

## **Enhanced Bioremediation Pilot-Test Results at a Site in Northwestern Georgia**

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**ABSTRACT:** Groundwater at a manufacturing facility in northwestern Georgia is affected by trichloroethene (TCE). While natural attenuation appears to have stabilized the TCE plume, the concentrations of TCE were not decreasing as quickly as desired. EPD commented that a more aggressive remediation may be necessary if decreasing concentration trends for TCE and other constituents are not observed. Enhanced bioremediation was selected as a preferred alternative to expedite remediation and a pilot test was conducted. Pilot testing consisted of (1) installing six injection wells, (2) injecting a commercially available emulsified soybean oil solution, and (3) monitoring groundwater. Pilot-testing results indicated enhanced bioremediation was effective based on groundwater concentrations of TCE concentrations decreasing to below detectable concentrations within five months, cis-1,2-dichloroethene (DCE) concentrations increasing for four months and then decreasing, vinyl chloride (VC) concentrations increased over five months and then decreased, and ethene/ethane concentrations increased. Additionally, other biodegradation indicator parameters and Bio-Trap<sup>®</sup> samples analyzed for *Dehalococcoides ethenogenes* (DHE) were positive for demonstrating enhanced biodegradation. Closure of this area is expected once the VC concentrations reach the remediation goal. Based on the positive results, a full-scale application will be implemented for the larger TCE source area at the site.

### **INTRODUCTION**

Soil and groundwater at a manufacturing facility located in northwestern Georgia are affected by TCE and other volatile organic compounds (VOCs). A Corrective Action Plan (CAP) was submitted to the Georgia Department of Natural Resources Environmental Protection Division (EPD) that proposed monitored natural attenuation (MNA) for the area of interest (vicinity of a loading dock) and active remediation for other areas. EPD approved the CAP.

Quarterly groundwater monitoring data supported that the plume was stable but TCE concentrations were not decreasing as quickly as hoped. EPD commented that a more aggressive remediation approach may be necessary if decreasing concentration trends for TCE and other constituents were not observed. Considering EPD's comments and the desire to expedite remediation, enhanced natural bioremediation was selected as a preferred alternative and a pilot test was conducted.

## **GEOLOGY AND HYDROGEOLOGY**

Subsurface conditions at the site consist of an unconsolidated overburden underlain by bedrock. The unconsolidated overburden consists of red brown, sandy, silty, clay and clayey, silty sand and ranges in thickness from 20 to 50 feet. The underlying bedrock is highly weathered and composed of limestone and dolomite of the eastern belt of the Canasauga Formation. A major northeast-southwest trending thrust fault dipping southeast passes very near the Site, to the north. The Site is located on the upthrown side of the fault. Tear faults trending southeast to northwest lie orthogonal to the thrust fault.

Overburden and bedrock aquifer systems in direct communication have been identified at the site. Overburden groundwater flows to the northwest and discharges to a spring and an unnamed tributary to the Etowah River. Bedrock groundwater flows from the facility to approximately 1,200 feet northeast where groundwater encounters a set of southeast-northwest trending tear faults. Groundwater entering these faults flows northwesterly until the major thrust fault feature is encountered. Once groundwater enters this highly transmissive fault zone, flow becomes southwesterly, and eventually discharges to the Etowah River.

## **MONITORED NATURAL ATTENUATION**

Natural attenuation appears to have stabilized the TCE plume throughout the site. Naturally-occurring biodegradation through reductive dechlorination was not a significant attenuation mechanism based on low concentrations of the TCE biodegradation products (DCE, VC, ethene). As such, active remediation was designed and implemented at the primary TCE source area. However, one area of the site, the area of interest, showed evidence of naturally-occurring biodegradation based the presence of each of the above biodegradation products and other indicators supporting that biodegradation via reductive dechlorination was occurring (e.g., anaerobic conditions, elevated ferrous iron and methane concentrations relative to background). The difference between the area of interest and other areas of the site is that TCE and its biodegradation products were present along with several petroleum hydrocarbons including ethyl benzene, toluene, and xylenes. TCE biodegradation appears to have been enhanced in this area due to the petroleum hydrocarbons serving as an organic carbon source.

Based on the above results, a CAP was prepared and submitted to EPD proposing MNA for the area of interest, and was approved by EPD. MNA consisted of conducting quarterly groundwater monitoring for two years, assessing plume stability using a statistical trend analysis, and annual monitoring until the applicable Georgia Risk Reduction Standards (RRS) were achieved.

Quarterly groundwater monitoring data over the past several years supported the conclusion that the plume was stable but TCE concentrations were not decreasing as quickly as hoped. TCE concentrations over this period ranged from 90 to 200 micrograms per liter ( $\mu\text{g/L}$ ) with a stable to slightly increasing trend. DCE, VC, and ethene concentrations over this time decreased from 80 to 10  $\mu\text{g/L}$ , 120  $\mu\text{g/L}$  to not detected, and 8,000 to 40 nanograms per liter ( $\text{ng/L}$ ), respectively. EPD commented that a more aggressive remediation approach may be necessary if decreasing concentration trends for TCE were not observed. Considering EPD's comments and the desire to expedite remediation, enhanced bioremediation was selected as a preferred alternative.

## WHY ENHANCED NATURAL BIOREMEDIATION?

Biodegradation was occurring, but the amount of organic carbon in the area of interest was not high enough to sustain the desired biodegradation of TCE and its biodegradation products. Providing a source of organic carbon was expected to enhance the naturally-occurring biodegradation of TCE and its biodegradation products. The cost to purchase a commercially available organic substrate and injecting it into the subsurface is low compared to other more aggressive remediation technologies.

Pilot testing at the area of interest was necessary to verify the effectiveness of this remedial approach. Additionally, an investigation was also conducted to evaluate whether *Dehalococcoides ethenogenes* (DHE) is present in the subsurface at the area of interest and other TCE source areas at the site to provide additional evidence that enhanced natural bioremediation would be effective. If pilot testing is successful, enhanced bioremediation could be applied at other TCE source areas at the site to enhance and expedite ongoing active remediation.

## DEHALOCOCCOIDES ETHENOGENES INVESTIGATION

An investigation was conducted to determine whether DHE is present in the subsurface at the area of interest and other TCE source areas. DHE is a microorganism that can completely biodegrade TCE to ethene, as reported by other environmental professionals and researchers in multiple literature references. Thus, its presence would provide additional evidence to support the premise that enhanced natural biodegradation would be effective.

The investigation consisted of placing Bio-Trap<sup>®</sup> samplers below the groundwater in five monitoring wells for 30 days and submitting the samplers to the laboratory for analysis. The Bio-Trap<sup>®</sup> samplers were provided by Microbial Insights, Inc. of Rockford, Tennessee. Figure 1 is a photograph of a sampler with the beads used to fill the sampler and serve as a growth media. Microbial Insights analyzed the samples using the Q Potential (DNA) method to specifically identify DHE.



FIGURE 1. Bio-Trap<sup>®</sup>.

DHE presence in each of the five monitoring wells was confirmed by the analyses. Results indicated that the DHE cell counts ranged from  $2.21 \times 10^2$  to  $7.76 \times 10^5$  cells/bead. These results provide additional evidence to support that enhanced natural bioremediation should be effective at the area of interest and other TCE source areas.

## PILOT-TEST FIELD PROCEDURES

Pilot testing consisted of (1) installing six injection wells, (2) injecting a commercially available emulsified soybean oil solution, and (3) monitoring groundwater to evaluate bioremediation performance. Well installation and injections occurred during October 2006 following approval of a work plan submitted to EPD and notification of the Georgia Geologic Survey Branch of the Georgia Department of Natural Resources of the planned work. An Underground Injection Control permit was not required for the pilot test.

Geoprobe<sup>®</sup> injection rods were initially planned to be used for the injection points. Instead, temporary injection wells were installed to improve solution injection and distribution because of the potential for short circuiting of substrate solution through the annulus around the injection rods to the ground surface. The wells were installed using a Geoprobe<sup>®</sup> to a depth of 18 to 20 feet below the ground surface (ft bgs), which is approximately the top of the bedrock, and a spacing of 10 feet. The wells were constructed of 1-inch diameter schedule 40 PVC well casing equipped with 5-feet of screen. A sand pack was placed around each well and sealed with bentonite, which resulted in a tighter seal and reduced the potential for organic substrate short circuiting.

Organic substrate injections were completed using a trailer-mounted mixing tank and injection pump. A piping manifold was constructed using PVC pipe and flexible hoses, and included control valves, pressure gauges, and flow meters for each injection well. Figure 2 shows the trailer-mounted mixing and injection equipment, and Figure 3 shows the injection manifold, one of the injection wells, and a monitoring well.



**FIGURE 2. Mixing and injection equipment.**



**FIGURE 3. Injection manifold and well.**

A total volume of 3,909 gallons of a 1.8 percent organic substrate solution was injected into the injection wells at rates of 0.75 to 1.0 gallons per minute and pressures ranging from 5 to 18 pounds per square inch, and included 150 to 200 gallons of water to flush out the lines and injection wells. The organic substrate selected was Newman's Zone manufactured by Remediation and Natural Attenuation Services of Brooklyn Center, Minnesota, which consists of emulsified vegetable oil, lactate, nutrients, a buffering agent, and other proprietary ingredients. This commercially available substrate was selected based on a comparison with other available products as well as technical, ease of mixing and injecting, and financial reasons.

Groundwater samples were collected from a monitoring well in the area of interest (i.e., MW-3R, screened from 15 to 30 ft bgs) before and after the organic substrate injections for laboratory analyses using low-flow purging and sampling techniques. Samples were collected on a nearly monthly basis between November 2006 and May 2007. Samples have not been collected since May 2007 due to the severe drought conditions experienced in the region resulting in a low water table and the well being dry. The samples were analyzed for field parameters (i.e., dissolved oxygen, oxidation-reduction

potential [ORP], pH, temperature, specific conductance, turbidity), VOCs, total organic carbon (TOC), and light hydrocarbons (i.e., ethane, ethene, methane).

## **PILOT-TEST RESULTS AND CONCLUSIONS**

Table 1 summarizes the groundwater analytical results and Figure 4 is a chart presenting the change in TCE, DCE, VC, ethane, and ethene concentrations before and after the injections. Table 1 and Figure 4 present the concentrations of these compounds in micro-molar ( $\mu\text{M}$ ) units to normalize the data for evaluation purposes. Pilot-testing results indicated that enhanced natural bioremediation is effective, and this conclusion is based on the following:

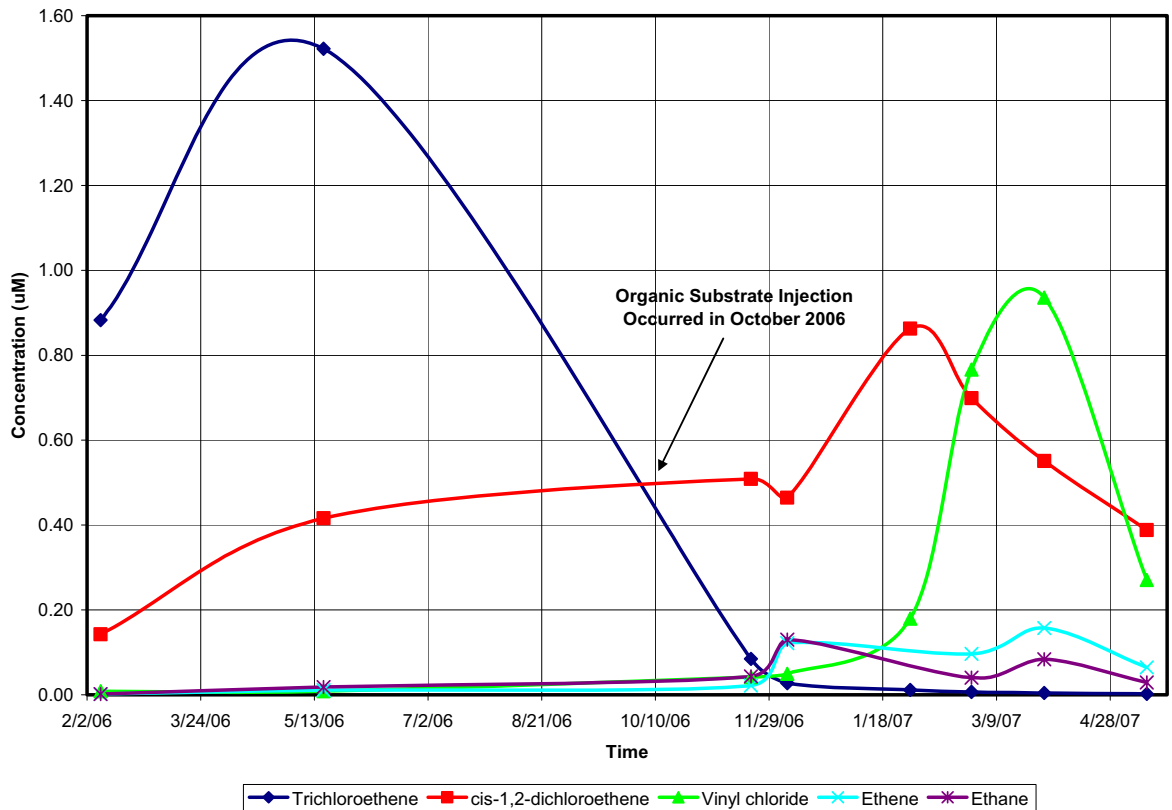
- TCE concentrations decreased to below detectable concentrations in five months, which is well below its RRS of  $40 \mu\text{g/L}$ ;
- DCE concentrations increased through four months, then decreased to below its RRS of  $93 \mu\text{g/L}$ , and indicated that DCE was produced as a result of TCE biodegradation and then decreased as TCE was depleted and DCE continued to biodegrade;
- VC concentrations increased over five months, then decreased, and indicated that VC was produced as a result of DCE biodegradation and then decreased as DCE decreased and VC continued to biodegrade;
- Ethene/ethane concentrations increased and indicated that VC was being biodegraded through reductive dechlorination and complete biodegradation of TCE occurred;
- Methane concentrations significantly increased following organic substrate injection and indicated that anaerobic biodegradation was stimulated by addition of the organic substrate because methane is produced by anaerobic biodegradation;
- ORP remained below zero following organic substrate injection, which indicates that organic substrate injection created sustainable anaerobic, reducing conditions required for complete reductive dechlorination of TCE to ethene.

One parameter that will need to be evaluated further is pH. The groundwater pH was approximately neutral throughout most of the monitoring period, but did show a decreasing trend near the end. The decreasing trend is likely due to organic acids being produced as a byproduct of biodegradation. The reason that low pH is a concern is that the optimum pH for reductive dechlorination is near neutral, and pH declines can slow the biodegradation rates compared to rates observed at a neutral pH. Although a buffered organic substrate was injected, additional buffering agent may need to be injected into the subsurface to counter the pH decline, and such agent may include calcium hydroxide or sodium bicarbonate.

TOC concentrations remained high enough to continue supporting anaerobic biodegradation for the seven-month monitoring period. This observation supports that the organic substrate should last in the subsurface for a year or more.

**TABLE 1. Pilot-test groundwater analytical results.**

| Parameter   | Unit | Groundwater Concentrations @ MW-3R |         |          |         |         |         |         |         |
|-------------|------|------------------------------------|---------|----------|---------|---------|---------|---------|---------|
|             |      | 2/8/06                             | 5/17/06 | 11/21/06 | 12/7/06 | 1/30/07 | 2/27/07 | 3/30/07 | 5/16/07 |
| TCE         | µg/L | 116.00                             | 200.00  | 11.10    | 3.60    | 1.50    | 0.91    | 0.54    | <0.25   |
| DCE         | µg/L | 13.80                              | 40.30   | 49.30    | 45.00   | 83.60   | 67.7    | 53.4    | 37.6    |
| VC          | µg/L | <0.50                              | <0.50   | 2.60     | 3.10    | 11.20   | 47.9    | 58.5    | 16.9    |
| Ethene      | µg/L | 0.04                               | 0.30    | 0.60     | 3.40    | NA      | 2.7     | 4.4     | 1.8     |
| Ethane      | µg/L | 0.04                               | 0.54    | 1.30     | 3.90    | NA      | 1.2     | 2.5     | 0.86    |
| Methane     | µg/L | 0.11                               | 0.31    | 3.80     | 440     | NA      | 2,200   | 8,600   | 3,800   |
| ORP         | mV   | 9.4                                | 109.2   | -115.0   | -40.4   | NA      | -113.2  | -123.9  | -81.3   |
| pH          | su   | 7.05                               | 7.16    | 6.94     | 6.54    | 6.72    | 7.09    | 6.80    | 6.42    |
| TOC         | mg/L | 1.7                                | 0.5     | 318      | 348     | 271     | 222     | 241     | 350     |
|             |      |                                    |         |          |         |         |         |         |         |
| TCE         | µM   | 0.88                               | 1.52    | 0.08     | 0.03    | 0.01    | 0.01    | 0.00    | 0.00    |
| DCE         | µM   | 0.14                               | 0.42    | 0.51     | 0.46    | 0.86    | 0.70    | 0.55    | 0.39    |
| VC          | µM   | <0.01                              | <0.01   | 0.04     | 0.05    | 0.18    | 0.77    | 0.94    | 0.27    |
| Ethene      | µM   | 0.0014                             | 0.0107  | 0.0214   | 0.1214  | NA      | 0.0964  | 0.1571  | 0.0643  |
| Ethane      | µM   | 0.0013                             | 0.0180  | 0.0433   | 0.1300  | NA      | 0.0400  | 0.0833  | 0.0287  |
| Total CVOCs | µM   | 1.04                               | 1.97    | 0.70     | 0.79    | NA      | 1.61    | 1.73    | 0.75    |



**FIGURE 4. Groundwater concentrations versus time.**

## **PATH FORWARD**

Closure of the area of interest is expected from EPD once the VC concentrations reach its RRS. Based on the positive results, a full-scale application will be implemented for the larger TCE source area at the site. The larger application is expected to include approximately 70 injection wells with about 35 being applied at the source area and the other 35 being applied in a barrier application. If successful, performance of the ongoing active remediation program will be expedited and is anticipated to be finished within 12 months of implementing enhanced natural bioremediation followed by MNA.