ATTACHMENT 18: Field-Scale Pilot Testing Guidance

The following are some of the key considerations in performing a pilot test of ISCO:

PILOT TEST OBJECTIVE

Realistic pilot test objectives should be developed based on the time and budget available, coupled with site-specific conditions and the desire to reduce uncertainty. Possible objectives of a pilot test include:

- Evaluation of possible treatment effectiveness (i.e., mass removal or achievable concentration reductions) to reduce the uncertainty in the full-scale performance
- Evaluation of reagent distribution and the zone of influence
- Refinement of input parameters for the design tool (i.e., design parameters) to help reduce the uncertainty in the design and cost
- Identification/troubleshooting of challenges on a smaller scale at lower cost
- Evaluation of the potential for fatal flaws that would make ISCO impractical for full-scale
- Achievement of some initial mass removal

The approach for pilot testing should take into account the fact that the Observational Method is likely to be required for full-scale application. In other words, multiple injections may be required, with the subsequent injections based on the performance of the first. Despite this, pilot testing may still be desired to reduce the uncertainty in the design, and thus the cost, and also to evaluate for fatal flaws.

Evaluating treatment effectiveness may be challenging to achieve with pilot tests. The factors that complicate this objective include:

- The potential for contaminants to flow into the treatment area from untreated upgradient areas. This potential may be significant in highly permeable sites with significant contamination upgradient. This potential may be managed by appropriate upgradient monitoring and modeling.
- The potential for the oxidant to persist in the formation beyond the time available for the pilot test, so that true endpoint concentrations cannot be obtained. The true end point concentrations should be obtained after time is allowed for the oxidant to dissipate, the subsurface to re-equilibrate and return to ambient geochemical conditions, and for rebound (if any) to occur.
- The potential for the water added as part of the oxidant injected to dilute the in situ contaminant concentrations temporarily. This dilution is especially challenging when the majority of the contaminant mass is in a dissolved state. At sites with significant sorbed or residual NAPL this dilution should be less of a concern since the contaminants that are in a sorbed state or residual NAPL are typically present in much higher mass and will equilibrate with the dissolved phase. The contaminants will be treated in the dissolved phase as long as the oxidant persists, but dissolved phase concentrations will likely increase after the oxidant is exhausted (rebound) if sorbed or residual NAPL remains.
- Some oxidants cause significant desorption and dissolution of sorbed or residual NAPL. This desorption and dissolution may cause a temporary increase in the aqueous phase concentration observed in groundwater samples and may mask mass removal that is actually occurring.

If assessment of the ultimate ability of the ISCO design to meet the ISCO Treatment Goals is one of the required pilot test objectives, significant thought should be put into the design of the pilot test to avoid the above issues (i.e., use large pilot area, allow sufficient time for re-equilibration of contaminants in the subsurface, and use an adequate number of monitoring wells).

The other pilot test objectives are focused more on obtaining information on the distribution of the chemicals and especially how they relate to the design. Design parameters that can be refined through pilot testing include:

- Contaminant mass and concentration in the target treatment zone. The additional wells installed will provide additional information on the characteristics of the site.

- Dimensions of the target treatment zone (area and depth).
- Thickness of mobile zone (through which the reagent will flow).
- Magnitude of the rate and extent of oxidant depletion due to reactions with the contaminant and natural media. These parameters may need to be back-calculated from the design tool.

Achieving some initial mass removal is not always explicitly stated as an objective of a pilot test, but it may still exist. It may drive the pilot test to be larger than it would otherwise need to be. The decision to conduct large scale pilot tests should be made by the site owner, in consultation with other site stakeholders. As with large full-scale implementation, the site owner should be aware of the financial risks of the technology not working as hoped.

WELL SPACING AND VOLUME / MASS OF OXIDANT

The number of injection wells used for the pilot test should be based on the objectives and the budget. Significant information can be learned (thus uncertainty reduced) with just one injection well which is especially true with respect to the distribution of the oxidant. To evaluate the performance of an ISCO approach in terms of contaminant reduction, multiple injection wells (at least 4) are desirable. The monitoring wells used to evaluate performance should be placed between the injection wells to avoid flow of contaminants into the area monitored.

If funds are limited, it may be beneficial to put more money into monitoring wells than injection wells. As a rule of thumb, the minimum number of monitoring wells is 3. These wells should be spaced at different distances from the injection well to evaluate the distribution of the oxidant during the injection period (and thus obtain information on the well space required). Using monitoring wells with short screens lengths (e.g., 2 ft), located at different depths is also desirable to obtain information on the vertical distribution of the oxidant during injections. Because distribution of injected chemicals will not be perfectly circular around an injection point, it is desirable to have wells located in different directions.

The proposed full-scale injection pattern should also be considered when developing the design of a pilot study. If an "inject and drift" approach is proposed for a persistent oxidant, monitoring wells placed down-gradient of the injection point should be used to evaluate the drift achievable (and thus the spacing between rows of injection wells). But, monitoring wells relatively close to the injection points should also be installed to evaluate the oxidant distribution during the injection period (used to space wells in the injection row). If a grid pattern is proposed for full-scale, then understanding the drift is not as critical. Figure A18-1 provides an example monitoring well layout. The design of injection wells and monitoring wells used for a pilot test will be the same as used for full-scale.

As with full-scale systems, care should be taken to avoid utilities during well installation. In addition, utilities and other possible preferential flow paths should be considered in laying out the wells to avoid sending oxidant down the utility bedding.

It should be noted that tracer tests may be a very useful part of a pilot tests. Injection of a tracer alone can be used to evaluate the "injectability" of fluids (i.e., detect a fatal flaw) and the potential distribution of an oxidant (and thus the mobile zone). For example, bromide is a commonly used tracer that can be injected prior to or during the injection of the oxidant. Caution should be used with combining bromide with some oxidants, as bromoform can be created under certain conditions (high oxidant concentrations and high organic matter concentrations).

The mass and volume of oxidant injected should be estimated with the aid of preliminary runs of the A11. ISCO Spreadsheet Design Tool. A range of possible parameters should be used in the tool, with a best guess used to select the mass and volume. Specific suggestions for mass and volume include:

- Avoid under-estimating the volume injected. It may be better to inject at a lower concentration with a higher volume for a pilot test to evaluate the distribution of the oxidant. Consideration should be given to injecting in the range of one pore volume of oxidant solution.
- Specific to permanganate: At sites with low natural demand for oxidant, avoid overdosing with too much permanganate. It may travel further and last longer than desired.

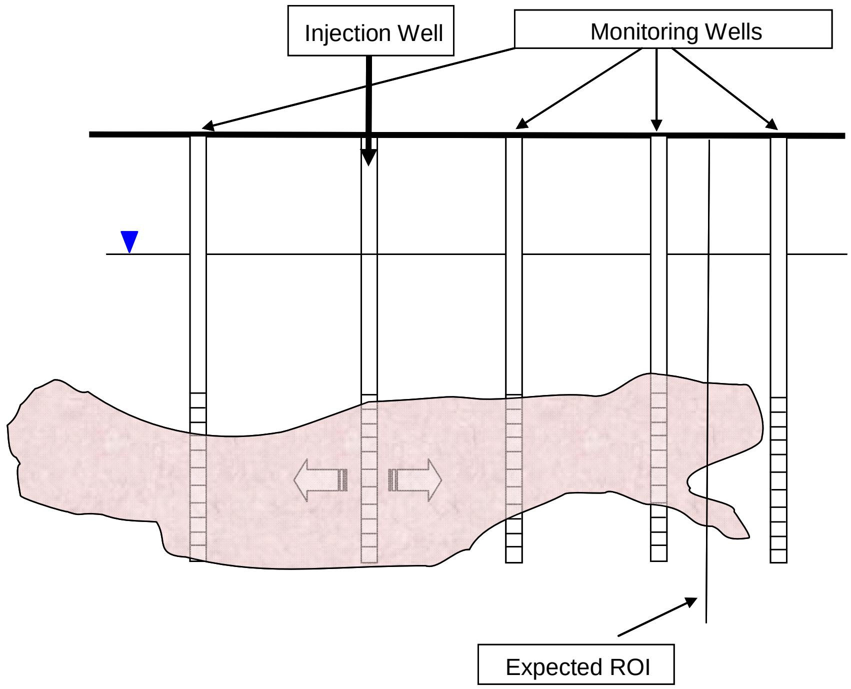

Figure A18-1. Possible Pilot Test Monitoring Well Arrangement.

EQUIPMENT

The equipment used to perform the pilot tests (i.e., the oxidant mixing, delivery system, and monitoring devices) may be similar to that used for the full-scale system. However, since the duration of injections will be much shorter and mass/volume injected much smaller, different equipment may be used. For example, although not typically economical for full-scale, a simple liquid sodium permanganate dilution system could be used for a pilot scale rather than a potassium permanganate system that requires mixing dry chemicals. However, practitioners are encouraged to weigh the cost savings realized by substituting different equipment than will be used in the full-scale application against the lessened ability to identify and troubleshoot potential operational issues with that equipment (e.g., pump bladders being corroded by oxidant, filtration systems not performing at designed etc.).

MONITORING

The monitoring program for a pilot test could be similar to that used for a full-scale system. More information on monitoring for full-scale systems is provided in ISCO Implementation and Performance Monitoring.

A few precautionary notes for monitoring are provided below.

- Provide sufficient baseline sampling to understand the natural variability in concentrations. This sufficient understanding is especially true of contaminant concentrations, which may vary over time under ambient conditions by as much as 50 percent.
- Sample frequently enough after the injections to be able to observe the distribution of the oxidants. This need is especially true with the short-lived oxidants, but may also be true with permanganate if the natural demand for oxidant is high.
- Consider using data loggers to help collect information on the distribution of the oxidants which may alleviate some of the need for very frequent sampling, and may be used to guide sample collection.

EXAMPLES

Three summary examples of a well-conducted pilot studies, including observations and lessons learned are presented below.

Example Pilot Study #1: Cooper Drum Superfund Site

South Gate, California

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References: Battelle Conference 2006 Proceedings papers D-21 and D-31. General information at http://cfpub.epa.gov/supercpad/ cursites/ csitinfo.cfm?id=0903253 and URS Group "Field Pilot Study of ISCO at the Cooper Drum Site" December 2006 at http://www.cooperdrum.com

Site Narrative:

The site is a drum refurbishing facility that has operated since the 1940s and was added to the NPL in 2001. The site is underlain by stratified deposits of sand and silt with clay lenses and groundwater is located at a depth of 45 feet below grade. Groundwater has been impacted by chloroethenes, dichloroethane, and 1,4-dioxane. A previous pilot study found that enhanced biological attenuation was not successful in degrading 1,4-dioxane. An ISCO treatability study found that ozone was capable of degrading 1,4-dioxane, both with and without hydrogen peroxide as an activator. The similarity of the results of the two systems was contrary to the literature, which indicates that ozone and hydrogen peroxide (peroxone) should react more quickly than ozone alone. Naturally occurring iron and alkalinity are possible reasons why the ozone system degraded 1,4-dioxane as quickly as it did. The ISCO pilot study was conducted for nearly one year beginning in July 2005. All COCs were successfully degraded by approximately 60-70%, including 1,4-dioxane. Monitoring results showed no secondary groundwater impacts. Based on the results, the engineer has recommended full scale use of ISCO with peroxone at this site.

COCs in Pilot Test Area:

- TCE max 940 ug/L GW; cis-DCE max 310 ug/L GW; 1,1-DCA max 74 ug/L GW; 1,4-dioxane max 750 ug/L GW
- DNAPL not present

Geology, Hydrology and Baseline Geochemistry of Pilot Test Area:

- Interbedded deposits of sand and silt with clay lenses
- Saturated hydraulic conductivity: 50 ft/day
- Depth to water: 45 ft
- Groundwater flow velocity: 0.3 ft/day
- pH: 7.2
- ORP: -51 mV
- TOC: 19.5 mg/L
- Alkalinity: 17 meq/L
- Iron: 2.8 mg/L

Site Characterization Methods:

- Began in 1996 and included soil, groundwater, and soil gas sampling for VOCs
- Cone penetrometer (CPT) testing was also used to assess the site geology and collect depth-discreet groundwater samples.

Pilot Test Objectives:

The goal of the pilot test was to assess the ability of ozone and peroxone to degrade the COCs present at the site, with particular interest in 1,4-dioxane, which at the time of the pilot test, had not been treated using ISCO according to case study source documents. A second goal of the pilot test was to assess the soil oxidant demand in situ. The success of the pilot test was gauged by: significant reduction of COCs; a lack of permanent increases in secondary biproducts (e.g. hexavalent chromium); and minimal rebound of COCs.

Pre-Pilot Treatability Testing:

- Batch testing used pilot test site groundwater and soil. Tests evaluated the destruction efficiency of the COCs using both ozone and peroxone. COC destruction was confirmed by comparing to similar materials sparged with inert nitrogen gas. COCs were measured in the aqueous phase, sparging off-gas, and solid phase (when present). Batch testing used 100 grams of soil and 1,000 mL of groundwater. Ozone concentrations were 26 to 31 mg/L in air, sparged at a rate of 200 mL/minute for a period of 3 hours.
- Due to the unexpectedly high destruction efficiency observed in the ozone tests, additional tests were run to analyze what constituents of the site groundwater might be acting as ozone enhancers. These tests were run using ferrous iron, chelated iron, TCE, and bicarbonate (to provide alkalinity). These tests were run with deionized water spiked with 1,4-dioxane.
- Batch tests also evaluated impacts of ozone and peroxone sparging on metals and bromate.

Pilot Study Design:

- Target Treatment Zone: 270,000 cubic feet
- Oxidant: Ozone alone at 0.55 to 1.9 lbs/day for first five months, followed by ozone with hydrogen peroxide delivered in 2:1 molar ratio of peroxide to ozone (2.5 to 5 gallons of 16% hydrogen peroxide per day) for the next five months.
- Activation Method: Hydrogen peroxide during second half of pilot test.
- Number of Delivery Events: 1
- Duration of Delivery Event: 321 days with 91% runtime
- Delivery Method: Three sparge wells constructed with two sparge points each, spaced 30 to 50 feet apart, pulsed with a one hour frequency.

Pilot Study Monitoring:

- Three monitoring wells were installed at distances between 10 and 30 feet downgradient of the sparge wells. Two additional monitoring locations were present already in the pilot test area.
- Monitoring wells were sampled for the following analytes: COCs, ozone, hydrogen peroxide, pH, DO, and ORP. The frequency of these analyses varied depending on the analyte.
- Down-hole data loggers were used to monitor DO and ORP. The real-time monitoring data was cited as being a critical component used to optimize the ozone and hydrogen peroxide dosing.
- Vertical profiling of DO and ORP in existing extraction wells with long screens was used to evaluate the variation of ozone impacts with depth.

ISCO Effectiveness:

- Goal: Significant reduction of COCs with minimal rebound and optimization of ISCO system design parameters.
- Goals Achieved: Yes.
- Post-ISCO maximum concentrations: 65 ug/L TCE, 44 ug/L cis-DCE, 6.2 ug/L 1,1-DCA, and 47 ug/L 1,4-dioxane.
- Byproducts Formation: Hexavalent chromium and bromate were not detected.
- Reduction in Microbial Activity: Not Analyzed.

- Case Status: Open.
- Current Plans for Future Work: The project engineer has designed a full scale peroxone system for the source zone.

Other Observations and Lessons Learned:

- Real time data-loggers measuring DO and ORP were valuable in optimizing system design.
- Modifications to the ozone loading rate were made and subsequent changes in COC reductions were measured to assess the impact of this design criterion.
- One well became plugged during the pilot test, presumably from scaling or biofouling. This well was successfully rehabilitated with dilute acid.

Example Pilot Study #2: Naval Air Station North Island OU-20 Persulfate Pilot Test

San Diego County, California

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References: Shaw Infrastructure Inc. “Persulfate Pilot Test Summary Report”, November 2007 and www.envirostor.dtsc.ca.gov/public/

Site Narrative:

Naval Air Station North Island is an operational military base located adjacent to the city of Coronado in San Diego County, California. The Operable Unit (OU) 20 groundwater plume is approximately ½ mile in length, up to 80 feet below ground surface, and contains TCE and associated degradation products resulting from aircraft maintenance and other base operations conducted in this area from 1945 onwards. In situ remediation is necessary due to the potential for TCE to impact San Diego Bay, which abuts the site to the northeast. The pilot test described in this document targeted a portion of the plume containing TCE at concentrations of approximately 4,000 ug/L, and was selected based on contaminant concentrations, accessibility, and infrastructure considerations. The pilot test location was relocated once due to elevated chromium concentrations associated with aircraft repair that were detected prior to ISCO implementation.

COCs in Pilot Test Area:

- TCE max 16,500 ug/L GW, 0.22 mg/kg soil; cis-DCE max 1,100 ug/L GW, 0.11 mg/kg soil
- DNAPL not present

Geology, Hydrology and Average Baseline Geochemistry of Pilot Test Area:

- Fine to very fine sand and silty sand
- Saturated hydraulic conductivity: 2 to 30 ft/day
- Depth to water: 20 ft
- Groundwater flow velocity: 0.04 to 0.05 ft/day
- pH: 7.5
- ORP: +112 mV
- Temperature: 21.9°C
- DO: 0.43 mg/L

Site Characterization Methods:

- Large-scale delineation of OU-20 plume in 2002
- Pilot test area COC concentrations confirmed with Membrane Interface Probe (MIP) testing at 7 locations and direct push groundwater sampling for VOCs and chromium in an area of approximately 6,400 sf.

Pilot Test Objectives:

The goal of the pilot test was to assess the ability of sodium persulfate to reduce TCE and cis-DCE concentrations in groundwater by at least 90% using ambient groundwater temperatures as the activation method. This plan included a contingency for steam activation if 90% reductions were not achieved. The pilot test also assessed the distance of influence, the impact on metals and secondary groundwater standards, and changes in formation permeability as a result of ISCO treatment.

Pre-Pilot Treatability Testing:

- Batch testing used a soil-water slurry comprised of contaminated materials collected from the pilot test site. The purpose of the batch tests was to evaluate natural oxidant demand (NOD) and degradation effectiveness of various activators, including heat, Fe-EDTA, alkaline conditions, and ambient groundwater temperature of 22°C. Pilot testing also evaluated gypsum solids precipitation ($CaSO_4 \bullet 2H_2O$). The slurries consisted of a 1.5:1 ratio of site groundwater to soil, and were also spiked with TCE to ensure aqueous phase TCE concentrations were similar to those recorded in the field. Slurries were mixed during testing and sampled for oxidant and TCE concentration at 0, 1, 3, and 7 days.
- The treatability testing results showed that Fe-EDTA activation resulted in very poor degradation. Heat activation was successful, and ambient groundwater temperatures were surprising successful at the bench scale as well.
- Treatability testing indicated that NOD was 2.3 g/kg at a persulfate concentration of 30 g/L after 7 days.
- Gypsum precipitation did not impact grainsize distribution, which was nearly identical after batch testing to an untreated sample.

Pilot Study Design:

- Target Treatment Zone: 17,000 cubic feet
- Oxidant: Sodium persulfate at 45 g/L
- Activation Method: Ambient heat of 22°C, with a contingency to introduce steam should the ambient temperature not result in the desired contaminant degradation.
- Pore Volumes Delivered: 1.7
- Oxidant Dose (g ox./kg media): 7
- Number of Delivery Events: 1
- Delivery Method: Continuous recirculation for five days with central injection well and four extraction wells located at distances of 20 or 30 feet from the injection well, all stainless steel (due to potential use of steam activation later) and screened from 44 to 54 ft bgs. Groundwater was filtered after extraction and after mixing prior to reinjection. The injection rate was 10 gpm at the start of the pilot test and was reduced to 6 gpm during the second half of the test due to the increased hydraulic head caused by the cone of injection.

Pilot Study Monitoring:

- Four monitoring wells were installed inside the treatment cell between the injection and extraction wells with a fifth monitoring well located outside and downgradient of the treatment cell.
- Monitoring wells, extraction wells, and injection well were sampled for the following analytes: VOCs, persulfate, pH, DO, ORP, salinity, chloride, sulfate, TDS, and metals. VOC analyses were performed prior to ISCO and 7, 19, 30, 60, and 90 days after ISCO was completed.

- During recirculation, persulfate analyses were conducted at the extraction wells using starch iodide test kits.

ISCO Effectiveness:

- Goal: 90% reduction
- Goal Achieved: Yes. At 19-days post-ISCO average concentrations among the ISCO performance monitoring wells had been reduced by 90%, indicating that steam activation would not be used per the project's scope of work.
- Post-ISCO monitoring well max concentration of TCE: 3,900 ug/L at 19 days, 12,500 ug/L at 30 days, 3,500 at 60 days, and 4,200 ug/L at 90 days. These results were all detected within the same upgradient monitoring well, and were likely due to an influx of untreated groundwater from upgradient.
- Post-ISCO mean concentration of PCE: 1,300 at 60 days and 2,000 ug/L at 90 days (86% and 78% reductions from baseline, respectively)
- Metals Mobilization: No
- Permeability Reduction: No (verified by slug testing)
- Reduction in Microbial Activity: Not Tested
- Current Plans for Future Work: Project team is evaluating implementing persulfate at full scale.

Other Observations and Lessons Learned:

- Increases in TCE concentrations in groundwater at some monitoring locations attributed to inflow of contaminated groundwater from upgradient areas that were outside the target treatment zone.
- Project team used low-flow sampling techniques during post-ISCO monitoring. It was hypothesized that anomalous high concentrations of TCE observed in monitoring wells during the 7-day post treatment sampling event were the result of untreated, stagnant groundwater remaining in those monitoring well after ISCO. For this reason the project team purged three well volumes from site monitoring wells and then resampled those wells for VOCs (19 day posttreatment sampling).
- Persulfate was observed to persist for up to 19 days in treatment area.
- Corrosive nature of persulfate required maintenance of certain equipment, such as pump bladders.
- During injection it was observed that the injection well seal was forced open by the pressure of injections. This caused the injected solution to flow through the buried piping trench and into an extraction well, causing short circuiting of the system. The well was resealed and additional persulfate added to the system to make up for the short circuiting.
- Through bench-scale testing it was identified that activation of the persulfate radical occurred under ambient conditions and produced significant VOC contaminant reduction without the application of an activator (elevated heat, pH adjustment, etc.). Because elevated groundwater temperature (~20 to 24 degrees Celsius) is the primary difference between OU-20 and other sites, generation of the persulfate radical is attributed to low temperature heat activation.

Example Pilot Study #3: Letterkenny Army Depot (LEAD) Southeast Disposal Area

Chambersburg, PA

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References: Weston “In Situ Chemical Oxidation Remediation Pilot Study of Bedrock Aquifer” and "Summary Report for the In Situ Chemical Oxidation Pilot Study of the Bedrock Aquifer at the Southeast (SE) Disposal Area (DA) Letterkenny Army Depot" October 2000, Weston

Site Narrative:

The site is located at a former disposal area whose use resulted in impacts to the subsurface. This pilot study was performed to test the effectiveness of CHP injections into a karst aquifer to treat chloroethene contaminants including DNAPL. Injections proceeded continuously over a period of 4 days. Extensive monitoring showed that hydrogen peroxide and the ferrous sulfate activator were distributed across the treatment area. Performance results showed that among wells in the treatment area that had detectable levels of hydrogen peroxide, some significant decreases were noted while others remained unchanged. Rebound was noted after treatment. Significant rainfall occurred during the post-treatment monitoring period, causing groundwater levels to rise several feet higher than during treatment and baseline sampling.

COCs in Pilot Test Area:

- PCE max 1,500 ug/L GW; TCE max 6,000 ug/L GW; cis-DCE max 5,600 ug/L GW; VC max 560 ug/L GW
- DNAPL observed to be present in treatment zone

Geology, Hydrology and Baseline Geochemistry of Pilot Test Area:

- Karst limestone
- Saturated hydraulic conductivity: 27 to 80 ft/day
- Rock matrix hydraulic conductivity: <1 ft/day
- Depth to water: 25 ft
- Groundwater flow velocity: 8 to 2,500 ft/day
- pH: 6.6
- Temperature: 16 deg C
- Alkalinity: 7 meq/L
- Iron: 37 mg/L
- Calcium: 115 mg/L

Site Characterization Methods:

- Dye tracer tests
- Packer testing (for COCs, specific capacity, and hydraulic communication)
- Borehole geophysics (temperature, caliper, fluid resistivity, optical, and acoustic televiewer logging)

Pilot Test Objectives:

The goal of the pilot test was to assess the ability of CHP to effectively degrade the chloroethene contaminants in this karst system. Specifically, the impacts of the formation's high conductivity and heterogeneity, the ability to lower pH to the optimal range for Fenton's chemistry, the necessity and effectiveness of continuous injection of reagents, and the effectiveness of the monitoring program were evaluated. Should the pilot program be deemed effective upon its completion, another goal of this study was to collect data for full scale system design.

Pre-Pilot Treatability Testing:

Bench scale testing was performed to meet the following objectives, utilizing site groundwater and rock cores:

- Evaluate the impact of the limestone bedrock on the pH of the activator solution.
- Evaluate the potential for the acidic activator to dissolve the limestone bedrock.
- Evaluate the clogging potential of the ferric iron precipitate that could result from the addition of the ferrous iron activator.

- Evaluate the potential of the limestone bedrock and mineral precipitates coating fracture surfaces to activate (or decompose) hydrogen peroxide.
- Optimize the concentrations of activator and hydrogen peroxide.

Pilot Study Design:

- Target Treatment Zone: 4,800,000 cubic feet
- Oxidant: 12,700 gallons of hydrogen peroxide at 596 g/L (50% by weight)
- Activation Method: 36,000 gallons of ferrous sulfate and phosphoric acid solution (concentration unreported)
- Pore Volumes Delivered: 0.0055 (based upon hydrogen peroxide volume)
- Oxidant Dose (g ox./kg media): 0.052
- Number of Delivery Events: 1
- Delivery Method: Continuous injection of reagents over a period of 3.5 days. Injection began using the activator solution only to obtain the optimal pH (determined to be 5 during bench scale testing). Once the aquifer was conditioned, hydrogen peroxide was added and supplemented with additional activator as necessary. Reagents were delivered through proprietary equipment designed to mix the hydrogen peroxide and activator solutions at the injector head located within the wells.

Pilot Study Monitoring:
The following parameters were monitored during the injections, measured with field instruments unless otherwise noted. Hydrogen peroxide interfered with some of the test methods, and therefore some tests could not be performed when hydrogen peroxide was detected above 3 mg/L.

- Iron (w/ test kit)
- pH
- specific conductivity
- temperature
- carbon dioxide
- dissolved oxygen
- hydrogen peroxide (w/ test kit)
- chloride (w/ test kit)
- hardness (w/ test kit – measured to assess degradation of limestone bedrock, if any)
- groundwater elevations.

VOCs were monitored in groundwater 10 days prior to injection, and 5 days, 20 days, 3 months, and 9 months after injections.

ISCO Effectiveness:

- Goal: Evaluate ability of CHP to remediate the chloroethene contamination in karst aquifer.
- Goal Achieved: Yes. CHP proved to be effective in some locations, though less so in others. Concentrations were observed to rebound during the post-ISCO monitoring period.
- Metals Mobilization: None reported.
- Permeability Reduction: None Reported.
- Reduction in Microbial Activity: Not Tested.
- Current Plans for Future Work: The project team gave several full scale design recommendations in the pilot study report. As of the data of this writing (July 2008) plans for ongoing remediation at this site are unknown to the preparers of this case study.

Other Observations and Lessons Learned:

- Significant rainfall events occurred during the post-ISCO monitoring period, causing groundwater elevations to rise several feet above historic levels and those that existed during this pilot test. This confounds the interpretation of contaminant rebound.

- Interference between oxidants and sampling methods (e.g. field test kits and instruments) are important to be aware of during ISCO monitoring.
- To avoid unnecessary, unproductive consumption of the oxidant during injection, the project team recommended monitoring the hydrogen peroxide concentration at the perimeter of the target treatment zone, and reducing the hydrogen peroxide injection rate once concentrations at the perimeter reached 100 mg/L.
- Injecting activator solution only around the perimeter of the planned injection zone was suggested as a means of providing an "oxidative barrier" to prevent VOCs from migrating outside the target treatment zone.