

ZVI + Organic Carbon (EHC®) for Anaerobic Bioremediation:

1. Dr. Alan G. Seech, FMC Corporation
2. Micro-scale zero valent iron (ZVI) + organic carbon including wheat bran, wheat germ, and wheat flour.
3. MSDS & Technical Data Sheet - Attached
4. Number of Field-scale Applications to Date: 500+ sites.
5. Case Studies – Attached
6. Technical Summary: EHC® ISCR Reagent is an *in situ* chemical reduction (ISCR) product for remediation of impacted groundwater. It is composed of a mixture of food grade organic carbon (wheat bran, wheat germ, wheat flour) and micro-scale zero-valent iron in a blended powder. EHC contains only natural compounds that are non-toxic to humans and the environment. EHC is not intended for treatment of potable water or for human or animal consumption.

The formulation of EHC is designed to promote rapid and complete dehalogenation of halogenated organic compounds in soil and groundwater through the creation of strong reducing conditions and maintaining ambient pH in soil and groundwater. Such conditions promote dehalogenation reactions because they make the thermodynamics of dehalogenation more favorable than they would be at less reduced (i.e., more oxic conditions). Reduced/pH neutral conditions favor the growth and physiological activity of native bacteria that mediate dehalogenation reactions (e.g., *Dehalococcoides* sp.). Typically, a single injection of EHC will support reductive dehalogenation reactions for a period of at least three to five years. The product has been employed for soil and groundwater remediation since 2005.

This product is food grade material and there are no health and safety issues involved with its use.

Material Safety Data Sheet
EHC® ISCR Amendment

MSDS #: EHC-C
Revision Date: 2013-04-16
Version 1.03



ENVIRONMENTAL SOLUTIONS

This MSDS has been prepared to meet U.S. OSHA Hazard Communication Standard 29 CFR 1910.1200 and Canada's Workplace Hazardous Materials Information System (WHMIS) requirements.

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	EHC® ISCR Amendment
Recommended use Uses advised against	Bioremediation product for the remediation of contaminated soil and groundwater Not for use in potable drinking water.
Manufacturer	Emergency telephone number
FMC CORPORATION Environmental Solutions 1735 Market Street Philadelphia, PA 19103 Phone: +1 215/ 299-6000 (General Information) E-Mail: msdsinfo@fmc.com	For leak, fire, spill or accident emergencies, call: +1 703-527-3887 (CHEMTREC) 1 303 / 595 9048 (Medical - U.S. - Call Collect)

2. Hazards identification

Emergency Overview

CONTAINMENT HAZARD:
Any vessel that contains wet wet EHC must be vented due to potential pressure build up from fermentation gases

Potential health effects

Acute Toxicity

Eyes

Skin

Inhalation

Ingestion

No significant health effects anticipated
Product dust may cause mechanical eye irritation.
None known .
Inhalation of dust in high concentration may cause irritation of respiratory system.
Ingestion may cause gastrointestinal irritation, nausea, vomiting and diarrhea.

Chronic Toxicity

No known chronic effects of components present at greater than 1%.

3. Composition/information on ingredients

Ingredients

Chemical Name	CAS-No	Weight %
Organic amendment	Proprietary	52-82
Iron	7439-89-6	18-48

4. First aid measures

Eye contact	In case of contact, immediately flush skin with plenty of water. Get medical attention if irritation develops and persists.
Skin contact	Wash off with soap and water.
Inhalation	Remove person to fresh air. If signs/symptoms continue, get medical attention.
Ingestion	Rinse mouth with water and afterwards drink plenty of water or milk. Call a poison control center or doctor immediately for treatment advice.

5. Fire-fighting measures

Flammable properties	Combustible material.
Suitable extinguishing media	Dry chemical, CO ₂ , sand, earth, water spray or regular foam.
Explosion Data	
Sensitivity to Mechanical Impact	not applicable
Sensitivity to Static Discharge	not applicable
Specific hazards arising from the chemical	Dry or powdered ingredients are combustible. Dispersal of finely divided dust from products into air may form mixtures that are ignitable and explosive. Minimize airborne dust generation and eliminate sources of ignition.

NFPA	Health Hazard 1	Flammability 1	Stability 0	Special Hazards -
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6. Accidental release measures

Personal precautions	Avoid dust formation. For personal protection see section 8.
Methods for containment	Cover powder spill with plastic sheet or tarp to minimize spreading and keep powder dry.
Methods for cleaning up	Sweep or vacuum up spillage and return to container. The waste may be recovered and recycled.

7. Handling and storage

Handling	Minimize dust generation and accumulation. Keep away from open flames, hot surfaces and sources of ignition. Refer to Section 8.
Storage	Keep tightly closed in a dry and cool place. Keep away from open flames, hot surfaces and sources of ignition. Any vessel that contains wet EHC must be vented due to potential pressure build up from fermentation gases.

8. Exposure controls/personal protectionExposure guidelines

Local nuisance dust standards apply.

Occupational exposure controls**Engineering measures**

None under normal use conditions. Provide appropriate exhaust ventilation at places where dust is formed.

General Information

If the product is used in mixtures, it is recommended that you contact the appropriate protective equipment suppliers. These recommendations apply to the product as supplied.

Respiratory protection

Whenever dust in the worker's breathing zone cannot be controlled with ventilation or other engineering means, workers should wear respirators or dust masks approved by NIOSH/MSHA, EU CEN or comparable organization to protect against airborne dust.

Eye/face protection

Safety glasses with side-shields

Skin and body protection

No special precautions required.

Hand protection

Use gloves if extended exposure is anticipated.

Hygiene measures

Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and immediately after handling the product.

9. Physical and chemical properties9.1 Information on basic physical and chemical properties

Appearance	Tan brown flakes,
Physical state	solid
Odor	odorless
Odor Threshold	not applicable
pH	5.6 (as aqueous solution)
Melting Point/Range	No information available.
Freezing point	No information available.
Boiling Point/Range	not applicable
Flash Point	not applicable
Evaporation rate	not applicable
Flammable properties	Combustible material
Vapor pressure	No information available.
Vapor density	No information available.
Density	0.80 g/mL
Bulk density	No data available
Water solubility	practically insoluble
Percent volatile	No information available.
Partition coefficient:	not applicable
Viscosity	No information available.

9.2 Other information**Autoignition Temperature**

No information available.

10. Stability and reactivity

Stability	Stable.
Conditions to avoid	Heat, flames and sparks
Materials to avoid	Oxidizing agents Strong acids
Hazardous decomposition products	Burning produces obnoxious and toxic fumes.
Hazardous polymerization	Hazardous polymerization does not occur.
Hazardous reactions	May react with water to release flammable hydrogen gas.

11. Toxicological information**Acute effects**

Remarks The product has not been tested. Data is based on component.

Eye irritation No data available for the formulation. Non-irritating (rabbit) (based on components)

Skin irritation No data available for the formulation. Non-irritating (rabbit) (based on components)

LD50 Oral Iron: 98.6 g/kg (rat)

LD50 Dermal No information available.

LC50 Inhalation: Iron: > 100 mg/m³ 6 hr (rat)

Chronic Toxicity

Chronic Toxicity No known chronic effects of components present at greater than 1%.

Carcinogenicity Contains no ingredient listed as a carcinogen

12. Ecological information**Ecotoxicity**

Contains no substances known to be hazardous to the environment or that are not degradable in waste water treatment plants

Persistence and degradability Biodegradability does not pertain to inorganic substances.

Bioaccumulation Does not bioaccumulate.

Mobility Is not likely mobile in the environment due its low water solubility.

Other adverse effects None known

13. Disposal considerations

Waste disposal methods This material, as supplied, is not a hazardous waste according to Federal regulations (40 CFR 261). This material could become a hazardous waste if it is mixed with or otherwise comes in contact with a hazardous waste, if chemical additions are made to this material, or if the material is processed or otherwise altered. Consult 40 CFR 261 to determine whether the altered material is a hazardous waste. Consult the appropriate state, regional, or local regulations for additional requirements.

Contaminated packaging Dispose of in accordance with local regulations.

14. Transport information

DOT not regulated

TDG not regulated

ICAO/IATA not regulated

IMDG/IMO not regulated

15. Regulatory information

International Inventories

TSCA Inventory (United States of America)	Complies
DSL (Canada)	Complies
NDSL (Canada)	Complies
EINECS/ELINCS (Europe)	Complies
ENCS (Japan)	-
IECSC (China)	Complies
KECL (Korea)	Complies
PICCS (Philippines)	Complies
AICS (Australia)	Complies
NZIoC (New Zealand)	Complies

U.S. Federal Regulations

SARA 313

Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA). This product does not contain any chemicals which are subject to the reporting requirements of the Act and Title 40 of the Code of Federal Regulations, Part 372.

SARA 311/312 Hazard Categories

Acute Health Hazard	no
Chronic Health Hazard	no
Fire Hazard	no
Sudden Release of Pressure Hazard	no
Reactive Hazard	no

CERCLA

This material, as supplied, does not contain any substances regulated as hazardous substances under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (40 CFR 302) or the Superfund Amendments and Reauthorization Act (SARA) (40 CFR 355). There may be specific reporting requirements at the local, regional, or state level pertaining to releases of this material.

International Regulations

Mexico - Grade No information available.

Canada

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all the information required by the CPR.

WHMIS Hazard Class
not determined

16. Other information

HMIS	Health Hazard 1	Flammability 1	Stability 0	Special precautions -
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NFPA/HMIS Ratings Legend

Severe = 4; Serious = 3; Moderate = 2; Slight = 1; Minimal = 0

Revision Date: 2013-04-16
Reason for revision: No information available.

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Prepared By

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End of Material Safety Data Sheet



Environmental Solutions



Soil & Groundwater remediation

TECHNICAL DATA SHEET

EHC[®] ISCR Reagent

Introduction

EHC[®] ISCR Reagent is an *in situ* chemical reduction (ISCR) product for remediation of impacted groundwater. It is composed of a mixture of food grade organic carbon and micro-scale zero-valent iron in a blended powder. EHC is composed of natural compounds that are non-toxic to humans and the environment. EHC is not intended for treatment of potable water or for human or animal consumption.

Technical Data	
Iron Content	Approx. 40%
Particle Size Distribution	> 99.8 % less than 2.000 mm
	> 99.3 % less than 1.000 mm
	> 80.0 % less than 0.500 mm
	> 70.0 % less than 0.300 mm
Typical Properties	
Appearance	Light-tan powder
Density	0.65 – 0.75 g/mL (40.6 – 46.8 lb/ft3)
Bulk Density	0.50 – 0.60 g/mL (31.2 – 37.5 lb/ft3)
pH (28.6% aqueous suspension, w/w)	5.5 – 7.4

Standard Containers

50 lb bags on pallets; 40 bags per 1 pallet (2,000 lb net wt). Available in supersacs upon request and on a made to order basis.

EHC is classified as non-hazardous by the US DOT.

Under cool, dry storage conditions the shelf life of EHC is 4 years.

Prior to working with EHC consult the Material Safety Data Sheet to understand proper safety, handling, storage and disposal procedures.

Any vessel that contains wet EHC or EHC and water must be vented due to potential pressure build up from fermentation gasses.

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PROJECT

Installation of EHC[®] Technology for Treatment of Chlorinated Volatile Organic Compounds
 Site: Former Unregulated Solid Waste Management Unit, Ohio
 Lead Consultant - Hull & Associates, Inc.

SUMMARY

Groundwater at a former unregulated solid waste management unit is impacted by various chlorinated volatile organic compounds (CVOCs), mainly chlorinated ethenes. Groundwater collection trenches totaling approximately 330 ft in length were previously constructed downgradient of the suspected source areas. In February 2006, EHC[®] was injected into the gravel trenches to convert them into permeable reactive barriers (PRBs). A microbial culture of Dehalococcoides species (KB-1 inoculant; SiREM) was also applied.

Subsequent field monitoring showed that trichloroethene (TCE) and cis-1,2-dichloroethene (cis-DCE) decreased below the detection limit within the trenches after just 6 months, without the accumulation of recognized catabolites, such as vinyl chloride (VC). Continued monitoring has shown that the PRBs remained active over 18 months and that the concentration of total chloroethenes is decreasing downgradient of the center of the PRB (over 99% removal since November 2006). A positive correlation between the presence of EHC breakdown products (TOC and dissolved Fe) and removal rates has been observed downgradient of the PRB.

THE CHALLENGE

Site groundwater proximal to a known area is impacted by TCE (maximum of 750 ppb; remedial objective = 5ppb) and its recognized anaerobic daughter products 1,2-DCE (maximum of 5,200 ppb; remedial objective = 70 ppb) and VC (maximum of 630 ppb; remedial objective = 2 ppb). In an effort to mitigate transport of groundwater CVOC's, collection trenches measuring approximately 250 long were previously installed along the southern and western boundaries of the former unregulated solid waste management unit. Another collection trench measuring approximately 80 ft long was installed inside of a building (Figure 1 - red lines).

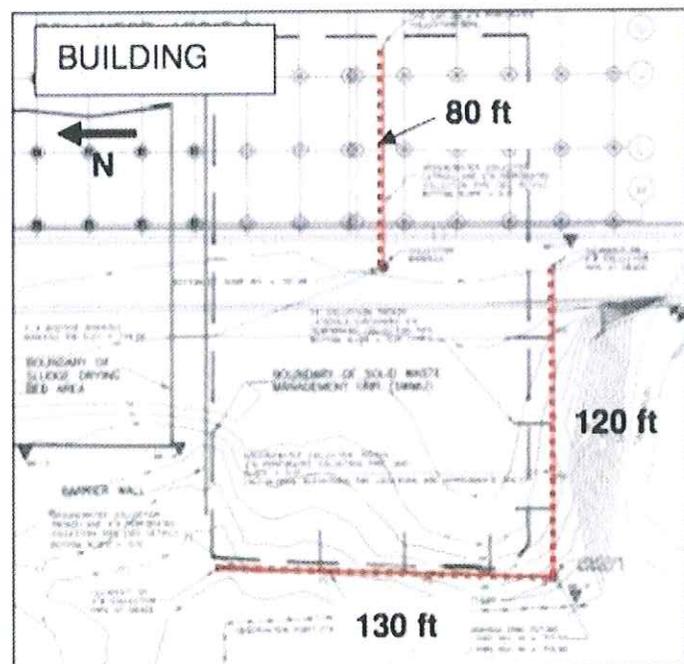


Figure 1: Groundwater collection trenches.

The goal of this current project was to turn these existing collection trenches into permeable reactive barriers (PRB's) to passively treat the groundwater as it flowed through the newly created reactive treatment zones. The groundwater table is generally at 6 ft below ground surface (bgs) and the trench extends down to approximately 12 ft bgs. The trenches measures 2 ft wide and are filled with washed river gravel up to a foot above the groundwater table.

THE SOLUTION

Using conventional direct push technology, 11,850 lbs of EHC were injected into the gravel zone to form a reactive zone thus creating an in situ PRB that would treat the groundwater as it flows through the reactive zone (**Figures 2 and 3**). The EHC product was delivered as a dry powder and consisted of solid organic carbon and zero-valent iron at 42%. The EHC powder was mixed with water on site into a slurry containing approximately 20 to 25 percent solids using a grout mixer.



Figure 2: EHC injections at trench along property lines.

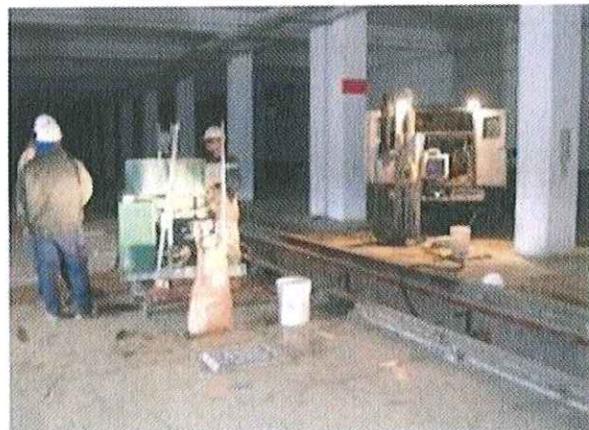


Figure 3: EHC injections inside building.

The injection points were spaced 10 ft apart, resulting in a total of 30 injection points. A total of 400 lbs of EHC (ca 200 USG of slurry) was designed for each injection point. Immediately following the EHC injections, KB-1 inoculant was added to accelerate removal of cis-1,2 dichloroethylene DCE. Monitoring Program Following the installation of the EHC PRB, the groundwater was samples for CVOC's on a quarterly basis at the following locations (**Figure 4**): - Manholes (CB-1 and CB-2), - Downgradient wells (MK-5 and MK-6) - Sitegradient well (MK-7), and - Upgradient and downgradient piezometers (P1-P5).

In addition, groundwater quality field parameters including pH, DO, temperature, water level and ORP

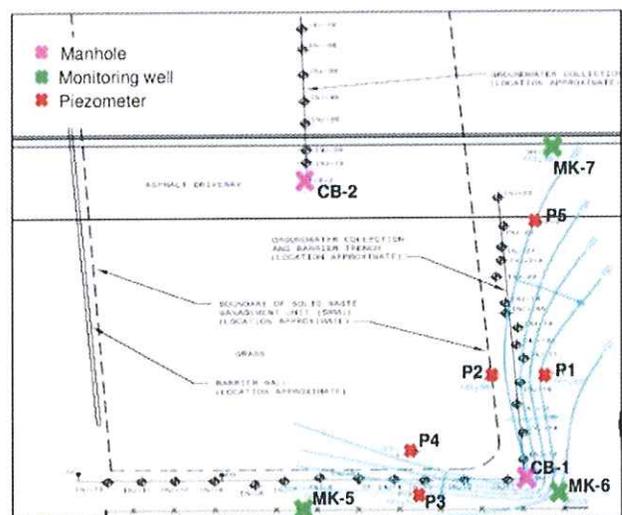


Figure 4: Monitoring locations.

have been collected monthly. Nine months following the installation of the PRB's the groundwater was analyzed for total iron, ferrous iron, and TOC to verify which sampling locations are within the EHC zone of influence. Samples from MK-5, MK-6 and P5 were also analyzed for Dehalococcoides species.

THE RESULT

Figures 5 and 6 shows the concentration of total chloroethenes in groundwater collected from the collection manholes at the downgradient end of the trenches. The first round of performance monitoring (May 2006) was conducted approximately three months after the EHC injections and did not show any discernible response.

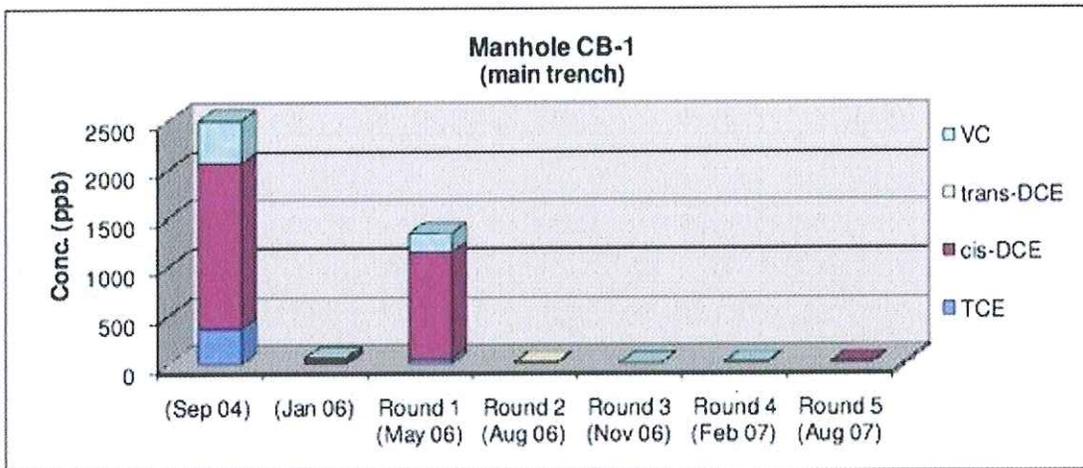


Figure 5: Influence of EHC injections on concentrations of chloroethenes in groundwater at collection manhole CB-1.

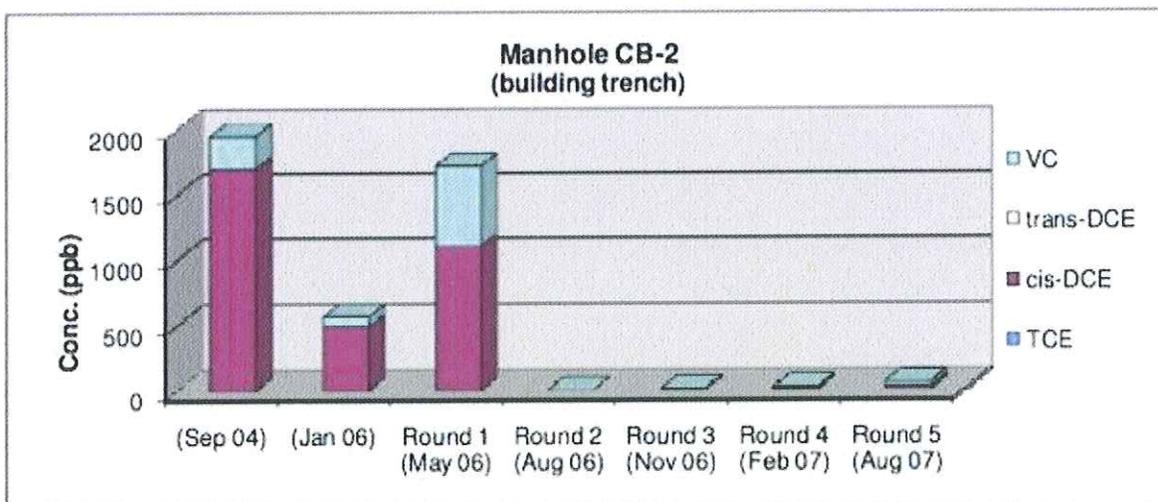


Figure 6: Influence of EHC injections on concentrations of chloroethenes in groundwater at collection manhole CB-2.

However, subsequent monitoring 6, 9, 12 and 18 months post EHC injection showed almost complete removal of all CVOCs, without the accumulation of catabolites. In the latest monitoring event, conducted in August 2007, total CVOCs decreased by 99.8% at the trench along the property line (from 2,700 to 6 ppb) and 97.0% at the building trench (from 1,950 to 58 ppb) compared to the initial concentrations measured in September, 2004.

In addition, a steady decline in CVOCs was observed at monitoring well MK-6, which is located 13 ft downgradient from the center of the trench (Figure 7). Eighteen months following the EHC injections total CVOCs had decreased by 99.7%; TCE decreased from 370 ppb to ND (<1 ppb), DCE from 2,800 to 4.5 ppb, and VC from 510 ppb to 4.8 ppb. No consistent CVOC removal has been observed in the other monitoring locations outside of the trench.

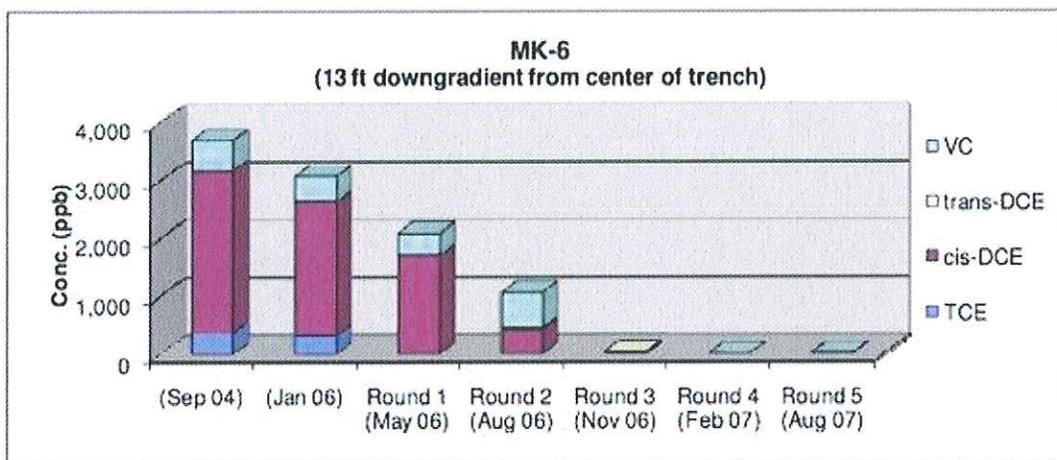


Figure 7: Influence of EHC on total chloroethenes 13 ft downgradient from EHC PRB.

To verify whether these points were within the direct zone of influence of the EHC, the groundwater was sampled for TOC and total and ferrous iron nine months following the injections. Following the injection of EHC into the subsurface a significant increase would be expected in these parameters within and directly downgradient of the injection zone. The extent of the zone with elevated levels of EHC breakdown products will depend on the linear groundwater velocity and direction. Elevated levels of TOC and iron were measured within the trenches and at MK-6, directly downgradient from the lowest point of the trench which correlates with the CVOV removal achieved at these locations.

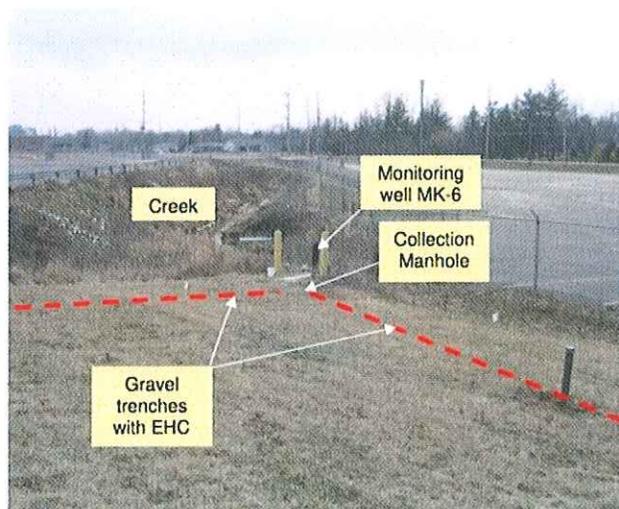


Figure 8: Approximate location of gravel trench, manhole CB-1 and MK-6.

No Significant increase of EHC breakdown products was observed at the remaining sampling locations and it could therefore be assumed that the EHC PRB has not directly impacted those locations et. This could possibly be explained by the flow-pattern created by the gravel trenches installed into the low-permeability clayey soil; the groundwater would be expected to be directed through the gravel collection trenches (as designed) and to be primarily released at the lowest point b collection manhole CB-1. This would also be supported by the significant and fast removal of CVOC's at MK-6 directly downgradient from manhole CB-1 (**Figure 8 Above**).

Nine months after the EHC injections, the groundwater was also analyzed for Dehalococoides at MK-5, MK-6 and P5. There appeared to be a positive correlation between the presence of EHC breakdown products, Dehalococoides levels and CVOC degradation (**Table 1 and Figure 9**).

Table 1: *TOC, iron and Dehalococoides measured in groundwater and corresponding CVOC removal rates nine months following the injection of EHC and KB-1.*

	Total Iron (ug/L)	Ferrous Iron (ug/L)	TOC (mg/L)	Fraction Dehalococoides ^a	Dehalococoides Count ^b	CVOC Removal ^c
MK-5	5400	0.14	7	2-4%	9 x 10 ⁶ per Liter	61% increase
MK-6	162000	101	1100	11-28%	4 x 10 ⁸ per Liter	99% decrease
P5	3560	0.14	10	2-7%	3 x 10 ⁷ per Liter	86% decrease

a. Calculated by dividing the number of Dehalococoides by the total number of bacteria

b. Dehalococoides assumed to contain one rRNA gene copy per organism; number interpreted to represent the number of Dehalococoides present in sample.

c. Change in concentrations of total chloroethenes nine months following injections.

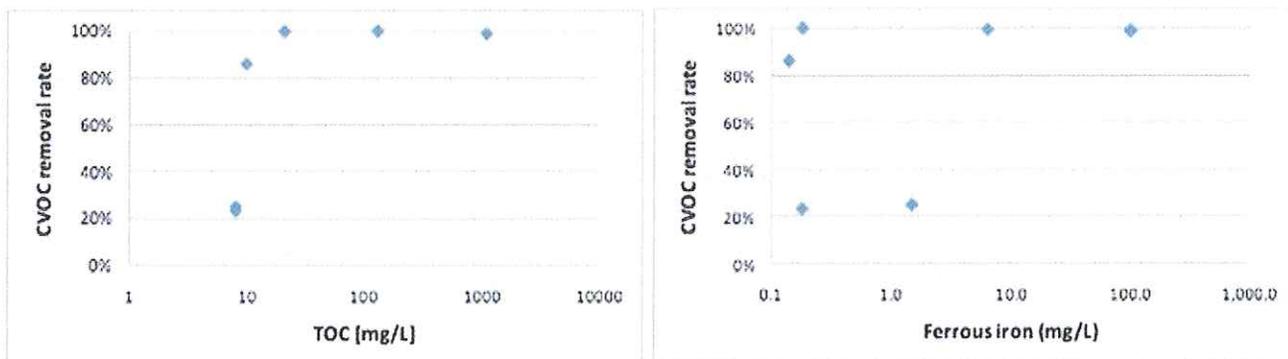


Figure 9: *Correlation between CVOC removal rates and TOC / ferrous iron in collection manholes and downgradient sampling locations.*

THE COST

The material cost of using EHC was \$12/ft² (\$129/m²) of PRB cross-section (a total of 11,850 lbs of EHC injected into PRBs measuring a total of 330 ft long x 6 ft deep on average).

Regulatory Contact OHIO EPA

PROJECT

EHC[®] Technology Treatment of Chlorinated Ethenes, Ethanes, and Methanes in Saprolite Soils and Partially Weathered Site: Rock, Manufacturing Facility - Western NC

SUMMARY

Field scale pilot tests were performed to evaluate the performance of enhanced reductive dechlorination (ERD) of chlorinated aliphatic hydrocarbons (CAHs) at a manufacturing facility in western North Carolina. The key CAHs found in groundwater at the site include 1,1,2,2 tetrachloroethane (TeCA), trichloroethene (TCE), and chloroform (CF), as high as 350, 1,100, and 1,500 ppb respectively. Adventus employed its EHC[®] *in situ* integrated biological and chemical reduction (ISCR) technology yielding safe, rapid, and effective treatment. Eleven weeks after injection, concentrations of TeCA, TCE, and CF in a nearby well reduced by 86%, 98% and 66%, respectively. After approximately 26 months, the key CAHs in the monitoring wells in the silty-clay (saprolite) zone indicated an overall decrease of up to 95%



THE CHALLENGE

The site is located in the Appalachian Piedmont physiographic province (mountainous) of North Carolina and consists of saprolite soils overlying a partially weathered rock (PWR) zone. Fractured bedrock underlies the PWR zone. Groundwater concentrations have rebounded since the historical treatment, indicating the potential for continuing sources, desorption, or complicated hydrogeology and geochemistry, or microbial conditions at the site. Presence of low permeability soils, low groundwater velocities and a mixture of CAHs presented a unique challenge for remediation.



THE SOLUTION

EHC[®] Technology is a patented combination of controlled-release carbon and zero valent iron (ZVI) particles used for stimulating reductive dechlorination of otherwise persistent organic compounds in groundwater. At this site, EHC was modified with BASF's micronscale ZVI (carbonyl iron powder). Two pilot-scale permeable reactive barriers (PRBs) were installed in January 2005 to evaluate the efficacy of EHC to control and treat the chlorinated solvents plume in two areas of the site. The first injection PRB was installed into the saprolite between 10 and 25 ft below ground surface (bgs) and the second injection PRB was installed into the partially weathered rock (PWR) between approximately 30 and 35 ft bgs. Each

PRB measured an estimated 40 ft long x 20 ft wide. Approximately 3,000 pounds of EHC was injected in two Geoprobe boreholes in the saprolite zone and 3,500 pounds of EHC was injected at four drilled locations in the PWR zone.

The presence of low permeability soils and the PWR zone required hydraulic fracturing to inject EHC at the site. Injection pressures and ground uplift were monitored, and soil boring and monitoring wells were installed to verify fracture propagation and distribution of the EHC. Soil samples collected around the injection points indicated the presence of EHC material. Based on field observations, the influence of EHC injection extended in a zone approximately 10 to 15 feet around the injection point in the saprolite. The injection in the PWR zone was controlled by the fracture orientation.

The presence of high concentrations of total organic carbon and metabolic acids and negative oxidation-reduction potential in the nearby monitoring wells indicated that the injected EHC created anaerobic zones favorable for CAH reduction.

THE RESULT

Eleven weeks after injection, concentrations of TeCA, TCE, and CF in a nearby well in the PWR zone reduced by 86%, 98% and 66%, respectively. After approximately 26 months, these compounds in the same well reduced over 98%. Potential degradation products of these CAHs such as 1,1,2-trichloroethane, methylene chloride, cis-1,2-dichloroethene, trans-1,2-dichloroethene, vinyl chloride, ethene, ethane and methane were detected in low concentrations, as shown in **Figure 1**. The concentrations of TeCA, TCE and CF initially increased in one downgradient well in the saprolite zone and gradually decreased. The test results indicated that reductive dechlorination was delayed in the aquifer despite the presence of dechlorinating bacteria such as *Dehalococcoides*, *Dehalobacter* and *Methanogens*. The likely reasons for the slow treatment response are the slow rate of groundwater flow, desorption of CAHs and due to presence of multiple CAHs (ethanes, ethenes, and methanes). After approximately 26 months, the key CAHs in the monitoring wells in the saprolite and PWR zone indicated a decrease of up to 99% (see **Figures 1, 2, and 3 Below**). Despite the reductions in CAH concentrations, organic carbon is still present supporting the reductive dechlorination process in the saprolite and PWR zone.

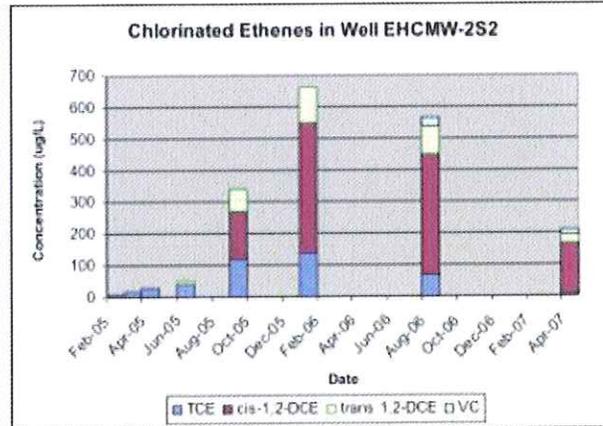
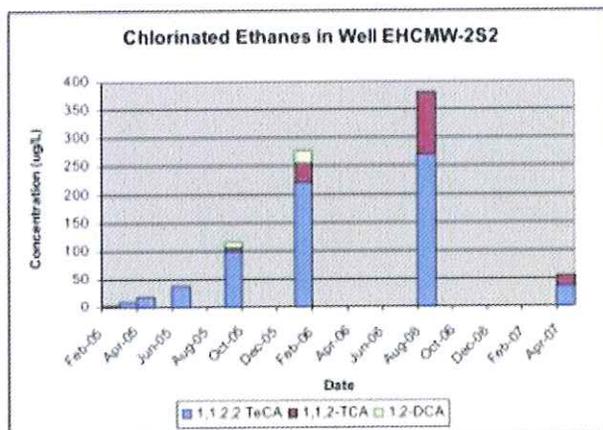
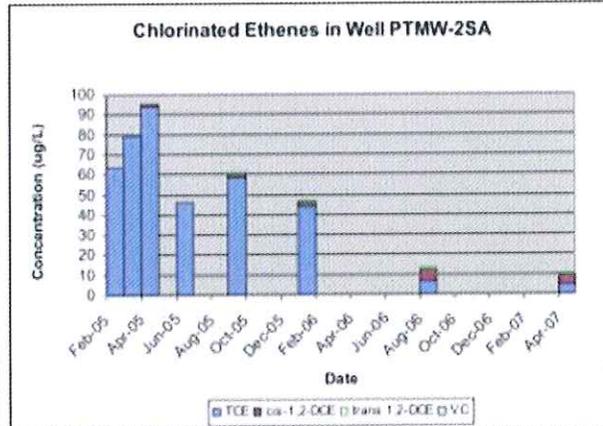
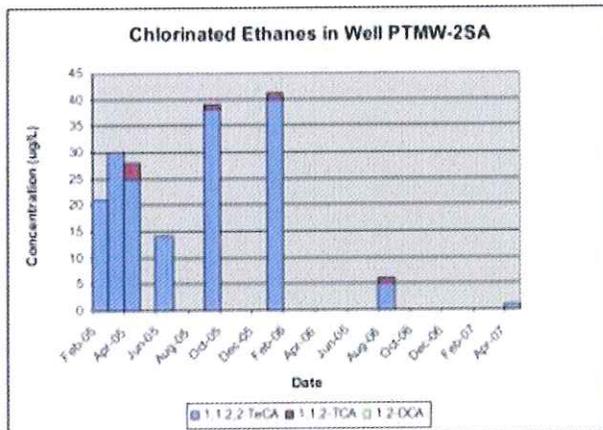
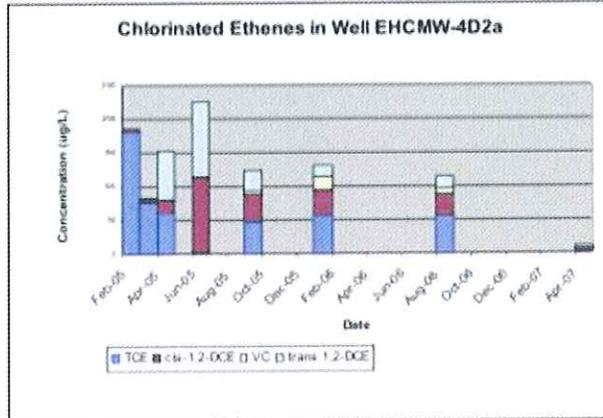
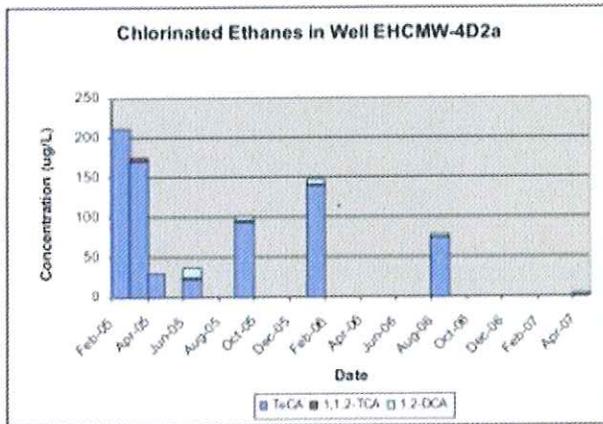
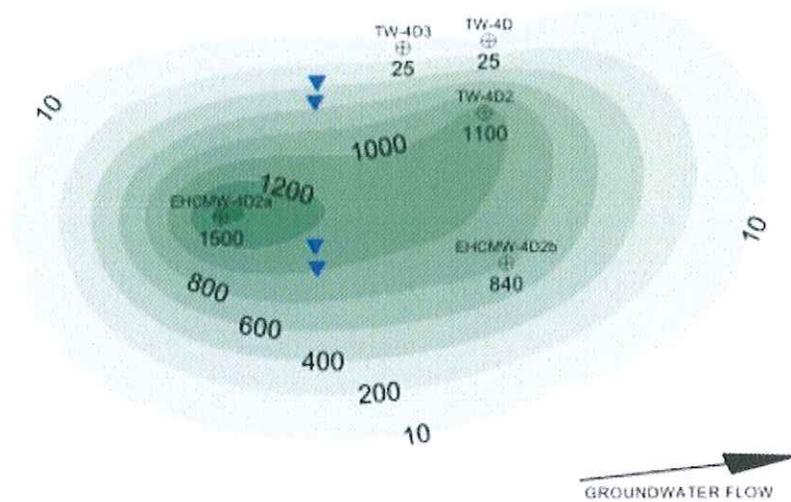
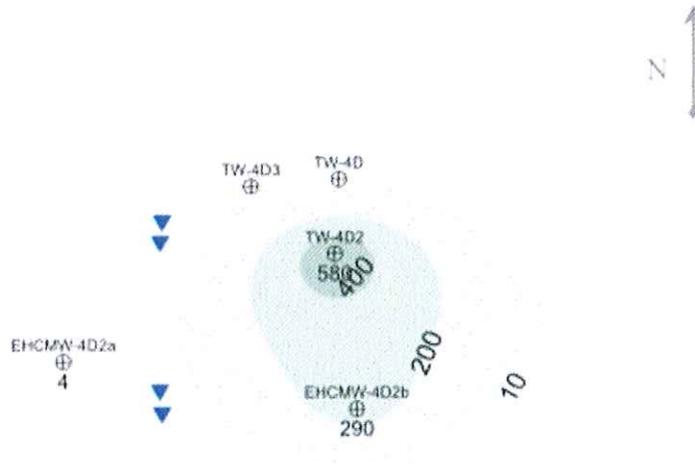


Figure 1: Chlorinated ethanes and ethenes in saprolite (PTMW-2SA, EHC MW2-2S2) and deeper PWR (EHCMW-4D2a) monitoring wells.



February, 2005



April, 2007

⊕ Existing Deep Saprolite Monitoring Well
▼ EHC Hydrofrac Injection Location

0 10 20
SCALE IN FEET

Figure 2: CF plume before and two years after EHC[®] injection in the PWR zone (µg/L).

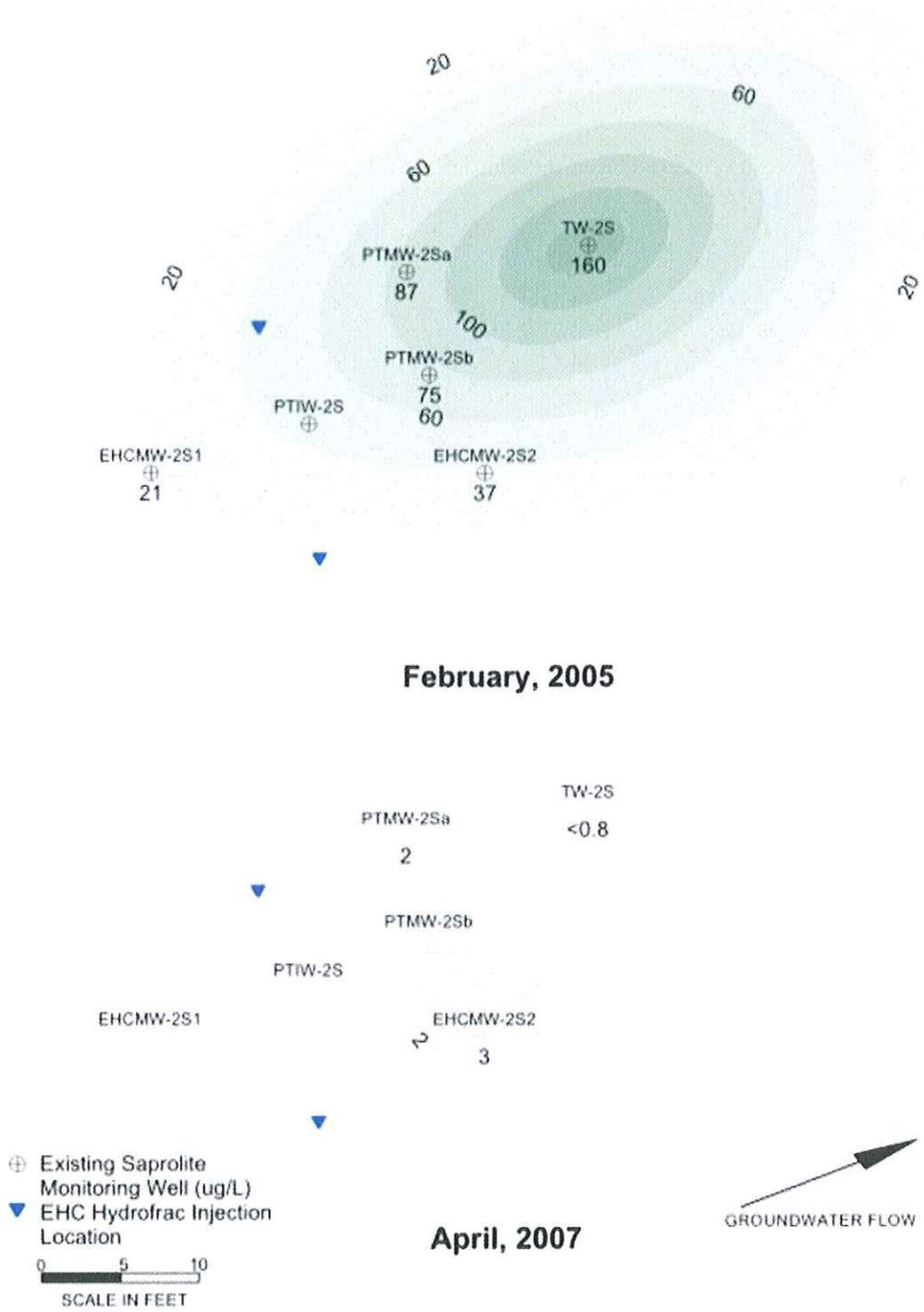


Figure 3: South plume of CF before and two years after EHC[®] injection in the Saprolite zone (ug/L).

PROJECT

EHC[®] Technology Plume Treatment for TCE and Daughters

Site: Former Delta Metals Site, Birmingham, UK

Lead Consultant/Contractor: WSP Remediation Ltd.

SUMMARY

The Meteor Park Development, formerly the Delta Metals engineering facility (**Figure 1**), lies close to Birmingham city centre. In the years prior to 2006, development had been marginal due to spiraling remediation costs associated with significant impacts to site groundwater and soil.

The lead consultant and remediation contractor (WSP Remediation Ltd.) adopted a combination of sustainable on-site treatment technologies to address a complex mixture of contaminants across a variety of media. This work was carried out as a fixed price contract.



Figure 1: The former Delta Metals engineering facility lies close to Birmingham city centre.

CHALLENGE

The site was heavily impacted by more than 60 years of heavy industrial use associated with the machining and manufacture of vehicle components. Extending over 4.4 hectares of land, the site is located above a major aquifer (the Sherwood Sandstone) and adjacent to the River Tame. These water

resources are the most sensitive environmental receptors in the area. Below a layer of granular made ground, the site consists of organic alluvial clays, and river terrace sands and gravels underlain by the sandstone aquifer.

Site investigations identified various impacted areas/media: diesel-oil hydrocarbons and chlorinated solvents in the made ground and alluvial soils; localized free product / LNAPL within perched water and sands, and widespread dissolved phase chlorinated solvent impacts within the underlying sands and gravel aquifer (**Figure 2**). This plume covered an area of approximately 3,150 m². The contaminants of concern were Trichloroethene (TCE) with a maximum concentration of 103 mg/L, and degradation products cis 1,2-Dichloroethene (DCE) and Vinyl Chloride (VC).

Previous proposed remediation strategies for the dissolved groundwater plume focussed on containment, incorporating treatment via a Permeable Reactive Barrier (PRB) setup as a funnel and gate system. This strategy however, presented several weaknesses and inefficiencies, due to the areal extent of the contamination, the absence of a demonstrable aquitard, the questionable long-term efficacy of a containment strategy given the potential for vertical migration of the solvent contamination into the underlying aquifer and requirement for an ongoing monitoring and maintenance programme.

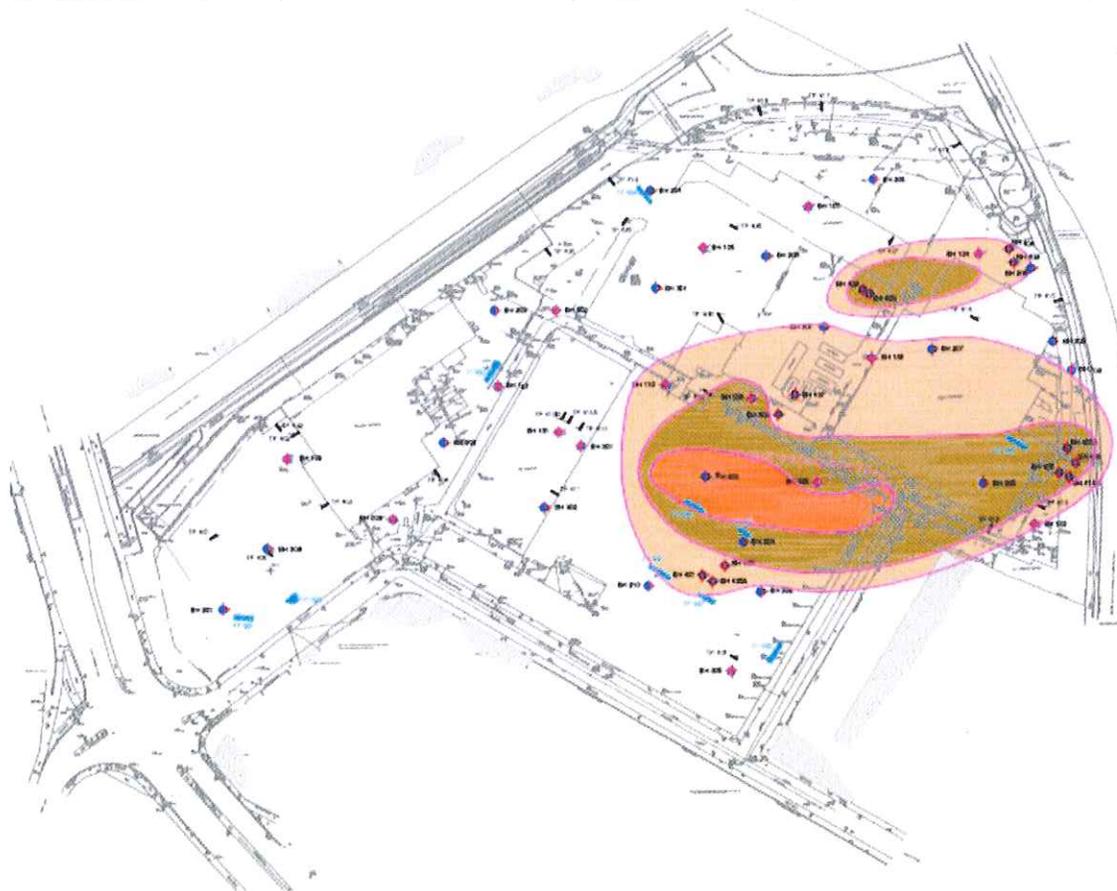


Figure 2: Chlorinated Solvent Plume

SOLUTION

Following more detailed investigations and trials, the technology chosen for remediation of the plume in the sand and gravels was In Situ Chemical Reduction (ISCR) using Adventus' EHC[®] technology. The combined effect of organic carbon and zero-valent iron in this product are designed to provide both chemical and biological treatment.

Treatment comprised of the injection of approximately 105,300 litres of slurry, formed by mixing the remediation substrate EHC[®] with water. In order to ensure complete plume coverage, EHC[®] was injected via more than 100 injection points installed at depths between 3-6 m below ground surface using a direct push drilling rig.

After substrate injection, the plume was monitored via a network of 20 wells. Field redox measurements and laboratory monitoring of chlorides, dissolved ethane and ethene were used to confirm the complete degradation of TCE, DCE, and VC.

Validation monitoring confirmed that the TCE concentrations had reduced to less than 0.05 mg/L in all monitoring wells, a value substantially below the agreed remediation standard of 10 mg/L for both TCE and DCE.

CONCLUSION

In addition to its success in removing the contamination beyond the levels expected, the ISCR/EHCR approach also proved to be a very cost effective since this approach provided a substantial cost saving versus the previously proposed Permeable Reactive Barrier. Also it was assessed to be a zero-waste process that resulted in the removal of the pollution burden within an impressive timescale. The minimal surface disruption caused by the in-situ approach also allowed for an optimized construction programme and phased release of the site to the owner's construction contractor.

This project was short-listed in the UK's Brownfield Briefing Remediation Innovation Awards in the category of 'Best Use of a Combination of Remediation Techniques'.

REFERENCE

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PROJECT

USACE Integrates Fracturing and Iron/Carbon¹ Injections at Colorado Site*

Site: The Atlas "E" Missile Site No. 12 (Atlas 12), former F.E. Warren Air Force Base facility, Windsor, CO
Lead Consultant/Contractor: North Wind, Inc., Frac Rite Environmental Ltd.

SUMMARY

The U.S. Army Corps of Engineers (USACE) performed a large-scale pilot test in 2009 for remediating TCE-contaminated groundwater at the "Atlas 12" formerly used defense site. Hydraulic fracturing was conducted to optimize emplacement of a zero-valent micro-iron/complex carbon amendment that chemically and biologically reduces contaminants in bedrock. Three-dimensional (3-D) mapping was used to monitor the amendment's subsurface pathways and evaluate its in situ performance. Nine months after fracturing and injections, changes in volume and concentration-weighted averages estimated an 82% TCE mass reduction in the contaminant source area.

The Atlas "E" Missile Site No. 12 (Atlas 12) is a former F.E. Warren Air Force Base facility in Windsor, CO. Site investigations in 1996 identified TCE and petroleum contamination in soil and shallow groundwater surrounding the facility's launch and service building, where TCE was used from 1960 to 1965 to flush the missile fuel tanks. The waste TCE and residual rocket fuel was released to a wastewater drainage sump that subsequently seeped into groundwater.

The water table at the facility is approximately 35-45 feet bgs. Prior to the treatment, the groundwater had TCE concentrations reaching 3,600 µg/L and associated degradation products. The site is underlain by a thin surficial soil layer of eolian sand and silt up to 10 feet thick that overlies 45-50 feet of sandstone, followed by a transitional zone of shale approximately 130 feet thick. The saturated zone targeted for pilot-scale treatment is estimated to be 30-40 feet thick.

The pilot test focused on groundwater treatment in the source area and portions of the distal end of the plume. Over 30 days in the spring of 2009, fracturing was conducted from nine pre-drilled boreholes using a skid-mounted fracture rig, primary and backup sets of downhole fracturing tools, and biodegradable fracture chemicals such as a linear protein gel viscosifier. Hollow stem augers were used to temporarily case the upper 30 feet of each hole and maintain borehole stability until fracturing was complete. Additional stability was gained by installing temporary 4-inch-diameter PVC casing that extended to the bottom of each borehole. Based on earlier core tests indicating rock cohesion values of 50-60 kPa, a triplex pump was used for fracturing and amendment delivery to the target bedrock in 5-foot increments at depths of 35-63 feet bgs.

Applied pressures for initiating fractures in the source area ranged from 124 to 838 psi, with the higher break pressures generally relating to deeper fractures or overburden pressure rather than cohesive strength of the bedrock. The average fracture propagation pressures ranged from 140 to 700 psi. Fracture pressures were typically lower in the distal plume area.

During fracturing, 6,000-32,000 pounds of amendment in the form of a biodegradable, linear protein gel slurry were emplaced in each borehole. The slurry contained sand and potable water mixed at a design loading rate of 0.27% amendment (by weight) for the seven source area boreholes and 0.10% amendment for the two boreholes reaching the distal end of the plume. Discrete fracture intervals were created by placement and pressurized inflation of straddle packers below and above the desired fracture depth at approximate 4-foot intervals. Slurry pumping rates ranged from 12 to 65 gpm with an average of 31 gpm.

Tilt sensors at ground surface were deployed to characterize each fracture's length, width, thickness, asymmetry, orientation, and angle of ascent (Figure 3). Tiltmetric data were correlated with operational fracturing data such as pressures and flow rates over time to create a dynamic 3-D model depicting individual boreholes as well as the entire fracture network.

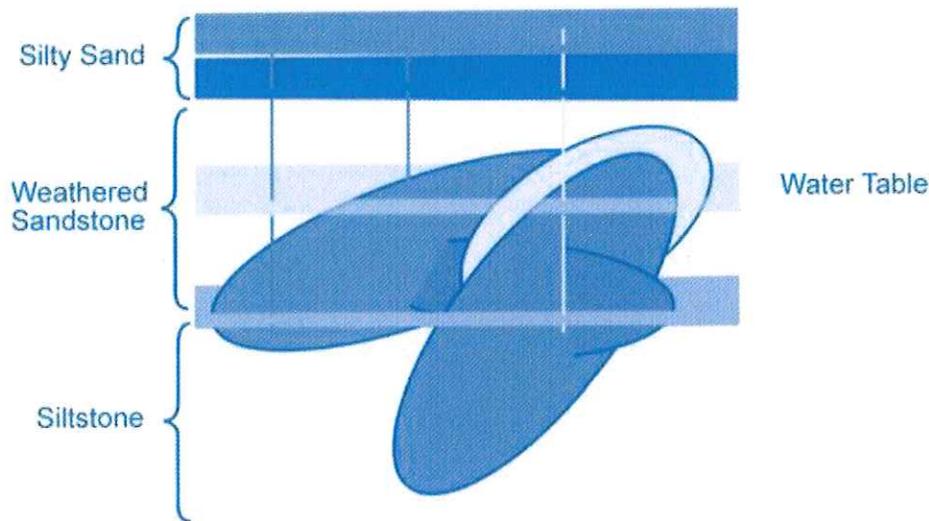


Figure 3. Tiltmetric mapping of fracture propagation from one Atlas 12 borehole provided a 3-D depiction of four disk-shaped fractures that emplaced the iron/carbon amendment into bedrock to treat TCE-contaminated groundwater.

A total of 188,085 pounds of amendment was emplaced in bedrock at target depths of 35-63 feet bgs, with an average borehole delivery rate of 2.2 pounds of amendment per gallon of injected slurry. The overall delivery efficiency was estimated at 98% with some slurry loss due to hydraulic communication with an open, pre-drilled borehole. This loss was rectified by installing a utility packer inside the well casing.

Field observations and tilt response showed that the radius of fracture emplacement in the bedrock reached nearly 80 feet, with a typical fracture overlap of 30-50%. Tiltmetric data indicated fractures with a median thickness of 0.33 inches and an average length of 79 feet along their inclination and 65 feet

horizontally. Six percent of the fractures were nearly horizontal, 12% slightly ascended, 57% moderately ascended, and 25% strongly ascended toward ground surface. Source area mapping indicated that the slurry had reached a 64,000 ft² area encompassing 52 individual fractures.

TCE concentrations were reduced more than 90% over the 9-month monitoring period following injection/fracturing in areas receiving the largest quantities of amendment and where fractures extensively interconnected and overlapped. The monitoring well with the highest pre-treatment TCE concentration (3,600 µg/L) had 160 µg/L TCE at the end of monitoring. Two nearby wells showed pre- and post-pilot test TCE concentration declines from 2,300 to 120 µg/L and 1,700 to 150 µg/L. TCE reductions greater than 50% were observed in areas with lower amendment mass, fewer fractures, and greater distance between boreholes.

Simultaneous declines of TCE and cis-DCE and production of ethene indicated that chemical reduction facilitated by zero valent micro-iron was the primary mechanism for contaminant degradation. The monitoring well with the highest cis-DCE concentration (470 µg/L) prior to treatment had 97 µg/L cis-DCE at the end of monitoring, and surrounding wells showed reductions from 110 to 13 µg/L and 100 to 10 µg/L. Biological reduction facilitated by the complex carbon was identified as a secondary degradation mechanism, as evidenced by redox conditions changing from aerobic to anaerobic and limited cis-DCE production in wells not exhibiting chemical reduction.

The unit cost for hydraulic fracturing, geophysical mapping, and over 100 tons of amendment is estimated at \$8/ton of bedrock treated. Costs for the amendment and hydraulic fracturing totaled approximately \$700,000.

The USACE is now integrating the pilot test results into design of a full-scale remedial action to be initiated at Atlas 12 in 2011. Full-scale application is expected to take over three years and include an amendment fracture network, institutional controls such as restricted groundwater use, and a long-term groundwater monitoring plan.

Contributed by Jeff Skog, USACE (jeffery.a.skog@usace.army.mil or 402-995-2739), Gordon Bures, Frac Rite Environmental Ltd., (gbures@fracrite.ca or 403-265-5533), and Dana Swift, North Wind, Inc. (dswift@northwind-inc.com or 208-528-8718)

1The iron/carbon amendment used at this site was Adventus' EHC-G product, described here:
<http://www.adventusgroup.com/products/ehc.shtml>

(*From EPA's Technology News Trends, <http://www.clu-in.org/products/newsletters/tnandt/view.cfm?issue=1210.cfm>, December 2010.)

PROJECT

Confidential Client - Former Industrial Site
Complete Source-Zone Treatment in Fractured Basalt
Consultant: Coffey Environments
Purpose: Removal of PCE/TCE from Fractured Rock

SUMMARY

The site is located in an Industrial District of the inner northern suburbs of Melbourne, Victoria, Australia. Prior remediation activity at the site with permanganate temporarily reduced PCE and TCE concentrations in groundwater; however, concentrations of PCE and TCE soon rebounded, prompting the Victorian EPA to seek a longer term remedy. Coffey Environments worked with FMC's Adventus Environmental Solutions Team to select EHC[®] ISCR Product, modify the formulation for site-specific needs and adopt suitable implementation techniques to conduct pilot and full-scale injections. Significant reductions in concentrations of PCE and TCE have now been achieved and the site is moving towards formal CUTEP (Clean Up to the Extent Practicable) determination as required by the Victorian Groundwater Protection Policy.

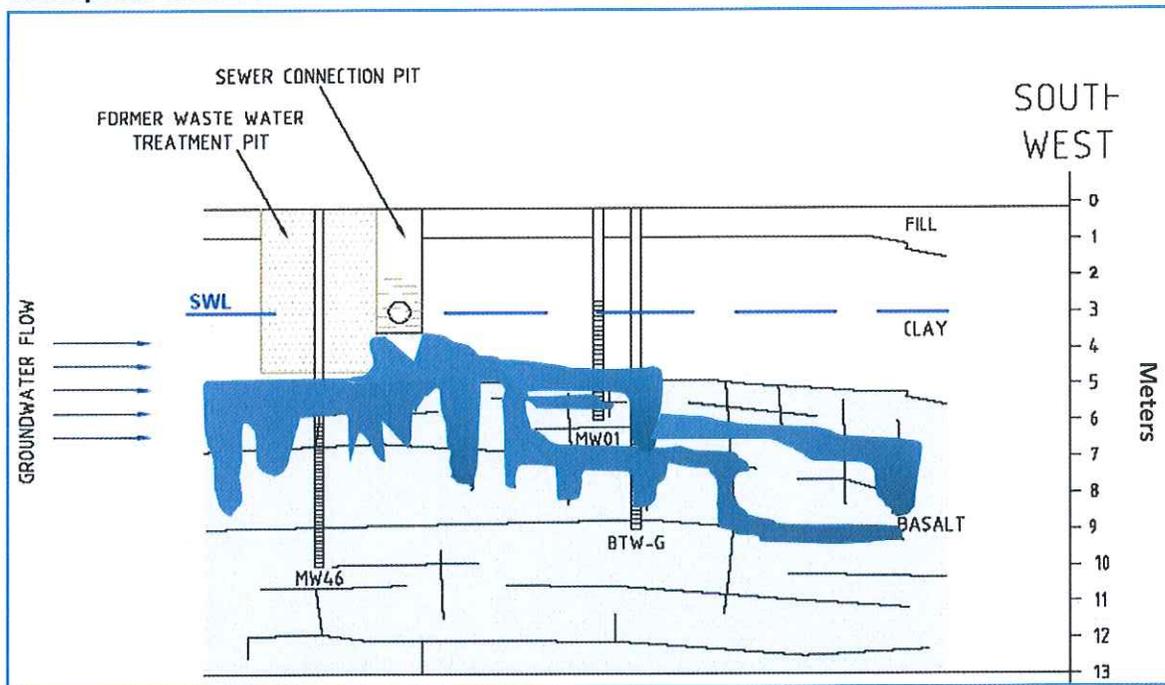


CHALLENGE

InChlorinated solvents were used for metal cleaning at the site from 1961 to 1999. Former wastewater treatment and UST pits are believed to be the source of PCE and TCE. EPA issued a Clean-up Notice in August 2003. *In Situ* Chemical Oxidation (ISCO) treatment of source areas with permanganate was conducted in 2004-2005 which resulted in PCE and TCE concentrations below detection limit for 3 months. Initial submittal for CUTEP was made to the EPA in November 2005, but concentrations of PCE and TCE subsequently rebounded.

The geologic environment was challenging for injections. The upper contact of the basalt ranges from near surface to greater than 13 m depth. Four to five meter (4-5 m) thick clay and 5 m thick basalt underlies the wastewater treatment pit (source area). Estimated hydraulic conductivities were <0.25 m/day in the clay and 3.9 to 6.7 m/day in the basalt, which had an estimated effective porosity of 4% (based on aquifer test specific yield).

Conceptual Cross Section



Contaminant rebound suggested that PCE and TCE mass had diffused into the rock matrix. Accordingly, EPA requested that a longer lasting remedial alternative be identified and implemented. This would require emplacing a longer-lasting treatment media within the basalt fractures. Given the combined abiotic and biotic treatment effects of EHC ISCR Product, it was identified as a possible remedy for the site. Conceptually, EHC ISCR Product injections would be used to facilitate treatment of contaminant mass that would diffuse out of the rock matrix.

FIELD WORK

Field work to conduct EHC ISCR Product injections was initiated in March 2008, when 17 injection wells were installed. Wells were constructed with surface casings cemented in place and open well bores in the underlying bedrock. In April 2008, the initial mixing/injection field work was conducted using a 16% - 33 wt% EHC ISCR Product slurry and low pressure (<100 psi) injection. Slurries were injected into wells until full (30 L – 100 L would fill the wells), and wells were allowed to drain by gravity.

This approach was found to be less than optimum, due to a variety of issues including:

- Difficulties during the first injection attempt due, in part, to the very small basalt pores (~100 μm) and the need to maintain low injection pressures to avoid damage to adjacent structures and associated infrastructure.
- Settling of solids in the mixing tank as a result of the type of mixing equipment used (i.e., a low speed paddle mixer modified from the food industry and a centrifugal pump).

- Settling of solids in the wells.

Based on these issues, the initial approach to EHC ISCR Product injections at the site was deemed unsatisfactory.

Accordingly, wet and dry sieve tests were conducted, and Adventus prepared three modified EHC ISCR Product formulations, intended to enhance injectability into the small pores of the basalt. The reformulation effort focused on the alternate carbon sources, as very fine zero valent iron (92% <45 µm) had already been used in the initial trial. The carbon substrates used were of low, moderate, and high solubility with the intent of using the least soluble (greatest longevity) substrate that could be effectively injected under the site conditions.

Concurrently, Coffey Environments modified the equipment used by increasing the working speed of the paddle mixer, utilizing a positive displacement (versus centrifugal) pump for the injections, enhancing tank recirculation (to minimize potential settling), and employing a stinger assembly to better direct flow into the target injection zone.

The equipment and formula modifications were utilized in a second field pilot test, in which water and two more dilute EHC ISCR Product slurries (13% and 20% w/w) were injected. From this second pilot, the dilute slurry of the soluble EHC ISCR Product formulation (identified as EHC-F) were found best suited to site injection, and the equipment modifications were also found to be beneficial. This combination effectively enabled the full-scale injections.

Injection Stinger Assembly

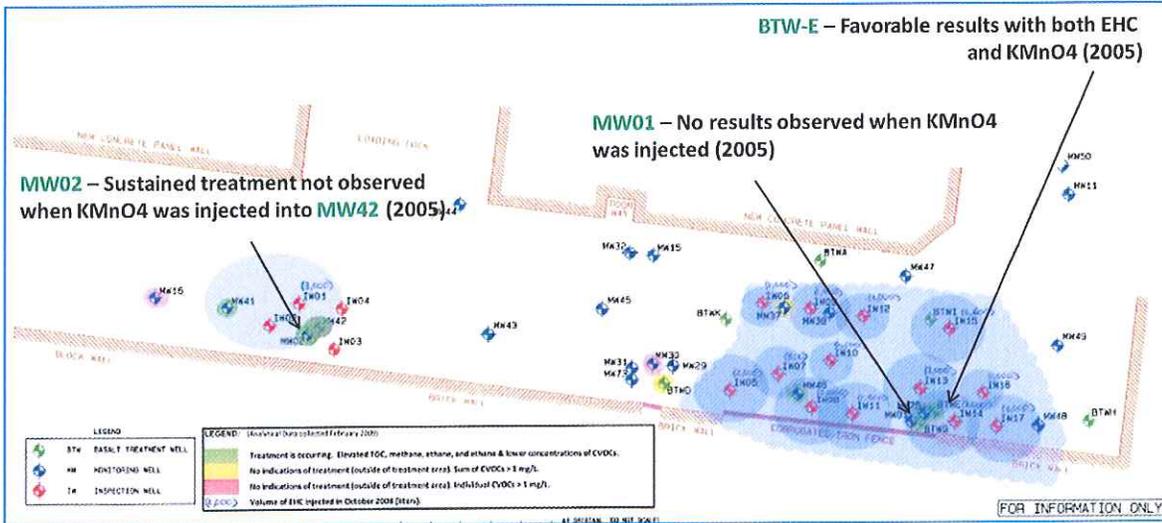


Full-scale injections were conducted from September to October 2008. In this effort 800 to 3,000 L of dilute EHC-F ISCR Product slurry was injected into each of fourteen targeted injection wells.

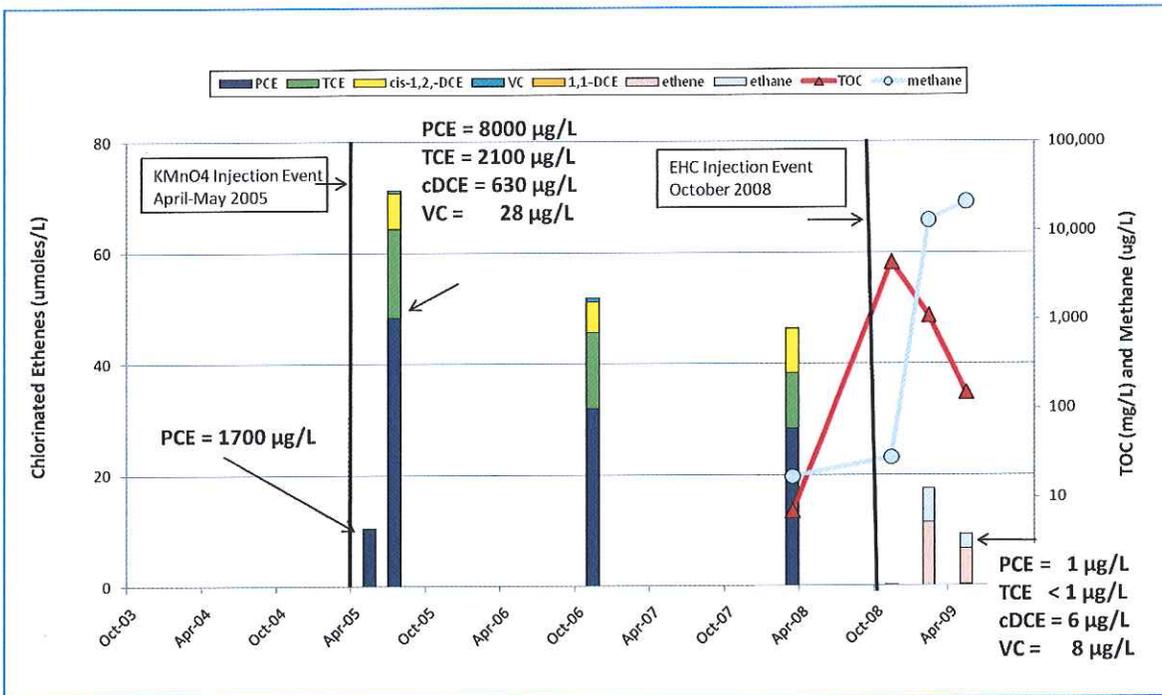
RESULTS

Excellent treatment results were observed where EHC-F ISCR Product distribution was successful. The charts below show results in three wells selected to contrast the range of treatment effects observed with permanganate from those with the EHC ISCR Product application.

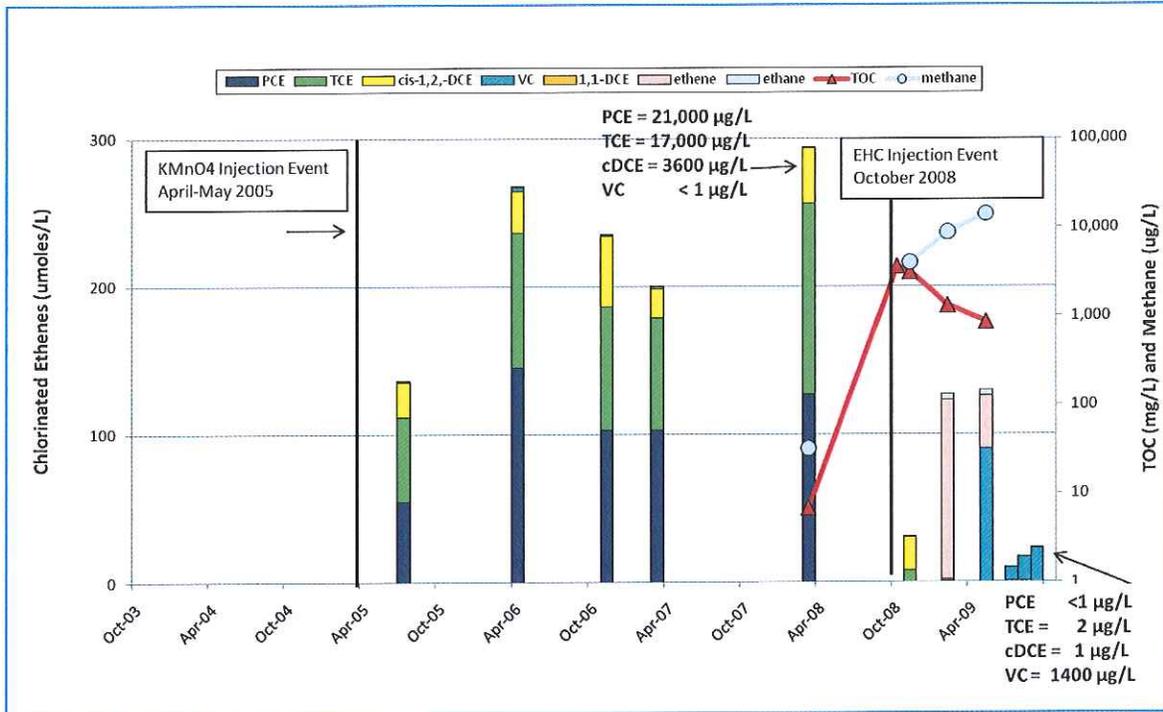
Relative Site Injection Locations



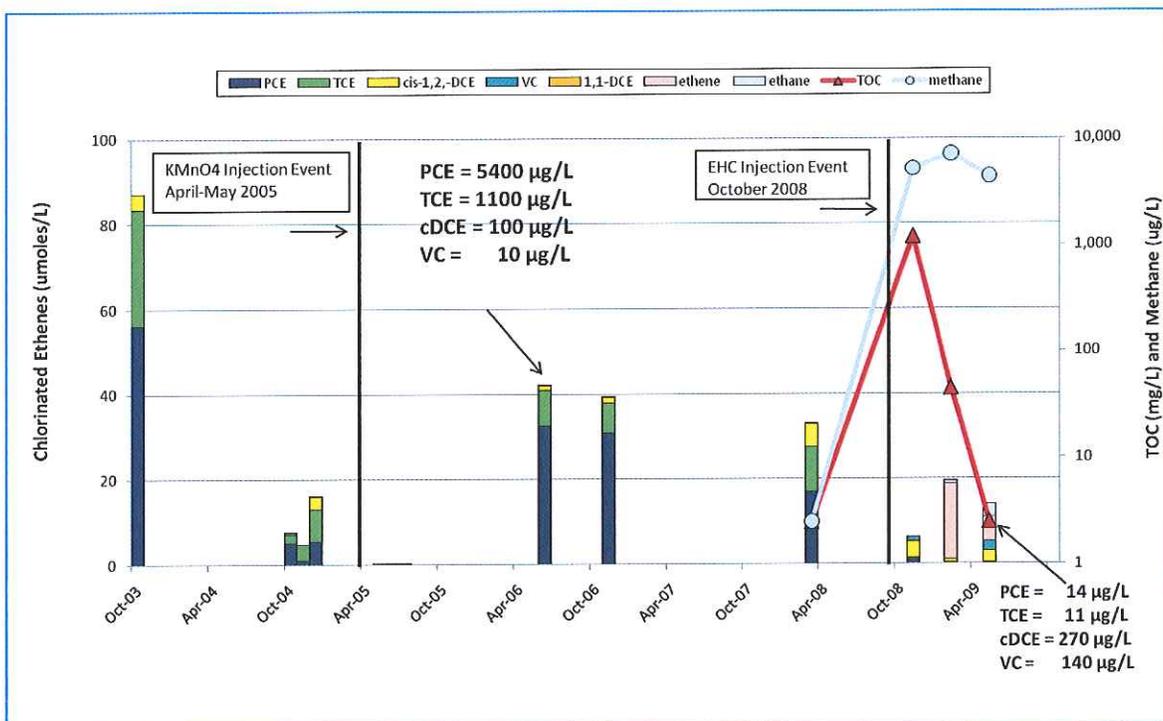
MW02 (UST Area) – Sustained treatment not observed when KMnO₄ was injected (2005)



MW01 (WWTP Area) - No results observed when KMnO₄ was injected (2005)



BTW-E – Favorable results with both EHC ISCR Product (2008) and KMnO₄ (2005)



CONCLUSION

The particle size of organic carbon in standard EHC ISCR Product was too large for low-pressure injections into site fracture apertures. The reformulated EHC-F ISCR Product used a finer, more soluble carbon source, and was successfully injected at low pressure with highly favorable results. Significant reduction in concentration of target compounds was achieved in response to the EHC-F ISCR Product injections. Continued monitoring of groundwater indicates that the remedy will be successful in obtaining CUTEP determination by EPA Victoria. The total EHC ISCR Product cost for this project was less than US\$20,000.

REFERENCE

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To discuss the technology or request a free estimate, please contact FMC's Environmental Solutions Team by visiting environmental.fmc.com.



OVERVIEW

A chlorinated solvent plume (PCE) was migrating onto a commercial site in Toronto area and a lending institution required mitigative measures implemented. An in-situ approach was required due to the proximity of the property boundary, on-site building and depth to water table (~5 m). The dissolved concentrations of the compounds of concern were:

- PCE (maximum concentration of 450 µg/L)
- TCE (maximum concentration of 47 µg/L)
- cis 1,2- DCE (maximum concentration of 50 µg/L)
- Vinyl chloride (maximum concentration of 12 µg/L)

SCOPE OF WORK

- Acquired all relevant permits to complete the remediation program.
- Designed and optimized an in-situ program to maximize treatment efficiencies.
- Implemented a program that minimized impact to the Site given the presence of buildings and property boundary.



THE VERTEX APPROACH

- Reductive dechlorination
- Reactive Zone including
 - Permanent Injection Wells
 - Temporary Injection Points
- Injection of multiple reactive compounds
 - > 225 kg of EHC®
 - > 80 kg of EHC®-A

OUTCOME

- Successful installation of a reactive zone
- Reductive dechlorination conditions created:
 - Redox reductions of up to -175 mV
 - PCE decreased from 450 µg/L to 60 µg/L
 - No vinyl chloride generation



PROJECT

EHC Treatment of Groundwater Plume Containing Chlorinated Solvents
Confidential Client at Former Manufacturing Facility - SE USA

CHALLENGE

Groundwater at a former manufacturing facility was impacted by chlorinated solvents, primarily carbon tetrachloride (CT) and trichloroethylene (TCE), as well as organochlorinated pesticides (OCPs). Adventus employed its EHC *in situ* integrated biological and chemical reduction (ISCR) technology yielding safe, rapid and effective *in situ* treatment.

After only 3 months of EHC application, the CT concentration decreased from 260 ppb to 7.8 ppb (**97% removal**) *without the accumulation of catabolic intermediates*. Treatment improved further at the 6-month sampling, showing a removal to 0.8 ppb (99.7% removal). All six of six monitoring wells met the groundwater clean up criteria for volatile organic compounds (VOCs).

SOLUTION

EHC is a patented combination of controlled-release carbon and zero valent iron (ZVI) particles used for stimulating reductive dechlorination of otherwise persistent organic compounds in groundwater. The volume requiring treatment was 110 ft (34 m) wide by approximately 190 ft (58 m) long, from 15 to 40 ft (4.6 to 12 m) below ground surface (bgs).

The approach was to create three, 10 ft (3 m) wide reactive zones: one at the upgradient edge, and two in the middle of the treatment area. The theory behind this approach is that the volatile fatty acids, hydrogen, and ferrous iron released from EHC would migrate downgradient to treat the plume. Further, contact between contaminants and the ZVI that is incorporated in the EHC product would be chemically treated. A total of 45,000 lbs (20,455 kg) of EHC were applied at the site. Within the reactive zones, the application rate was 0.5% by dry soil mass; however, the overall application rate for the total area treated was 0.08%.

The injections were completed in June of 2005 using direct injection (**Figure 1**). The first round of monitoring well sampling occurred in September of 2005. The Result Excellent treatment results were attained, as shown in **Table 1** where the pre-treatment and 3-month post-treatment results are presented for all wells in the treatment area. The full range of analyzed chloroethenes and chloromethanes are shown in **Figure 2** for the most highly contaminated well. All constituents at this well were reduced by significant amounts, with CT being reduced by 99.7%. **Figure 3** shows the contoured field data for carbon tetrachloride one year prior to injection, and three and six months following the injections. All values were less than 1 ppb at the six-month sampling, and all VOC treatment goals were met. **Figure 4** shows the degradation of OCPs over time due to EHC application.

TIMELINE AND COST

The EHC injection was completed in twenty days. Three months following EHC additions the concentration of chlorinated solvents decreased by as much as 97%, and as much as 99.7% after 6 months. The concentrations of all VOCs were below the site clean up criteria for all sample locations.

The EHC product cost was US\$0.17/ft³ (US\$6/m³).



Figure 1: Application of EHC slurry using direct injection.

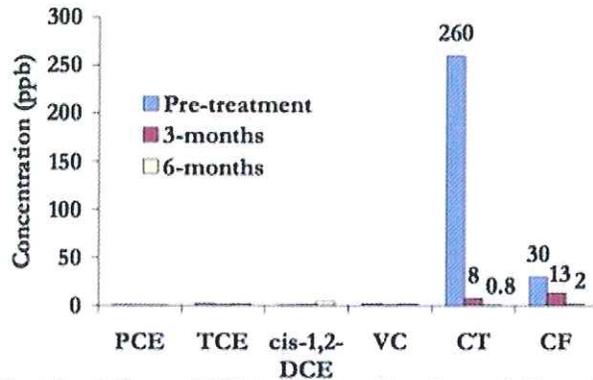


Figure 2: Influence of EHC treatment on chloroethene and chloromethane concentrations (MW #2).

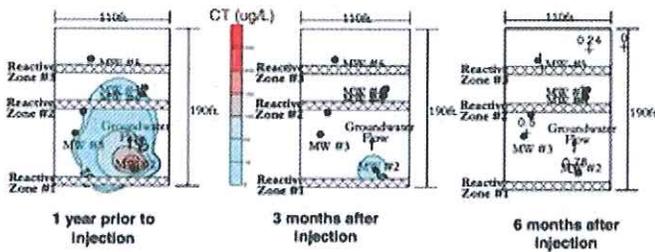


Figure 3: Influence of EHC treatment on contoured carbon tetrachloride data.

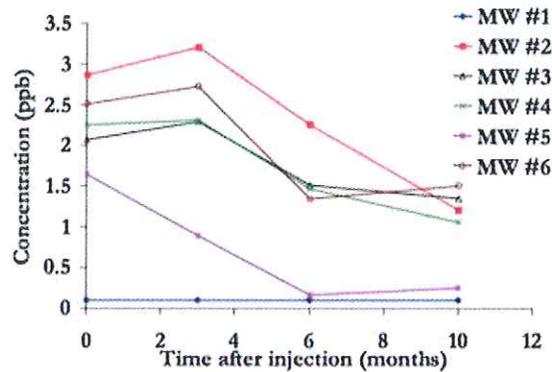


Figure 4: Influence of EHC treatment on OCPs in groundwater.

Table 1: Influence of 3 months of EHC treatment on TCE and CT concentrations in groundwater from all wells in treatment area. All values in ppb.

	MW #1	MW #2	MW #3	MW #4	MW #5	MW #6
TCE Pre-treatment	<1.0	2.5	1.5	44	<1.0	1.0
TCE Post-treatment	<1.0	1.1	<1.0	1.3	<1.0	<1.0
CT Pre-treatment	<1.0	260	<1.0	3.7	0.34 (est.)	4.2
CT Post-treatment	<1.0	7.8	<1.0	<1.0	<1.0	<1.0