Challenges in Planning for Groundwater Remedy Transition at a Complex Site

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Abstract

Complex groundwater contamination sites require comprehensive, structured groundwater monitoring in planning for transition to a new groundwater remedy. An example is the Medley Farm Superfund Site, a former waste solvent dump located in South Carolina. Groundwater contaminants at the Site are primarily tetrachloroethene, trichloroethene, and their degradation products. Groundwater remedial action began at Medley Farm in 1995, using a groundwater extraction and treatment system. In 2004, in response to declining efficiency, groundwater extraction was suspended. Enhanced reductive dechlorination (ERD) via injection of lactate solution into the groundwater was initiated as a remedial optimization measure. Between October 2004 and April 2012, lactate solution was injected on multiple occasions. Responses of the hydrogeochemistry and groundwater quality to lactate treatment have been positive. In August 2012, EPA issued an Amended Record of Decision, changing the groundwater remedy to ERD. Monitored natural attenuation (MNA) was selected as a contingency remedy with the anticipation that as cleanup progresses, ERD may transition to MNA.

The Medley Farm Site presents challenges to transitioning from ERD to MNA. Prior lactate injections have varied with respect to injection volumes, locations, and timing. Groundwater monitoring and data analysis during the injection period have been structured to evaluate responses to the individual, irregular injection events. These factors limit data interpretation and predictive analysis. Site geologic features create variable and complex groundwater flow patterns. The spatial and temporal extent of lactate influence and sustainability of favorable conditions without lactate treatments are incompletely understood but are apparently highly variable, consistent with Site complexities. Transition from ERD to MNA and evaluation of MNA as a potential final remedial action will require changing the current Site monitoring and data evaluation paradigm. EPA is planning for restructuring the monitoring and data evaluation program to better discern treatment effects and facilitate MNA evaluation.

Introduction

Complex groundwater contamination sites require comprehensive, structured groundwater monitoring in planning for transition to a new groundwater remedy. An example is the Medley Farm Drum Dump Superfund Site, a former waste solvent dump located in South Carolina (Figure 1).

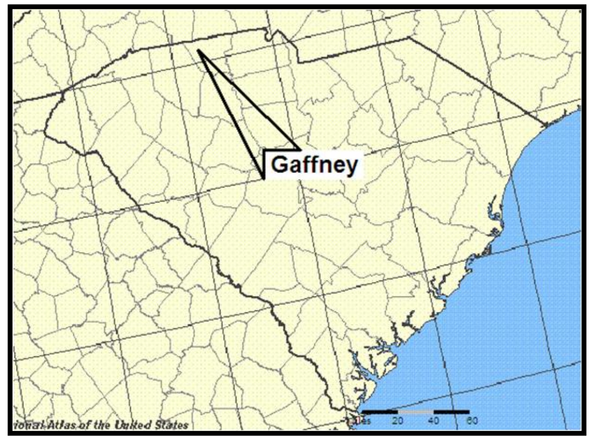

Figure 1. Medley Farm Drum Dump Site location

The Medley Farm Site history is illustrated by Figure 2. A pump and treat groundwater remedial action began at the Site in March 1995. Along with the groundwater remedial action, soil vapor extraction (SVE) removed solvents from the unsaturated zone. Various optimization measures to both the groundwater remedial action and SVE were employed from the late 1990s until 2004. These measures led to a short-term improvement in contaminant mass removal efficiency (mass per volume removed). In 2004, EPA agreed to a proposal to end SVE, as soil performance objectives had been met. Concurrently, EPA agreed to a proposal to suspend the groundwater remedial action and implement a trial program of injections of a sodium lactate and oxygen scavenger solution to produce conditions more favorable for reductive dechlorination of the remaining groundwater contamination of concern, consisting primarily of chlorinated ethenes. Enhanced reductive dechlorination (ERD) was initiated on a trial basis in September 2004. In August 2012, EPA issued an Amended Record of Decision (AROD) for the Medley Farm Site, which specified ERD as the selected groundwater remedial technology. Monitored natural attenuation (MNA) was identified as a potential contingency groundwater remedial action.

The Medley Farm Site is located in a complex hydrogeologic setting in the Piedmont physiographic province of South Carolina. The surrounding Inner Piedmont belt is comprised of thrust-faulted stacks of metamorphic rocks. Site bedrock types are schists and phyllites of metavolcanic and metasedimentary origin. Exploratory trenches and detailed geologic mapping identified two distinct near-surface lithologies. One rock type is light-colored and predominantly felsic in character, while the second rock type is primarily mafic and has a much darker appearance. These distinct lithologies are separated by a northeastward-striking, steeply dipping reverse fault. Portable geophysics tools were used to map the fault trace across the Site. Waste disposal areas are topographically upslope from the fault. The fault trend is consistent with numerous local and regional northeast-southwest oriented structural features (mapped faults, rock fractures, and rock foliation). Two dominant orientations of rock fractures have been identified at the Site, one set striking parallel to the fault and the second set striking at near right angles. The depth to the top of bedrock differs by about 20 to 70 feet across the fault. Overlying the bedrock is a variable thickness of highly weathered bedrock (transition zone), which grades into a variable thickness of overlying saprolite. The saprolite is up to 50 to 70 feet thick around the former waste disposal areas (Sirrine Environmental Consultants, 1991). The saprolite consists primarily of silt. There are zones of quartz gravel which are interpreted as relict fracture fill.

1973 **Waste disposal begins**

1976 **Waste disposal ends**

June-July 1983 **EPA drum and waste removal action. More than 5,000 drums or other waste containers are removed, along with waste liquids and other materials**

January 1991 **Remedial Investigation Complete**
February 1991 **Feasibility Study Complete**

March 1995 **Groundwater pump and treat begins**

1998-early 2000s **Pulse pumping done as a remedial optimization measure**

September 2004 **Groundwater pump and treat is suspended. Enhanced reductive dechlorination (ERD) is begun on a trial basis**

August 2012 **EPA issues the amended Record of Decision. ERD is selected as the groundwater remedy, with potential transition to monitored natural attenuation (MNA) as conditions warrant**

Figure 2. Medley Farm Drum Dump Site History

Groundwater in the saprolite, transition zone, and bedrock is hydraulically connected. Hydraulic head monitoring has indicated generally upward hydraulic gradients from the shallow bedrock into the transition zone and saprolite in both upslope and downslope areas, with some localized exceptions. Depth to groundwater may be as much as about 70 feet in upslope areas, including the area of contaminant waste disposal, and about 10 feet in downslope areas.

The Site Remedial Investigation (RI) concluded that groundwater flow was downslope, generally at right angles to equipotentials. During the Site Remedial Design (RD), further investigation revealed that groundwater flow in the bedrock is strongly controlled by geologic structures. The fault bisecting the Site is a zone of preferential bedrock groundwater flow. Groundwater flow from beneath upslope contaminant source areas that moves southeastward through intergranular porosity and rock fractures oriented subparallel to topography is diverted northeastward, either along the fault or through nearby subordinate rock fractures. The fault therefore separates an upslope area of significant groundwater contamination from a downslope area of inconsequential groundwater contamination. Other fault-parallel fractures well upslope from the fault zone are additional potential conduits for northeastward groundwater flow, although some groundwater flow in this part of the Site is also oriented downslope towards a southeastward trending tributary stream that appears to be aligned along a northwest-southeast trending bedrock structure.

Measurements during the Rl and RD indicate the hydraulic conductivity of the saprolite is on the order of 10^{-5} to 10^{-3} cm/s; the transition zone hydraulic conductivity is on the order of 10^{-4} to 10^{-3} cm/s; and the shallow fractured bedrock hydraulic conductivity is on the order of 10^{-5} to 10^{-3} cm/s. Limited data from deeper bedrock wells indicates hydraulic conductivity is on the order of 10^{-7} cm/s. A decrease in bedrock hydraulic conductivity with depth is consistent with LeGrand's conceptual model of Piedmont hydrogeology (LeGrand, 2004).

Groundwater Pump and Treat Remedial Action (1995-2004)

Groundwater pump and treat remedial action began in March 1995 and continued until September 2004. Pre-remedial groundwater quality from early 1995 indicated contamination primarily by chlorinated ethenes, with lesser but significant detections of chloroethanes and chloromethanes and inconsequential detections of a few nonchlorinated volatile organic compounds. Chlorinated ethenes were almost entirely tetrachloroethene (PCE), trichloroethene (TCE), and 1,1-dichloroethene (1,1-DCE). 1,2-dichloroethene was present in a few samples at inconsequential concentrations, and vinyl chloride was not detected. Measured baseline chlorinated ethene concentrations ranged from 41 µg/L to 2,300 µg/L in saprolite monitoring well samples and from 196 µg/L to 1,085 µg/L in samples from monitoring wells completed in the saprolite, transition zone, and/or the bedrock.

The pump and treat remedial action began with 11 extraction wells. Extraction wells were designed with long screened intervals (from 55 to > 100 feet) to maximize available drawdown and contaminant recovery. These wells were generally completed in the saprolite, transition zone, and upper bedrock. Several of the wells were located downslope of contaminant source areas, while other wells were aligned along the footwall of the fault, to capture contaminated groundwater migrating to and then northeastward along the fault.

As the remedial action progressed, the initial extraction well array was augmented by additional wells placed in the core of the contaminant source areas and designed as dual phase extraction wells (groundwater and soil vapor extraction). Additionally, beginning in 1998 and continuing for several years afterward, pulse pumping was done as a remedial optimization measure.

By 2003, the Medley Farm Site groundwater remedial action was characterized by greatly reduced extraction well mass removal efficiency, complete or near-complete vadose zone remedial action (SVE), and marginal benefits of groundwater remedial optimization. The potentially responsible parties' (PRPs') contractor proposed that enhanced reductive dechlorination (ERD) be implemented on a provisional basis. EPA concurred with the proposal and the groundwater remedy transitioned to ERD in September 2004.

Enhanced Reductive Dechlorination

Baseline groundwater monitoring was done in September 2004, before beginning the first injection of the sodium lactate solution. At that time PCE, TCE, and their daughter products were present at a maximum summed concentration of about 400 µg/L in the wells completed in bedrock or in the bedrock and overlying zones. Saprolite in the area of the most highly contaminated groundwater had been dewatered by groundwater extraction, and therefore baseline data were unavailable for saprolite monitoring wells in this area. Baseline monitoring of key geochemical indicator constituents indicated that none of the wells in the area of significant groundwater contamination were in an optimal environment for reductive dechlorination (Figure 3); while baseline monitoring of groundwater contaminants found that together, PCE and TCE were the principal chlorinated ethenes present (Figure 4).

Lactate injections have occurred on seven occasions, beginning in late 2004 and continuing to April 2012. Initially, lactate injections occurred through the 11 wells that were a part of the original groundwater recovery well network, plus two of the three dual-phase recovery wells. Follow-up groundwater monitoring in approximately three months and five months after the first injection led to the May 2005 injection of more lactate solution at the same 13 injection wells, with the same approximate volume of solution injected at each well.

As the lactate injection and monitoring program continued, additional wells were added to the injection program, and some of the initial injection points were omitted from some of the injection events. Throughout the period of lactate injection and monitoring, both the lactate injection and post-injection monitoring timing and location and the magnitude of lactate injections were adjusted to fit observed groundwater quality responses to previous injections.

In September 2007 (after six monitoring events following the first injection and more than a year following the last injection), groundwater monitoring showed that geochemical conditions were substantially improved relative to baseline (Figure 3). More than half of the bedrock or saprolite/transition zone/bedrock monitoring wells and injection points in the area of significant contamination showed that dissolved oxygen levels were in the range of nondetect to less than 0.5 mg/L (Figure 3). The groundwater pH for these wells was much more uniform than at baseline (Figure 3), with values clustered in the range of about 6 to 7. Saprolite groundwater quality was not as closely considered at this time, but was a decision factor in targeting additional lactate injections to areas of more significant or persistent chlorinated ethene contamination.

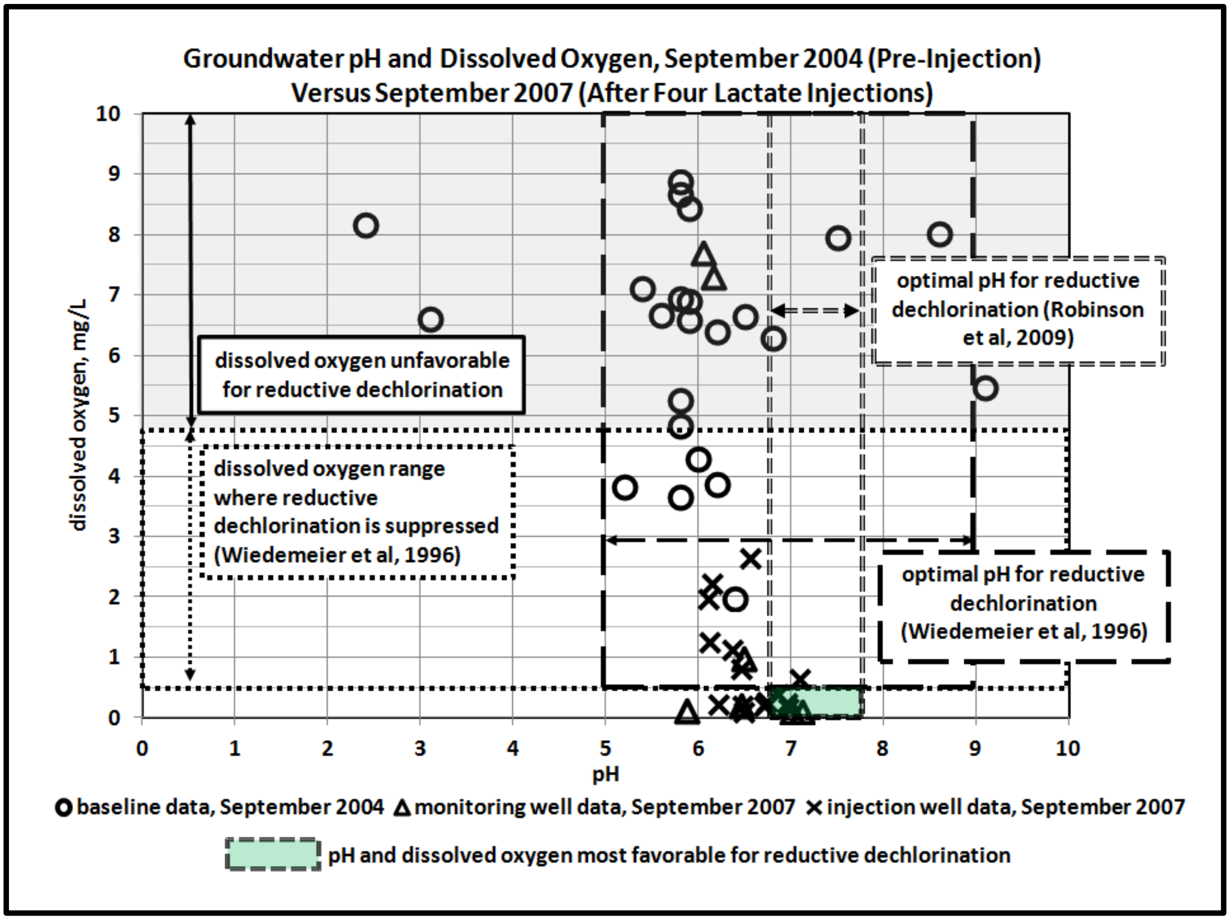

Figure 3. Baseline and post-injection groundwater geochemistry comparison

Groundwater contaminant monitoring in September 2007 showed that cis 1,2-DCE and vinyl chloride had replaced PCE and TCE as the principal chlorinated ethenes at many of the monitoring points (Figure 4). Exceptions to this change were seen at some monitoring points. At some wells, total chlorinated ethenes increased, relative to baseline conditions. EPA interpreted the increases as probably representing untreated or less treated groundwater from upgradient locations that had migrated downgradient to those wells or possibly resulting from matrix diffusion of the more chlorinated ethenes into the principal groundwater conduits intersected by those wells (O’Steen, 2008). A close review of geochemical indicator data from those monitoring points also revealed some probable reversion toward baseline geochemistry in the September 2007 sample.

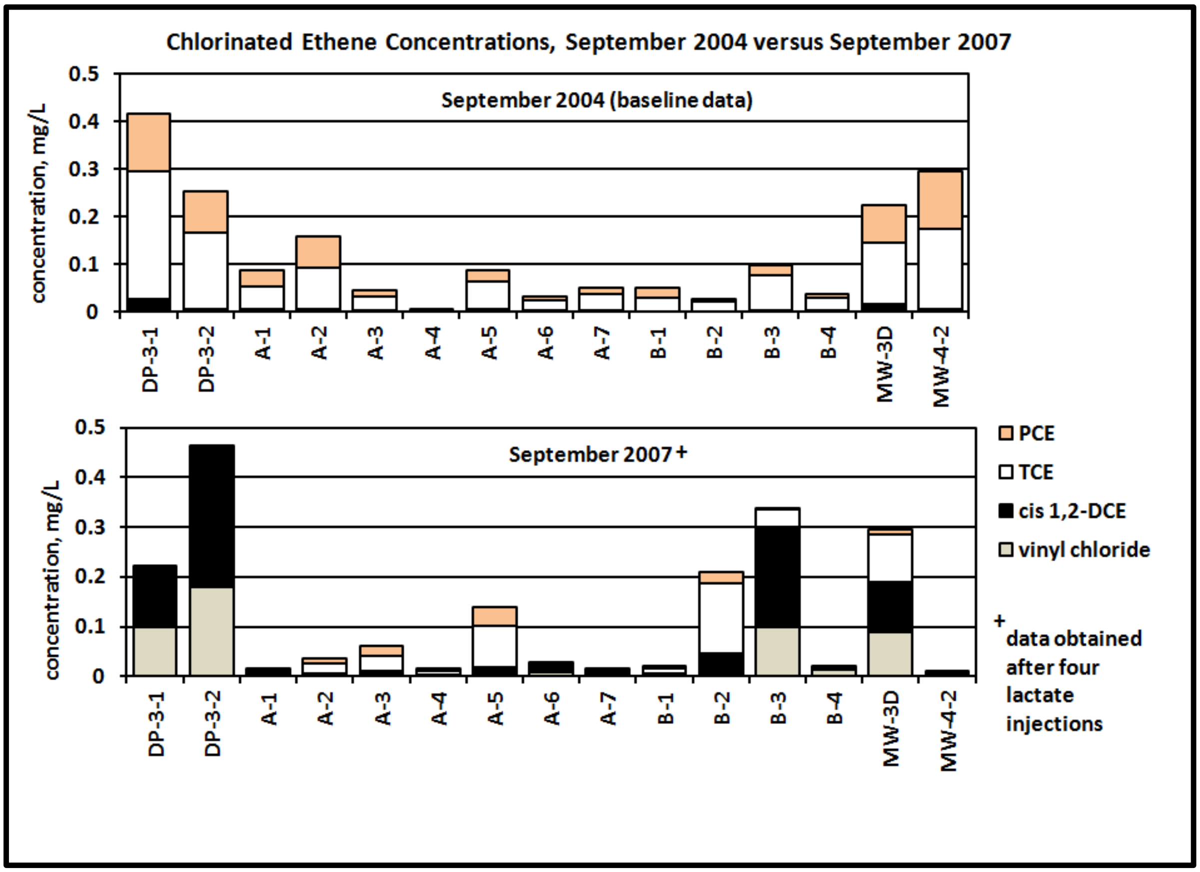

Figure 4. Baseline and post-injection groundwater quality comparison

By early 2008, EPA began to discern that several challenges were associated with implementation of the ERD remedial action. Review of data obtained from baseline monitoring ~~up~~ through September 2007 indicated that different areas of groundwater were responding differently to lactate injections and that no straightforward relationship was evident between baseline groundwater quality, lactate injection parameters, and resultant groundwater geochemistry and contaminant levels. EPA expressed concerns regarding the conceptual hydrogeologic model and the attendant groundwater flow and lactate transport pathways. It was also becoming apparent that the resaturated saprolite in the zone of pump and treat remedial action dewatering was not favorably responding to the lactate injections. EPA continued to work closely with the PRPs' contractor to refine the lactate injection and monitoring program. The approach of performing lactate injections and monitoring in response to observed contaminant concentrations remained in place.

EPA conducted a more detailed evaluation of the ERD process in 2009, in a report prepared in support of the third Five-Year Review of the Site remedial action (O'Steen 2009). In this report, EPA further observed differential responses to repeated lactate injections in various areas of groundwater contamination, with some wells still monitoring areas with predominantly PCE and

TCE contamination after five lactate injection events. However, as additional lactate injections occurred, the range of ratios of parent chlorinated ethenes (PCE and TCE) to daughter chlorinated ethenes (cis 1,2-DCE and vinyl chloride) was becoming increasingly smaller. Such a condition was considered to be consistent with more complete spreading of lactate solution away from injection points, or with more complete spreading of altered geochemical conditions resulting from the injections and diminution of pockets of unremediated groundwater between injection points.

By 2010, the PRPs' contractor had identified three core areas of residual contamination and considered the intervening areas to have been remediated by the ERD and natural attenuation processes. The contractor also believed that monitored natural attenuation (MNA) was now likely to be an effective follow-up remedial action for much of the area of groundwater contamination. EPA expressed concerns about the lack of groundwater monitoring points across a substantial area between the larger two of the areas of residual contamination. EPA was also concerned that groundwater monitoring and lactate injection activities in the 2004-2010 period were structured such that any natural attenuation component to groundwater cleanup could not be discerned, and that potential post-injection concentration rebound was insufficiently understood to allow concluding that MNA could be an effective remedial strategy for any of the Site. Additionally, EPA recommended that the contractor should consider co-injecting an inert groundwater tracer with the next round of lactate solution, to help with an evaluation of the injectate retention time at the injection points and improve the understanding of the movement of the injected solution.

Responding to EPA's concerns, the PRPs' contractor constructed three new lactate injection wells in the more upgradient area of groundwater contamination and upslope of the area without monitoring wells. These wells were completed from the lower saprolite through the upper bedrock.

In a lactate injection event in March 2012, a sodium bromide tracer was added to the lactate solution injected into two of the new wells, as well as three existing injection wells. Following this lactate injection, quarterly monitoring of bromide concentrations occurred at the bromide injection points and key locations downgradient or potentially downgradient of the bromide injection wells.

Before the 2012 lactate injection, baseline monitoring of chlorinated ethenes and geochemical indicators was done at the three new injection wells. The baseline monitoring revealed groundwater quality similar to that observed elsewhere in groundwater before the initial lactate injection in late 2004, with minimal cis 1,2-DCE and vinyl chloride and substantive concentrations of both PCE and TCE. Dissolved oxygen exceeded 1 mg/L in two of the three new wells and at all of the new wells, dissolved oxygen was within the range where reductive dechlorination is suppressed. Post-injection monitoring in November/December 2012 found the relative amounts of chlorinated ethene parents and daughters in samples from these wells were reversed. Two of the three samples had chlorinated ethene concentrations below groundwater performance standards and the third sample contained mostly cis 1,2-DCE and vinyl chloride rather than PCE and TCE. Dissolved oxygen was nondetect in all three samples.

2012 bromide tracer monitoring found a varied bromide retention pattern at the tracer injection wells and variable rate and direction of bromide movement. From a bromide injection point upslope from the fault, bromide was transported in a downslope direction, reached the fault area, then migrated in a fault-parallel direction. Bromide was detected at the closest downgradient monitoring point (a well located in the vicinity of the fault and approximately 180 feet away from the tracer injection) in the first post-injection bromide monitoring, between three to four months after the injection. Although receiving a relatively small volume of injectate, bromide quickly migrated away from the two bromide injection points in close proximity to the fault bisecting the Site, with baseline or near-baseline bromide concentrations detected three to four months after the injection. At the two new bromide injection wells in the upgradient area of groundwater contamination, post-injection tracer monitoring found that groundwater flow is in a direction subparallel to the northeast-trending fault. Some of the tracer was present in post-injection samples from these new wells almost a year after March 2012 injection. One of the new wells included multilevel sampling to gauge the retention of bromide in the saprolite, transition zone, and upper bedrock intercepted by the well screen. This effort found inconsequential flushing of bromide out of the bedrock. Conversely, at the other new lactate injection well without co-injection of bromide, monitoring found that bromide injected approximately 200 feet upgradient was present in both the transition zone and bedrock in sub-equivalent concentrations at the first post-injection monitoring three to four months after the injection.

In 2012, EPA issued an Amended Record of Decision (AROD), establishing ERD as the groundwater remedial action for the Medley Farm Drum Dump Site. The AROD anticipated an additional five years of continued ERD treatment of the groundwater would be needed in order to attain remedial objectives. The AROD also considered that MNA would be substituted in place of ERD where and when appropriate, as a finishing step to meet remedial objectives. The transition from ERD to MNA is a challenging problem for the Site.

Challenges in Transitioning from ERD to MNA

Both EPA and the PRPs for the Medley Farm Superfund Site are interested in facilitating the ERD remedial action and, assuming it becomes appropriate, the transition from ERD to MNA. While the onsite lactate injections continue, EPA has begun an analysis of the transition from ERD to MNA as the groundwater remedy for the Medley Farm Drum Dump Site. In the most recent analysis of groundwater monitoring data from the Site (O'Steen, 2013) EPA identified several important considerations in the transition from ERD to MNA, and reviewed the Site-specific challenges to planning such a remedy transition.

Lactate injection and post-injection monitoring to date have occurred in response to monitoring results at individual wells. While this approach addresses observed water quality, it is inadequate to account for either the effects of previous upgradient lactate injections on water quality at downgradient monitoring points, or the magnitude and timing of potential geochemical and contaminant concentration rebound. The irregular lactate injection and post-injection monitoring events, complex and incompletely understood groundwater flow paths, variable lactate migration rates, and absence of monitoring points in key locations create a generally incomplete understanding of the progress of ERD in treating sufficient contaminant mass to transition to MNA as a groundwater remedial option.

EPA's evaluation of the timing and magnitude of lactate injections relative to post-injection monitoring events has led to the generation of a preliminary assessment of the favorability of the geochemical environment for reductive dechlorination in the absence of further lactate injection events. Conditions are either unfavorable or uncertain for continued reductive dechlorination without further lactate injection at 21 of the 24 evaluated wells completed in the transition zone and/or bedrock. Saprolite monitoring wells in the core area of residual groundwater contamination have shown little or no response to the lactate injection program and an alternate lactate treatment strategy is needed to address this residual contamination.

EPA has concluded that a transition from ERD to MNA, or from either treatment to a possible termination of the remedial action, will not be appropriate at the same time across the entire area of contaminated groundwater. There has clearly been a different response of groundwater in different locations to lactate treatment. This condition alone will result in varied times at which conditions are appropriate for remedy transition. EPA also anticipates a monitoring period without further lactate injection before MNA can be evaluated as a potential groundwater remedial action. This period is required in order to define a time at which the geochemical effects of lactate injection are no longer a significant factor in groundwater geochemistry. EPA's expectations are that over time, post-injection groundwater geochemistry will return to a pre-injection condition, with dissolved oxygen increasing to the point that reductive dechlorination is no longer an important influence on water quality. The time required for such a chemical change will vary from location to location. There is a possibility that lactate treatment will still be needed for groundwater upgradient of a well where conditions are favorable for ERD termination. Continuing lactate treatment upgradient of a well where MNA evaluation is ongoing will confound interpretation of data collected to assess MNA. In attempting to evaluate if natural attenuation is the primary influence on groundwater quality at a monitoring point, the timing and volume of upgradient lactate injections and the distance from those lactate injections to the monitoring point are important considerations.

EPA has also concluded that the Site groundwater monitoring program will need to be revised. At critical monitoring locations, EPA expects that more frequent and structured groundwater monitoring will be needed during the post-injection period when contaminant and geochemical indicator rebound are being assessed. Structured groundwater monitoring is also needed during a formal evaluation of MNA as a potential remedy, with the MNA assessment to follow EPA's guidance (EPA, 1999).

EPA has developed a draft flowchart that provides a starting point for development of the process for transitioning from ERD to MNA. The PRPs contractor has suggested an alternate flowchart developed by the ITRC (ITRC, 2007) as a suitable starting point for defining the ERD to MNA transition process. EPA is working with the contractor to create a site-specific flowchart to guide the ERD to MNA transition.

Next steps in the ERD to MNA transition process include establishing a more transition-based lactate injection and monitoring scheme, refining the understanding of groundwater flowpaths and lactate migration rates through further tracer testing, and developing a plan for ERD treatment of recalcitrant chlorinated ethene contamination in core areas of residual saprolite contamination. EPA is optimistic that with mindful changes to the lactate injection and groundwater monitoring program, the challenges in the ERD to MNA transition at the Medley Farm Drum Dump Site can be surmounted.

This technical paper was originally presented at the National Groundwater Association 2014 Groundwater Summit. It has been slightly edited for clarity but is otherwise unmodified. The views expressed in this presentation are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency. The corresponding author may be contacted at osteen.bill@epa.gov.

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