COLLOIDAL CARBON BARRIER PROTECTS NEIGHBORHOOD FROM CHLORINATED SOLVENT PLUME

CASE STUDY:
A Sorption-Enhanced Reductive Dechlorination Pilot Test Demonstrates Complete Removal of Contaminants

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Introduction

A Novel Approach for Treating High Concentrations of Chlorinated Solvents in A High Flow Aquifer

Pilot Test for *In Situ* Permeable Reactive Barrier

A Combined Remedy Approach Reduces Risk of Exposure to a Residential Neighborhood

Groundwater Contaminants Included PCE, TCE, DCE, and VC

The application is a field-scale pilot test for *in situ* groundwater treatment of chlorinated volatile organic compounds (CVOCs) at high concentrations, in a fast-moving, aerobic aquifer beneath a central Michigan residential neighborhood. The CVOCs were treated using a unique combination of remediation technologies, symbiotically promoting sorption-enhanced reductive dechlorination (ERD) via biotic and abiotic processes. The project is state funded and Hamp, Mathews & Associates, Inc. (HMA), is working on behalf of the Michigan Department of Great Lakes and Energy (EGLE). HMA enlisted REGENESIS® to design and install an *in situ* permeable reactive barrier (PRB) to fully treat the tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-DCE (cis-DCE), and vinyl chloride, converting them into non-toxic end products such as ethene, ethane, carbon dioxide, and chloride.

REGENESIS Remediation Services successfully installed the PRB in May 2020, applying these remedial technologies:

PLUME STOP Liquid Activated Carbon · S-Micro ZVI Sulfidated Zero-Valent Iron · HRC-X HYDROGEN RELEASE COMPOUND · MERICHLOR DEHALOS AMERICHLOR, LLC

Early performance data are presented following the *in situ* application; and will be updated as performance monitoring continues.

Background

Designing a PlumeStop PRB Pilot Test in an Extreme Contaminant Flux Environment

Extreme Contaminant Flux Conditions

CVOC Concentrations

More than 50,000 µg/L

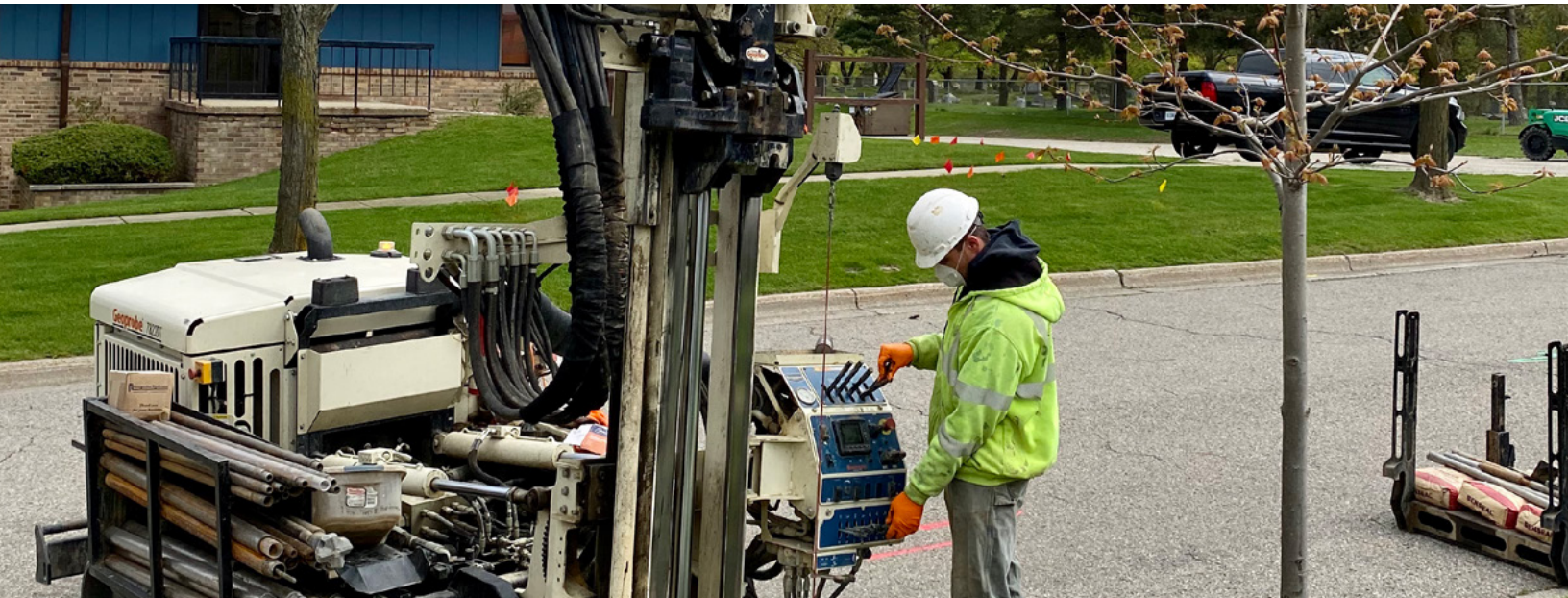
Groundwater Velocity

More than 1 foot per day

The project site is a residential property and municipal right-of-way downgradient of an active chemical manufacturing and distribution facility in central Michigan. During past industrial activities, chemical solvents, primarily PCE and TCE, leaked into the subsurface, creating a soil vapor and groundwater CVOC plume extending thousands of feet downgradient beneath a residential neighborhood. Environmental investigations began in the late 1990s, and subsequent EGLE-led remediation efforts have included source removal, vapor mitigation systems installed at residences above the plume, and periodic injections of dairy whey to biologically treat the CVOCs in groundwater at various risk/compliance points throughout a bifurcated plume.

High concentrations of CVOCs, greater than 50,000 micrograms per liter (µg/L), have been detected in groundwater observation wells near the pilot study area. Petroleum hydrocarbon compounds (PHCs) were also spilled at the facility, forming light non-aqueous phase liquids (LNAPL) and creating a commingled plume beneath and near the facility. This commingling resulted in the formation of highly mobile daughter CVOCs, cis-DCE, and VC, increasing the overall plume extent and severity.

The hydrogeologic setting is controlled by a prominent esker, a linear-shaped, glacially-deposited feature comprised of coarse sand, gravel, and cobbles. Groundwater velocities in the esker range from 1 to 10 feet (ft) per day. This combination of factors resulted in a persistent, high contaminant flux environment in the area and bifurcation of the plume.



What is a PlumeStop PRB and How Does it Work?

A PlumeStop PRB is constructed of an injection point array with its orientation perpendicular to the principal groundwater flow direction. Soon after injection, PlumeStop binds to the aquifer soil, leaving the soil grains coated with carbon and creating a reactive sorption zone.

As groundwater passes through the treatment zone, the flow of CVOCs is slowed (i.e., retarded) by orders of magnitude, effectively binding them, halting their movement, and eliminating exposure to down-gradient receptors. As the exposure to downgradient receptors is eliminated, so is the risk. While CVOCS are sequestered in the PRB, they are actively degraded by added biogeochemical reduction amendments. In essence, a PlumeStop PRB functions as an *in situ* purifying filter for groundwater.

This combination of the geologically dominating Mason Esker and high CVOC concentrations, along with high concentrations of mobile daughter products, (cis-1,2-DCE, and VC, caused by PHC commingling) results in an extreme transient plume condition that is very difficult to treat using *in situ* injection approaches. Specifically, the location and severity of the plume presents a threat to the vapor intrusion (VI) pathway in a downgradient residential neighborhood. Although previous injections of dairy whey had reduced concentrations at other areas of the site, biological treatment alone is not capable of achieving VI-related remedial objectives, which are very low aqueous concentrations for CVOCs.

As a result, HMA and EGLE contacted REGENESIS to learn if there was a remedial approach that could be employed to address the contaminant plume. Through the evaluation of the data and modeling, REGENESIS determined that a sorption-ERD approach was feasible. Following consultation with REGENESIS, and approval by EGLE, HMA chose to implement a sorption-ERD pilot test, utilizing in an *in situ* PRB configuration (i.e., PlumeStop PRB).

Application Design Summary

CVOC Concentrations (avg.)

TCE	2,000 µg/L
cis-DCE	19,500 µg/L
VC	1,600 µg/L

Seepage Velocity

170-660 feet per year

PRB Construction

PlumeStop/S-MicroZVI
18 injection points

HRC-X
8 injection points

Application Volume

5,600 gallons

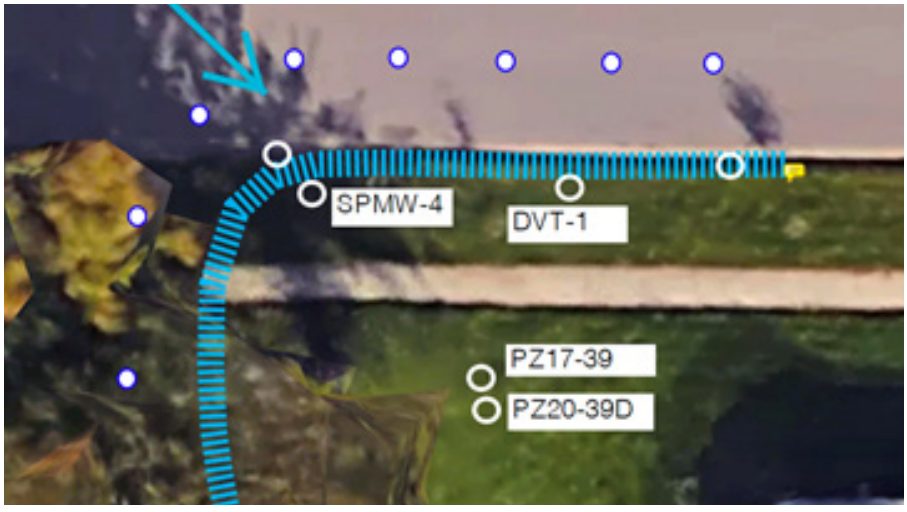
Remedial Design Development

Following approval by EGLE, REGENESIS and HMA moved quickly to develop a pilot test design for the PlumeStop PRB and coordinate its application. The goal of the pilot test was to demonstrate a sustained removal and degradation of the CVOCs, at a high rate of efficiency, as they passed through the I-PRB under natural flow conditions.

To determine the amount of PlumeStop needed for the PRB, REGENESIS utilized a proprietary finite-difference model explicitly developed for PlumeStop. This model accounts for site-specific factors such as hydrogeology and contaminant flux and considers competitive sorption and biodegradation to determine the quantity of PlumeStop needed over a user-defined period.

REGENESIS modeled contaminant flux over a 3-year PRB performance period for the pilot test. The model input concentrations, approximately 23 mg/L total CVOCs, were based on prior year average concentrations from a nearby observation well, PZ-17-39. This well is screened in the upper section of the saturated zone from 16 to 21 feet below ground surface (ft bgs).

The application design consisted of a 70-ft long, single row of direct-push injection points with the center and highest flux zone of the PRB oriented nearly perpendicular to groundwater flow. The PRB's L-shape accounts for localized variabilities in groundwater gradient. The vertical interval targeted for application ranged from 15 to 28 ft bgs, corresponding to the upper section of the water column and vertically spanning the high-contaminant flux zone. REGENESIS specified 5,600 gallons of total fluid volume for all PRB reagents.



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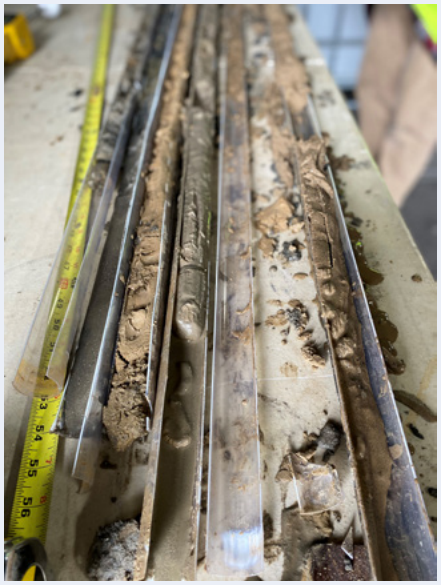
Design Verification Testing

Design Verification Testing (DVT) is a program comprising various in-field and laboratory testing methods that REGENESIS employs to verify remedial design assumptions in the specified treatment areas. Design assumptions that require verification of preliminary modeling estimates on most PlumeStop I-PRB applications include: the treatment depth interval, groundwater velocity and geochemistry.



Design Verification Testing

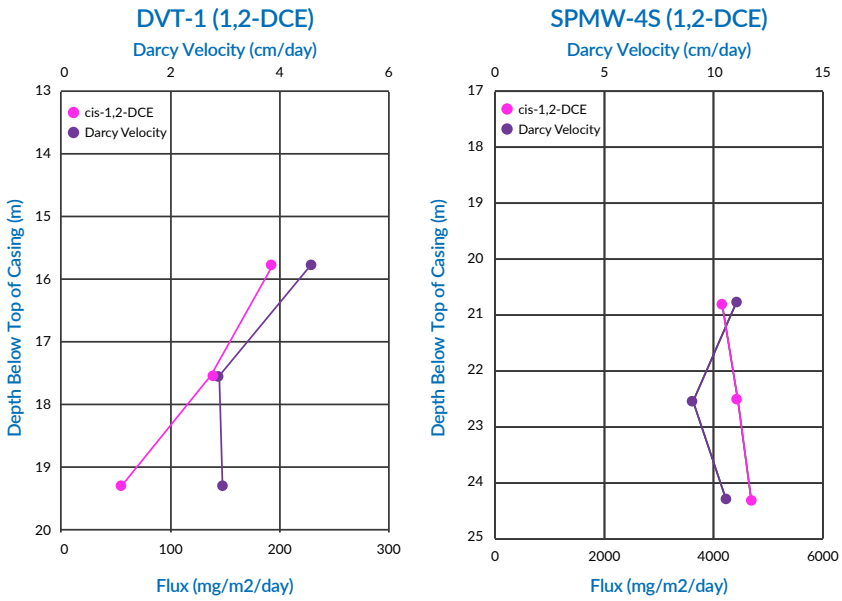
REGENESIS and HMA teamed to develop a design verification testing (DVT) plan. The DVT plan's purpose was to verify design assumptions, concurrent with the pilot test program, that critically impact material quantities needed and barrier performance (i.e., the longevity for effective contaminant removal).

As part of the DVT, HMA collected soil cores, visually observed and logged the soil grain size, degree of saturation, and color. Additionally, soil samples were submitted for analysis of grain size and VOCs. The upper section of the target interval's soil grain size is approximately 90 percent fine to medium sand. Lower in the interval, between 23 and 24 ft bgs, the soil grain size coarsens abruptly, becoming predominantly gravel (i.e., greater than 75 percent), consistent with glacial esker deposits. The samples submitted for VOC analysis indicated up to two times higher CVOC concentrations in the gravel layer.

Contaminant flux is the most critical parameter in assigning the amounts of remediation products needed for a PlumeStop *in situ* PRB. Contaminant flux is the product of contaminant concentrations and groundwater velocity. In many cases, there is high variability in contaminant flux within a target interval and this variability is important to know when prescribing product dosages. To better understand contaminant flux for this application, the DVT plan specified the use of passive flux samplers (PFS) in select monitoring wells.

Soil core showing grain size change between 23 and 24 feet bgs.

HMA installed PFS in two monitoring wells and later submitted the samples for analysis. Samples collected from the PFS indicates a groundwater velocity ranging from 170 feet to more than 660 ft per year. CVOC flux was observed to be 35 times higher in the deeper screened well, SPMW-4S (20 to 25 ft bgs), compared to the shallow screened well, DVT-1 (15 to 20 feet bgs), based on a three-sample average per 5-ft sampling interval. This increase in flux correlates to the higher soil concentrations that were observed in the lower section of the target vertical interval.



Passive Flux Sampler Results for Cis-1,2-DCE at DVT-1 (15 to 20 feet bgs) and SPMW-4S (20 to 25 feet bgs)

According to the PFS, the groundwater Darcy velocity is approximately three times faster in the lower, coarser-grained interval, meaning that contaminant flux is principally controlled by contaminant concentration in this case. Based on these PFS results, the PlumeStop PRB would be expected to have greater effective longevity in the upper section of the treatment interval for a constant product dose applied to the whole interval. This flux variance is an important consideration for designing a full-scale treatment.

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Pilot Test Installation

The PlumeStop PRB was Successfully Installed During the COVID-19 Pandemic

Low Injection Pressures

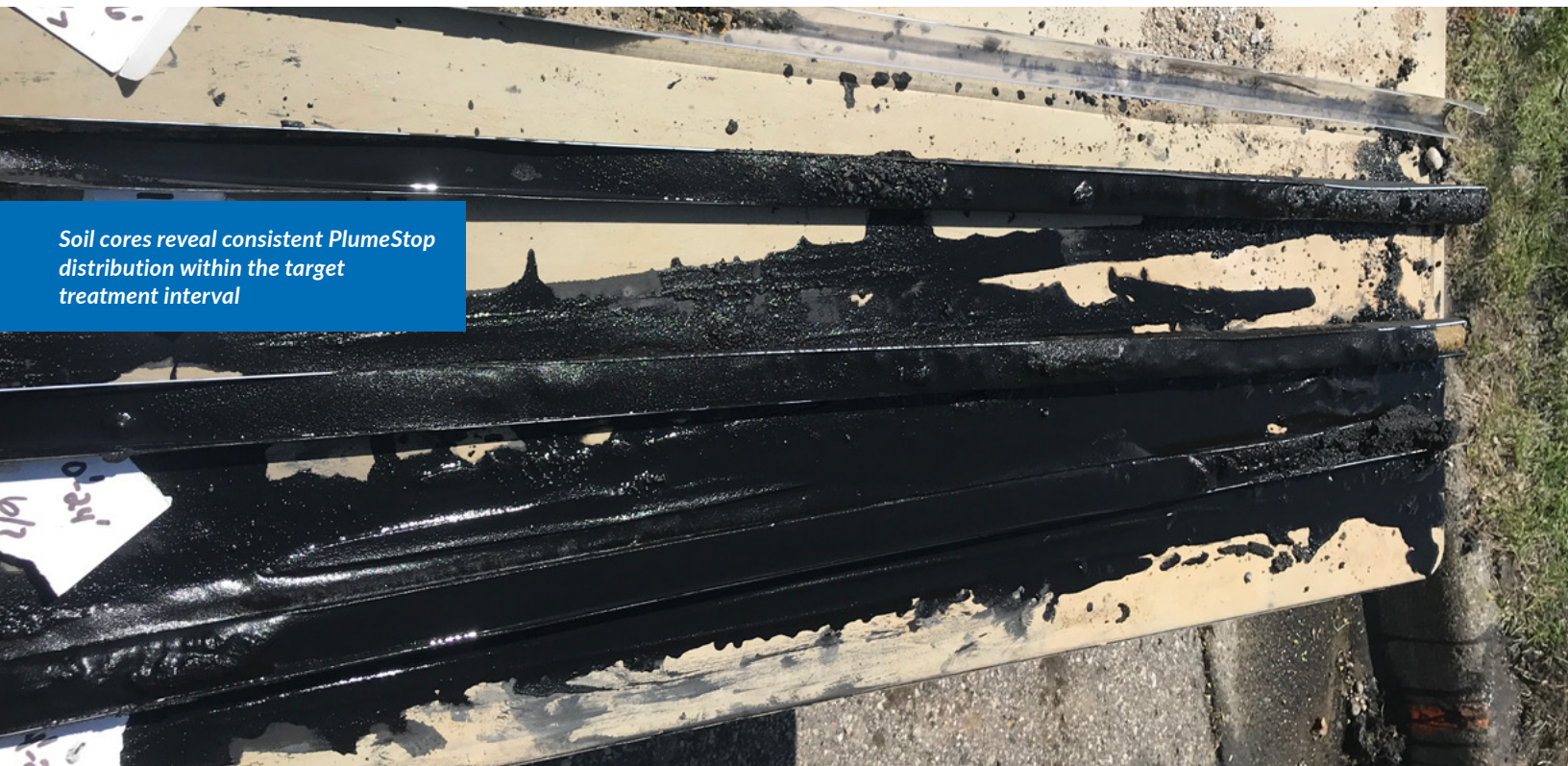
Injection pressures averaged less than 30 pounds per square inch.

Distribution Testing

Soil cores and groundwater samples confirmed consistent PlumeStop distribution in the *in situ* PRB.

REGENESIS Remediation Services (RRS) commenced the PlumeStop PRB application in May, 2020. A hydraulic percussion rig was used to drive to depth, using 1.5-inch diameter drilling rods and attached retractable screens. The reagents were mixed and applied through the rod-screen assembly. Utilities were located and marked before the application. RRS completed the application in less than four days while conforming to strict safety protocols, including special safety procedures, to prevent the spread of the COVID-19 virus.

RRS performed optimization testing at the outset, methodically adjusting the injection flow rate to maximize volumetric delivery rates while maintaining injection pressures averaging less than 30 pounds per square inch. RRS documented PlumeStop distribution by collecting soil cores and groundwater samples from temporary piezometers placed between injection points. The soil cores revealed consistent PlumeStop distribution over the target interval. The groundwater samples collected from the piezometers and in-barrier observation wells indicated a robust PlumeStop presence in groundwater. There were no significant physical obstructions that altered the PRB layout and no deviations from the original application design.



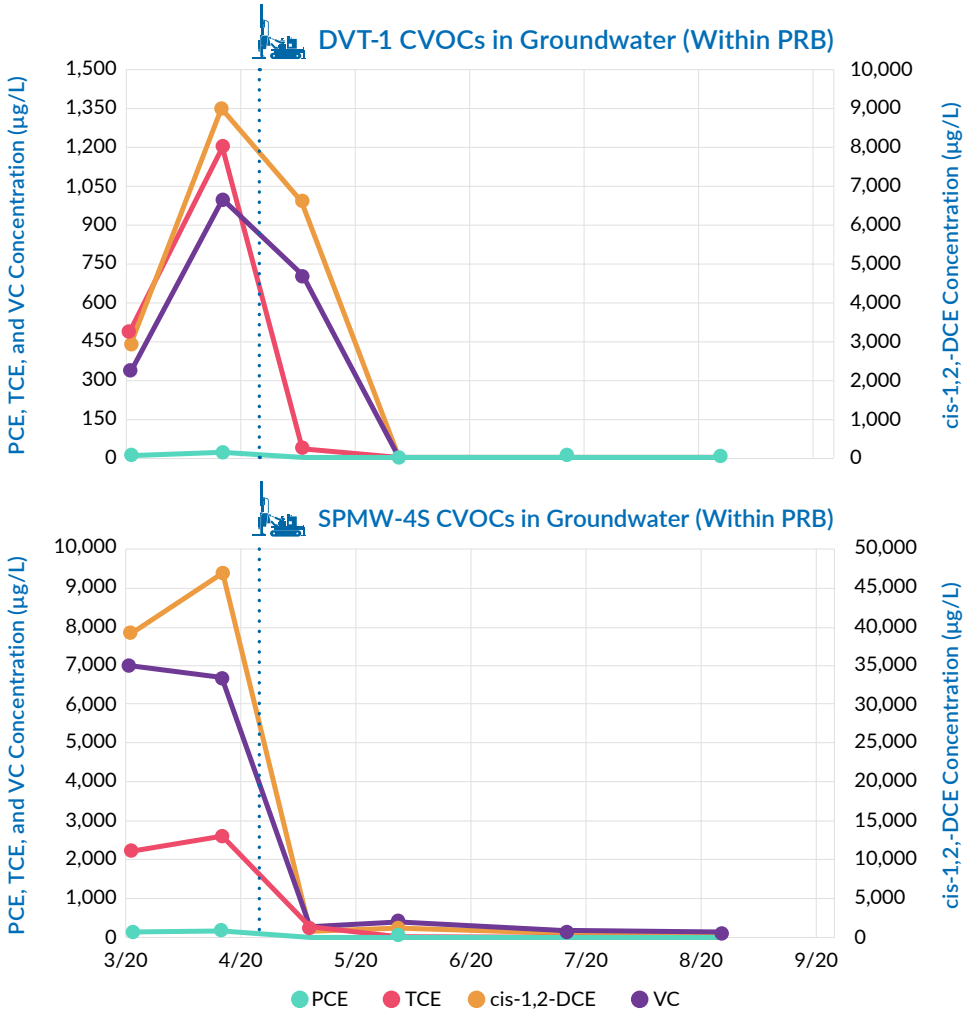
Soil cores reveal consistent PlumeStop distribution within the target treatment interval

Results and Conclusions

The PlumeStop PRB Pilot Test Demonstrates Complete Elimination of CVOCs

Within the PlumeStop *in situ* PRB, CVOC contaminants have been fully eliminated (i.e., 99.6% effective removal) from baseline concentrations exceeding 10,000 µg/L and 50,000 µg/L in-barrier performance wells, DVT-1 and SPMW-4S, respectively.

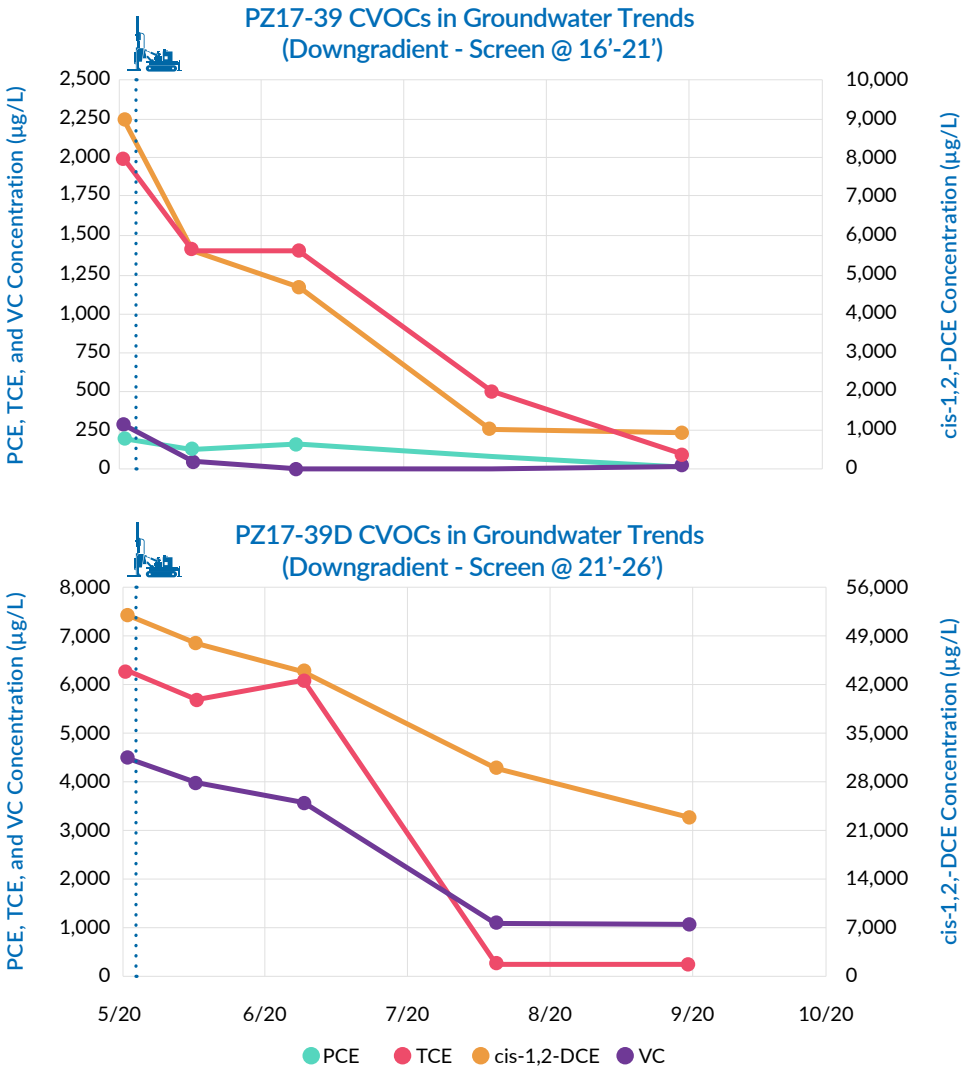
The geochemical response at the in-barrier performance wells shows that the application has created reduced conditions in the treatment area with dissolved oxygen sustained near zero parts per million and oxidation-reduction potential reduced significantly from baseline. The pH levels are near neutral and similar to baseline in the two wells.



In Situ PRB Performance at In-Barrier Performance Wells, DVT-1 and SPMW-4S

In the downgradient performance observation well pair, PZ17-39 and PZ20-39D, approximately 15 ft downgradient of the PRB, contaminants have been reduced by 65% thus far. Significant reductions have also been observed in wells further downgradient. Further contaminant reductions are anticipated as the PlumeStop PRB-treated groundwater displaces the contaminated water, gradually over time.

The geochemical response at the downgradient performance wells is similar to that observed in the barrier with dissolved oxygen reduced to near zero parts per million, and oxidation-reduction potential reduced significantly from baseline.



In Situ PRB Performance at Downgradient Performance Wells, PZ17-39 and PZ20-39D

The pilot test has demonstrated effectiveness, meeting performance expectations, and conforming with modeling projections thus far in the monitoring period's early stage. Based on these results, HMA proposes expanding the treatment beyond the current pilot test scope, which will likely commence in 2021. The treatment will be targeted to eliminate residential exposure to potential CVOCs by drastically reducing contaminant flux in the plume, as demonstrated by the pilot test.

About The Consultant

Hamp Mathews & Associates, Inc.

Hamp, Mathews & Associates (HMA) was formed in 2002 by Lonn Hamp and Alan Mathews in Michigan. Lonn's education in geology culminated in a Master of Science degree that lead to employment with EarthFax Engineering where he eventually met Alan, who earned a Master of Science degree in petroleum engineering from Texas A&M. Their combined qualifications have enabled HMA to support the interests of their clients through the passionate pursuit of well-balanced solutions to complex technical and regulatory challenges.

About The Principal Engineer

Joel Parker

Joel Parker, Principal Engineer with Hamp, Mathews & Associates, joined the firm after serving in a variety of positions at other environmental engineering firms. These included stints as a Senior Environmental Engineer and Remediation Group Manager, roles which provided exposure to both the scientific aspects and hands-on field work of remediation. In his current role, he is responsible for providing technical direction and guidance on environmental project strategy. Parker attended Alma College, in Alma, MI, where he earned his BS in Physics. He followed this with a MS in Environmental Engineering at Michigan State University, East Lansing, MI.

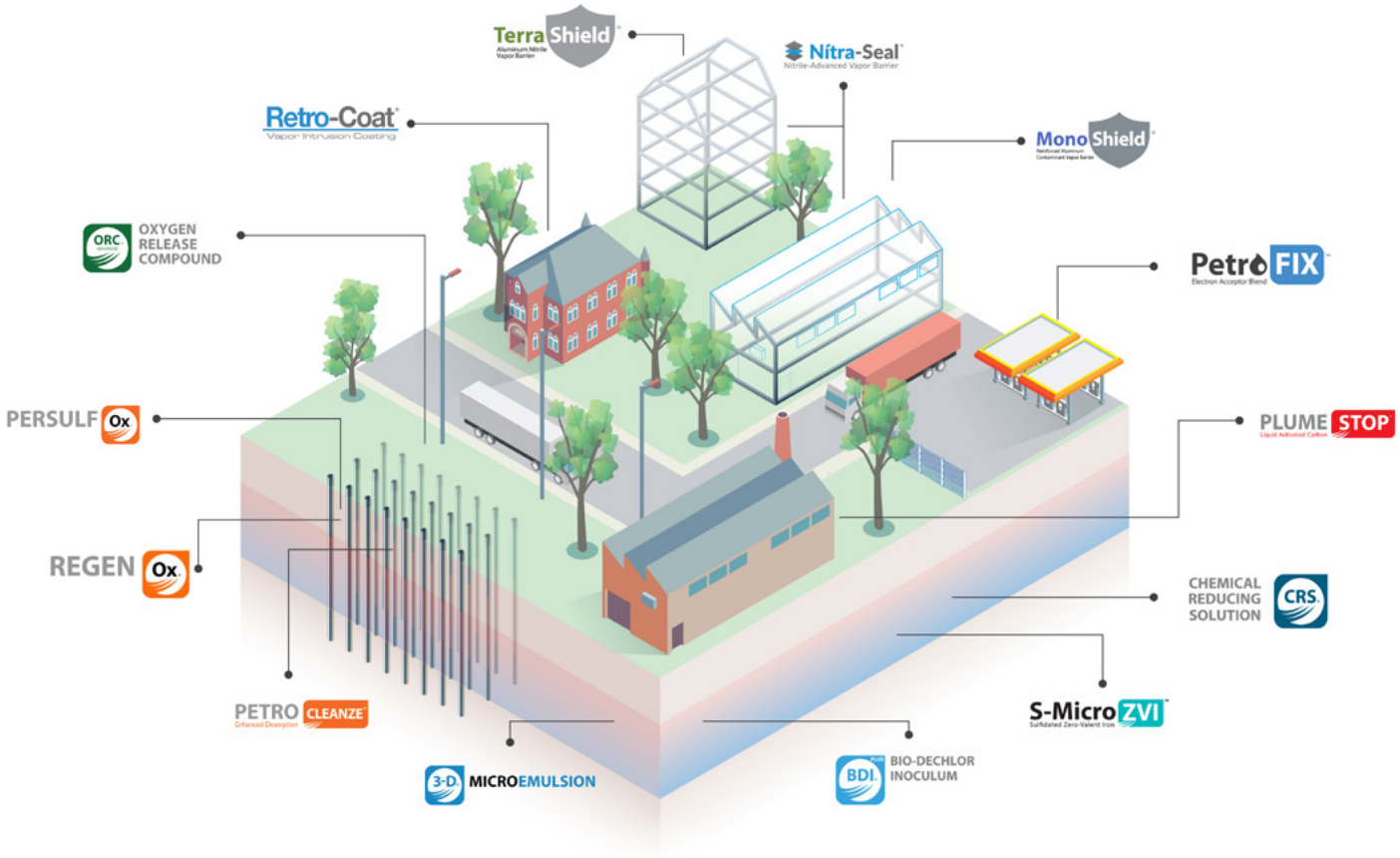
Technologies Used

PlumeStop, S-MicroZVI, HRC-X

PlumeStop® Liquid Activated Carbon™ is a fast-acting groundwater remediation reagent which captures and biodegrades a range of contaminants, thus accelerating the successful treatment of impacted sites and leading to their permanent closure. As a science-based, *in situ* treatment technology, REGENESIS' PlumeStop rapidly removes contaminants from groundwater and stimulates their permanent degradation.

S-MicroZVI® is an *In Situ* Chemical Reduction (ISCR) reagent that promotes the destruction of many organic pollutants and is most commonly used with chlorinated hydrocarbons. It is engineered to provide an optimal source of micro-scale zero valent iron (ZVI) that is both easy to use and delivers enhanced reactivity with the target contaminants via multiple pathways. S-MicroZVI can destroy many chlorinated contaminants through a direct chemical reaction. S-MicroZVI will also stimulate anaerobic biological degradation by rapidly creating a reducing environment that is favorable for reductive dechlorination.

HRC® is an engineered, hydrogen release compound designed specifically for enhanced, *in situ* anaerobic bioremediation of chlorinated compounds in groundwater or highly saturated soils. Upon contact with groundwater, this viscous, poly-lactate ester material becomes hydrated and subject to microbial breakdown producing a controlled-release of hydrogen for periods of up to 18-24 months on a single application. HRC enables enhanced anaerobic biodegradation by adding hydrogen (an electron donor) to groundwater and/or soil to increase the number and vitality of indigenous microorganisms able to perform the naturally occurring process of enhanced reductive dechlorination.



About REGENESIS

At REGENESIS we value innovation, technology, expertise and people which together form the unique framework we operate in as an organization. We see innovation and technology as inseparably linked with one being born out of the other.

Inherently, innovation imparts new and better ways of thinking and doing. For us this means delivering expert environmental solutions in the form of the most advanced and effective technologies and services available today.

We value expertise, both our customers' and our own. We find that when our experienced staff collaborates directly with customers on complex problems there is a high potential for success including savings in time, resources and cost.

At REGENESIS we are driven by a strong sense of responsibility to the people charged with managing the complex environmental problems we encounter and to the people involved in developing and implementing our technology-based solutions. We are committed to investing in lasting relationships by taking time to understand the people we work with and their circumstances. We believe this is a key factor in achieving successful project outcomes.

We believe that by acting under this set of values, we can work with our customers to achieve a cleaner, healthier, and more prosperous world.

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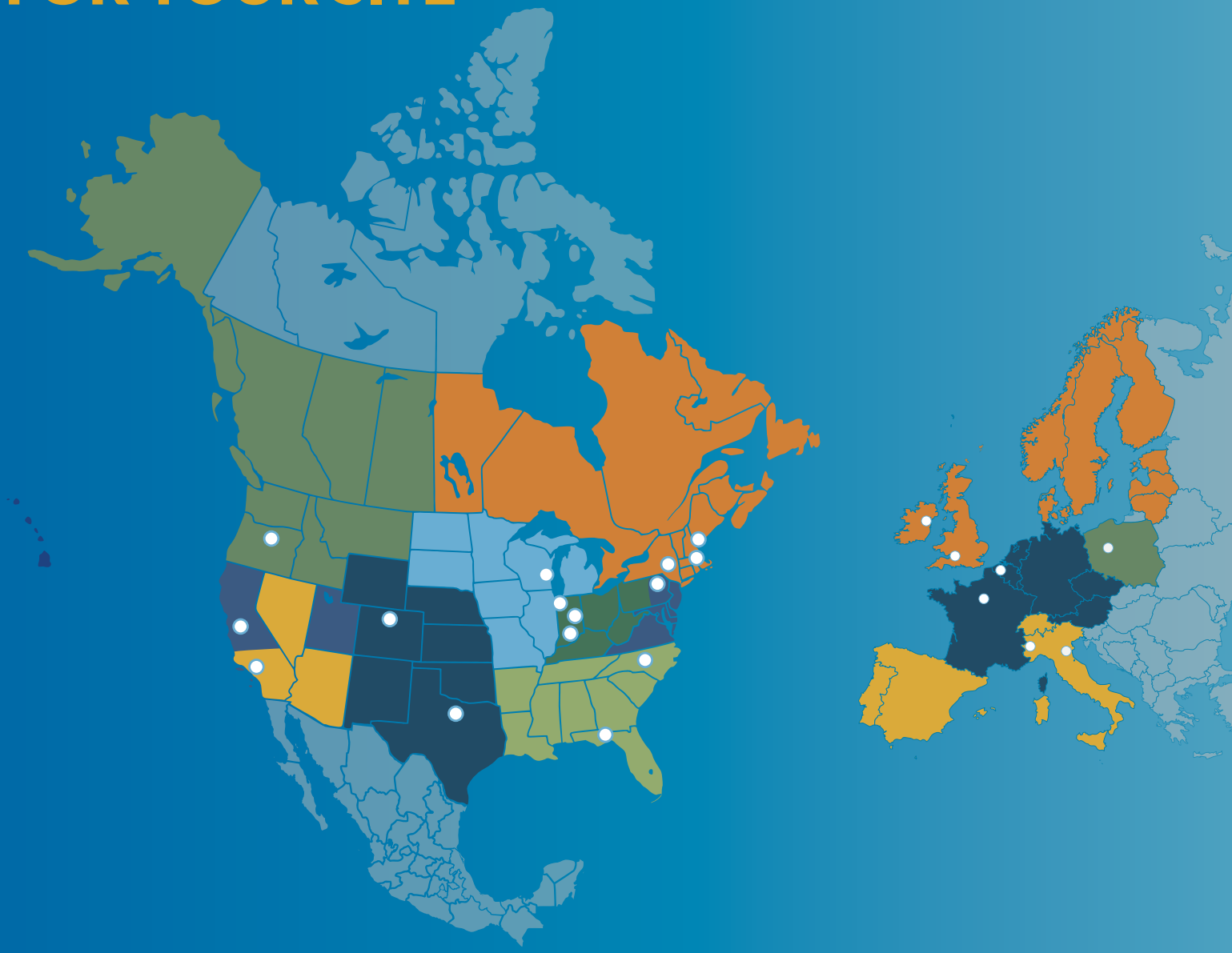
WE'RE READY TO HELP YOU

FIND THE RIGHT SOLUTION FOR YOUR SITE



Global Headquarters

1011 Calle Sombra
San Clemente, CA 92673 USA
Ph: (949) 366-8000
Fax: (949) 366-8090

Europe

Bath, United Kingdom
Ph: +44 (0) 1225 731 447

Dublin, Ireland
Ph: +353 (0) 1 9059 663

Torino, Italia
Ph: +39 (0) 11 19781549

Ieper, België
Ph: +32 (0) 57 35 97 28

www.REGENESIS.com

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