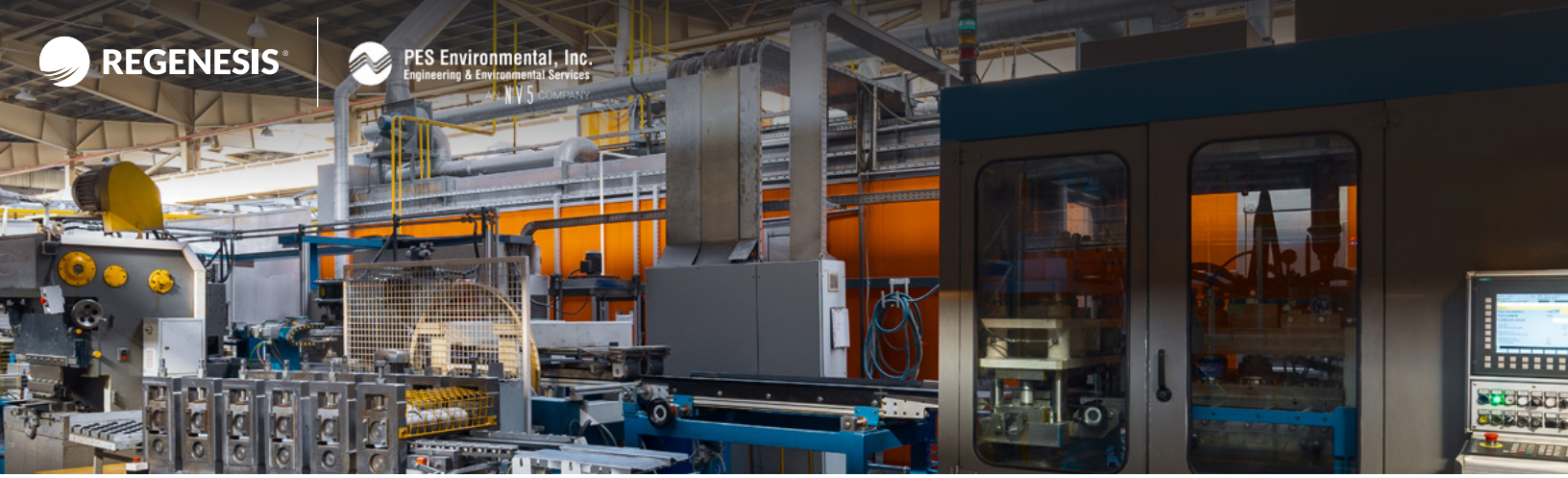
PLUMESTOP APPLICATION PAVES THE WAY FOR REDEVELOPMENT

CASE STUDY:
DVT and Predictive Modeling Contribute to Achieving Remediation Goals

PES Environmental, Inc.
Engineering & Environmental Services
AN NV5 COMPANY

REGENESIS®



Overview

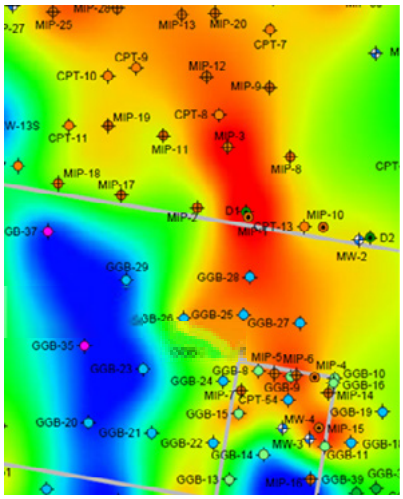
Advanced Site Characterization Methods Help to Achieve Ambitious Site Goals

Advanced design verification testing and predictive modeling methods were used at a contaminanted chlorinated solvent site in northern California to guide a remarkably successful *in situ* remediation effort. Complete reduction of chlorinated volatile organic compounds (CVOCs) in the treatment areas and remedial objectives achieved allowed redevelopment of the property.

The site is a former industrial facility where chlorinated solvents were spilled during industrial manufacturing processes occurring from 1941 to 1970. In 1972, a retail shopping center was constructed over the site following the removal of the industrial facility's structures. In anticipation of redevelopment, buildings in the western portion of the shopping center where the former industrial building sat were removed in 2019.

The redevelopment plan includes an apartment complex and commercial buildings. Remediation to address the CVOC contamination was necessary to allow the development to proceed. The primary CVOC chemicals of concern were tetrachloroethene (PCE) and degradation products, trichloroethene (TCE), cis-1,2-dichloroethene (cis-DCE), and vinyl chloride (VC). PES Environmental, Inc., an NV5 Company, (PES) of Novato, California, was selected by the developer as their Environmental Consultant for this project.

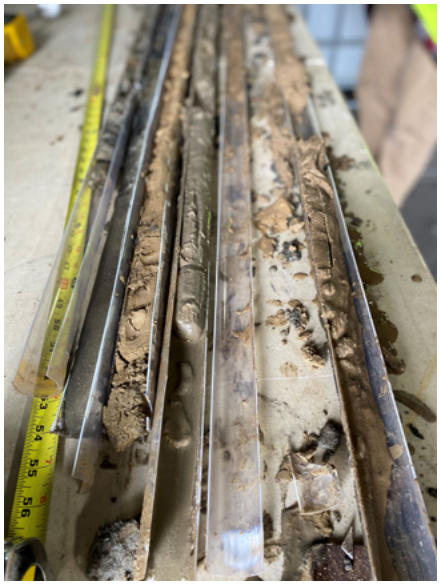
Investigations to define the nature, extent, and general structure of the groundwater plume had been ongoing at the site since the 1980s. More recent characterization activities included membrane interface probe (MIP) and cone penetrometer testing (CPT) study, which identified an approximate 1.5-acre plume area requiring remediation.



When PES engaged REGENESIS on the project, the overall plume features were understood. Critical to developing a remediation plan, the following data was needed:

- groundwater velocity,
- location of primary contaminant transport zones, and
- groundwater CVOC concentrations beyond the source and near-source areas.

A better understanding of contaminant flux was needed. By understanding the contaminant flux, a cost-effective remediation plan could be designed, specifically engineered to achieve a project goal. In this case, the goal was to fully remediate the CVOCs in the target treatment areas within two years following application of the treatment approach.



Example of soil cores collected as part of design verification testing procedures. These cores help to verify soil conditions and confirm the presense of remedial amendments within the target treatment interval.

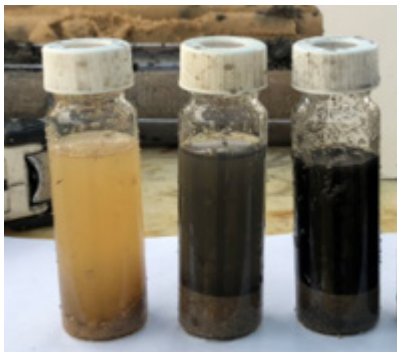
Design Verification Testing

DVT is Especially Effective at Pin-Pointing the Specific Dosing and Treatment Unique to a Site

Design verification testing or DVT is a proprietary approach employed by REGENESIS comprising various in-field and laboratory testing methods to verify remedial design assumptions. Each project site is unique and requires different testing methods based on the site conditions and the project's goals.

A DVT plan was prepared for this site through a collaborative effort between REGENESIS and PES. The DVT plan was devised to gather the information needed to design a remediation approach that could meet the two-year remediation objective with the greatest efficiency and economy, with a primary focus on defining contaminant flux.

Injection testing using clear water was also a key DVT component since it confirmed the volumes needed to achieve the pore-volume filling required. The injection test also established a pumping rate that RRS could sustain without pressure build-up, which allowed a reasonably precise estimate of the time to complete the fieldwork. A list of DVT items conducted, their purpose, and who completed each item is summarized below.



Example of settling tubes used as part of design verification testing

DVT Summary

DVT Item	Completed by	Purpose
Continuous Soil Cores/Soil Settling Tubes	REGENESIS	Identify transmissive zones through grain size analysis
Performance Monitoring Well Installation	PES	Track performance and demonstrate progress toward remedial goals
Passive Flux Study	PES Field Deployment and Collection REGENESIS Flux analysis and Predictive Models	Define contaminant flux to determine product dosing and optimize treatment row placement needed to meet remedial timeframes
Clear Water Injection Test	REGENESIS and PES	Assess optimal product injection radius, and define remediation injection timeframe

DVT Results

Following the DVT, REGENESIS was able to reduce the target treatment volume by approximately 20 percent. The clear water injection test confirmed that RRS could maintain low injection pressures at a moderate injection pumping rate.

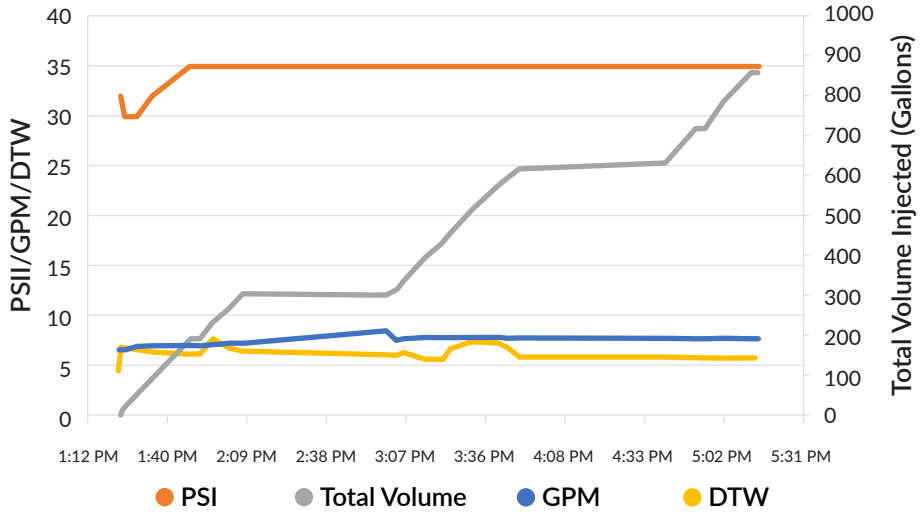


Chart showing pumping rate, injection pressures, depth to water and total volume injected.

Predictive Modeling and Remedial Design

Flux-Based Predictive Modeling Used to Optimize Remediation to Meet Two-Year Timeline

REGENESIS utilizes a proprietary flux-based modeling program to predict remediation cleanup timeframes. The relative certainty of the predicted timeframes is dependent on the understanding of contaminant flux. To determine flux model inputs, passive flux meters (PFMs) were placed within the plume body to delineate the prominent flux zones and magnitude.

The PFMs indicated that the average groundwater velocity was less than 300 feet per year at the site, roughly four times less than the earliest estimates using traditional hydraulic characterization methods. However, the PFM-confirmed velocity matched closely to a plume-aspect ratio curve-fitting method REGENESIS employs for plume treatments. Thus, the PFM study mostly aligned with REGENESIS product dosing estimates.

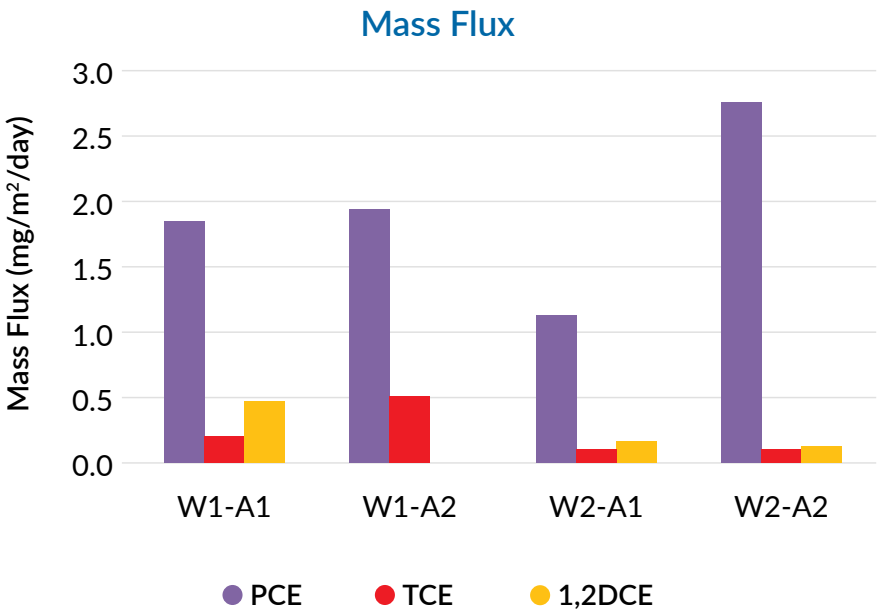


Chart Depicts CVOC Mass Flux at two well pairs, W1 and W2

From this information, REGENESIS confirmed the remediation approach and optimized the remediation design to achieve the two-year remediation goal with the greatest economic efficiency, leading to the submittal of a Response Plan to the Regional Water Quality Control Board (RWQCB). The following components were specified in the Response Plan:

- *In situ* source area shallow groundwater remediation using 3-D Microemulsion®, S-MicroZVI® and Bio-Dechlor INOCULUM Plus® (BDI) to promote enhanced reductive dechlorination (ERD) via biological and direct chemical reduction.
- Source area excavation and disposal of CVOC-impacted soils.
- *In situ* groundwater plume remediation via sorption enhanced chemical reduction using PlumeStop® and S-MicroZVI.
- Supplemental ERD injections into lower sand unit beneath the source area utilizing S-MicroZVI and 3-D Microemulsion (including supplemental well installation to monitor performance in source area).

Application Design Summary

Contaminants of Concern

PCE, TCE, cis-DCE, VC

Concentrations	<10 µg/L - 200 µg/L

Remedial Application

Application Area	68,000 ft^2
Treatment Volume	1.36 million ft^3
Treatment Interval	10-30 ft bgs.
Timespan	28 field days

Products Applied

PlumeStop, S-MicroZVI	208,560 gal

Remediation
Project Timeline

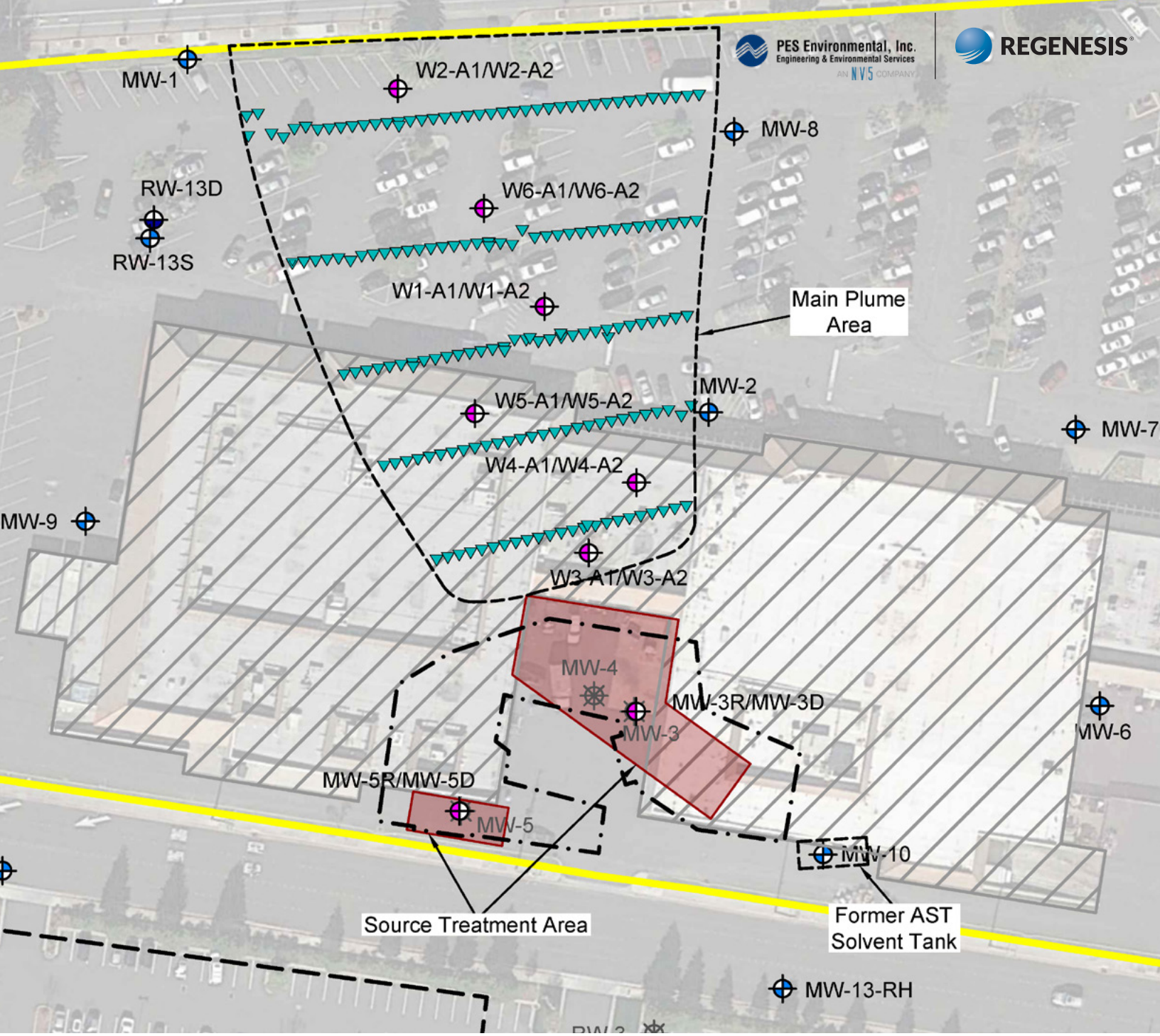
The remediation was completed during four separate phases spanning from March 2019 through March 2020.

- **March 2019**
  In situ source area shallow groundwater remediation. Approximately 26,600 gallons of 3-D Microemulsion, S-MicroZVI, and BDI were injected.

- **September – October 2019**
  Source area excavation and disposal of over 4,400 cubic yards of CVOC-impacted soils.

- **October – November 2019**
  In situ groundwater plume remediation. Over 200,000 gallons of diluted PlumeStop and S-MicroZVI mixtures were injected.

- **March 2020**
  Supplemental injections into lower sand unit beneath source area. Approximately 35,000 gallons of diluted S-MicroZVI and 3-D Microemulsion mixtures were injected.



The remedial design included in the Response Plan specified grid-array injections in the source area and a series of transects in the main plume area, optimally spaced to achieve full plume reductions within two years.

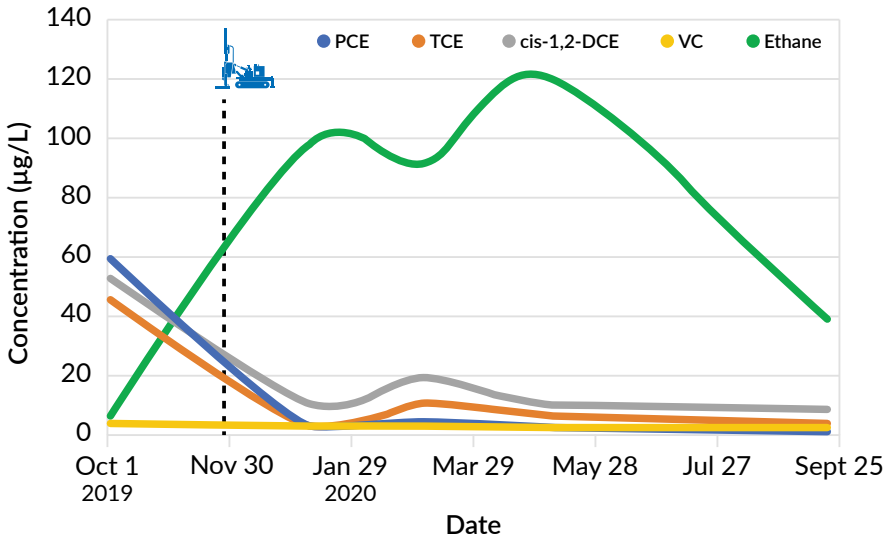
REGENESIS Remediation Services (RRS) injected all remedial reagents, completing the project on time and budget with PES' oversight. As predicted by the clear water injection testing, RRS maintained low injection pressures and moderate flow rates throughout the project.

Results

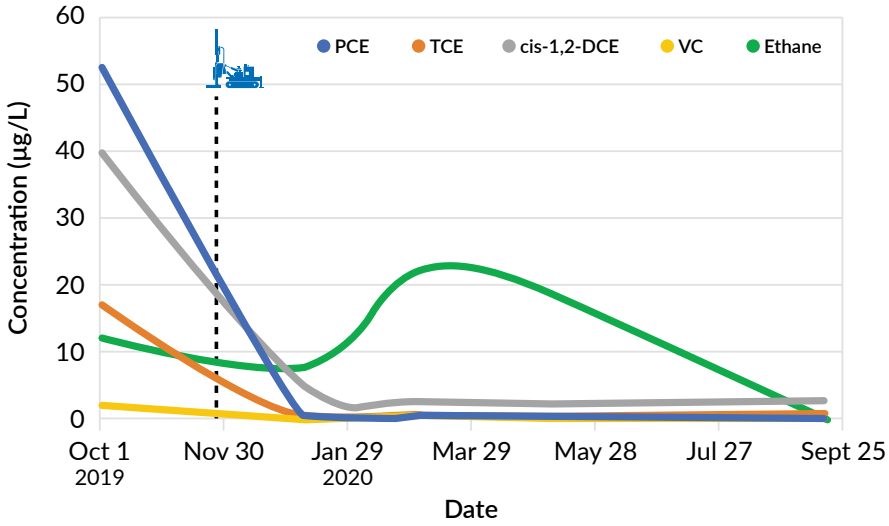
The Highly Successful Remediation Paves the Way for Property Redevelopment

To monitor performance in the main plume area, paired wells were installed downgradient of each transect beyond the injection radius of influence. The wells were screened in defined sections of the treatment interval: A1-Upper and A2-Lower Treatment Zones. In the source area, performance replacement monitoring wells were installed following the excavation and before source injection treatments. Four post-application monitoring events have been completed in the main plume area, and three post-application events have been completed in the source area.

W4-A1
Downgradient of Barrier 1



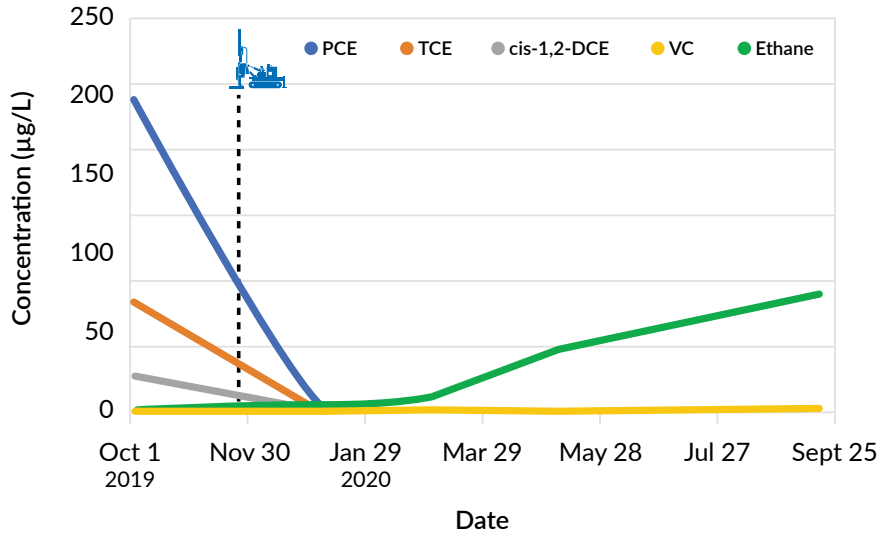
W5-A1
Downgradient of Barrier 2



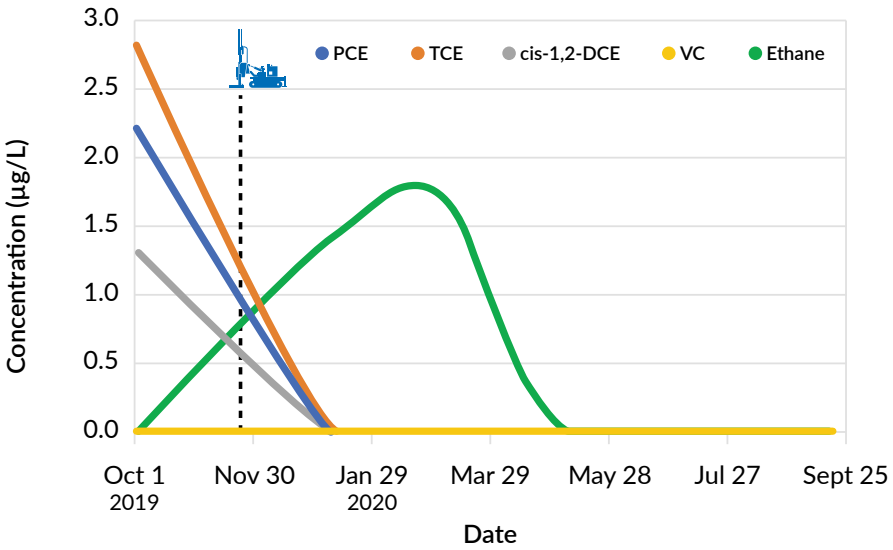
Charts Showing Remedial Performance in the A1-Upper Treatment Zone. Chart data provided by PES

The remediation has met the predicted performance expectations. After approximately one year post-injection, greater than 90 percent CVOC reductions have been achieved in the main plume area. Reductions have been most pronounced, 98 percent, in the lower A2 Zone thus far, correlating with the overall higher groundwater velocities observed in this zone during the PFM study. Significant concentrations of ethane, an abiotic degradation byproduct, have been observed in both the A1 and A2 Zones, indicating complete degradation of the CVOCs is occurring with little to no daughter product formation.

W6-A2
Downgradient of Barrier 1



W4-A2
Downgradient of Barrier 2



Charts Showing Remedial Performance in the A2-Lower Treatment Zone. Chart data provided by PES

In the source area, the combined excavation and *in situ* injection have reduced CVOC concentrations by 98 percent, indicating the virtual elimination of the CVOC source. The source area treatment is anticipated to be effective for several more years. As monitoring progresses, the source-elimination effect will be further reflected in the downgradient plume, which has already demonstrated substantial reductions.

The use of DVT and predictive modeling tools allowed the REGENESIS and PES team to maximize the injected remediation technologies' functionality to achieve the greatest benefit and attain the remedial objectives within the two-year timeframe. Based on the observed performance after one year, PES has successfully petitioned the RWQCB to end plume monitoring and remove the performance monitoring wells so that the property redevelopment can proceed.

REGENESIS®

Technologies Used

PlumeStop, S-MicroZVI, and 3-D Microemulsion

PLUME STOP® Liquid Activated Carbon

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-Micro ZVI® Sulfidated Zero-Valent Iron

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

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.

About The Consultant

PES Environmental

PES Environmental, Inc., an NV5 Company, (PES), with offices in Novato, California; Seattle, Washington; and Veneta, Oregon, was formed in 1989 in response to the demand for experienced environmental consultants capable of providing high quality services in environmental engineering, hydrogeologic consulting, hazardous waste management, and regulatory compliance. PES is a highly respected, client-oriented company with a reputation for solving environmental problems.

PES provides high quality environmental consulting in the following areas: Site Investigation, Monitoring, and Remediation Services; Multi-PRP/ Superfund Services; Underground Storage Tank Management Services; Real Estate Transaction-Related Services; Industrial Hygiene / Lead, Asbestos and Mold Surveys and Abatement Services; Facility Permitting, Compliance, and Closure Services; Third Party (Peer) Review, Litigation Support, and Expert Witness Services; Storm Water Management Services; and Dredging and Dredged Sediment Management Services.

About The Project Manager

Wenqian Dou, PhD, PE

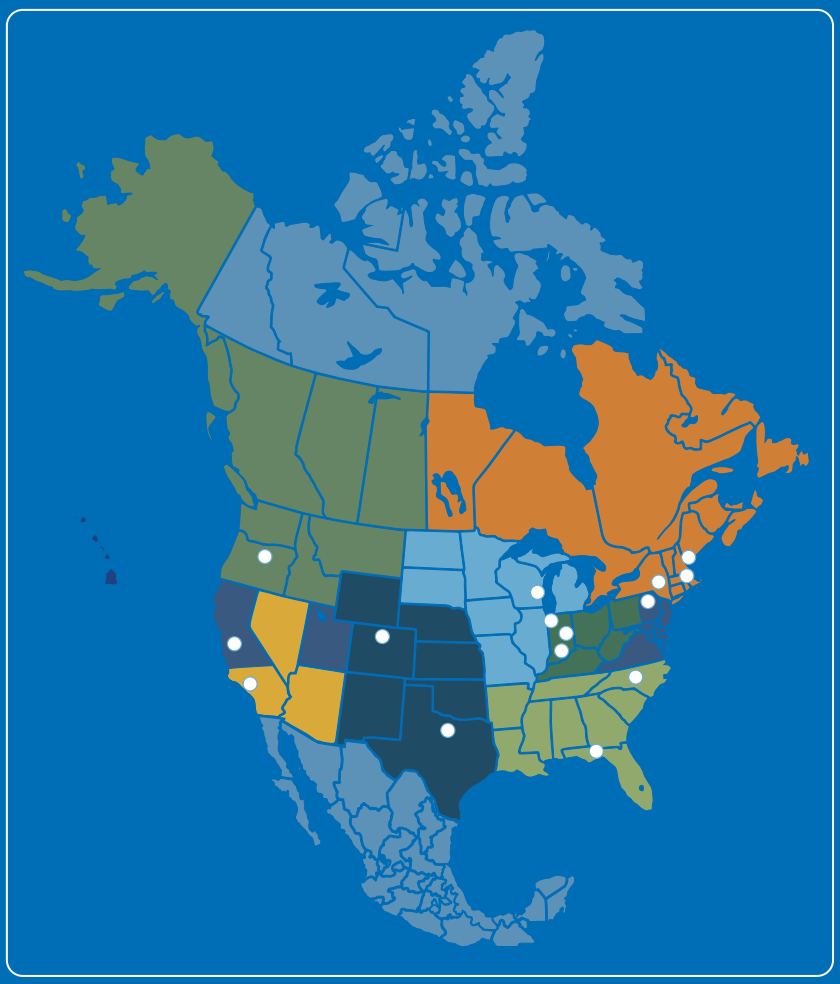
Dr. Dou is a Registered Civil Engineer in California specialized in environmental engineering. She has over 13 years of environmental consulting experience, providing technical support, oversight, and project management for various environmental projects throughout the nation. She has acquired extensive experience with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) regulations.

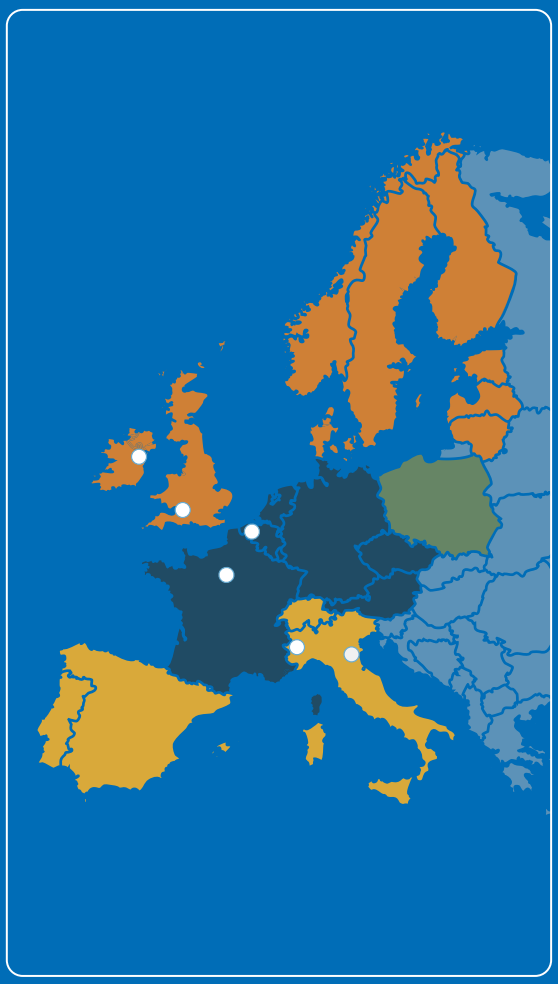
Dr. Dou has worked on remediation projects with a wide range of chemicals, including volatile organic compounds (VOCs), such as tetrachloroethene (PCE) and trichloroethene (TCE), semivolatile organic compounds (SVOCs), polychlorinated biphenyls (PCBs), total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAHs), and heavy metals. She is experienced in cost estimating, proposal writing, litigation support, negotiating with regulators, and interacting with community members.

REGENESIS®

We're Ready to Help You

Find the Right Solution For Your Site





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