



## ***SITE Technology Capsule***

### **Metal-Enhanced Dechlorination of Volatile Organic Compounds Using an Above-Ground Reactor**

**EnviroMetal Technologies, Inc.**

#### **Introduction**

In 1980 the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, to protect human health and the environment from uncontrolled hazardous waste sites. CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA) in 1986. SARA mandates implementing permanent solutions and using alternative treatment technologies or resource recovery technologies to the maximum extent possible to clean up hazardous waste sites.

The more than 1,200 sites on the National Priorities List involve a broad spectrum of physical, chemical, and environmental conditions requiring diverse remedial approaches. The U.S. Environmental Protection Agency (EPA) has focused on policy, technical, and informational issues related to exploring and applying new technologies to Superfund site remediation. One EPA initiative to accelerate the development, demonstration, and use of innovative remediation technologies is the Superfund Innovative Technology Evaluation (SITE) Program.

State and federal agencies and private organizations are exploring a growing number of innovative technologies for treating hazardous wastes. The SITE Program provides a forum for demonstrating the effectiveness of innovative technologies at hazardous waste sites. The SITE Program evaluates technology performance through collection of independent data and publishes the results of these studies.

EPA Site Technology Capsules summarize the latest information available on innovative treatment and site remediation technologies selected for demonstration in the SITE Program. The Technology Capsules assist EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision-makers in the evaluation of site-specific chemical and physical characteristics to determine a technology's applicability for site remediation.

This Technology Capsule provides the latest available information on the EnviroMetal Technologies, Inc. (ETI), process for metal-enhanced dechlorination of chlorinated volatile organic compounds (VOCs) in aqueous media. The EPA SITE Program evaluated the process in an aboveground reactor at the SGL Printed Circuits (SGL) site in Wayne, Passaic County, NJ. Groundwater at the site contains the chlorinated VOCs tetrachloroethene (PCE), trichloroethene (TCE), and cis-1,2-dichloroethene (cDCE). ETI claims that, when properly designed and constructed, the technology can completely dechlorinate certain chlorinated aliphatic VOCs in water after one pass through a reactive, zero-valent, iron medium.

This Technology Capsule summarizes the results of the SITE demonstration and contains the following information:

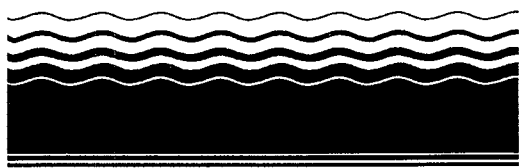
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#### **Abstract**

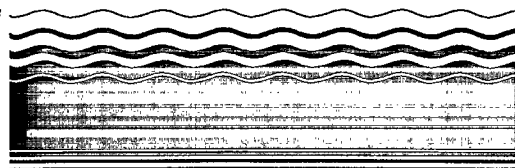
A metal-enhanced dechlorination processing using reactive, zero-valent, granular iron to dechlorinate VOCs in aqueous media was demonstrated at the SGL site in New Jersey. The developer is ETI of Guelph, ON, Canada. The technology can be operated as an aboveground reactor or can alternatively perform *in situ* groundwater remediation. Chlorinated VOCs such as PCE, TCE, cDCE, and vinyl chloride are among the most pervasive groundwater contaminants at hazardous waste



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sites. The metal-enhanced dechlorination process is designed to degrade chlorinated VOCs to nonhazardous substances, and therefore offers an alternative to conventional technologies that simply transfer VOCs from groundwater to other media, such as air or carbon filters.

The SITE Program evaluated the metal-enhanced dechlorination process in an aboveground reactor during the 13-week demonstration. About 61,000 gal of groundwater containing PCE, TCE, and cDCE was treated during the demonstration.

Analysis of influent and effluent groundwater samples indicated that PCE and TCE were reduced below regulatory levels after a single pass through the reactive iron medium. The removal efficiency for PCE was greater than 99.9% throughout the demonstration.

During the latter portion of the demonstration, cDCE and vinyl chloride were occasionally detected in the effluent. Several factors may have contributed to the incomplete dechlorination of VOCs. A review of inorganic data indicated that carbonate and hydroxide minerals precipitated in the reactive iron, and precipitation of these minerals may have affected system performance. Sedimentation on the reactive iron surface, variations in reactor temperature, and other factors may also affect the technology's performance.

The metal-enhanced dechlorination process may be applied at Superfund and other hazardous waste sites where groundwater or other liquid wastes are contaminated with chlorinated VOCs. The aboveground reactor design evaluated during the SITE demonstration may be used for pilot- or full-scale remedial applications.

## Technology Description and System Design

The metal-enhanced dechlorination process is an electrochemical process that uses zero-valent, reactive iron to dechlorinate chlorinated VOCs in aqueous media. In the presence of water, the reactive, zero-valent, granular iron is oxidized and releases electrons. Water molecules dissociate to produce hydrogen and hydroxyl ions. The electrons and hydrogen ions react with chlorinated VOCs present in the water, including substitution of chlorine atoms by hydrogen atoms, dechlorinating the chlorinated VOCs. The dechlorination process yields hydrocarbons and chloride.

The metal-enhanced dechlorination process may be used in an aboveground reactor supporting a groundwater pump-and-treat system, or can be applied *in situ*. For aboveground reactors, contaminated water is extracted from the source (typically an aquifer) and transferred to the reactor for treatment. The aboveground reactor design is appropriate for pilot-scale evaluations or may be used as the full-scale remedial design. For *in situ* remediation, the need for extracting contaminated groundwater before treatment is eliminated. Contaminated groundwater flows through a permeable iron wall constructed in the subsurface. For large-scale remediation projects, *in situ* systems may either be constructed as a continuous, permeable treatment zone or as a funnel-and-gate configuration. For "funnel-and-gate" designs, permeable reactive iron walls or "gates" are flanked by impermeable sheet piling or slurry wall "funnels" that direct flow through the gate.

The design for the aboveground reactor used at the SGL site was based on established site-specific conditions and preliminary bench-scale studies. The highest concentrations of VOCs occur in a shallow, unconsolidated overburden aquifer; lower

concentrations are present in an underlying, semiconfined, fractured bedrock aquifer. Groundwater from both zones was treated during the SITE demonstration. Groundwater was extracted from the bedrock aquifer using two wells, and pumped directly to the reactor for treatment. Groundwater was also passively collected from the overburden zone using two collection trenches that drained to a common sump, and pumped from the sump to the reactor.

A schematic diagram of the treatment reactor at the SGL site is shown in Figure 1. Groundwater pumped from the extraction wells and the sump passes through a check valve, a 5-micron water filter, a flow meter, and an air eliminator before entering the treatment reactor. The water filter removes suspended solids from influent water, eliminating the need for a layer of well sand or pea gravel above the reactive iron medium. The air eliminator releases excess air from the highest elevation of the influent line when interior pressure exceeds exterior atmospheric pressure. A sight glass and pressure release outlet are located on top of the reactor. The sight glass allows observation of the surface of the reactive iron, and the pressure release outlet prevents a buildup of excessive internal gaseous pressure in the reactor.

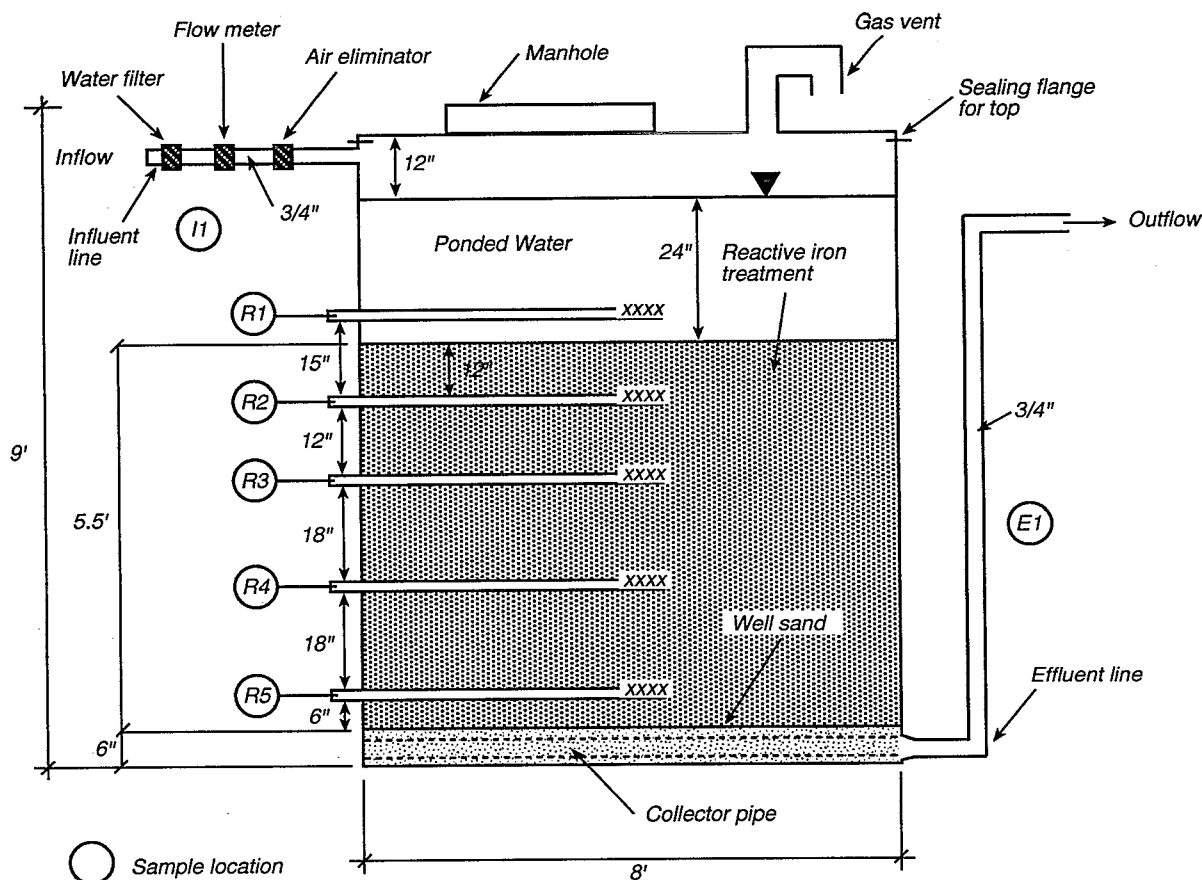
After entering the treatment reactor, the water flows by gravity through the reactive iron medium. The 8-ft diameter fiberglass reactor contained a 5.5-ft thick layer of the reactive iron medium. About 39,600 lb of granular iron was used in the reactor. The porosity of the iron medium, after placement and settling in the reactor, was estimated to be about 0.4. The iron rests on a 6-in. layer of coarse silica sand, referred to as "well sand." The well sand acts as a strainer, preventing the granular iron from washing out into the effluent line. An additional layer of pea gravel or well sand is sometimes placed above the iron to filter out suspended solids, although this additional layer was not used during the SITE demonstration.

The reactor drains through a collector line located in the well sand at the bottom of the reactor, and the collector line directs the treated water to the effluent line. The volume of water in the reactor tank is controlled by the configuration of the effluent line, which is plumbed so that about 2 ft of groundwater remains ponded inside the reactor above the surface of the reactive iron medium. During the SITE demonstration, the treated effluent was returned to the shallow, unconsolidated aquifer through several monitoring wells modified to serve as reinjection wells.

Contact time between groundwater and the reactive iron medium is primarily controlled by the thickness of the layer of reactive iron and by the flow rate. The design of the reactor is site-specific. The required contact time depends on the half-lives and concentrations of the contaminants in the influent water, and the target limits for effluent concentrations. Generally, higher influent contaminant concentrations require greater contact time for treatment. The design for the reactor at the SGL site allowed for a contact time of about 1 day during the demonstration. The contact time was based on laboratory bench-scale studies performed using contaminated groundwater from the SGL site.

## Technology Applicability

The metal-enhanced dechlorination technology may be applied at hazardous waste sites where an aqueous medium, usually groundwater, is contaminated with chlorinated aliphatic VOCs such as PCE and TCE. Chlorinated aliphatic VOCs are among the most pervasive contaminants at hazardous waste sites.



**Figure 1.** The metal-enhanced dechlorination process as demonstrated.

ETI claims that this process may be applicable for treating organic compounds other than chlorinated aliphatic hydrocarbons. However, the technology's ability to destroy other types of organic compounds was not evaluated during the SITE demonstration.

An aboveground reactor, as tested during the SITE demonstration, may be used to evaluate the metal-enhanced dechlorination process at pilot scale, allowing for measurement and optimization of design and operating parameters. Depending on site-specific factors, aboveground reactors may be operated as stand-alone treatment units or in conjunction with other treatment technologies. Aboveground reactors may be especially applicable for short-term remediation projects at sites with relatively small amounts of contaminated groundwater, or for sites where excavation and construction activities in the immediate vicinity of a contaminated plume are impractical.

In general, the technology applicability is affected by site-specific factors. The volume of contaminated groundwater requiring treatment may affect the applicability of aboveground reactors. Groundwater chemistry, contaminant types and concentrations, and hydrogeologic conditions may also affect the technology applicability. Applicability to a specific site should be evaluated through treatability tests using contaminated groundwater from the site. Hydrogeologic studies may also be required, especially for *in situ* systems where factors such as depth to groundwater, aquifer thickness, hydraulic gradient and flow velocity affect the technology's applicability.

For aboveground systems, permits (or waivers) from regulatory agencies may be required to allow discharge of treated effluent to surface water or groundwater. Regulations or site-specific permit stipulations may require additional treatment or "polishing" of system effluent before discharge, depending on system performance.

The applicability of the technology was evaluated against the nine criteria used for decision-making in the Superfund feasibility process. Each criterion and its relevance to the metal-enhanced dechlorination process's applicability is summarized in Table 1.

## Technology Limitations

The oxidation-reduction reaction that drives the metal-enhanced dechlorination process creates physical and chemical conditions (high pH and low Eh) that may cause precipitation of ferrous hydroxide [ $\text{Fe}(\text{OH})_2$ ], siderite ( $\text{FeCO}_3$ ), calcium carbonate ( $\text{CaCO}_3$ ), and other minerals when influent groundwater contains soluble metal compounds. Precipitation of these minerals may eventually reduce the porosity of the granular iron, decreasing volumetric flow through the system and possibly inducing channelized flow in the reactor. Precipitates may also block the available surface area of the reactive iron, increasing the half-lives of chlorinated compounds in the system and potentially resulting in incomplete dechlorination. Due to the potential for precipitation, groundwater containing high concen-

**Table 1. Superfund Feasibility Criteria for the Metal-Enhanced Dechlorination Process**

Criterion	Technology Performance
1 Overall Protection of Human Health and the Environment	<p>The metal-enhanced dechlorination process is expected to protect human health by providing treated water that has significantly lower concentrations of chlorinated VOCs.</p> <p>Overall reduction of human health risk should be evaluated on a site-specific basis due to the potential for formation of harmful treatment byproducts (for example, cDCE and vinyl chloride). However, when properly designed and implemented, the technology can degrade these byproducts.</p> <p>Protection of the environment at and beyond the point of discharge should be evaluated based on uses of the receiving water body, concentrations of residual contaminants and treatment byproducts, and the dilution factor.</p>
2 Compliance with Applicable or Relevant and Appropriate Requirements (ARAR)	<p>The technology's ability to comply with existing federal, state or local ARARs (for example, maximum contaminant levels [MCL]) should be determined on a site-specific basis.</p> <p>The technology's ability to meet any chemical-specific ARARs for byproducts should be considered because of the potential of forming byproducts such as cDCE and vinyl chloride during treatment. However, when properly designed and implemented, the technology can degrade these byproducts.</p>
3 Long-Term Effectiveness and Permanence	<p>Human health risk can be reduced to acceptable levels by treating groundwater to site-specific cleanup levels; the time needed to achieve cleanup goals depends primarily on contaminated aquifer characteristics.</p> <p>The long-term effectiveness of the metal-enhanced dechlorination process applied as an aboveground reactor may depend on periodically replacing the iron medium or chemical/physical treatment of the system.</p> <p>The treatment is permanent because the metal-enhanced dechlorination process is a degradation technology.</p> <p>Periodic review of treatment system performance is needed because application of this technology to contaminated groundwater at hazardous waste sites is relatively recent and long-term performance data are not available.</p>
4 Reduction of Toxicity, Mobility, or Volume Through Treatment	<p>When properly designed and implemented, the technology reduces the toxicity of contaminated groundwater by lowering total chlorinated aliphatic VOC concentrations and by degrading chlorinated aliphatic VOCs to nonhazardous substances.</p>
5 Short-Term Effectiveness	<p>Frequent monitoring of system performance is particularly important for the initial start-up phase, before the system reaches "steady state."</p>
6 Implementability	<p>The site must be accessible to typical construction equipment and delivery vehicles.</p> <p>The aboveground reactor system used during the SITE demonstration required an area of about 400 ft<sup>2</sup>. The actual space requirements will be site-specific and will vary.</p> <p><i>In situ</i> systems vary in size and require installation of sheet piling or slurry walls in addition to the reactive iron wall.</p> <p>Site-specific needs may dictate the need for additional services and supplies.</p> <p>Construction and discharge permit requirements will depend on site-specific conditions.</p>
7 Cost	<p>ETI estimates that capital costs for installing an aboveground treatment reactor similar to the one used at the SGL site are about \$48,000. This figure includes costs for all equipment (the reactor tank, reactive iron, piping, and wiring) and construction costs. Additional costs for hydrogeologic characterization, bench-scale studies, permitting, and installation of groundwater extraction/reinjection systems are not included. These additional costs will vary widely depending on site-specific conditions, and may constitute a significant portion of the total initial cost.</p> <p>ETI estimates that minimum annual operation and maintenance costs for an aboveground reactor similar to the one used at the SGL site are about \$10,000. This figure includes electrical consumption, expendable supplies (such as sediment filters) and maintenance labor costs, but does not include effluent sampling and analysis. Additional annual costs may be incurred and will vary widely depending on sampling requirements, useful life of the reactive iron medium, management of process residuals, and other site-specific factors.</p>
8 Community Acceptance	<p>This criterion is generally addressed in the record of decision after community responses are received during the public comment period; because communities are not expected to be exposed to harmful levels of VOCs, noise, or fugitive emissions, community acceptance of the technology is expected to be high.</p>
9 State Acceptance	<p>This criterion is generally addressed in the record of decision; state acceptance of the technology will likely depend on the concentrations of residual organic contaminants and treatment byproducts.</p>

trations of dissolved metal compounds, inorganic carbon, or other compounds may impact operation and maintenance (O&M) requirements.

High concentrations of suspended solids in influent groundwater may "blind" or accumulate and physically block the reactive iron medium, reducing flow. Blinding of the top of the reactive iron layer occurred early in the SITE demonstration. A rake was used to disturb the layer of gray, silty material that had formed and improved flow through the reactor.

During the SITE demonstration, algae was observed in the ponded water above the surface of the iron and on the upper, exposed portions of the interior reactor walls. Algae in the ponded water may have retarded flow through the system; however, the effects of algae and bacterial growth on the dechlorination reaction are unknown. During the SITE demonstration, algal growth was controlled by adding sodium hypochlorite and using an opaque cover on the reactor tank to block sunlight.

Freezing may affect flow through outdoor aboveground reactors in cold climates. However, although temperatures dropped below freezing for short periods during the SITE demonstration, groundwater flow limitations due to icing were not observed.

Data collected during the SITE demonstration indicate that the temperature of influent groundwater and the reactor were probably affected by changes in ambient air temperature. According to ETI, temperature may affect the dechlorination reaction rate for some compounds. If so, ambient temperature may affect the performance of the metal-enhanced dechlorination process, especially in aboveground reactors, and site-specific designs may need to consider potential temperature effects. The potential effects of ambient temperature on the rate of PCE dechlorination were not evaluated during the SITE demonstration.

## Process Residuals

Process residuals generated by the metal-enhanced dechlorination process during the SITE demonstration consisted primarily of treated effluent water. The New Jersey Department of Environmental Protection (NJDEP) permitted reinjection of the treated water to the shallow, unconsolidated aquifer through reinjection wells. For other sites using aboveground reactors, site-specific conditions may require alternate management and disposal methods for treated groundwater.

The reactive granular iron may eventually require replacement if the iron surfaces become irreversibly blocked with precipitates, or if the iron loses its reactivity. If so, the spent iron would also constitute a process residual. Disposal options for the spent reactive iron have not been evaluated. It is possible that the iron may require management as a hazardous waste. However, unlike conventional filtering and sorptive material such as granular activated carbon, the iron degrades contaminants to nonhazardous materials, and therefore may not be hazardous. ETI is also currently evaluating means of regenerating spent iron through chemical and physical treatment. *In situ* implementation of the technology may not require disposal of the used granular iron. Extensive long-term data regarding the useful life of the reactive iron under a wide range of field conditions are not currently available.

Additional process residuals may be generated depending on site-specific conditions. If required, use of secondary treatment for an aboveground reactor could generate process residuals

such as spent carbon. For some sites, it may be necessary to periodically replace the pea gravel, well sand, or other pretreatment filtration devices if they become completely blocked with sediments.

During evaluation of the aboveground reactor, air emissions consisting of PCE and TCE vapors were potentially released by the pressure release outlet at the top of the reactor. Changes in temperature or the water volume within the reactor could force headspace gases out through the opening. Gas samples collected in the headspace above the water surface in the reactor indicated the presence of PCE and TCE. If required, treatment of airborne VOC emissions from aboveground reactors could generate additional process residuals consisting of spent filtration or sorptive media, such as activated carbon.

## Site Requirements

Area requirements for the metal-enhanced dechlorination technology range from about 400 ft<sup>2</sup> for a pilot-scale, aboveground reactor system to much larger areas for *in situ* installations. Additional space for extraction wells or trenches, reinjection wells, and monitoring wells may be necessary, depending on site-specific characteristics. Truck access for delivery of the tank and granular iron (typically in 55-gal drums, 1-ton bags, or bulk delivery) is also required. Other heavy equipment access is required for construction, particularly for *in situ* applications.

The aboveground reactor at the New Jersey demonstration site was constructed on a concrete pad and was surrounded by a security fence. Ancillary piping and water and electrical meters were also housed in the fenced area, which comprised about 400 ft<sup>2</sup>.

## Performance Data

Primary and secondary objectives for the SITE demonstration were established to provide criteria for evaluating the performance of the metal-enhanced dechlorination process. The primary objectives were to (1) determine if treated effluent met NJDEP and federal MCL requirements for all chlorinated VOCs present in influent water or possibly generated as degradation products and (2) determine the removal efficiency of PCE. The secondary objectives of the demonstration were to (1) examine how the concentration of PCE changed as groundwater passed through the treatment reactor; (2) examine concentrations of metals, chloride, sulfate, and inorganic carbon to evaluate precipitation, dechlorination, and biological activities; and (3) document geochemical changes in the water (specific conductance, Eh, pH, dissolved oxygen, and temperature) as it passed through the reactor. As with all SITE demonstrations, data were gathered to evaluate the operating and design parameters, and the costs of using the technology.

To achieve the demonstration objectives, water samples were collected each week at influent (I1) and effluent (E1) sampling locations and analyzed for VOCs. During weeks 1, 5, 9, and 13 samples were also collected from intermediate sampling locations within the reactor (R1, R2, R3, R4, and R5). The sampling locations are shown on Figure 1. Samples collected during weeks 1, 5, 9, and 13 were analyzed for VOCs, field parameters, metals, chloride, sulfate, and inorganic carbon. Analytical results for chlorinated VOCs are shown in Table 2; select inorganic and field parameter data are shown in Table 3. To provide additional information on the technology, samples of gases were also collected and analyzed for VOCs. These data are shown in Table 4.

**Table 2. Metal-Enhanced Dechlorination Technology - Preliminary Results: Volatile Organic Compounds**

Contaminant	Influent Concentration			Effluent Concentration			Regulatory Limits	
	Range <sup>a</sup>	Mean	Detection Limit	Range <sup>a,b</sup>	Mean	Detection Limit	MCL <sup>c</sup>	NJDEP <sup>d</sup>
PCE	4,100-13,000	8,000	25-250	ND	ND	0.9	5	1
TCE	54-590	160	25-250	ND	ND	0.9-1.0	5	1
cDCE	ND-1,600 <sup>a</sup>	340 <sup>f</sup>	25-250	1.3-37	9.2	1.0	70	2
VC	ND	ND	25-250	1.2-8.4	3.5	1.0	2	5

**Notes:**

All concentrations in micrograms per liter (µg/L)

ND Not detected

PCE Tetrachloroethene

TCE Trichloroethene

cDCE cis-1,2-dichloroethene

VC Vinyl Chloride

<sup>a</sup>Range of contaminant concentrations detected in weekly samples collected over 13-week demonstration period<sup>b</sup>No contaminants detected until week 9<sup>c</sup>Federal maximum contaminant level<sup>d</sup>NJDEP groundwater discharge standards<sup>e</sup>Not detected until week 6<sup>f</sup>Nonzero (detected) values only**Table 3. Metal-Enhanced Dechlorination Technology - Preliminary Results: Inorganic Analytes and Field Parameters**

Analytes	Mean Concentration or Measured Value at Sample Location						
	I1	R1	R2	R3	R4 <sup>a</sup>	R5	E1
Barium	0.309	0.283	0.079	0.082	0.108	0.093	0.079
Calcium	73.7	69.0	43.5	32.7	24.0	23.1	26.7
Magnesium	23.8	21.6	22.0	19.9	12.5	13.8	16.8
TIC	34	33	20	12	5.7	4.4	5.8
pH (SU)	7.9	7.8	8.2	8.3	9.3	9.3	9.4
Eh (mV)	95.1	46.8	-198	-304	-379	-333	-272
Specific Conductance (µS) <sup>a</sup>	407	367	286	259	226	228	236

**Notes:**

All concentrations reported are in milligrams per liter (mg/L); the units for measured values are noted.

All concentrations or values based on mean of data collected during weeks 1, 5, 9, and 13 unless otherwise noted.

TIC total inorganic carbon.

SU standard units.

Eh oxidation-reduction potential.

mV millivolts.

µS microsiemens.

<sup>a</sup>Sampling location R4 was inaccessible during week 13.<sup>b</sup>Specific conductance was not measured at any location during week 5; in addition, specific conductance was not measured at sampling location R4 during week 13.**Table 4. Metal-Enhanced Dechlorination Technology - Preliminary Results: Headspace Gas Analyses**

Contaminant	Headspace Gas Concentrations (ppb V/V)		
	Range <sup>a</sup>	Mean	Detection Limit
PCE	19,000-39,000	27,000	180-590
TCE	230-650	440	180-590

**Notes:**

ppb parts per billion

V/V volume per volume

<sup>a</sup>Range of contaminant concentrations detected in samples collected during weeks 5, 9, and 13.

About 61,000 gal of groundwater was treated during the 13-week demonstration period. A flow rate of about 0.5 gal/min was maintained throughout most of the demonstration period.

PCE and TCE were detected in the influent (I1) samples throughout the 13-week demonstration. The average influent PCE and TCE concentrations were about 8,000 micrograms per liter ( $\mu\text{g/L}$ ) and 160  $\mu\text{g/L}$ , respectively. cDCE was occasionally detected in the influent samples during the latter part of the demonstration (after week 6). No other chlorinated VOCs were detected in the influent samples.

Analysis of the effluent (E1) samples indicated that the technology effectively reduced PCE and TCE. Effluent concentrations of PCE and TCE were consistently below detection limits. Detection limits in the effluent were 0.9 or 1.0  $\mu\text{g/L}$ ; the NJDEP and federal regulatory limits are 1.0  $\mu\text{g/L}$  or higher (see Table 2).

Removal efficiency for PCE, which is based on comparison of effluent concentrations to influent concentrations, was greater than 99.9% for each of the 13 weekly sampling events. Although TCE and cDCE were detected in the influent groundwater, removal efficiencies were not calculated for these contaminants because the dechlorination of PCE may introduce TCE, cDCE, and vinyl chloride at any point in the system. During some weeks, concentrations of these potential degradation products were higher at intermediate locations within the reactor than in the influent. Based on the sampling performed during the SITE demonstration, it was not possible to account for the quantity of TCE or cDCE introduced by the dechlorination process.

Effluent cDCE was detected after 9 weeks of operation, and vinyl chloride appeared in the effluent after 11 weeks of operation. The maximum concentrations of cDCE and vinyl chloride detected in the effluent were 37  $\mu\text{g/L}$  and 8.4  $\mu\text{g/L}$ , respectively. Concentrations of cDCE and vinyl chloride occasionally exceeded regulatory standards. The presence of these compounds in the effluent may be due to insufficient contact time with the reactive iron to carry the dechlorination reaction beyond the formation of cDCE or vinyl chloride. This effect may have been caused by the parent compound (PCE) persisting to greater depths in the reactive iron than anticipated, or by accelerated flow through some parts of the reactor due to channeling.

Incomplete dechlorination may also have been the result of reduction of the iron's reactive capacity due to metal precipitates. These precipitates may limit the surface area of the iron available for reaction. During the demonstration, PCE concentrations in lower parts of the reactor steadily increased. For example, PCE was not detected in the samples collected from location R3 during weeks 1 and 5. At week 9, PCE was detected at 69  $\mu\text{g/L}$  in the sample from location R3; by week 13, the PCE concentration at R3 had increased to 1,600  $\mu\text{g/L}$ . The increase in PCE concentrations at R3 suggests that the upper portion of the reactive iron lost some of its reactive capacity.

Results of the metals and total inorganic carbon analyses, shown in Table 3, also suggest that precipitates may have been forming in the reactor. Concentrations of barium, calcium, magnesium, and total inorganic carbon decreased as groundwater passed through the reactor. It is possible that metallic-carbonate compounds were precipitating. A high potential for precipitate forma-

tion is consistent with the results of the pH; precipitate formation is consistent with the results of the pH, Eh and conductivity analyses (see Table 3), which indicate that chemical and physical conditions within the reactor were conducive to precipitation of calcium carbonate and other compounds. Chloride and sulfate concentrations in influent groundwater were relatively high, but did not change significantly as groundwater moved through the reactor.

## Summary

The EPA SITE Program evaluated the metal-enhanced dechlorination process during a 13-week demonstration. The process effectively dechlorinated PCE and TCE in groundwater treated during the demonstration. The process also significantly reduced the total concentration of chlorinated VOCs in groundwater treated. Two VOCs (cDCE and vinyl chloride) that appear to have been byproducts of the dechlorination process were detected in the treatment system effluent during the latter part of the demonstration. Although site-specific designs for metal-enhanced dechlorination systems allow for dechlorination of treatment byproducts, the potential for incomplete dechlorination should be considered during the system design phase. The design should allow for system modification and contingent O&M procedures to enhance performance, if necessary.

## Technology Status

According to ETI, the metal-enhanced dechlorination process is currently available for all phases of remediation, from treatability studies and pilot projects to remedial actions. As discussed in the Technology Applicability section, extensive long-term performance data are not yet available. However, ETI is currently working on several projects that are in design, construction, or implementation phases. The EPA SITE Program is evaluating one of these projects, an *in situ* funnel-and-gate system, at a New York site. The results of the New York demonstration will be available in 1997.

## Disclaimer

The data and conclusions presented in this Technology Capsule have not been reviewed by the National Risk Management Research Laboratory (NRMRL) Quality Assurance Office. The NRMRL QA office has reviewed the ITER for QA requirements.

## Sources of Further Information

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