REGENESIS®

Reductive Dechlorination Approach Treats Large Chlorinated Solvent Plume

Innovative Combined Remedy on Active Site Effectively Eliminates Risk to Adjacent Property

Background

Large Chlorinated Solvent Plume Migrating Toward Former Public Water Supply Well Poses Risk

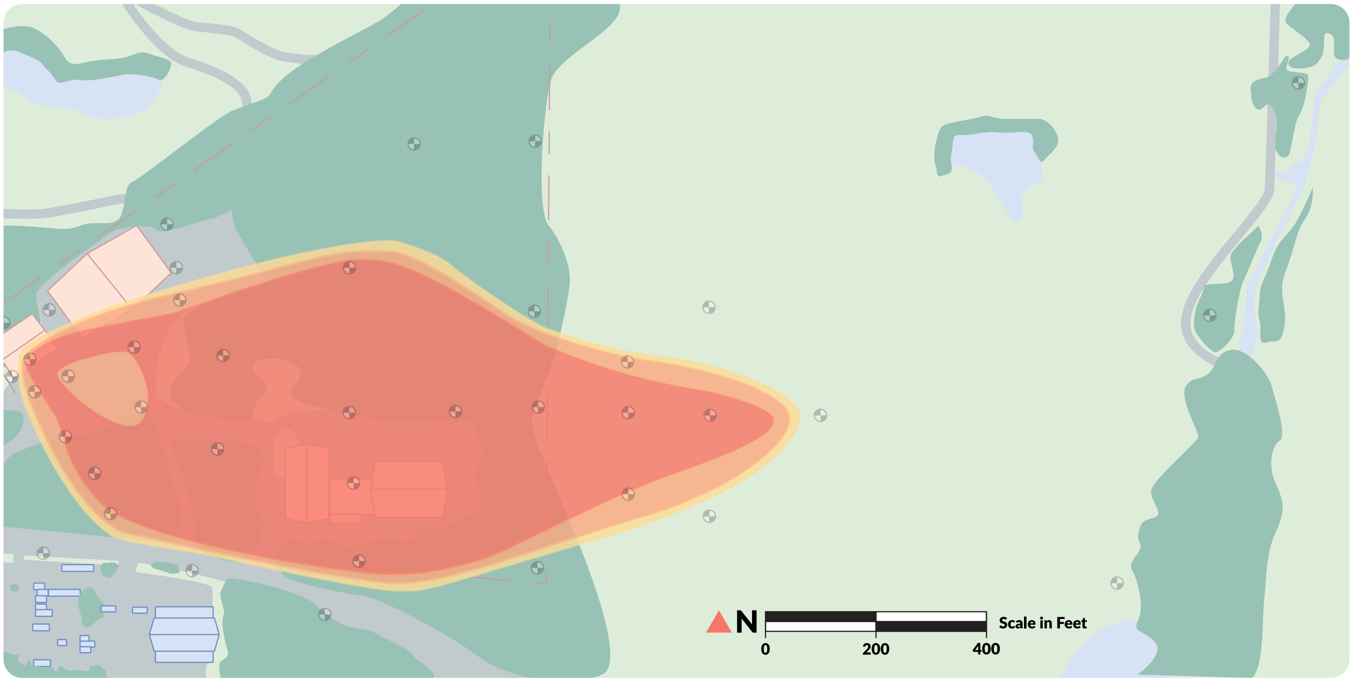
"After the plant was shut down, the buildings were leased to a variety of tenants and we have not been able to identify the responsible party for the cVOC release. The adjacent upgradient property owners completed their investigation and it was determined one of the primary sources was an overgrown area that straddled the property boundary between the two sites."

Michael F. Casper, LPG
Principal
Patriot Engineering
and Environmental

The project site is a former food processing plant located in a suburb south of Indianapolis with operations dating back to the late 1890s. Once a prominent driver of the local economy, the company seasonally employed hundreds of residents to work in the factory, office, and surrounding fields. The plant operated for more than half a century before closing in the 1950s.

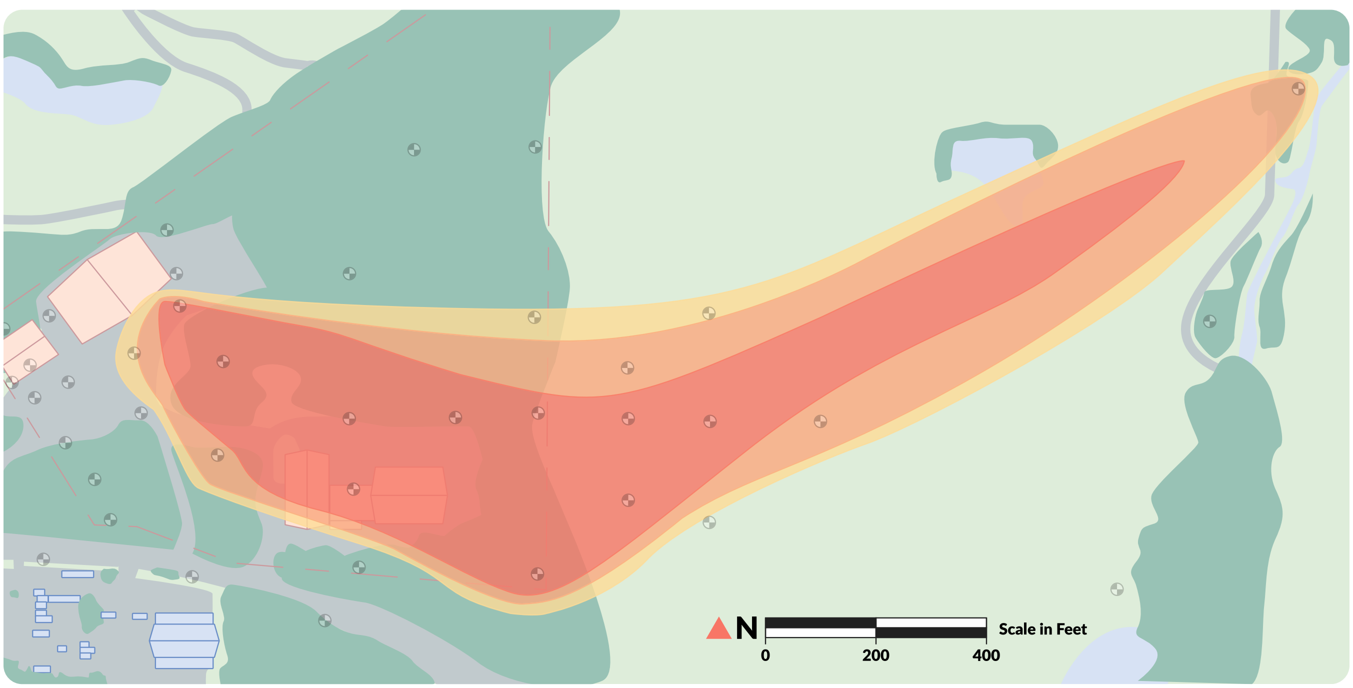
In the early 2000s, chlorinated solvent contaminants were discovered in a nearby wellfield, downgradient of the property. Patriot Engineering and Environmental, Inc. (Patriot), a leading consulting firm based in Indianapolis, investigated the site, discovering contaminants had migrated from an unidentified source and formed a large plume. In addition, it was found that the plume was being pulled toward a former (now inactive) public water supply well.

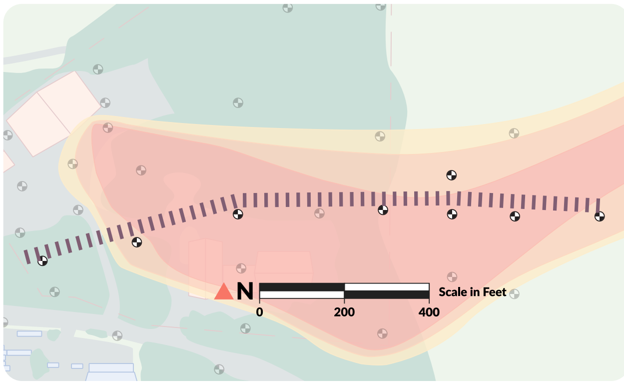
The primary chlorinated volatile organic compounds (CVOCs) detected in the plume were tetrachloroethene (PCE), trichloroethene (TCE), and cis-1,2-dichloroethene (cis-DCE). The plume migrated through shallow and deep aquifer zones as the sand unit carrying the contaminants (i.e., the mass flux zone) thickened from west to east across the site and offsite.



Pre-Treatment Plume Extents

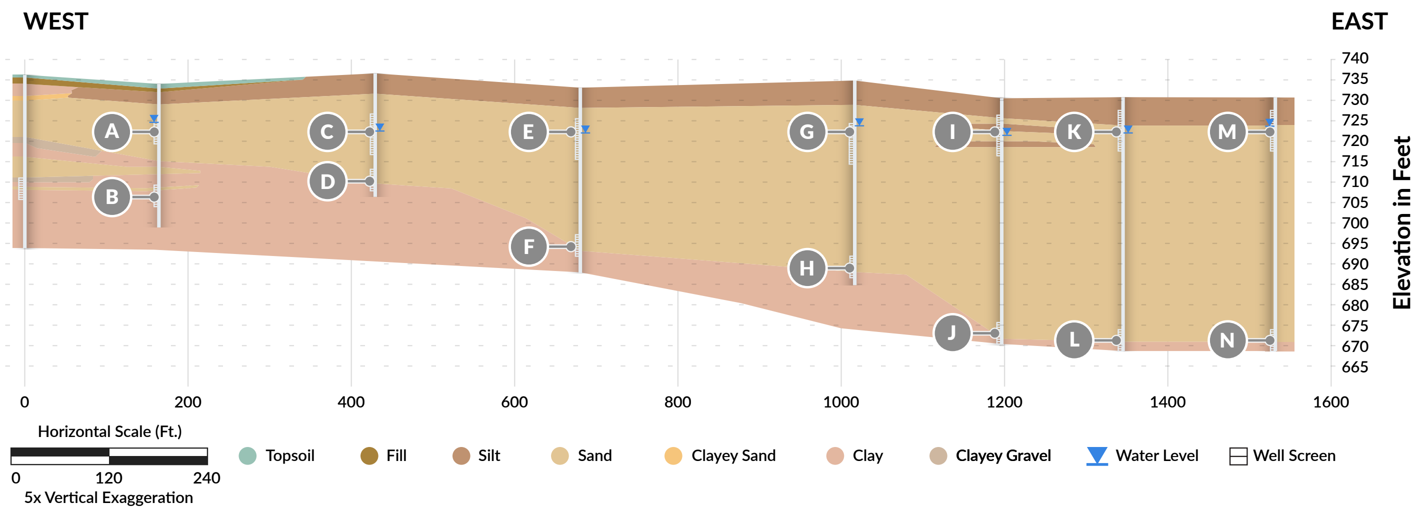
Rendering of pre-treatment plume extents as observed in shallow (above) and deep (below) aquifer zones





In 2020, remedial measures were completed at an adjoining upgradient property that extended into the site's far western end. These measures included excavation and offsite disposal of approximately 2,500 tons of non-hazardous soil and groundwater *in situ* chemical oxidation (ISCO) treatment using potassium permanganate. Additionally, a vapor recovery/filtration system was installed in one of the buildings on the active property.

Plume Map showing cross section line and cross section over a portion of the site showing a substantially increasing sand unit thickness from west to east.



A
PCE: 293 µg/L
TCE: 163 µg/L

C
PCE: 5.8 µg/L
TCE: 30 µg/L

D
PCE: 13.3 µg/L
TCE: 43.6 µg/L

E
TCE: 15.7 µg/L

F
PCE: 14.4 µg/L
TCE: 124 µg/L
cis-1,2-DCE: 21.2 µg/L

H
TCE: 7.8 µg/L
cis-1,2-DCE: 430 µg/L
trans-1,2-DCE: 17.9 µg/L

I
TCE: 106 µg/L

J
TCE: 40.9 µg/L
cis-1,2-DCE: 250 µg/L

K
TCE: 311 µg/L

L
TCE: 444 µg/L
cis-1,2-DCE: 1040 µg/L

N
TCE: 19.2 µg/L
cis-1,2-DCE: 246 µg/L
trans-1,2-DCE: 14.2 µg/L

B G M
All VOCs Below Required Levels

Unlisted VOCs were found to have concentrations below required levels at the time of sampling. Samples were collected in Spring 2019.

In Situ Groundwater Remediation

> *"When we do design verification, we want to make sure that the material will go into the ground correctly because distribution is probably half the battle. If we get poor distribution, the chemistry doesn't matter. So, the design verification is used to determine and ensure that our design is correct in real-time as we're injecting. We use placement validation on the back end as we inject the chemical to make sure that our chemical is getting to where we want it to be."*

Keith Gaskill
Senior Design Specialist
REGENESIS

REGENESIS' Remedy is Chosen Based on Proven Effectiveness in Treating Similar Large CVOC Plumes

Concurrent with final CVOC plume delineation efforts, Patriot completed a Remedial Work Plan (RWP). The cleanup objective was to reduce the CVOCs in onsite groundwater to below the IDEM RCG Commercial/ Industrial Vapor Intrusion from Groundwater Screening Levels (VIGWSLs) and demonstrate plume stability via post-remediation groundwater monitoring (i.e., Monitored Natural Attenuation or MNA). The long-term remediation goal in the groundwater plume offsite is to reduce contaminant concentrations below IDEM tap water standards. The closure strategy outlined in the RWP also specified an Environmental Restrictive Covenant (ERC) to restrict groundwater usage onsite.

In selecting a remedy for the large CVOC plume, Patriot evaluated several options, including:

- Groundwater pump and treat
- Air sparging/soil vapor extraction (AS/SVE)
- ISCO combined with enhanced reductive dechlorination (ERD)
- PlumeStop® Liquid Activated Carbon™ (PlumeStop) combined with ERD

Factors for consideration in selecting the appropriate remedial technology primarily included the site geology and hydrogeology, the cleanup objectives, and the physical characteristics controlling contaminant degradation behavior.

Ultimately, the combined PlumeStop/ERD remedy was selected as the preferred remedial alternative. The approach would utilize a sequence of permeable reactive barriers (PRBs), transecting the plume, and engineered to site-specific hydrological conditions. PlumeStop, S-MicroZVI®, 3-D Microemulsion®, and Bio-Dechlor Inoculum® (BDI) were used in combination to strongly inhibit CVOC plume migration near the site property boundary while enhancing abiotic and biotic degradation of CVOCs at this location and in the upgradient plume area.

Process Employed Efficient Use of Natural Groundwater Advection Moving Contaminants Through the Treatment Zone

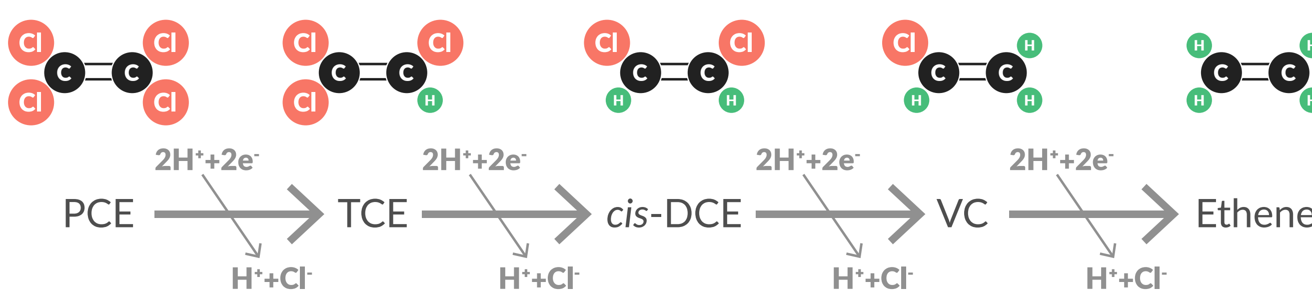
> *"The challenge is it's a very large site, with part of the treatment area being wooded and difficult to access. As a result, we designed a system of barriers on-site to treat the source, and then a property boundary barrier to manage migration off-site."*

Keith Gaskill
Senior Design Specialist
REGENESIS

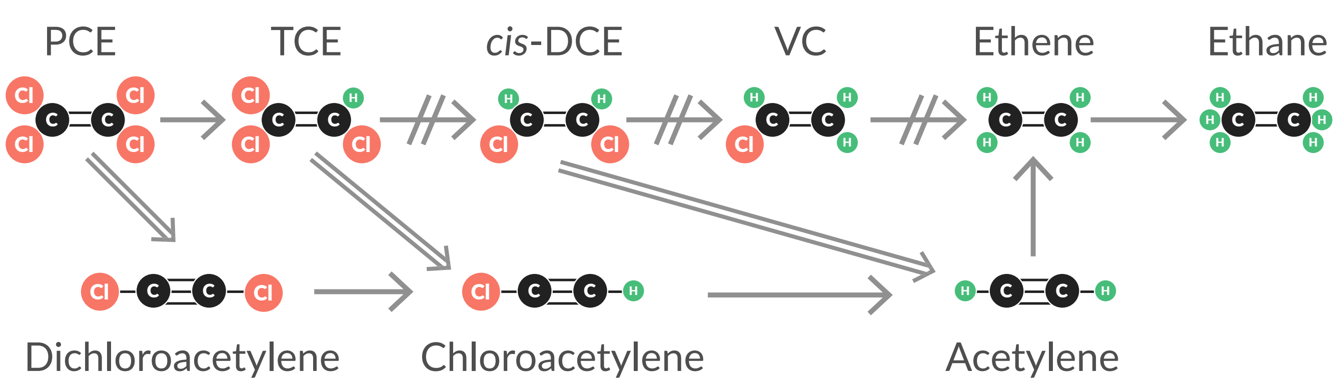
One of the key features of the PlumeStop/ERD remedy involves the recycling of sorption sites due to the enhanced abiotic and biotic degradation of contaminants within the biomatrix (i.e., carbon film coating the aquifer materials). The degradation to non-sorptive and non-toxic end products such as ethene, ethane, and carbon dioxide frees up sorption sites, allowing contaminants to further partition out of the groundwater.

As contaminants are sequestered onto the biomatrix, it is rapidly colonized by *Dehalococcoides sp.* and other CVOC-degrading bacteria contained in BDI, substantially increasing the rate and extent of contaminant destruction. This unique degradation process allows for a treatment system that efficiently uses natural groundwater advection to move contaminants through the treatment zone. Employing the approach enables large sections of the plume to be treated with relatively minimal effort. It is favored as a Green and Sustainable Remediation (GSR) alternative with no permanent subsurface installations or energy-intensive inputs required.

Biological ERD Pathway



Abiotic ERD Pathway



"One of the unique challenges at this site is the different injection depths that we have to inject at. On one side of the site, the injection depths range from 10 to 30 feet and on another portion of the property, the depths range from 10 to 60, 70 feet. A really strong conceptual site model was key to success on this project."

James Cody
Project Manager
Patriot Engineering and Environmental

Patriot's experience successfully implementing the combined PlumeStop/ERD remedy at similar sites guided the decision, giving the project stakeholders confidence in the technical merit, efficiency, and cost-effectiveness of the approach. The remedy is utilized in combination with MNA, and ERCs, as necessary, to eliminate any potential exposure pathways and the associated human health risk.

PRBs were oriented nearly perpendicular to groundwater flow in the Onsite and Offsite Plume Areas. In the Offsite Plume Area, natural groundwater flow was to the southeast, which was realized once the water supply wells from the adjacent well field were shut off. Consequently, the PRB is oriented parallel to the long axis of the CVOC plume in the Offsite Plume Area.

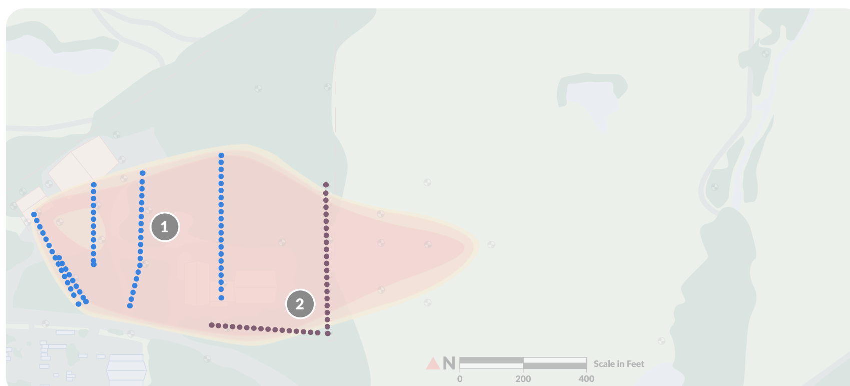
Onsite Treatment Area

1 2,500 Linear Foot PRB

3-D MICROEMULSION — S-Micro ZVI Sulfidated Zero-Valent Iron

2 850 Linear Foot PRB

PLUMESTOP Liquid Activated Carbon — S-Micro ZVI Sulfidated Zero-Valent Iron



Offsite Treatment Area

3 650 Linear Foot PRB

3-D MICROEMULSION — S-Micro ZVI Sulfidated Zero-Valent Iron

In total, more than 200,000 gallons of remedial amendments were proposed for application through more than 500 injection points, utilizing REGENESIS Remediation Services' (RRS's) self-contained injection trailer and hydraulic percussion (i.e., direct push) injection tooling.

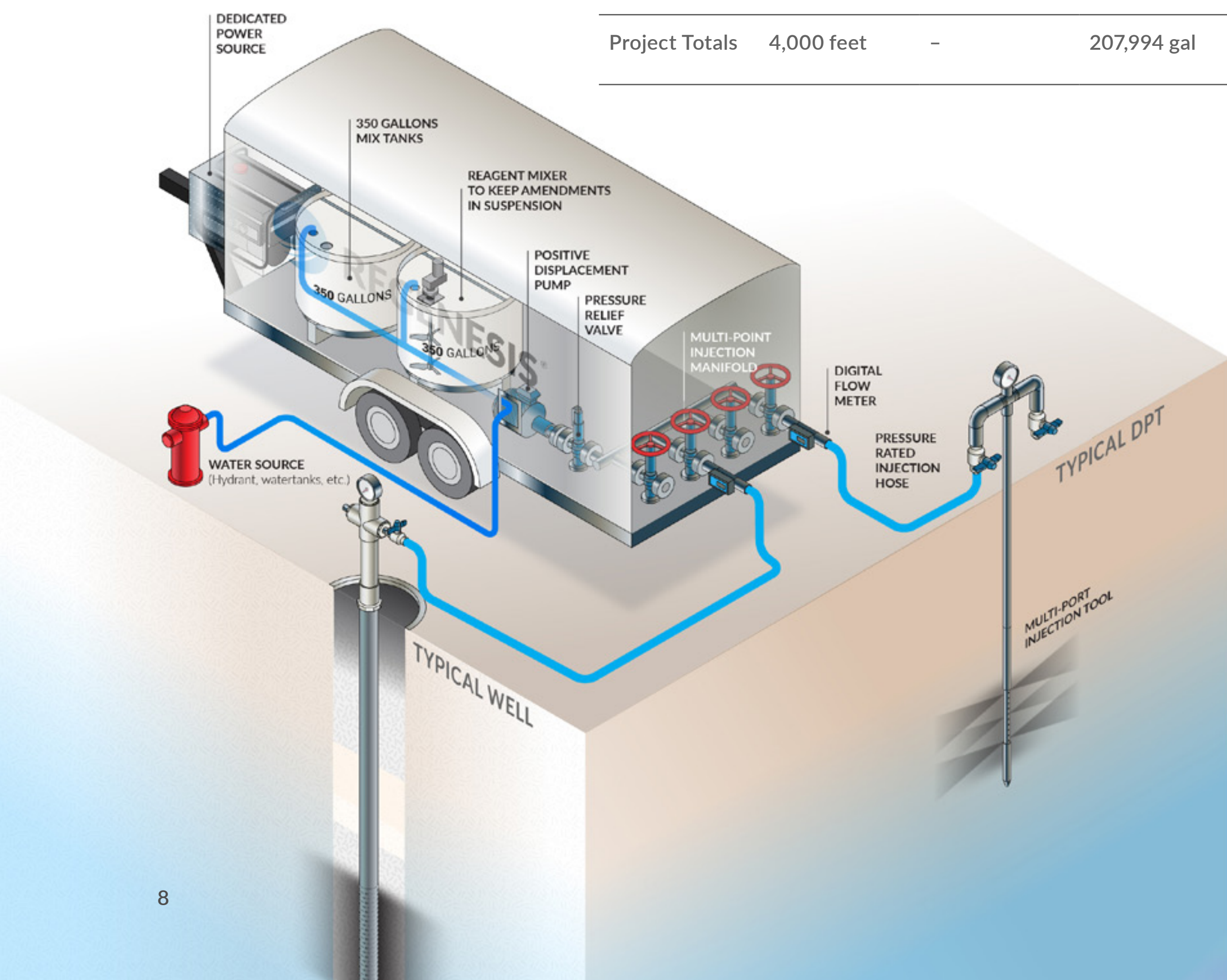
> *"When RRS starts a project, we align ourselves with the client's goals, and we're up-front about what needs to happen for the project to be successful. And that way, when something comes up, we can quickly decipher what the issue is, and then how to overcome it."*

Andrew Kavanagh
Project Manager
REGENESIS
Remediation Services

In Situ Groundwater Remediation Design Summary

Treatment Area	Barrier Length	Treatment Depths	Injection Volume	Injection Points
Onsite	2,500 feet	10-30	70,242 gal	313
3-D MICROEMULSION		BDI PLUS BIO-DECHLOR INOCULUM	S-Micro ZVI Sulfidated Zero-Valent Iron	
Onsite	850 feet	10-30	91,664 gal	142
PLUME STOP Liquid Activated Carbon		BDI PLUS BIO-DECHLOR INOCULUM	S-Micro ZVI Sulfidated Zero-Valent Iron	
Offsite	650 feet	10-60	46,088 gal	81
3-D MICROEMULSION		BDI PLUS BIO-DECHLOR INOCULUM	S-Micro ZVI Sulfidated Zero-Valent Iron	
Project Totals	4,000 feet	–	207,994 gal	536

Diagram of the Mobile Injection System used by RRS to apply remedial amendments



Results

Design Verification Testing and Placement Validation Guide a Successful Remedial Application

RRS safely completed the application, on time and within budget, during the Fall/Winter of 2021. Real-time design verification testing (DVT) and distribution monitoring (i.e., placement validation) of the remedial amendments were used to confirm the design and modify injection parameters such as injection volumes/depths and point spacing.

This large-scale application involved multiple treatment areas with different remedial amendments, variable injection intervals, and concurrently operating injection crews working in different areas. With the groundwater remedy in place, the groundwater contamination is mitigated, with the potential exposure pathway and the associated risk removed.

> *"One of the best parts about a site like this is being a part of the solution. At the end of the day, the entire REGENESIS team and I feel good about what we're doing."*

Andrew Kavanagh
Project Manager
REGENESIS
Remediation Services

About the Consultant

Patriot Engineering and Environmental, Inc.

Patriot Engineering and Environmental, Inc. (Patriot) is a diverse engineering firm providing geotechnical, environmental, and construction materials testing services and consultation to commercial, industrial, and governmental clients. Patriot provides the specific information needed to make informed, cost-effective business decisions which will help reduce net cost, decrease risk, and improve the quality of your project outcomes. With decades of experience, Patriot's staff has the technical expertise needed to address most environmental, geotechnical, or construction materials testing projects. Senior engineers and technical professionals serve as actual project managers and not just advisors, which is common practice with most consulting companies. They have the full responsibility for getting the job done and the authority and resources to ensure the work is completed quickly, correctly, and economically.

Technologies Used

PlumeStop, S-MicroZVI, 3-D Microemulsion, and Bio-Dechlor INOCULUM Plus

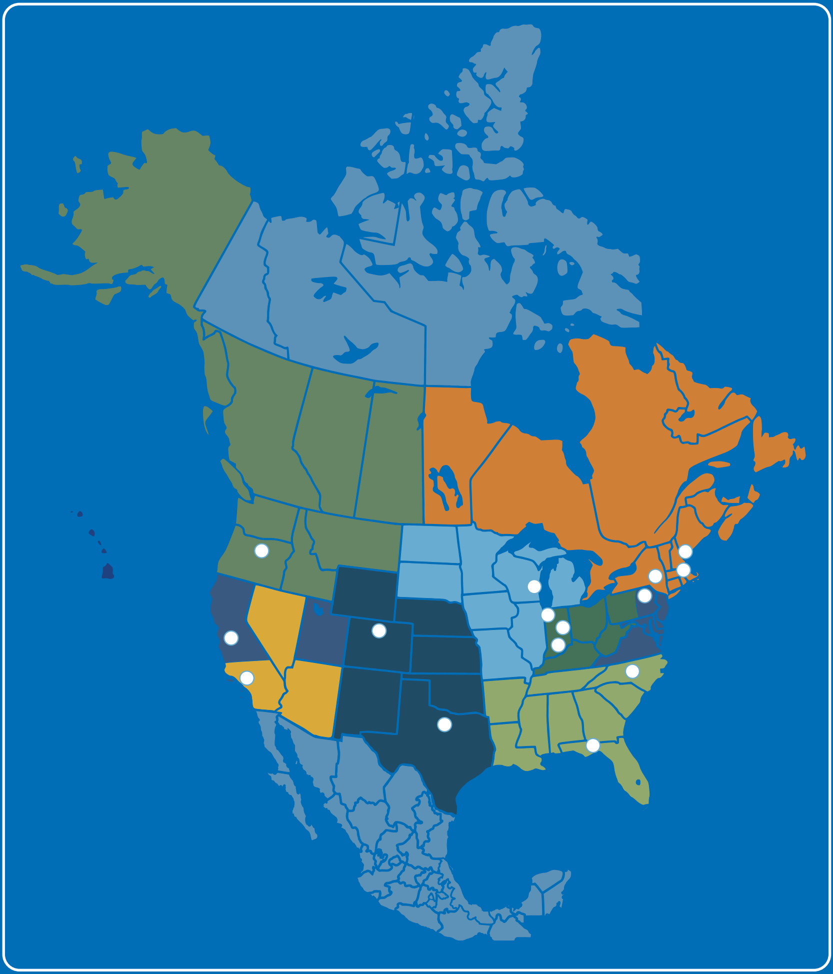
PlumeStop® Liquid Activated Carbon™ is a fast-acting groundwater remediation reagent which captures and biodegrades a range of contaminants, thus accelerating the successful treatment of impacted sites and leading to their permanent closure. As a science-based, *in situ* treatment technology, REGENESIS'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

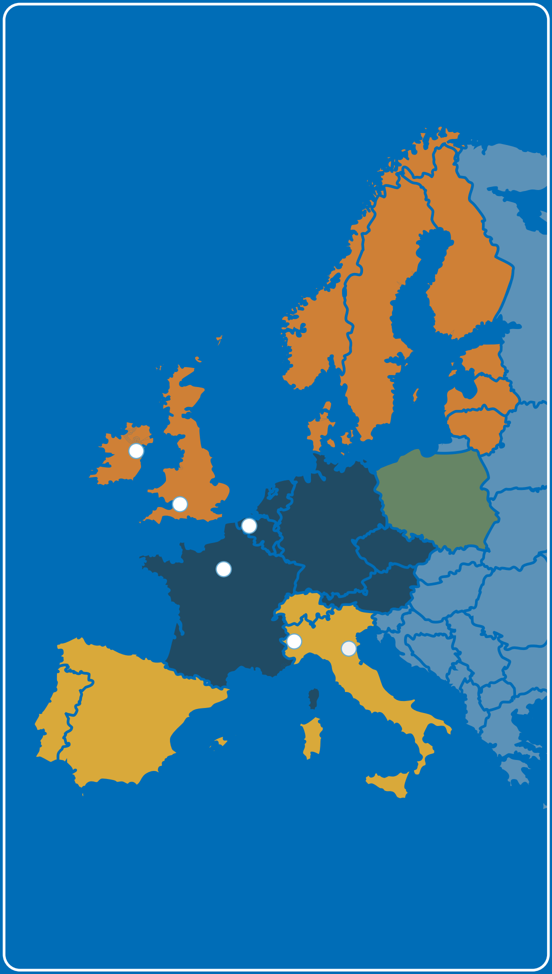
S-MicroZVI® is an *In Situ* Chemical Reduction (ISCR) reagent that promotes the destruction of many organic pollutants and is most commonly used with chlorinated hydrocarbons. It is engineered to provide an optimal source of micro-scale zero valent iron (ZVI) that is both easy to use and delivers enhanced 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.

3-D Microemulsion® is an injectable liquid material specifically designed for *in situ* remediation projects where the anaerobic biodegradation of chlorinated compounds through the enhanced reductive dechlorination (ERD) process is possible. ERD is the primary anaerobic biological process by which problematic chlorinated solvents such as tetrachloroethylene (PCE) and trichloroethene (TCE), dichloroethene (DCE) and vinyl chloride (VC) in groundwater are biologically transformed into less harmful end products such as ethene.

Bio-Dechlor INOCULUM® Plus (BDI Plus) is designed for use at sites where chlorinated contaminants are present and unable to be completely biodegraded via the existing microbial communities. BDI Plus is an enriched, natural microbial consortium containing species of *Dehalococcoides sp.* (DHC) which are capable of completely dechlorinating contaminants during *in situ* anaerobic bioremediation processes. BDI Plus has been shown to stimulate the rapid dechlorination of chlorinated compounds such as tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE), and vinyl chloride (VC). It also contains microbes capable of dehalogenating halomethanes (e.g. carbon tetrachloride and chloroform) and haloethanes (e.g. 1,1,1 TCA and 1,1, DCA) as well as mixtures of these halogenated contaminants.

We're Ready to Help You Find the Right Solution For Your Site





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