REGENESIS®

No Further Action for Large PCE Plume Under Main Street, USA

Multi-Faceted, Enhanced Reductive Dechlorination Approach Overcomes Access Restrictions to Achieve Closure

Overview

Achieving Closure for a Large Chlorinated Solvent Plume in an Urban Area

Large plume with limited treatment access

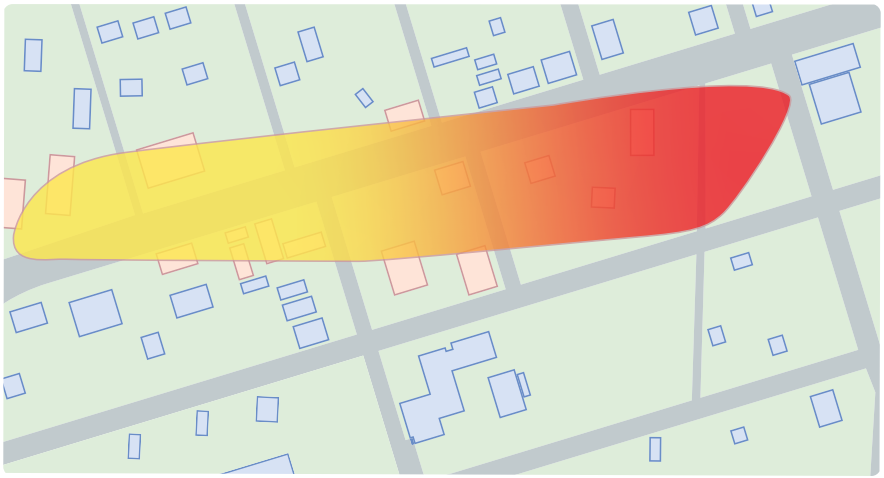
PCE plume virtually eliminated

Seamless collaboration effort between teams involved

Regulatory closure achieved

At a former dry cleaner site in a small town in western Indiana, tetrachloroethene (PCE) spilled and migrated into groundwater, creating a dissolved-phase PCE plume 1,500 feet long and encompassing 340,000 square feet. From the site, the PCE plume tracked along the town's east-west running main thoroughfare, U.S. Route 40.

The historic "Main Street of America" is lined with commercial and residential properties to the north and south, presenting a challenge for remediating PCE and chlorinated volatile organic compound (CVOC) degradation products in groundwater.



Patriot Engineering, a leading Midwest environmental consulting firm headquartered in Indianapolis, specified enhanced reductive dechlorination (ERD) as the most practical and economically viable method to treat the large plume. Patriot's strategy to achieve closure was to significantly reduce the magnitude and extent of the CVOC plume while demonstrating plume stability through post-remediation monitoring.

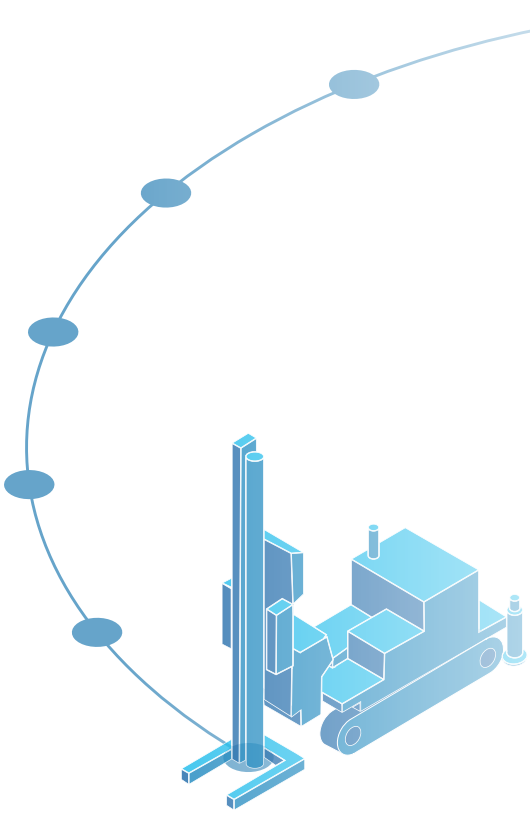
The project site area is serviced by municipal water, and the City prohibits the installation and use of private wells in the project site area, leaving vapor intrusion to indoor air as the only potential exposure pathway. Therefore, CVOC concentrations in the plume needed to be reduced below the Indiana Department of Environmental Management's (IDEM's) Groundwater Vapor Intrusion Screening Levels.

The five-lane highway, utilities, and buildings severely restricted access for treating the dissolved phase PCE plume. These restrictions meant much of the treatment needed to be conducted on City right-of-way property.

There are thousands of similar cases worldwide where dry-cleaning solvents have made their way into groundwater, forming plumes stretching underneath multiple city blocks, major roadways, and buildings impeding groundwater remediation success. In these instances, most ERD approaches employ widely spaced lines of injection points (i.e., barriers or transects) that must conform to the access limitations. Most remedial approaches and *in situ*-applied amendments are unable to fully treat these plumes since they are unable to achieve sufficient plume treatment between the accessible areas.

REGENESIS® has developed PlumeStop® Liquid Activated Carbon™ and 3-D Microemulsion®—*in situ* remediation amendments with advanced distribution properties that effectively overcome these limited access challenges to fully treat CVOC plumes. By combining these technologies with a highly efficient and cost-effective remediation design, Patriot's treatment approach eliminated the PCE plume. Subsequent performance monitoring and analysis completed by Patriot demonstrated plume stability, earning the site a No Further Action status from the IDEM.

This site can be viewed as a prototype for sizeable chlorinated ethene plumes in urban areas where complete plume treatment is required for closure despite substantial plume access limitations that are commonly encountered.



Design Approach and Treatment

Rapidly Eliminating the PCE Sources and Efficiently Treating the Plume

The remediation approach relied on a combination of source area elimination and dissolved plume treatment. In and near the PCE source zones, there were fewer limitations for direct plume treatment. Using this situation to their advantage, Patriot proposed a PlumeStop sorption-ERD design to eliminate PCE sources and shut off further PCE contribution to the larger plume. PlumeStop was formulated to permeate aquifer materials, easily passing through soil pore throats while coating individual soil grains with a carbon film. A PlumeStop treatment creates an immense activated carbon surface area, resulting in rapid sorption kinetics to immediately eliminate contaminant flux.

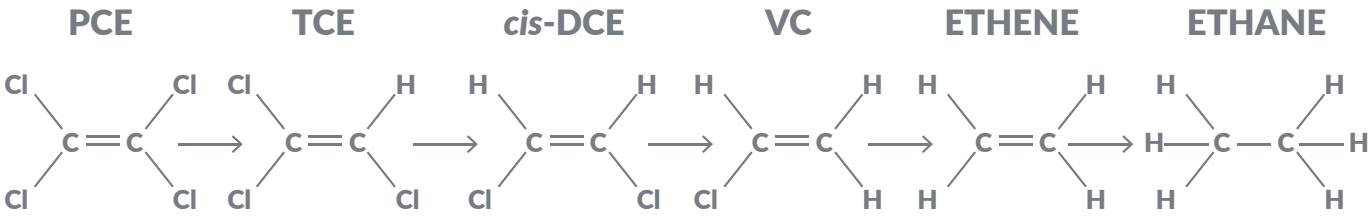
PLUME STOP® Liquid Activated Carbon HRC® HYDROGEN RELEASE COMPOUND BDI® PLUS BIO-DECHLOR INOCULUM

PlumeStop, Hydrogen Release Compound (HRC), and Bio-Dechlor INOCULUM® Plus (BDI+) were applied in multiple grid arrays onsite where PCE "sources" were identified and in a permeable reactive barrier (PRB) along the downgradient property boundary to halt further PCE migration.

3-D MICROEMULSION CRS® CHEMICAL REDUCING SOLUTION

In the plume where the urban environment restricted access, 3-D Microemulsion was specified for application at strategic locations within the plume core to enable a groundwater advection-driven, sweeping PCE plume treatment. CRS®, a soluble iron amendment, and BDI+ were co-applied to increase the rate of chlorinated ethene degradation, as demonstrated in previous studies.[1]

1. *Addition of divalent iron to electron donor mixtures for remediation of chlorinated ethenes: A study of 100 wells - Davis - 2018 - Remediation Journal - Wiley Online Library. Accessed May 4, 2021. https://onlinelibrary.wiley.com/doi/abs/10.1002/rem.21581*



3-D MICROEMULSION

3-D Microemulsion Overcomes the Challenges of Treating Large Chlorinated Solvent Plumes in Urban Areas

Two ERD substrate types widely used for treating large, chlorinated solvent plumes in urban areas are emulsified vegetable oils (i.e., EVOs) and soluble substrates (e.g., lactates, sugars, or other carbohydrates). Blends of these two electron donor materials are also used. In both cases, but for different reasons, EVOs and soluble substrates leave large treatment gaps between the widely spaced lines necessitated by the urban landscapes.

Treatment limitations for each product class in these environments can be viewed in terms of mobility and longevity. EVO's are hydrophobic, which limits their mobility only to the extent achieved during pumping. Their hydrophobicity leaves EVO's prominently fixed near the injection points, promoting discretized, concentrated bands of hydrogen while large volumes of the plume remain untreated.

Soluble substrates, by contrast, are hydrophilic, making them highly consumable and flashing the aquifer with short bursts of hydrogen that persist only for a few weeks to a couple of months. Although they are highly mobile, these soluble amendments do not persist long enough to adequately treat the large plume sections between lines of injection points.

For the ERD approach to work in this limited-access environment, the electron donor material providing the fuel source for the ERD reactions must be balanced in two essential properties: longevity and mobility. 3-D Microemulsion is the only electron donor material purposefully engineered to provide this hydrophilic/lipophilic balance (HLB).

Applied as a micellar suspension, 3-D Microemulsion provides a controlled, staged release of hydrogen that facilitates ERD for several years. 3-D Microemulsion moves at a rate similar to PCE in groundwater. These features result in an expansive hydrogen footprint downgradient of the injection points, enhancing the contact time between contaminants and eluted hydrogen to promote the complete dechlorination of PCE to non-toxic end products.

S-MicroZVI® Sulfidated Zero-Valent Iron

*Note -A small quantity of micro-scale zero-valent iron (S-MicroZVI®) was also applied to the southern PRB section in a supplemental application to enhance the reducing conditions further. This step was considered necessary to combat the potential infiltration of fresh, oxygenated water due to unpaved surface in this area.

Project Remedial Timeline

Autumn 2016
Onsite source zones and PlumeStop PRB treatments

Summer 2017
Offsite groundwater plume treatment

Autumn 2018
Limited supplemental treatment in offsite plume

Autumn 2016- February 2021
Performance and plume stability monitoring

Autumn 2022
IDEM Issues No Further Action

Patriot and REGENESIS teamed on the application design, which included the following components and amendments:

Component	Amendments Applied
Onsite Source Zones	PlumeStop, HRC, and BDI
PlumeStop PRB*	PlumeStop, HRC, and BDI
ERD Plume Treatment	3-D Microemulsion, CRS, BDI

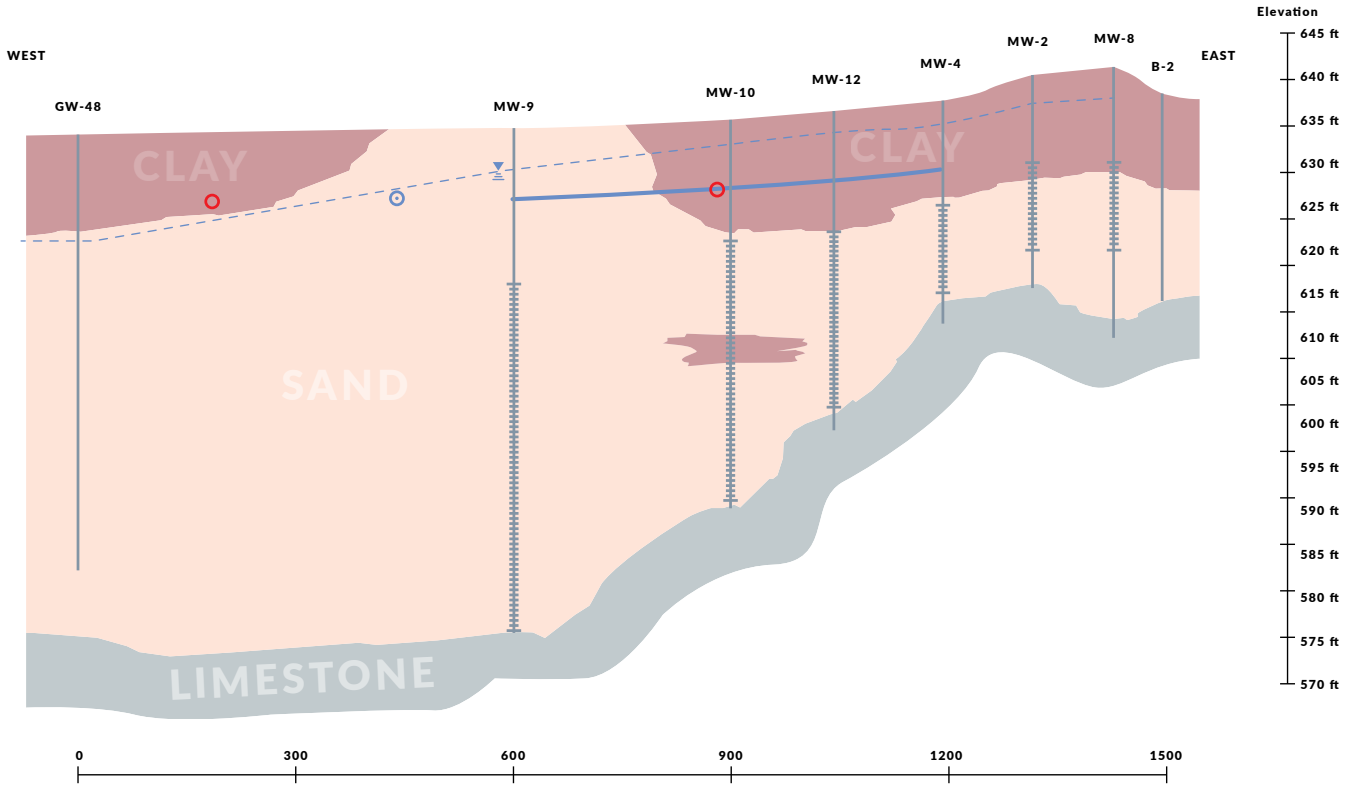
Patriot contracted REGENESIS Remediation Services (RRS) to conduct the remediation program. RRS completed the Onsite Source Zones and PlumeStop PRB during an initial phase, followed by the ERD Plume Treatment nine months later. A limited supplemental treatment was completed in a few discrete areas of the offsite plume more than a year following the ERD Plume Treatment. Performance monitoring was conducted throughout the treatment program.

Design Summary

Total Plume Area Targeted	Maxium Vertical Extent	Injection Points	Injected Volume
340,000 ft^2	8-48 ft bgs *(below ground surface)*	206	82,288 gallons

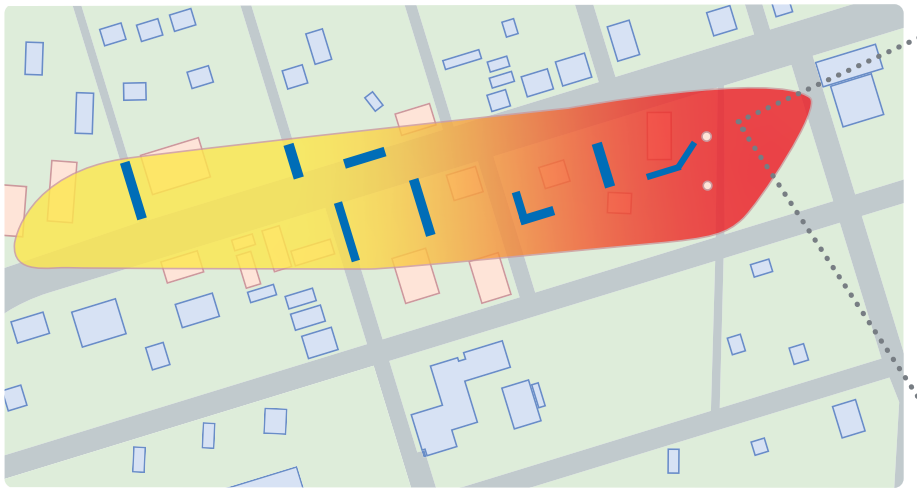
Remedial Amendments

Amendment	Quantity
PlumeStop	56,000 lbs
HRC	3,480 lbs
S-MicroZVI	800 lbs
3DME	40,803 lbs
CRS	8,803 lbs
BDI	167 L

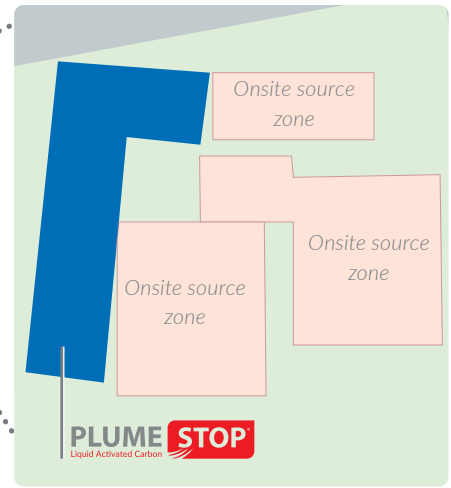


East West Cross-Section along Dissolved-Phase PCE Plume Depicting a Westward Dipping Bedrock Surface (necessitating a deeper treatment interval).

The vertical extent of the treatment interval ranged from 8 feet to 48 feet below ground surface (bgs), targeting a sand unit overlying westward-dipping limestone bedrock. This dipping unit resulted in a thicker and deeper treatment zone in the downgradient plume section. Patriot and REGENESIS collaborated on assigning the treatment dimensions for each of these areas to provide the maximum benefit for a minimum level of effort and cost. Patriot obtained groundwater analytical data using passive diffusion bag (PDB) samplers, which helped to delineate the most impactful zones of contaminant flux and restrain the overall treatment volume.



Approximate locations of offsite ERD barriers



Onsite source zones and PlumeStop PRB treatment area.

Results and Conclusion

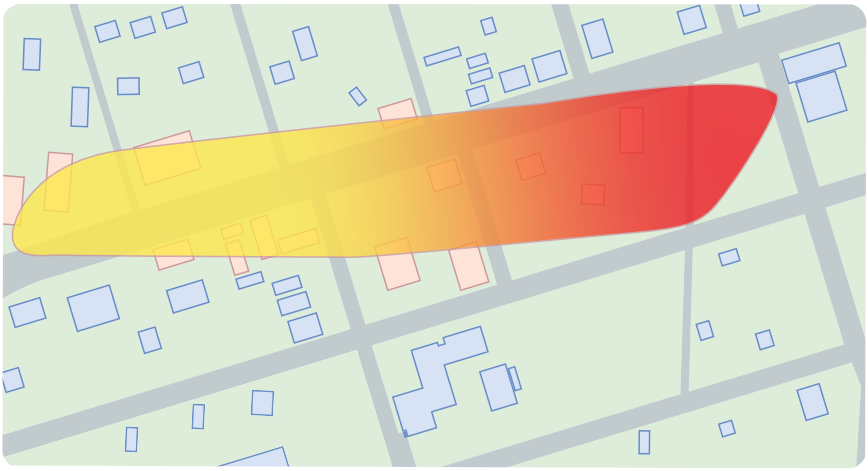
Despite Access Limitations, Large PCE Plume is Eliminated, Resulting in NFA

99.98% **PCE Mass Reduction**

Since the start of the remedial program, the following performance statistics are observed.

- PCE mass in the plume has been reduced by 99.98% (i.e., 100% correcting for significant figures) relative to baseline.
- The PCE plume extent has been reduced by 96% from 340,000 to 12,400 square feet with no concentrations remaining above the Residential Vapor Exposure Groundwater Screening Level for PCE.

Approximate extent of the PCE plume prior to treatment



Vestiges of the PCE plume post-application. No concentrations remain above the Residential Vapor Exposure Groundwater Screening Level for PCE.

- The median total chlorinated ethene concentration reduction is near 90%. This result indicates only a negligible degree of daughter product formation, mainly concentrated at a single Source Zone monitoring well adjacent to the former dry cleaner building. Total CVOCs at the nearest downgradient well, MW-2, have remained near 100 percent reduced relative to baseline. Therefore, no further treatment is warranted at this location.

- At the PlumeStop PRB, PCE has been eliminated, and total CVOC concentrations remain reduced by 99 percent more than four years after the application. Thus, the goal of shutting off any further source contribution to the dissolved phase plume has been achieved.

No Further Action

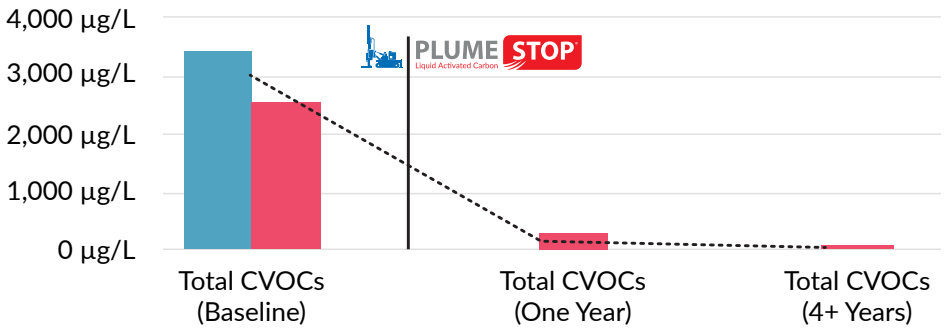
No Further Action granted by the IDEM after two years of performance monitoring demonstrating plume treatment stability.

By combining rapid and sustained elimination of the PCE source using PlumeStop, and by minimizing gaps between treatment lines in the downgradient plume section using 3-D Microemulsion, the remedy has met the performance goals and achieved the target cleanup objectives. Based on these results, IDEM issued a No Further Action (NFA) Status for the site in September 2022.

PlumeStop PRB Performance

99% Total CVOC Reduction 4+ Years Post-Application

MW-2 MW-5A Average



Reduction Percentages

Sample Event	Avg. PCE Concentration	PCE Plume Surface Area	PCE Concentration x Surface Area
Before Treatment	1,196 µg/L	340,000 ft^2	4.07 x 10^8
After Treatment	8 µg/L	12,400 ft^2	9.92 x 10^4
% Reduction		-96%	-100%

The Project Team

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 its clients with the information they need to make informed, cost-effective business decisions, which will help reduce net cost, decrease risk and improve the quality of project outcomes.

Patriot is a company with very experienced professionals with fresh attitudes, modern technology, and a commitment to being responsive. The men and woman employed by Patriot have first-hand knowledge of the business environment and regulatory climate. With decades of experience, the staff has the technical expertise needed to address most environmental, geotechnical, or construction materials testing projects. Senior engineers and technical professionals serve as project managers and single points of contact for the client. Patriot project managers receive internal technical review of their work but are entrusted with the full responsibility for getting the job done and the authority and resources to ensure the work is completed correctly and economically.

About The Project Manager

Gary Weinreb, LPG

Gary Weinreb, LPG is a Principal and Sr. Project Manager for Patriot Engineering & Environmental, Inc., a leading Midwest-based environmental and geotechnical consulting firm, and he wears two different “hats” in his day-to-day role. As one of the firm’s Principals, he provides seasoned management and leadership expertise to the entire company and provides input to the Company’s Board of Managers regarding financial decisions and new business initiatives. In his Senior Project Management role, he oversees an array of responsibilities that include mentoring younger staff, technical review and preparation of reports, client communication and development, project team management, new business development, as well as developing internal policies and procedures. Mr. Weinreb began his career as a field environmental geologist in Southern California and has been practicing in Indiana since 1990. He joined Patriot in 2003 as a Senior Project Manager and became a Principal in 2017.

With over 33 years of professional experience, Mr. Weinreb is an Indiana Licensed Professional Geologist who specializes in soil and groundwater investigation and remediation associated with RCRA, CERCLA, and state voluntary programs; regulatory compliance; vapor intrusion assessments and mitigation; and property transaction due diligence. His clients have included dry cleaners, attorneys, foundries, steel manufacturers, commercial property management companies, banks, schools, health care facilities, municipalities, commercial real estate companies, insurance companies, gas stations, property developers, chemical and food manufacturers, and general contractors. Weinreb earned his BS in Geology from the State University of New York (SUNY) at Binghamton, and subsequently earned his MS in Geology & Hydrogeology from Purdue University. Weinreb is an Indiana Licensed Professional Geologist.

Project Oversight and Cost Control

Johnson Wright, Inc.

Insurance companies are often in the position of paying for environmental remediation without having direct control of the project. This can result in projects becoming misdirected or not cost effective. Johnson Wright provides our clients with highly experienced personnel to oversee, evaluate and help control costs for environmental projects. Using robust project strategy and management protocols, Johnson Wright brings clarity, efficiency and effectiveness to the table on behalf of our clients. Johnson Wright works with all stakeholders using a collaborative approach that focuses on questions that need to be answered by those with direct responsibility, rather than giving specific direction. This maintains clear delineation of liability for the ultimate management decisions for projects, while creating a more accountable process.

Oftentimes a small change in strategic approach, goal setting, or regulatory interaction can mean the difference between projects that escalate or change direction inappropriately, and those that maintain a cost-efficiency focus. Cost control can be implemented at any stage of a project, but is most effective when it "begins at the beginning". Reasonable and necessary project costs are the result of the appropriate and effective use of Project Management principles, strategies, and techniques.

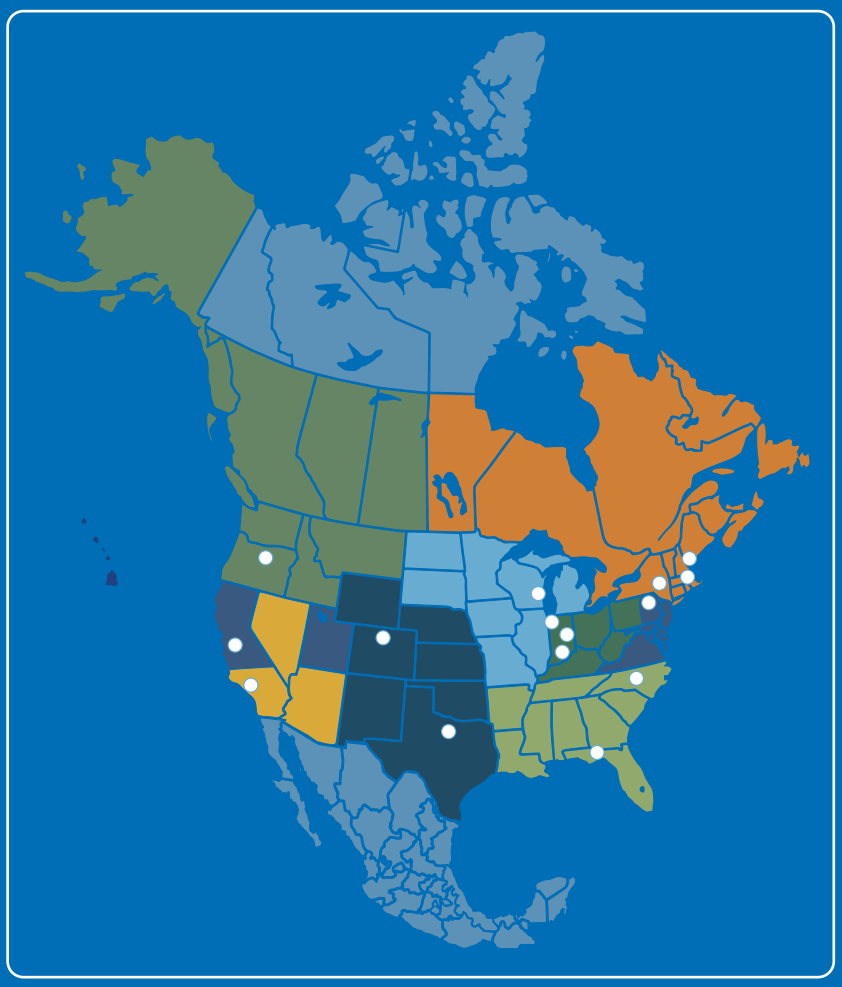
About The Insurance Representative

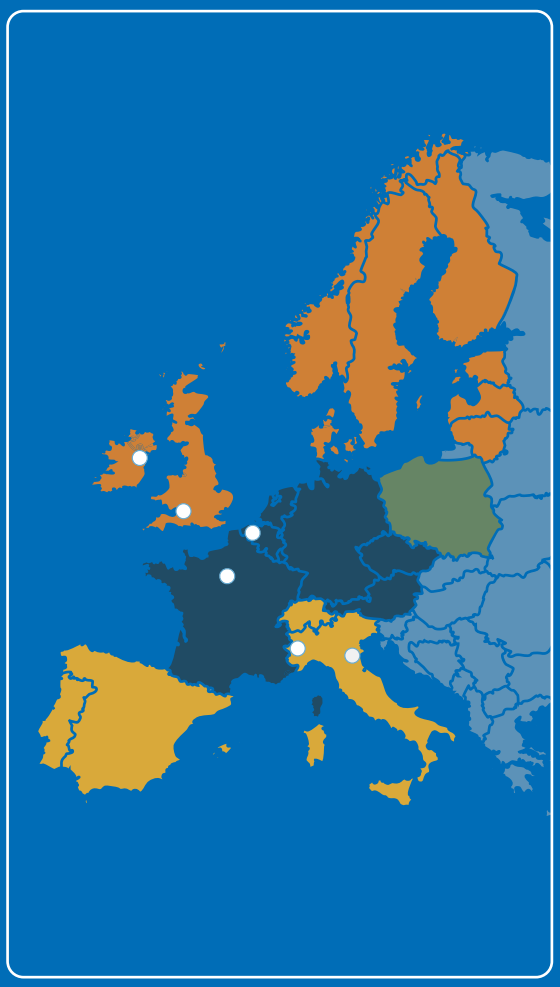
John D. Elliot III, P.E.

Mr. Elliott has over 25 years of consulting experience on environmental projects, including assessment and remediation, project management, litigation support, regulatory compliance, and insurance claim evaluation. His experience includes environmental investigation, site remediation, permitting, cost estimating, due diligence and report preparation. Mr. Elliott has expertise in environmental site assessments, site characterization studies, remedial alternative feasibility studies, site cleanups, and remedial system optimization, operation and maintenance. Projects include CERCLA and RCRA facilities, petroleum and solvent UST sites, and a variety of industrial sites throughout the United States. Mr. Elliott's previous work includes extensive experience in designing treatment systems for remediation of chlorinated solvents in soil and groundwater, conducting performance evaluations for existing treatment systems, installing remote monitoring and operation control systems and implementing and assessment of innovative remedial technologies, including the injection of biological and chemical products to enhance cleanup.

On behalf of the insurance carriers, Mr. Elliott provided valuable input to the project team and assisted with the development of the project closure strategy. In addition, Mr. Elliott performed review of work plans, technical reports, monitored budgets and billings and overall project progress.

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





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