

This guidance includes recommended remedy evaluation questions and provides some recommended evaluation criteria to consider during remedy selection and implementation. As with other EPA guidance documents, site teams are encouraged to use this document when making site-specific decisions. **This guidance**

[1] The Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986, and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) provide the statutory and regulatory foundation for Superfund response actions.

does not alter or supersede existing CERCLA guidance (including existing policy regarding remedial objectives or cleanup levels).

This guidance is designed to help promote a consistent national approach for implementing groundwater remedies to completion. It does not, however, substitute for CERCLA or EPA's regulations, nor is it a regulation itself. EPA, state, tribal and local decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate. Any decisions regarding a particular facility will be made based on the applicable statutes and regulations. It does not impose legally binding requirements on EPA, states, tribes or the regulated community, and may not apply to a particular situation based upon the circumstances. Furthermore, this guidance does not address groundwater classifications or groundwater use designations, and should not be used to request states or tribes to address that issue.

1.2 Background

The Superfund law, implementing regulations, policy and guidance provide the science-based technical foundation for Superfund groundwater response actions. 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 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 threatened release."

Furthermore, the NCP (40 CFR §300.430(a)(1)(iii)(F)) 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."

This document complements existing EPA guidance for evaluation of groundwater remedies (EPA, 1994; EPA, 1996; EPA 1999b; EPA, 2002; EPA, 2004b; EPA, 2005), the *Summary of Key Existing EPA CERCLA Policies for Groundwater Restoration* (EPA, 2009), the *Groundwater Road Map* (EPA, 2011b) and *Guidance for Evaluating Completion of Groundwater Restoration Remedial Actions* (EPA, 2013a). The *Road Map* summarizes the recommended steps when conducting a groundwater remedy and along with other existing Superfund guidance documents provides a basis for developing groundwater strategies. For other groundwater guidances, please refer to the Superfund groundwater website[2].

2. Elements of a Groundwater Remedy Completion Strategy

An overview of the groundwater completion strategy process is shown graphically in Figure 1 and in greater detail in Figures 2 and 3.

More information on several important components of an effective groundwater remedy completion strategy is described in Appendix 1. These include: (1) improving the current and comprehensive understanding of the site characteristics; (2) developing definitive RAOs and associated cleanup levels and timeframes; and (3) improving the current understanding of other site actions related to the groundwater cleanup.

[2] http://www.epa.gov/superfund/health/conmedia/gwdocs/.

Key recommended steps for developing and implementing a groundwater completion strategy include:

Understand the Site Conditions. An important foundation for the remedy completion strategy development typically is a comprehensive understanding of the site. An accurate and updated conceptual site model (CSM), including current site and remedy characteristics, is a key component in developing a completion strategy (EPA, 2011c). The existing CSM, especially if it was developed as part of the ROD development, may need to be re-evaluated for modification based on recent data collection. Understanding site specifics related to the groundwater contamination and how it is translated into a CSM normally is a dynamic process and typically evolves as the cleanup actions progress.

Design Site-specific Remedy Evaluations. Site-specific remedy evaluations normally should be based on questions that can help evaluate how the remedy selected in the ROD is being implemented throughout the cleanup process. Performance monitoring results often can be used to inform decisions about remedy performance and progress toward attainment of RAOs and cleanup levels. Examples of recommended remedy evaluation questions include:

- Are the treatment units functioning as intended?
- Are concentrations of the contaminants of concern (COC) identified in the ROD decreasing as anticipated?
- Is the plume shrinking as anticipated?

Develop Performance Metrics and Collect Monitoring Data. Performance metrics may include site-specific remedy performance criteria, hydrogeologic parameters or contaminant concentration trends that can be used to evaluate remedy performance and measure progress. Examples of recommended performance metrics include effluent discharge concentrations, diagnostic parameters values (*e.g.*, O_2 levels), and contaminant concentrations trends in a monitoring well. Performance metrics should be selected to help generate information that can be used to answer the site-specific remedy evaluations discussed above. A site-specific monitoring program generally should be developed, and updated as appropriate, to collect data that can be used to evaluate these metrics.

Conduct Remedy Evaluations. Using the performance metrics and monitoring data, the remedy operation, progress and attainment of RAOs and cleanup levels should be assessed in a timely manner to address the remedy evaluation questions. As part of the exit strategy, an attainment evaluation is recommended at each well after it has been determined that the groundwater remediation phase has been completed.

Make Management Decisions. Based on the remedy evaluations, decisions should be made regarding remedy next steps and any changes that may be appropriate. Depending on the significance of any changes, a ROD Amendment or ESD may be needed (EPA, 1999a). Remedy optimization or alternate response approaches may be warranted if performance indicates that the selected remedy may be unable to achieve the groundwater RAOs and cleanup levels in a reasonable timeframe as defined in the ROD.

Site-specific Remedy Evaluations should be conducted throughout the life cycle of the groundwater remedy to make decisions about remedy performance and progress toward attainment of remedial action objectives and cleanup levels (*e.g.*, Are treatment units functioning as intended?; Are the concentration trends as anticipated?). Evaluations should be conducted using site-specific performance metrics and site data.

Performance Metrics should be site-specific remedy performance criteria, hydrogeologic parameters or contaminant concentration trends typically used to evaluate remedy performance and measure progress (*e.g.*, effluent discharge concentrations, contaminant concentrations trends in a monitoring well).

The remedy completion strategy approach is modeled on the EPA-endorsed Data Quality Objectives (DQO) process that is designed to refine project information needs and focus monitoring efforts on collecting the appropriate type and amount of data that can adequately support key decisions (EPA, 2000a; EPA, 2004a; EPA, 2004b). This strategy is intended to provide a technical and scientific process for evaluating when sufficient data have been obtained to assess the likelihood that the groundwater remedy has or will achieve the RAOs and associated cleanup levels.

It is recommended that the completion strategy include a schedule for monitoring and evaluations to help ensure efficient and timely decision making. Implementation of the groundwater completion strategy is usually dynamic and iterative. With ongoing data collection, evaluation of the performance metrics and remedy assessment, the completion strategy process and findings should be updated periodically to facilitate open and transparent communications within the project team and site stakeholders.

It is recommended that the completion strategy be developed as early as possible in the remedy selection and implementation process. Depending on the stage of cleanup when the strategy is first developed, it may be described in one or more site documents. As appropriate, the strategy may be described conceptually as part of a remedy decision document (*e.g.,* ROD, ROD Amendment, Explanation of Significant Differences [ESD]). Development of the strategy as a component of the remedy design phase can help lay the foundation for effective remedy implementation. The strategy also may be described in more detail in the site Operations and Maintenance Plan, monitoring reports and the Five-Year Review. A stand alone document may also be appropriate for describing a completion strategy. Consistent with the NCP's provisions regarding site records management, the completion strategy should be documented in the site file.

A modest level of effort may be needed to create and maintain the remedy-specific strategy. An increased focus on gathering data to support cleanup decisions generally should help document how and when remedial objectives are being achieved.

The remedy completion strategy should be dynamic and as such should be reevaluated and updated as the cleanup progresses and changes (if any) are made to the remedy, remedy operation or monitoring plans. The review frequency should reflect the level of site activity and rate of changing site conditions. It is recommended that the remedy completion strategy be evaluated concurrently with the Five-Year Review.

3. Understand the Site Conditions

As part of completion strategy development, it generally is important to have accurate knowledge of the historical site activities as well as a current and updated understanding of the site conditions and response actions. This may include consideration of:

- A current CSM and associated data;
- State groundwater classification or groundwater use designations;
- Site groundwater RAOs, the associated cleanup levels for all contaminants of concern (COCs), and the area of attainment or point of compliance;
- Timeframe estimated to achieve cleanup;
- Groundwater cleanup actions;
- Other site remedies for groundwater and other media including the status, goals and potential impact on the groundwater remedy; and
- Results of any optimization or other remedy or site reviews.

Some of these factors (in particular the CSM) are often likely to change as the cleanup progresses. See Appendix 1 for further discussion of the CSM, RAOs and other technical foundations that are relevant to development of site-specific groundwater completion strategies.

4. Design Site-specific Remedy Evaluations

The remedy completion strategy normally should describe how groundwater remedial actions at the site can be evaluated during implementation. A systematic approach can be used to develop the questions to evaluate groundwater remedy operation, as well as progress toward, and attainment of RAOs and cleanup levels (EPA, 2000; EPA, 2004a; EPA, 2013a). Multiple lines of evidence generally can strengthen the remedy evaluation conclusions. Figures 2 and 3 provide a graphical example of a recommended remedy evaluation structure.

The process of developing evaluation questions should serve to refine and focus the information needed to inform project decision points. The remedy evaluations may help address and explain challenging situations with sources of groundwater contamination from nearby sites or asymptotic declines in contaminants to concentrations above RAOs. The recommended strategy structure is intended to help the project team characterize the situation as well as identify in advance the information and data that should be useful for evaluation of the remedy with an appropriate level of confidence.

Remedy performance evaluations typically include the following categories:

- Remedy operation;
- Progress toward groundwater RAOs and associated cleanup levels; and
- Attainment of RAOs and cleanup levels.

Other factors, such as source remediation and hydrogeologic features, generally are also important to consider at decision points. It is recommended that the evaluation questions be periodically reviewed to ensure they remain valid and appropriate. If remedy evaluation questions change, then it may also be appropriate to revise the performance metrics and the monitoring plan accordingly.

4.1 Design Remedy Operation Evaluations

This guidance recommends developing questions to evaluate remedy operation during implementation which consider all facets of the selected remediation approach that may impact the groundwater remedy performance and operation. Below are examples of questions that may be appropriate to ask concerning remedy operation:

- Are the groundwater well extraction rates and locations adequate to capture the contaminated groundwater?
- Are the treatment units functioning as intended?
- Are effluent levels/discharge performance levels being achieved?
- Is contaminated groundwater migration under control?
- Are there remedy optimization opportunities?

Analysis of site-specific remedy evaluations is discussed in Section 6.1.

4.2 Design Remedy Progress Evaluations

During remediation, generally data are collected to monitor cleanup progress toward attainment of RAOs and associated cleanup levels in the expected timeframe. Below are example questions that may be included in the completion strategy to evaluate cleanup progress:

- Are there decreases in COC concentrations occurring in the contaminated groundwater, and in a reasonable timeframe, as discussed in the ROD?
- Is there a reduction in mass discharge as measured in the extraction wells?

- Is the groundwater flow direction as expected and have temporal, seasonal or tidal influences been assessed and considered?
- Is the mass removal rate as expected?
- Are there potentially hazardous and/or mobile breakdown products present in sampling data?
- Is there evidence of attenuation, degradation and/or stabilization of COCs?
- Is the extent of contaminated groundwater shrinking in all three dimensions?
- Are there unacceptable impacts to receptors via water supply wells, surface water bodies, indoor air or other pathways?
- Do contaminant concentrations trends indicate that RAOs and cleanup levels are likely to be met in the expected timeframe discussed in the ROD?
- Are there opportunities for system or monitoring network optimization?

Evaluation of site-specific remedy progress considerations is discussed in Section 6.2.

4.3 Design Attainment Evaluations

As part of the completion strategy, an attainment evaluation is recommended at each well after it has been determined that the groundwater remediation phase is complete. During the attainment monitoring phase, monitoring well specific conclusions should be used “to provide a scientific basis supporting the Agency’s conclusion that the groundwater has met and will continue to meet cleanup levels for all COCs in the future” (EPA, 2013a). The data set for the attainment evaluation should reflect post remediation, or steady state, site conditions where remediation activities, if employed, are no longer influencing the groundwater in the well. Site-specific attainment evaluation questions for each well may include:

- Has the contaminant cleanup level for each COC been met? and
- Will the groundwater continue to meet the contaminant cleanup level for each COC in the future?

Evaluation of attainment is discussed further in Section 6.3.

4.4 Evaluate Other Site Factors

In general, the success of groundwater remedial actions is related to the removal or containment of contaminant sources. However, groundwater remedy performance also may be affected by other outside influences. Some examples of other site factors that may be relevant include:

- Is source remediation to protect groundwater progressing as intended?
- Do data indicate that source containment and/or reduction continue to meet RAOs?
- Has the groundwater elevation or site flow regime changed due to drought, flood, off-site pumping or other circumstances?
- Is there a change in land use that impacts groundwater and/or the monitoring system?
- Are there changes in groundwater use or land use that may impact the treatment system or monitoring network?

Evaluation of other site factors as part of the completion strategy is discussed in Section 6.4.

5. Develop Performance Metrics and Collect Monitoring Data

The remedy operation, progress and attainment evaluation questions generally should be answered using site-specific performance metrics and monitoring data.

5.1 Develop Performance Metrics

In the completion strategy context, effective decision making is usually dependent upon quantifiable, transparent metrics of remedy performance and progress. Performance metrics normally should include remedy performance criteria, contaminant concentration trends and hydrogeologic parameters used to evaluate the remedy performance and measure progress (EPA 1994; EPA, 2004b; EPA 2011b). Performance metrics are typically objective, quantitative measurements. Since some remedies may require a long time to achieve completion, metrics may include interim measures of progress toward the RAOs and cleanup levels. Over the life of the remedy, the metrics may change as the remedy evolves. Well-defined metrics generally are important tools for informing remedy evaluations (see also Figure 3).

Performance metrics included in the strategy may include the following:

- Remedy operation metrics (*e.g.*, extraction rate, capture zone, effluent concentration, influent concentration trend, carbon usage rate);
- Progress metrics (*e.g.,* rates of reduction of contaminant volume and/or mass, COC trends, microbial populations); and
- Attainment metrics (*e.g.,* individual well COC concentration mean and confidence levels, individual well COC trends, overall COC trends).

Multiple metrics and the resulting lines of evidence generally can help strengthen the data and information used to support decision making throughout the remedy implementation process.

5.2 Develop or Update the Monitoring Plan

During remedy implementation, "groundwater sampling and monitoring data are typically collected to evaluate contaminant concentrations through time at appropriate locations" (EPA, 2011b). Monitoring usually includes system performance parameters, contaminant concentrations and hydrogeologic parameters. Consistent with existing Superfund guidance, the groundwater monitoring network should be evaluated at an appropriate frequency and spatial density during the remedial action to ensure adequate and accurate evaluation of groundwater contaminant concentrations and footprint changes over time. Long-term monitoring "…should involve repeated sampling over time in order to define the trends in the parameters of interest relative to clearly defined management interests" (EPA, 2004a). The monitoring well network should adequately delineate the lateral and vertical extent of contamination in the groundwater aquifer(s) and enable evaluations of contaminant concentrations and contaminated groundwater migration over time.

Site monitoring plans generally should be reviewed regularly (at least at the same time as the Five-Year Review) to ensure that sufficient data are being collected to support decision making. The monitoring parameters and frequency may change as the site progresses from characterization to long-term remedial action effectiveness monitoring to attainment monitoring (EPA, 2004a; EPA, 2004b).

Data over a period of several years are usually collected to gather information sufficient to accurately analyze trends or changes in contaminant concentrations, to assess capture of the contaminated groundwater and to evaluate cleanup progress. Data evaluation methods should be identified early to help ensure that adequate data can be collected to support analysis and decision making (EPA, 2008).

6. Conduct Remedy Evaluations

As operational and monitoring data are collected, these data should be examined by the project team to assess trends and patterns, to verify or update the CSM and to evaluate the performance metrics (EPA, 2000a; EPA, 2004a; EPA, 2004b). Trend analysis often is an important component of remedy evaluation. "Trend analysis evaluates data collected at specified intervals over a specified period in order to determine if conditions are changing over time, and if so, how they are changing (*i.e.*, the magnitude and direction of the change" (EPA, 2004a). A typical key component of the evaluations is determining if concentrations are decreasing, increasing or if there is no trend. Data variability and uncertainty associated with the sample matrix, sampling techniques and analytical methods also should be considered as part of the evaluation.

6.1 Evaluate Remedy Operation

The evaluation of engineering, operating and monitoring components of the remedy should indicate whether the system is functioning adequately to achieve the RAOs and associated cleanup levels.

If data indicates that the remedy is meeting performance metrics as anticipated, then the system is generally considered to be operating adequately. While system operations may be adequate, it may be beneficial to consider remedial system and/or monitoring optimization (EPA and USACE, 2005; EPA, 2007; EPA, 2012). There may be opportunities to improve remedy efficiency to reduce costs and/or achieve cleanup levels more effectively.

If the remedy is not meeting or may not be able to meet the performance metrics as expected, then this may indicate the need for an optimization review and/or revaluation of the existing remedy (EPA, 2012). Situations that may indicate that the system is not meeting the performance goals include, but are not limited to, the following:

- Engineering specifications not met;
- Contaminant levels not decreasing as anticipated;
- Plumes are expanding or migrating;
- Treatment efficiencies not met;
- Extraction/injection rates not met; or
- Discharge limitations exceeded.

Following the evaluation, a decision should be made whether to consider changes or other adjustments to the selected remedy in order to improve remedy performance, as discussed in more detail in Section 7.

6.2 Evaluate Remedy Progress

Evaluation of the remedy performance metrics and monitoring data should indicate whether it is likely that the RAOs and cleanup levels will be achieved in a reasonable timeframe with the existing system. If contaminant concentrations are decreasing in a timely manner and other progress performance metrics are being achieved, then it is likely that the remedial approach is functioning as intended and the remedy is likely to achieve RAOs and cleanup levels in a reasonable timeframe as selected in the ROD. If this is the case, then it is generally recommended that remedy implementation continue.

If a well-by-well progress evaluation indicates that cleanup levels have initially been reached for all COCs, then it may be appropriate to conduct an evaluation of attainment (EPA, 2013a). See section 6.3 for further discussion of the attainment evaluation.

If monitoring data and analyses suggest that the remedy is not achieving sufficient progress, then the remedy may need to be revisited. It is recommended that the project team evaluate whether:

- The remedial action may achieve RAOs and cleanup levels with modification to the selected remedy;
- The remedy is not likely to achieve RAOs and associated cleanup levels in the timeframe envisioned in the ROD;
- The remedy is not likely to achieve RAOs and associated cleanup levels in the timeframe envisioned in the ROD, but a new projected timeframe is still deemed reasonable; or
- The remedy is not likely to achieve RAOs and cleanup levels in any reasonable timeframe.

If the cleanup is not making sufficient progress toward implementing the remedy selected in the ROD, then next steps may include:

- Conduct further investigation to define the source and plume geometry.
- Update the CSM.

- Optimize the remedy.
- Optimize long-term monitoring.
- Evaluate other cleanup technologies.
- Implement ROD contingency remedy[3]
- Amend the ROD.

Any additional investigations normally should target information that is designed to effectively and efficiently inform next steps specifically and the decision making process. Additional investigations/evaluations may lead to a focused feasibility study and potentially modification of the existing remedy. Depending on the significance of any modifications, a revised decision document may be required (EPA, 1999a).

6.3 Evaluate Attainment of RAOs and Cleanup Levels

An attainment evaluation generally evaluates "contaminant of concern (COC) concentration levels on a well-by-well basis to assess whether aquifer restoration is complete" (EPA, 2013a). To the extent practicable, before an attainment evaluation is conducted at a well, operation of the active system in the vicinity of the monitoring well should be terminated. This allows for re-equilibration of the local hydrogeologic system and for the groundwater to reach steady state. Groundwater restoration remedial actions should generally be considered complete when monitoring well-specific data and provide a scientific basis to conclude that the groundwater has met and will continue to meet cleanup levels for all COCs in the future, in accordance with the decision document.

At the beginning of the attainment monitoring phase, it may be appropriate to review the monitoring plan to ensure an adequate amount of supporting data will be collected to conduct the evaluation. During the attainment monitoring phase, the data from each monitoring well should be evaluated to confirm that the groundwater remedy continues to meet the cleanup levels for each COC and will continue to meet cleanup levels for all COCs in the future (EPA, 2013a).

"If the monitoring well-specific conclusions and other site information support a conclusion that the groundwater restoration remedial action is complete in accordance with the decision document(s), this determination typically is documented in the final close out report for the site" (EPA, 2013a).

If the evaluation indicates that the RAOs and associated cleanup levels have not been met throughout the contaminated aquifer, then the project team should evaluate what changes (if any) can be implemented to achieve the remedy selected in the ROD (see Section 6.2 of this document). It may be that continued operation of the existing system will achieve cleanup levels, but just over a longer timeframe. However, additional site characterization may be warranted (such as additional delineation of the source or groundwater contamination) or the remedial technology may benefit from optimization, or may be determined to be no longer viable. If, based on the evaluation, the Region determines that RAOs and cleanup levels are not likely to be achieved, it generally is appropriate to consider other cleanup approaches as discussed in Section 7. This iterative decision making process, which should include consideration of other cleanup approaches, generally is an important part of the strategy process, as is discussed further in the Section 7 of this document.

[3] USEPA, "A Guide to Preparing Superfund Proposed Plans, Records of Decision, and other Remedy Selection Decision Documents" (OSWER 9200.1-23P, July 1999a). "Generally, an ESD will be required to invoke a contingency. However, if the contingency remedy or the criteria for its selection are not well-documented in the ROD, a ROD amendment may be required to invoke this cleanup option at a later point in time." (See page 8-3 to 8-4.)

6.4 Evaluate Other Site Factors

In conjunction with the above remedy-specific evaluations, it may be appropriate to evaluate other site factors to fully assess whether a remedial action is likely to meet and maintain the RAOs and associated cleanup levels selected in the ROD. For example, if a previously unidentified contaminant source is discovered, this may require re-evaluation of the remedy (and potentially a revised decision document). These evaluations may be conducted in parallel with or separately from the remedy operation, progress and attainment evaluations discussed above.

7. Make Management Decisions

This section describes some of the key options to consider if it appears that the remedial action will not be able to achieve the groundwater RAOs and associated cleanup levels selected in the ROD. These factors may be considered at the same time as the Region evaluates the protectiveness of the remedy under the Five-Year Review (EPA, 2001). Consideration of other cleanup approaches should involve all states, tribes, PRPs and all other appropriate stakeholders. Consistent with CERCLA and the NCP, Changes that significantly or fundamentally alter the selected remedy require an ESD or ROD Amendment (EPA, 1999a).

7.1 Other Remedial Alternatives

If remedy evaluations indicate that the selected remedy may not attain the RAOs and cleanup levels in a reasonable timeframe, as selected in the ROD, then it may be appropriate to consider other remedial alternatives (EPA, 1999a; EPA, 2011b). Depending on the nature of site data and data gaps, additional data gathering may be appropriate to support evaluations and decision making. For example, other treatment approaches or technologies may have become available since the current remedial action was selected. Activities that may be considered to achieve the RAOs and associated cleanup levels in a reasonable timeframe, as selected in the ROD, include:

- Additional site investigation to address critical data gaps identified in the evaluations described above;
- Evaluation of additional source removal, containment or treatment;
- Optimization of existing remedial technology; or
- Selection of additional treatment approaches.

It may be appropriate to prepare a focused feasibility study (FFS) to evaluate and document consideration of new remedial alternatives (EPA, 1988a). The FFS may consider many activities, including but not limited to remedy optimization, alternative treatment technologies, and a change from an active to a passive remedy or other remedial approaches (*e.g.*, greater reliance on institutional controls if active remediation cannot achieve RAOs and associated cleanup levels). In cases where there is a high degree of certainty that cleanup levels cannot be achieved with the current remedy, it may be appropriate to consider an ARAR waiver consistent with technical impracticability (TI) guidance (EPA, 1993).

7.2 Consider the Need for an ARAR Waiver

If remedy operation, progress or attainment evaluations indicate that the current RAOs and associated cleanup levels selected in the ROD are not likely to be achieved, even after optimization and after considering other cleanup approaches, then it may be appropriate to modify the groundwater restoration RAOs and explore whether a TI waiver should be considered. "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 from an engineering perspective, protective of human health and the environment, and satisfies the statutory and regulatory requirements of Superfund" (EPA, 1993).

8.0 Conclusion

Groundwater remediation can be a lengthy process. As discussed in this guidance, a groundwater remedy completion strategy is a recommended process for evaluating groundwater remedy performance and guiding Agency decision making to ensure remedial actions protect human health and the environment. The decision points, performance metrics and monitoring that typically comprise the remedy completion strategy can help assess remedy performance and evaluate whether the remedial action is working as anticipated or if the remedy selected in the ROD may need to be modified in order to achieve RAOs and associated cleanup levels. Consideration of a completion strategy generally may be appropriate throughout the cleanup process, and should help focus resources on evaluating the remedy selected in the ROD, its operation and progress toward attaining the RAOs and associated cleanup levels in a reasonable timeframe.

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Appendix 1 - Recommended Technical Foundations for Site-Specific Completion Strategy Development

An effective groundwater remedy completion strategy generally should consider several related features of a site and the remedy selected in the ROD. These recommended "technical foundations" normally should include: (1) improving the current and comprehensive understanding of the site characteristics; (2) developing definitive RAOs and associated cleanup levels and timeframes; and (3) improving the current understanding of other site actions related to groundwater cleanup. This appendix describes these technical aspects in more detail.

Update or Verify the Conceptual Site Model
A good understanding of subsurface structure and processes as depicted in a current CSM generally is important for development of a groundwater completion strategy. The CSM should be an iterative, "living representation" of a site that summarizes and helps project teams visualize and understand available information (EPA, 2011c). The CSM "synthesizes data acquired from historical research, site characterization, and remediation system operation… the CSM, like any theory or hypothesis, is a dynamic tool that should be tested and refined throughout the life of the project" (EPA, 1993). The CSM also is designed to foster consistent site understanding among the members of the project team and site stakeholders.

CSMs generally should build upon findings from past site investigations, historic and current site operations and intended site reuse. 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 ecological exposure through contaminant release and migration to potential receptors" (EPA, 1999a). As appropriate, a component or outcome of the CSM may be identification of uncertainties and data gaps.

The level of effort to develop the CSM should roughly correlate with the site maturity, site complexity and the extent of site characterization. Technical teams are encouraged to use the CSM in a framework that evolves and continues to incorporate new information as the project characterization and remediation progresses[4]. A life-cycle CSM is essential to identify the need for additional information to minimize the data gaps that may be impeding an understanding of why a remedy may not be performing as anticipated.

"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" (EPA, 1988a). The improved site understanding that can emerge from an updated CSM can help the project team understand and evaluate remedy progress.

Identify Groundwater Remedial Action Objectives, Associated Cleanup Levels and Timeframe
Groundwater RAOs generally provide a solid foundation for effective remedy implementation, development of the groundwater completion strategy and ultimately site completion and deletion. "RAOs provide a general description of what the cleanup will accomplish (*e.g.,* restoration of groundwater to drinking water levels)" (EPA, 1999a). The basis and rationale for RAOs (*e.g.*, current and reasonably anticipated future land use and potential beneficial ground-water use) are typically developed as part of the feasibility study. Consistent with CERCLA, the

[4] The importance of a life cycle CSM that can be used as a project management and decision making tool is further discussed in EPA, 2011c. Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Model. OSWER Directive 542-F-11-011 - see http://www.epa.gov/tio/download/remed/csm-life-cycle-fact-sheet-final.pdf.

NCP and Superfund guidance documents, site decision documents (ROD, ROD Amendment or ESD) should describe the groundwater RAOs and cleanup levels (EPA, 1999a; EPA, 2009; EPA, 2011).

Depending on site conditions, multiple RAOs may be appropriate for groundwater remedies. "RAOs and associated cleanup levels should be easily identified and "clearly present the intended results of the remedial action" (EPA, 1999a). "A range of RAOs may be applicable to ground-water [*sic*] remedy decisions. Some of these objectives may be achievable in a relatively short timeframe (*e.g*., exposure control, plume containment), while other objectives may require a much longer timeframe (*e.g*., restoration)" (EPA, 1999a). In addition to groundwater RAOs, groundwater remedies it may also be appropriate to include RAOs for other media (*e.g.*, soils, sediment, surface water).
The basic foundation for groundwater RAOs generally includes 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)"* (EPA, 1999a).

"Basic RAO structures are generally used as a starting point for RAO development and should be modified to include site-specific exposure scenarios and more specificity" (EPA, 2011b). The groundwater RAOs should state if the remedy objective is restoration or containment. Commonly used terms in groundwater RAOs are restore, prevent and minimize. Definitions of these terms are provided in the glossary of this document. The use of these terms as defined in the glossary is encouraged to promote consistency in the development of RAOs. Groundwater remedies will often have a restoration RAO based on the NCP expectation that groundwater will be restored to beneficial use[5]. If there is a waste management unit or a Technical Impracticability Waiver, then inclusion of containment RAO will be appropriate. In cases where there are both groundwater restoration and containment RAOs, the decision document should clearly identify the applicable portion of the aquifers.

In addition to RAOs, proposed and final decision documents should include "cleanup levels for each medium (i.e., contaminant specific remediation goals), basis for cleanup levels, and risk at cleanup levels (if appropriate)" (EPA, 1999a)[6]. Cleanup levels should be identified for each contaminant of concern. In many cases, ARARs, for example MCLs for groundwater, are generally the cleanup level or measurable remedy endpoint" (EPA, 1999a). "Final cleanup levels establish acceptable contaminant-specific exposure levels that are protective of human health and the environment (EPA, 1999a). "Groundwater cleanup levels are established based on promulgated standards (*e.g*., federal or state MCLs or non-zero MCLGs, or other standards to be found to be ARARs, or risk-based levels (*e.g.,* for contaminants when there are no standards that define protectiveness)" (EPA, 2009). This measure is crucial in determining when an RAO has been achieved to allow the Agency to move the operable unit or site to completion.

Understand Site Actions Related to Groundwater Cleanup
The site team should understand past, ongoing and future site activities related to the groundwater contaminants and groundwater cleanup. Information is typically available from the remedial

[5] *"EPA expects to return usable ground waters to their beneficial uses wherever practicable, within a time frame 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" 40 CFR 300.430(a)(1)(iii)(F).*

[6] Interim decisions may be issued and are followed by a final ROD which identifies the final ARARs and cleanup levels (EPA, 1999a).

investigation/feasibility study, remedy decision documents, Five-Year Review reports and other site related documents. Other activities or conditions at the site (*e.g.*, source control actions) that may impact the groundwater remedy and long-term operation and maintenance of the remedy should also be considered (EPA, 1988a; EPA 1999a; EPA 2001; EPA 2005; EPA, 2011b; EPA, 2012).

Groundwater Remedy
The site-specific strategy developed by the Region typically should note if the groundwater remedy actions are phased, interim or final and whether it is a restoration response and/or groundwater containment response[7]. The status of the remedy implementation, timeframe and anticipated next phases, if applicable, should be described.

Other Remedy Components
In addition to the selected groundwater remedy, other media information may also be important to consider. Identify if early actions were taken to control sources, exposure and/or contaminant migration. Superfund site cleanups may include remedial actions that address other media such as source areas, surface water, soil, sediment and air. Examples of other cleanup components which may influence the groundwater remedy include removal actions, source remediation activities (*e.g.*, excavation and off-site disposal, NAPL recovery, soil vapor extraction and/or destruction), source containment features (*e.g.*, landfill cap, subsurface barriers) and institutional controls. Depending on the site, it may also be important to consider impacts from flooding, drought and climate change. The completion strategy should briefly summarize these site-related activities since they impact the groundwater remedy and influence definition of the strategy decision points. The discussion should include the implementation status and anticipated next phases of these actions.

Operation and Maintenance (O&M) and Long-term Monitoring
During groundwater remedy implementation, operational and monitoring data should be regularly collected to evaluate and monitor progress toward attainment of RAOs and associated cleanup levels as well as evaluating the efficiency of the system (EPA, 2004a, EPA, 2005; EPA, 2011a).

Optimization Reviews (if conducted to date)
Periodic optimization reviews can improve the operation and efficiency of groundwater remedies. Optimization of remedy performance considers improvements to operational parameters (*e.g.*, flow rate, well locations); treatment components and other remedy elements related to ensuring efficacy of the groundwater remedy (EPA, 2005; EPA, 2007; EPA, 2012). Long-term monitoring optimization considers whether the monitoring network is sufficient to provide the appropriate data to evaluate remedy progress, protectiveness and attainment of RAOs and cleanup levels.

If remedy engineering performance or monitoring optimization efforts have been previously conducted for the groundwater remedy, the outcomes and findings should be considered during development of the groundwater completion strategy. The nature of the evaluations, findings and any outcomes should be considered as these may provide additional information supportive of the strategy. The results of previous optimization reviews can help inform and frame the utility of any subsequent optimization reviews that may be part of the strategy.

[7] Groundwater remedy features that should be briefly described include, but are not limited to, the following: in situ/ex situ treatment components; monitored natural attenuation components; groundwater-related institutional controls; and groundwater monitoring.

Other Site Factors
Other site factors may affect groundwater remedy components and cleanup progress. These normally will be site-specific and could include current site and surrounding land uses as well as reasonably anticipated future land uses. Examples of other factors that may impact the groundwater remedy include public, domestic, irrigation and other water supply wells; water applied for landscaping, irrigation or other purposes; subsurface injection or drainage; nearby construction projects; extreme weather events such as floods and droughts; and others.

Appendix 2 - Glossary

For purposes of this guidance, the following terms are defined as follows:

Attainment – an outcome which occurs at each monitoring well and is determined complete "when contaminant-specific data provide a scientific basis that: 1) the contaminant cleanup level for each COC has been met; and 2) the groundwater will continue to meet the cleanup level for each COC in the future" (EPA, 2013a).

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, 1999a).

Conceptual Site Model (CSM) - "an iterative, 'living representation' of a site that summarizes and helps project teams visualize and understand available information" (EPA, 2011c).

Remedy completion strategy - a recommended site-specific course of action(s) and decision making process(es) to achieve groundwater RAOs and associated cleanup levels using an updated conceptual site model, performance metrics and data derived from site-specific remedy evaluations.

Long-term monitoring optimization (LTMO) - efforts to "improve the cost-effectiveness of long-term monitoring by assuring that monitoring achieves its objectives with an appropriate level of effort." (EPA and USACE, 2005).

Maximum Contaminant Level (MCL) - drinking water standards established under the Safe Drinking Water Act which as ARARs typically represent cleanup levels at CERCLA sites. "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." Consistent with CERCLA and the NCP, MCLs typically are relevant and appropriate when establishing cleanup levels for contaminated groundwater that is or may be used as drinking water (EPA, 1988b).

Maximum Contaminant Level Goals (MCLG) -"strictly health-based levels established under the Safe Drinking Water Act that do not take cost or feasibility into account. As health goals, MCLGs are established at levels at which no known or anticipated adverse effects on the health of persons occur and which allow an adequate margin of safety" (EPA, 1988b).

Minimize -a term that can be used in RAOs to describe curtailing the release of hazardous substances so that they do not migrate to cause substantial danger to present or future public health or welfare or the environment [from CERCLA Section 101(24)].

Monitored natural attenuation (MNA) - typically physical or biological processes (unassisted by human intervention) that will "attain cleanup levels (or other remedial action objectives) in a timeframe that is reasonable when compared to the cleanup timeframes of the other alternatives and when compared to the timeframe of the anticipated resource use" (EPA, 1999b).

Operation and maintenance (O&M) - "the activities required to maintain the effectiveness and integrity of a remedy; in the case of Fund-financed measures to restore groundwater or surface water, O&M refers to the continued operation of such measures beyond the LTRA (long-term response action) period until cleanup levels are achieved" (EPA, 2011a).

Optimization - "Efforts at any phase of the removal or remedial response to identify and implement specific actions that improve the effectiveness and cost-efficiency of that phase" (EPA, 2012).

Performance metrics - site-specific remedy performance criterion, hydrogeologic parameters or contaminant concentration trends typically used to evaluate remedy performance and measure progress (*e.g.*, effluent discharge concentrations, contaminant concentrations trends in a monitoring well).

Prevent - a term that may be used in RAOs to describe stopping the release of hazardous substances, pollutants or contaminants so that they do not migrate to cause substantial danger to present or future public health or welfare or the environment [from CERCLA Section 101(24)].

Reasonable timeframe - the time period "to return usable ground waters to their beneficial uses wherever practicable… given the particular circumstances of the site." [(40 CFR 300.430(a)(1)(iii)(F)].

Remedial action objectives (RAOs) - RAOs specify "contaminants and media of concern, potential exposure pathways, and remedial goals" (40 CFR 300.430(e)(2)(i). Consistent with the NCP, "RAOs are designed to provide a general description of what the cleanup will accomplish (*e.g.*, restoration of groundwater to drinking water levels)" (EPA, 1999a).

Remedy evaluations -normally conducted throughout the life cycle of the remedy to make decisions about remedy performance and progress toward attainment of RAOs and cleanup levels (*e.g.*, Are treatment units functioning as intended?; Are the concentration trends as anticipated?). Evaluations should be conducted using site-specific performance metrics and site data.

Restoration - a term used to describe reduction of concentrations of COCs identified in the ROD to levels that ensure protectiveness of human health and the environment, consistent with 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 or federal MCLs or MCLGs. Other cleanup levels may be appropriate for groundwater used or potentially used for non-drinking purposes [EPA, 1993].

Restore - a term used to describe "returning usable ground waters to their beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site" [40 CFR 300.430(a)(1)(iii)(F)].

Technical Impracticability (TI) - an ARAR waiver that may be authorized under CERCLA. The TI waiver may be appropriate when compliance with an ARAR specified in a ROD "is technically impracticable from an engineering perspective." [40 CFR 300.430(f)(2)(ii)(C)(3)].

Figure 1: Overview of Groundwater Remedy Completion Strategy

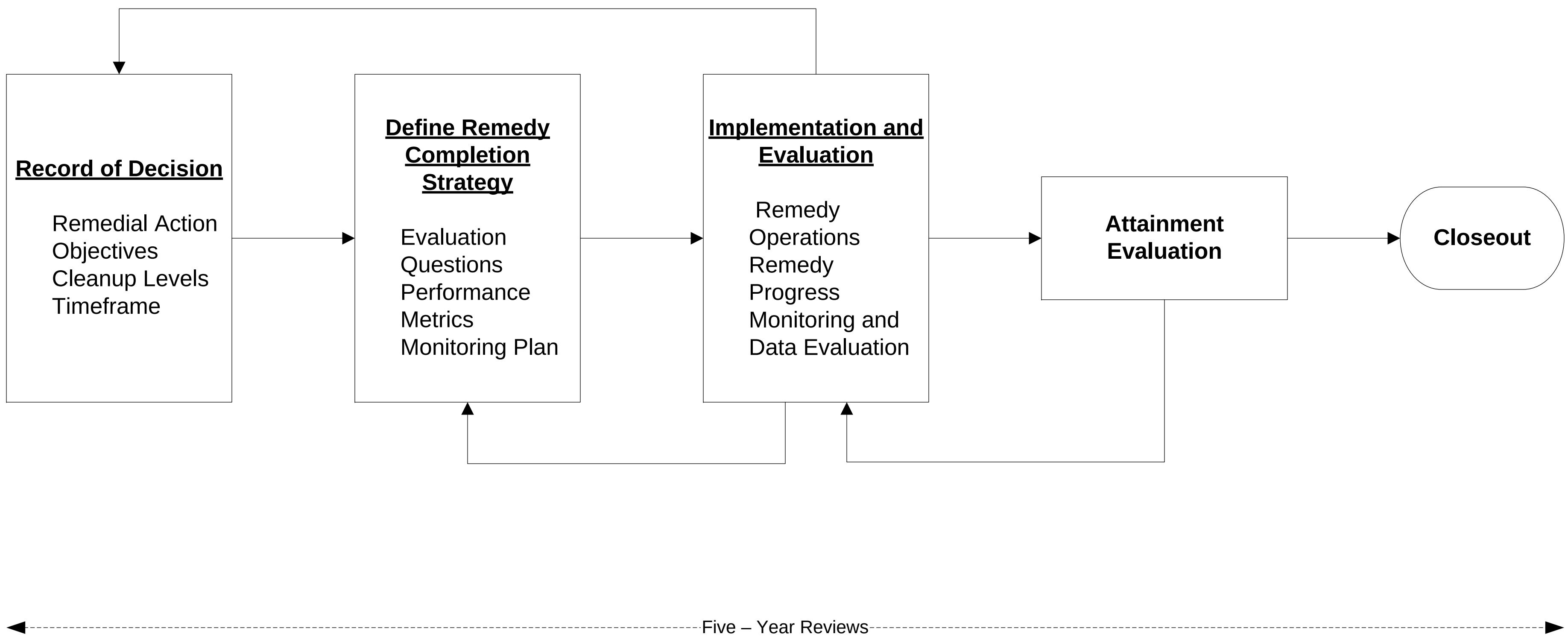

Figure 2: Groundwater Remedy Completion Strategy Implementation

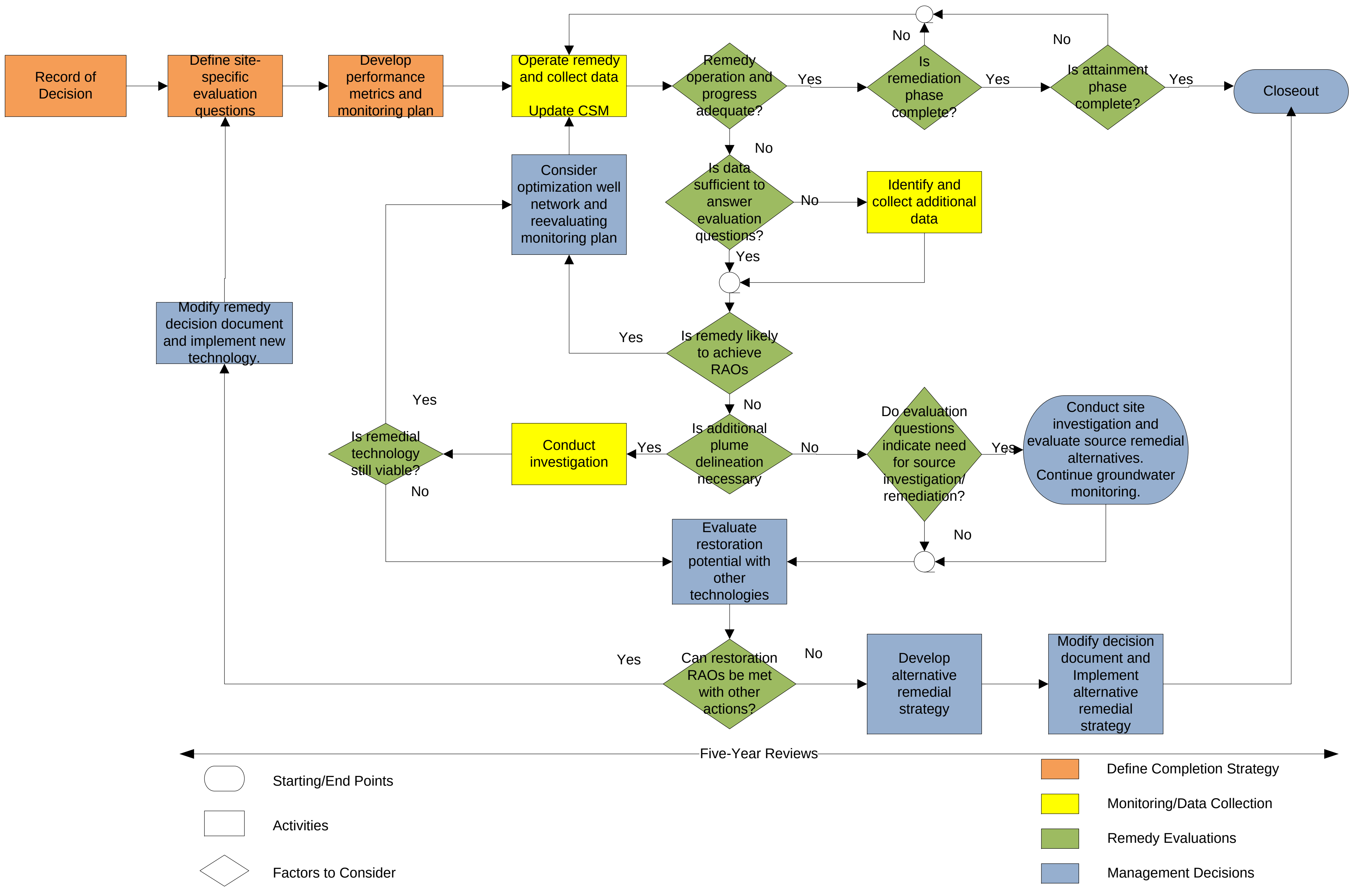

Figure 3: EXAMPLE OF A REMEDY EVALUATION STRUCTURE