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Appendix F. Performance Evaluation & Optimization of In situ Remediation using Amendment Delivery

This checklist is meant to assist the optimization team in evaluating the overall performance of an in situ remediation system for removing contaminants from groundwater and soil. It is intended for use in the implementation and feedback/monitoring phase for the evaluation of full-scale implementation or pilot testing. The checklist is divided into the following sections:

1. Evaluation team composition
2. Typical treatment objectives
3. References
4. Data collection requirements
5. Performance analysis
6. Alternatives for performance improvement and possible cost savings
7. Supplemental notes and data

The checklist provides suggestions for information gathering and possible project recommendations. Space has been provided to record data and notes from the site visit. Supplementary notes, if required, should be numbered to correspond to the appropriate checklist sections.

Typical Performance Problems

A number of general performance problems commonly occur at sites where amendment injection is attempted.

- The amendments are not adequately distributed so reactions of the amendments with the contaminants are not occurring. An inadequate density of injection points, unrecognized subsurface heterogeneity, or inadequate persistence of amendments may prevent proper distribution of amendments throughout the target zone. This includes inadvertent injection of amendments intended for the saturated zone into the vadose zone and excessive daylighting.
- The amendments are not delivered at an adequate dose or volume to support and sustain the desired decrease in contaminant concentrations. The degradation of contaminants may not proceed to desired (innocuous) end products or unexpectedly large rebounds in concentrations may occur.
- The chosen amendments are not effective at creating conditions necessary for degradation/destruction of all of the contaminants to innocuous end products. This could include the previously unrecognized need for activation of a specific oxidant (for example, persulfate) or for bioaugmentation for successful bioremediation. The chosen amendments may not persist adequately to be delivered to the target treatment volume or to address rebound due to diffusion from low permeability zones.
- The monitoring of the subsurface conditions and delivery process is inadequate to assess success. This may include spatial, temporal, and analytical limitations in the monitoring program. This may also include use of inappropriate sampling methods to assess performance. Operational data such as volumes, pressures, etc., may not be recorded or may be recorded only in field forms or log books and subject to more errors than electronic records.

The questions below are meant to help determine if these problems have occurred at the site. Recommendations to address these conditions to improve performance (and to reduce cost) are presented in a following section.

1) Evaluation Team Composition

The following disciplines would typically be included in the evaluation team for an in situ amendment injection system:

- Hydrogeologist
- Environmental, civil, or chemical engineer with relevant experience
- Environmental scientist

- Regulatory specialist

2) Typical Treatment Objectives

In situ amendment injection is typically done to alter geochemical conditions to destroy and/or immobilize contaminants in the saturated zone and occasionally in the vadose zone. Clean up goals may include the reduction of contaminant concentrations to below some standard or threshold throughout the source area, plume, or downgradient of an injection line/trench.

Verify that the treatment objectives, established for when the in situ remediation project was designed and implemented, are SMART (specific, measurable, attainable, relevant, and timely).

3) References

See references provided in the ITRC Optimizing Injection Strategies and In situ Remediation Performance Technical Regulatory Guidance**.**

4) Data Collection Requirements

It is recommended that the following information be collected on a scheduled basis and routinely evaluated to assess the performance of the in situ treatment system. Record the appropriate units with each value.

a) Describe the objectives for the amendment injection. These may be general *(for example, reduce groundwater contaminant concentrations; reduce mass flux to allow natural attenuation to be effective; alleviate vapor intrusion, etc.),* but should be SMART (*for example, attain a specific amendment concentration at certain monitoring points within a specific time; achieve a certain zone of influence as measured by specific parameters*). If current objectives are poorly defined or not defined at all, describe what might be reasonable objectives given information from the owner and regulator.

b) What is the estimated time frame for injection operations and attainment of objectives? What is the basis for this estimate? What statistical methods will be employed to evaluate whether or not remediation is on track?

c) Obtain/display available hydrogeologic information, with specific emphasis on the degree and complexity of heterogeneity in the TTZ. This would include detailed geologic cross-sections. Summarize the hydrogeologic factors, including high permeability layers or lenses, bedrock valleys, and higher transmissivity weathered rock that would affect the delivery and transport of the amendment.

d) What is/was the three-dimensional TTZ? Describe (or attach map and cross-sections).

e) Access maps of the injection locations and describe the injection strategy (for example, whether the injection is done via wells or temporary points; injection barrier or grid; recurring injections).

f) Gather the performance monitoring data, including:

- concentrations trend analysis and raw concentration data of contaminants in all media and potential treatment byproducts
- applicable geochemical and, if applicable, biological data
- concentrations of amendments (or tracers) in monitoring wells
- recent injection volumes, pressures, depths, and concentrations
- piezometric levels for the aquifer, if applicable

g) Describe the performance monitoring network, including source area wells, sentinel wells, plume migration wells, and point of compliance wells. Determine what vertical intervals the wells monitor relative to the target treatment intervals. Describe how these wells will be monitored (for example, low flow sampling, passive diffusion bags, in situ monitoring data loggers, etc.) and for what parameters?

5) Performance Analysis

a) Performance monitoring data:

Are the correct media and vertical interval being monitored/sampled? Link (Section 4.4.2)

Are the monitoring locations and vertical intervals adequate to allow reliable data to be collected regarding injection distribution and concentration reduction? Link (Section 4.4.2)

Are the constituents of concern (CoCs) and all potential byproducts being monitored?

What other parameters represent “lines of evidence” to support the attainment of remedial or treatment goals for the site in question?

Is the current level of data collection sufficient to enable the performance metrics to be reliably and conclusively analyzed?

b) Subsurface amendment distribution

Was there adequate evidence the amendment was distributed laterally and vertically to address the TTZ (for example, based on amendment concentrations, tracers, or other indirect indicators of the presence of amendments)? _______ If not, indicate the areas on a map and/or cross-section.

If advective and dispersive transport of amendments was anticipated to distribute the amendment, did the arrival of the amendment roughly coincide with the time expected and at the concentration expected? _______

Is the distribution of amendment and/or effects on contaminant concentrations consistent with the CSM (that is, are there unexpected flow directions or preferred pathways)? _______

If the amendments are intended to persist at concentrations needed to promote on-going degradation and address diffusion limitations, are the declines in amendment concentrations consistent with expectations? _______ If not, what is the likely cause (for example, higher than expected groundwater velocities; more rapid reactions than anticipated)?

Was there evidence that injection of amendments displaced contaminants outside of the target zone into other areas at unacceptable concentrations? ______

c) Injection/Amendment Delivery

Were injected volumes smaller than planned at some points (for example, due to low permeability, surfacing, inadequate supply)?

Were there any leaks/spills of the amendments that were not appropriately cleaned up/addressed? _______

Were there excessive occurrences of daylighting? _______ If yes, where did it occur (for example, by the injection point or away from the borehole)?

Were the appropriate amendments added at the appropriate dosage/concentrations, based on the available records? _____

Was the rate at which injection occurred slower than planned? _______

Were injection pressures higher than expected or did they spike to a value greater than the overburden pressure such that fracturing is likely? _______

Were the injection flow rates substantially greater than or less than expected based on the design or pilot testing (indicate which condition occurred)? ______

Is there evidence that any permanent/temporary injection wells have experienced decreased injection capacity due to scaling or biofouling? ______

Can the injection depths be verified and were they at planned intervals or intervals appropriate based on data collected during the remedy implementation? _______

Was there evidence of amendment loss to the vadose zone, such as daylighting, infiltration to vapor wells, injection into points with screen or fractures above the water table, or ground displacement monitoring (if the saturated zone was the target)? _______

Were the injection points/wells placed as close as practical to the intended locations shown in the plans? _______

Was anisotropy observed as a major issue that would affect adequate distribution, based on information generated during site characterization (for example, pumping test response, observed fracture orientation, hydrogeologic setting)? ______

If yes, does the well network have sufficient well density and the proper distribution of wells to identify the impacts of that anisotropy on amendment distribution?

d) Effectiveness in Reactions with Site Contaminants/Modification of Subsurface Conditions

Are COC concentrations decreasing at a statistically significant rate?____ If so, do subsequent data indicate a statistically significant reduction? ____Are COC concentrations increasing as a result of desorption? ____

Is there evidence for unexpectedly large rebounds in concentration? _____ If so, where and by what contaminant?

Where amendment delivery was adequate, are all target contaminant concentrations decreasing as expected? _______ If not, what contaminants are not degrading as anticipated?

Are there accumulations of unwanted/unexpected byproducts of degradation observed? _______ If there are some, how long may they persist?

Are other indicators of effectiveness, such as microbial counts/composition or redox conditions, changing as anticipated? _______

Is there evidence that contaminant destruction or transformation is progressing to completion or is the process stalling at an intermediate daughter product (for example, is trichloroethylene completely degraded to ethene/ethane)? _______ Or is a different degradation pathway being used (for example, abiotic)? ______

Are related changes in subsurface conditions impeding the desired reactions (for example, is pH changing in a way that inhibits microbial activity or that supports activation of persulfate)? ______

Are there other previously known compounds or recently discovered contaminants (for example, emerging contaminants such as perfluorinated compounds) that were not targeted for destruction and now need to be addressed by the remedial activities but are not amenable to destruction by the chosen amendments? ______ Describe.

6) Alternatives for Performance Improvement and Possible Cost Savings

Can the delivery of amendments (possibly in select areas with poor injection response) be improved by:

Additional characterization of hydrogeology (for example, permeable zones) or contaminant mass/extent using high-resolution site characterization to better define target areas and pathways? Is additional characterization of the microbial community required (for example, qPCR)?

Tighter spacing of injection points or injection lines based on a re-evaluation of actual delivery extent? If so, where?

Enhancing permeability in fine-grained soils or weathered bedrock by creating new delivery pathways via sand-filled fractures?

Use of recirculation (paired pumping and injection of amended liquid)?

Targeting more specific vertical intervals?

Altering sequence/locations of injection to address displacement of contaminants (for example, injecting from the outside in)?

Use of a different delivery method (for example, use of permanent points can reduce injection if many rounds of injection are planned)?

Reduction of injection pressures (to reduce inadvertent injection outside of the target zone, excessive daylighting)?

Rehabilitation of permanent injection points to address poor injection performance?

Can the adequacy of the amount and type of amendment delivered to the target zone be improved to allow desired concentration declines and amendment persistence by:

Increasing volume of injected amendment per injection point?

Increasing the concentrations of the amendment (though care must be taken to avoid negative buoyancy issues, auto-decomposition of the amendment, or toxicity issues with bioaugmentation cultures)?

Changing the type of amendment (for example, emulsified vegetable oil rather than lactate solution for reductive dechlorination)?

Addition of different but appropriate buffers, activators, etc.?

Can the destruction of all contaminants, including byproducts of reaction or any newly discovered contaminants, be enhanced by:

Adding other amendments to improve performance or address other contaminants (for example, bioaugmentation, different activator chemical for oxidants, a buffer to control pH)?

Completely changing the amendment (for example, replacing a carbon source with a chemical reductant)?

Using a form of the amendment that has a longer life span in the subsurface (for example, permanganate rather than a modified Fenton's reagent or emulsified vegetable oil rather than lactate)?

Switching to an amendment that has a lower cost for similar performance?

Can the remedy be better implemented and managed through changes in the performance and operational monitoring, including:

Adding more monitoring points in critical areas inside and outside the TTZ?

Increasing frequency of monitoring of concentrations of contaminants, amendments, or other indicators (frequency may depend on the expected rate of change in contaminant or amendment concentrations)?

Adding other performance parameters (for example, genetic testing such as QuantArray, oxidation/reduction potential, isotopic data, byproducts of treatment) or sampling of other media (for example, soil, soil gas)?

Decreasing sampling frequency, locations, and analytes to reduce costs, particularly for projects that have been undergoing treatment for an extended time period?

More detailed monitoring of injection volumes, pressures, and depths to assess adequacy of delivery of amendments (digital recording offers much more detail)?

Taking steps to reduce daylighting of amendments and/or to develop better plans for addressing spills/discharge of amendments and potentially contaminated media at the surface, especially where there are old boreholes, pits, etc., that could be conduits?

Does the injection equipment/crew have the capability to adequately address the project?

Is the equipment/crew provided for additional injections at the site capable of delivering and documenting reagents in conformance with the design and field performance expectations?

Do the contract specifications or plans for future work need to add more specific directions/requirements to ensure the equipment/crew would be suitable to meet the performance expectations?

7) Supplemental Notes and Data. Attach any additional notes, data, calculations, etc., to this checklist.

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