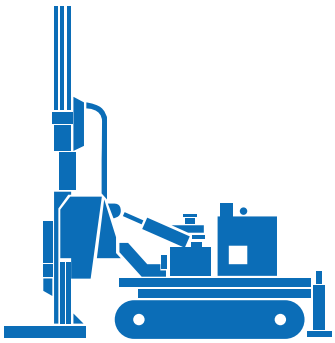
REGENESIS®

7 Reasons

To Consider an *In Situ* Permeable Reactive Barrier to Treat Groundwater Contaminants

REGENESIS®



Introduction

Permeable reactive barriers (PRBs) are a proven, sustainable, and cost-effective solution for treating groundwater contaminants *in situ*. PRBs use reactive media injected directly into the subsurface to treat contaminated groundwater as it flows naturally through the barrier, maintaining natural water movement while reducing contaminant levels. With minimal operational costs and recent advances in innovative injectable remediation technologies, PRBs offer a long-term remedy for a range of contaminants, including chlorinated solvents, petroleum hydrocarbons, per- and polyfluoroalkyl substances (PFAS), and metals.

7 Key Reasons to Implement a PRB

PRBs offer numerous advantages over traditional plume contaminant methods like groundwater extraction and treatment (pump-and-treat). Here are seven key reasons to consider a PRB for your remediation needs:

Low Cost: PRBs operate passively, reducing both initial investment and long-term operational costs compared to traditional systems like pump-and-treat.

Versatile: PRBs can be tailored to address a diverse range of contaminants, including organic compounds and metals.

Minimal Disruption: PRBs require no large infrastructure, making them ideal for installation with minimal surface disruption in developed areas.

Rapid Results: PRBs often achieve significant contaminant reductions quickly, allowing for faster attainment of cleanup objectives than traditional methods.

Long-Term Performance: Once installed, PRBs can provide sustained, low-maintenance treatment over years or even decades.

Reduced Liability: By effectively addressing groundwater contamination, PRBs help reduce the long-term liability associated with contaminant migration and regulatory scrutiny.

Environmentally Sustainable: PRBs require no energy input to operate, making them a greener alternative to energy-intensive systems.

This e-book will explore each of these reasons in detail, providing insights into the advantages of using a PRB for groundwater remediation.

#1

Low-Cost Alternative to Traditional Methods

PRBs provide a low-cost alternative to traditional groundwater treatment systems like pump-and-treat, offering significant long-term savings through passive operation and minimal maintenance requirements.

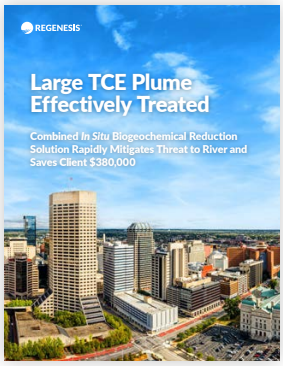
Unlike pump-and-treat systems, which incur ongoing expenses for equipment, energy, and frequent maintenance, PRBs require only periodic monitoring and occasional replenishment of reactive media. This low operational cost makes PRBs particularly advantageous for sites with long-term contamination, where cumulative savings can be substantial.

"Unlike pump-and-treat systems, which incur ongoing expenses for equipment, energy, and frequent maintenance, PRBs require only periodic monitoring and occasional replenishment of reactive media."

Advanced colloidal PRB materials, such as PlumeStop®, S-MicroZVI®, AquiFix™, and PetroFix®, further reduce installation and maintenance costs. These materials are designed for easy application, eliminating the need for complex handling equipment and allowing for simpler, faster deployment, reducing both labor and equipment expenses.

PRBs also maximize cost-efficiency by precisely targeting contaminants. Tools like REGENESIS® FluxTracer® enable accurate mapping of contaminant flux zones, allowing for optimized dosing to halt plume migration effectively.

For sites with extensive contaminant plumes or challenging logistics, PRBs offer a reliable and low-cost solution that provides sustained remediation without the high ongoing costs of active systems. REGENESIS's advanced colloidal technologies further improve performance by addressing the inefficiencies of traditional materials.



Case Study: Cost-Effective TCE Plume Remediation in Indiana

A 2,000-foot-long trichloroethylene (TCE) plume beneath downtown Indianapolis was treated using a permeable reactive barrier (PRB) with advanced colloidal technologies, including PlumeStop, 3-D Microemulsion, and S-MicroZVI.

Within months, TCE levels dropped significantly, and after 1.5 years of monitoring, the plume was nearly eliminated. Precise flux mapping enabled targeted treatment, saving $380,000 by avoiding treatment of non- or minimally impacted areas. This approach delivered millions of dollars in lifecycle cost savings and achieved results in a fraction of the time compared to traditional pump-and-treat methods.

Side-by-side comparison depicting TCE plume extents before and after treatment.

#2

PRBs are Versatile

PRBs were first developed in the early 1990s at the University of Waterloo's Borden Aquifer site, where a mixture of granular iron and sand was used to treat chlorinated ethenes. Since then, PRB technology has evolved significantly, most recently with cutting edge injection technologies using the IBIS (In-Line Blending and Injection System) and advanced colloidal amendments that expand the range of treatable contaminants and improve PRB's longevity and performance.

PRBs use different amendments to treat different types of contaminants. Each amendment facilitates different contaminant removal methods—such as sorption, chemical reduction, and biodegradation—either individually or in combination.

"PRBs have demonstrated effectiveness for both single and mixed contaminant plumes, offering a versatile and adaptable solution for complex groundwater contamination challenges."

PlumeStop, a patented colloidal activated carbon (CAC), is injected into the subsurface to create barriers that rely on strong sorption to halt contaminant migration for extended periods. By coating soil and rock surfaces, PlumeStop effectively converts a contaminated aquifer into a purifying filter. For persistent contaminants like PFAS, single treatments are designed to prevent plume migration for decades, eliminating years of pumping, treating, and waste generation.

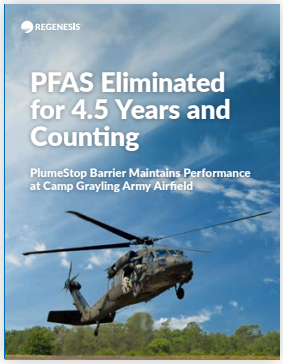
Chlorinated solvents, including perchloroethene (PCE) and TCE, can be addressed using all the sorption, chemical reduction, and biodegradation contaminant removal methods. Key factors such as contaminant type, mass flux, and the treatment objectives guide the selection of amendments, with technologies such as PlumeStop, S-MicroZVI, and AquiFix providing highly effective solutions.

For petroleum hydrocarbon compounds like BTEX (benzene, toluene, ethylbenzene, and xylene), polyaromatic hydrocarbons (PAHs), and other petroleum hydrocarbons (PHCs), PetroFix barriers have proven successful.

These barriers leverage a combination of sorption and added electron acceptors to accelerate biodegradation, effectively protecting sensitive receptors, including surface water bodies.

Heavy metals like hexavalent chromium can also be treated with PRBs. S-MicroZVI, for example, creates a powerful reducing environment in the subsurface, quickly converting toxic chromium to its insoluble, non-toxic trivalent form.

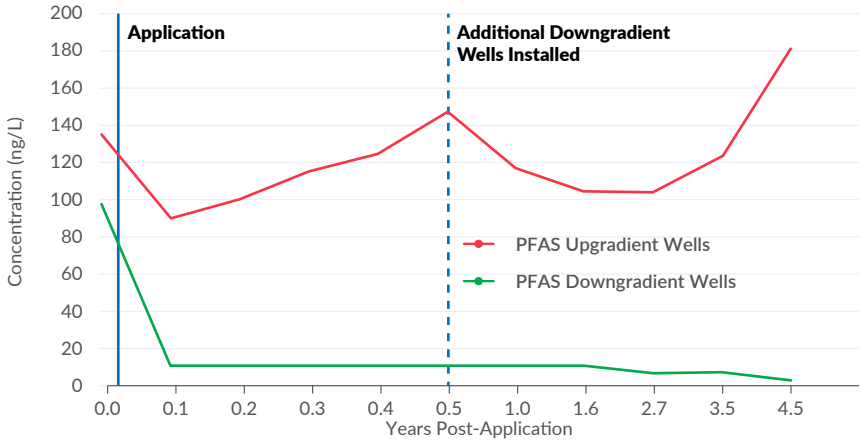
PRBs have demonstrated effectiveness for both single and mixed contaminant plumes, offering a versatile and adaptable solution for complex groundwater contamination challenges.



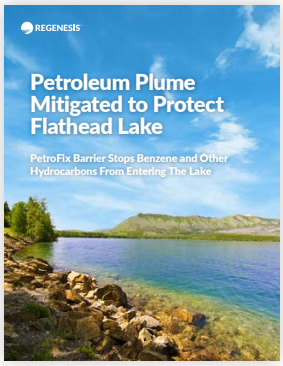
Case Study: PFAS and PCE Contamination Eliminated for 4.5 Years at a Former Army Airfield in Michigan

A PlumeStop barrier was installed to remove PFAS in groundwater at Camp Grayling in Crawford County, Michigan, a large military training center operated by the Michigan Army National Guard.

The PlumeStop PRB approach had a significantly lower overall project cost compared to installing and operating a mechanical system. The barrier has effectively treated both PFAS and PCE, maintaining reductions below Michigan's stringent groundwater cleanup standards through 4.5 years of monitoring. Even with increased PFAS concentrations entering the barrier over the last two years, it has continued to perform successfully, demonstrating the effectiveness of PRBs in managing mixed contaminant plumes.



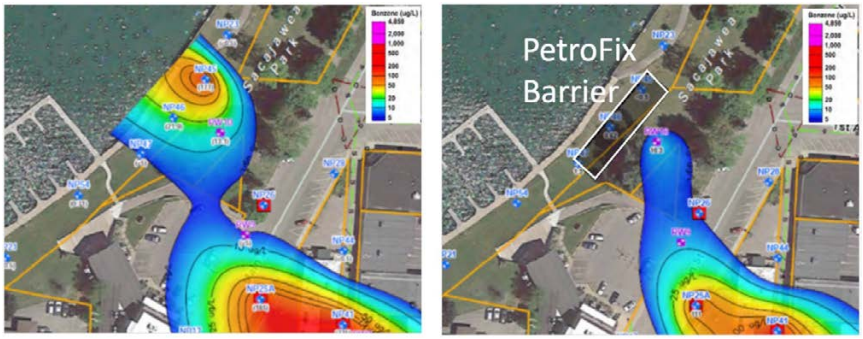
PFAS in Upgradient and Downgradient Well Pairs Following PlumeStop Application. PFAS reductions are shown as an average of 4 well pairs at 6, 16, 26, and 45 feet downgradient of barrier.



Case Study: PetroFix Barrier Protects Flathead Lake from Petroleum Plume

In Polson, Montana, a legacy petroleum hydrocarbon plume was migrating toward Flathead Lake, threatening this pristine recreational area.

After completing high-resolution site characterization and evaluating remedial options with multiple regulatory stakeholders, a PetroFix PRB was selected as the most effective solution. The PRB was installed to intercept groundwater upgradient of the lake, with PetroFix removing the benzene and other hydrocarbons from the groundwater. Benzene levels have remained non-detect for over 3.5 years since the barrier was implemented, effectively protecting Flathead Lake.



Areal maps showing benzene plume extents before and after PetroFix barrier installation. The barrier has eliminated contaminant migration into Flathead Lake for over 3.5 years.

Case Study: Rapid Remediation of Hexavalent Chromium in Swiss Aquifer

At a former precision component factory site in Northern Switzerland, groundwater contamination from hexavalent chromium (Cr(VI)) was detected at levels of 100-200 µg/L, stemming from historical leaks in chrome-plating tanks and a water treatment plant. The fast-moving, aerobic aquifer posed a significant remediation challenge, with Swiss regulations requiring stringent clean-up to below 10 µg/L to protect a nearby river and account for periodic flooding.

To meet these objectives, an *in situ* chemical reduction (ISCR) approach was chosen, involving the injection of a controlled-release electron donor and chemical reducing agent into a PRB. Within three months of the ISCR treatment, Cr(VI) levels fell below the regulatory target in all monitoring wells, with conditions stabilized to sustain these reductions. Long-term monitoring continues to confirm the effectiveness of this approach in managing Cr(VI) in complex, fast-flowing aquifers.

#3

PRBs are Minimally Disruptive

PRBs offer an *in situ* remediation solution that minimizes surface disruption, making them especially suitable for sites where traditional excavation or extensive infrastructure installations would interfere with ongoing operations. Unlike pump-and-treat systems, which require visible infrastructure, power supplies, and frequent maintenance, PRBs operate underground and passively intercept contaminated groundwater as it flows through the treatment zone.

"This targeted approach allows remediation to proceed without disturbing surface structures, landscapes, or adjacent areas."

The installation process for PRBs typically involves using direct-push or rotary drilling to inject reactive media into specific contaminant flux zones. This targeted approach allows remediation to proceed without disturbing surface structures, landscapes, or adjacent areas. Additionally, PRBs that use injectable amendments eliminate the need for heavy equipment or extensive excavation, which can be crucial for industrial sites, commercial and residential properties, or sensitive environmental areas.

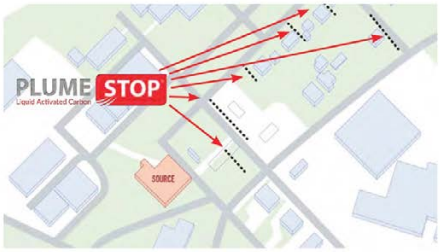
Colloidal amendments, such as PlumeStop, 3-D Microemulsion, and S-MicroZVI, are particularly effective for minimally invasive applications. These materials can be injected through small-diameter wells or injection points, distributing efficiently even in low-permeability soils. This enables the applied remediation to reach contaminants under buildings, paved areas, or other obstacles without costly and disruptive deconstruction.

Case Study: CVOC Eliminated Below Residential Neighborhood

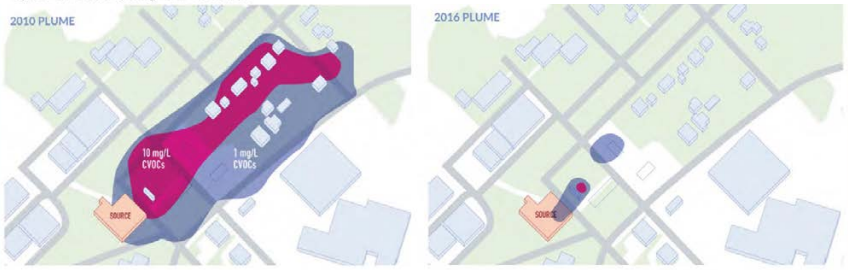
Historical operations a former plating facility in Southwest Michigan caused a chlorinated solvent plume to develop and intrude below a residential neighborhood as it migrated toward a nearby river.

Using 3-D Microemulsion and PlumeStop, the chlorinated solvent contaminant plume has been nearly eliminated. This result was achieved despite limited access for drilling, relying on a series of progressively spaced PRBs designed according to groundwater speed and contaminant flux. These technologies enabled comprehensive cleanup of the plume with minimal surface disruption, effectively protecting groundwater quality and preventing impacts on surface water—all without affecting the residential properties.

Site Plan Depicting The 3DME Full Scale Injection Layout. Neighborhood Treatment Lines Are Spaced Approximately 200Feet. Apart With Closer Spacing Near The Source.



PlumeStop Biobarriers



Pictured are two figures comparing the CVOC plume before treatment to the CVOC plume following the groundwater remediation treatment. These treatments reduced the total CVOC areal plume extent by 95% and cumulative mass by 99.8%, thus far, while ongoing biodegradation continues.

#4

PRBs Provide Immediate Results

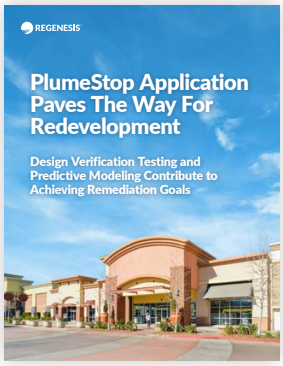
Though PRBs are typically designed for long-term groundwater treatment, they can also deliver rapid results following installation. Advanced colloidal technologies like PlumeStop and S-MicroZVI are known for high efficiency and fast reactivity. Their ability to distribute through soil pores allows for immediate contact with contaminants, leading to swift reductions both within the treatment zone and in downgradient areas.

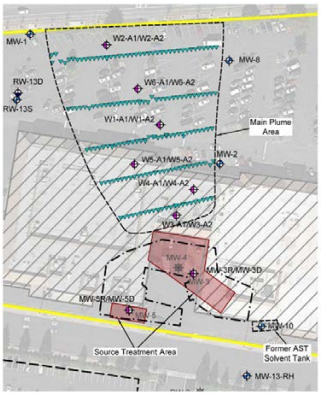
PlumeStop has demonstrated rapid contaminant reduction by quickly immobilizing contaminants through sorption, thereby reducing their mobility in groundwater. At many sites, PlumeStop barriers have driven significant contaminant concentration declines within days, helping to achieve site goals quickly. This fast action is particularly beneficial in areas with high groundwater flow, where rapid containment is critical.

"At many sites, PlumeStop barriers have driven significant contaminant concentration declines within days, helping to achieve site goals quickly."

S-MicroZVI is also highly effective in accelerating contaminant degradation. The sulfidation process enhances the reactivity of ZVI particles, increasing reduction rates for chlorinated solvents like PCE, TCE, and 1,1,1-TCA. Bench tests show that S-MicroZVI is up to 28 times more reactive than unsulfidated ZVI, enabling faster contaminant removal with less material. This enhanced reactivity also minimizes byproducts like cis-1,2-DCE and 1,1-DCA, ensuring a more efficient degradation process.

With these advanced PRB technologies, sites benefit from faster, more effective remediation, providing both immediate and long-term protection for sensitive environments, while allowing redevelopment to proceed more quickly.

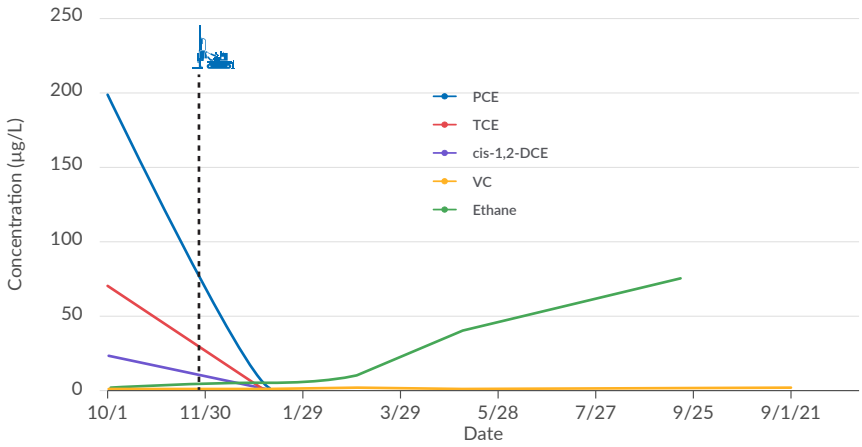




Case Study: PlumeStop and S-MicroZVI Enable Rapid Redevelopment

At a redevelopment site in California, a series of PRBs incorporating PlumeStop and S-MicroZVI, along with targeted source treatment, achieved a 90-98% reduction in chlorinated contaminants in groundwater within the first year.

This cost-effective approach leveraged natural groundwater flow to transport contaminants into the PRBs, where they were efficiently treated. Design verification testing (DVT), including contaminant flux measurements, played an essential role in optimizing the *in situ* design. The successful treatment eliminated the chlorinated VOC plume, allowing property redevelopment to proceed in under two years, exceeding the original remediation timeline.



#5

PRBs Deliver Long-Term Performance

Designed for longevity, PRBs provide effective, low-maintenance contaminant treatment that can last decades. This sustainable approach reduces the high, ongoing costs associated with active systems, offering a consistent, passive solution for extended remediation. Advanced materials like AquiFix and S-MicroZVI maintain reactivity over time, delivering steady remediation in complex conditions while reducing the need for additional treatments. Additionally, materials such as PlumeStop and PetroFix enable continuous contaminant capture, slowing migration and allowing natural biological and chemical processes within the barrier to degrade contaminants into non-toxic end products. As contaminants break down, new sorption sites on the carbon-coated matrix are freed, extending the PRB's functionality and efficiency.

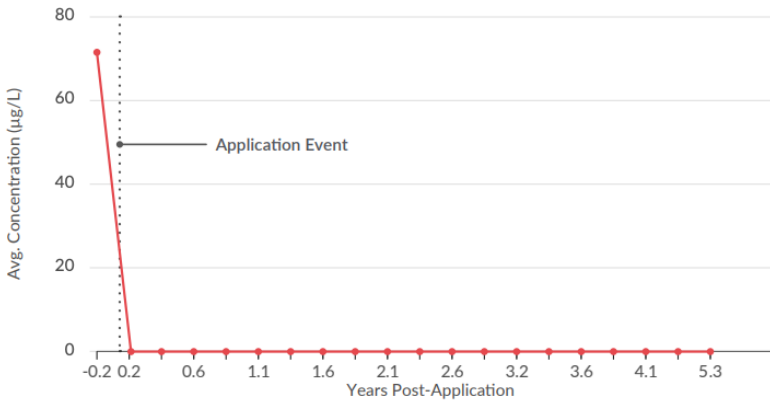
"Many sites have shown sustained low contaminant levels for years without the need for reinjection."

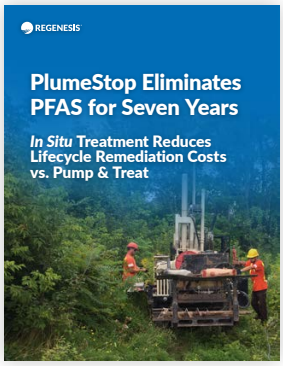
Many sites have shown sustained low contaminant levels for years without the need for reinjection.

Case Study: PRB Halts TCE Plume for Over Five Years

At a chlorinated solvent site in the Midwest, a PRB with PlumeStop and Hydrogen Release Compound (HRC) was installed to address a trichloroethylene (TCE) plume. Within just 60 days, TCE levels dropped below detectable limits, effectively halting offsite plume migration.

This solution has maintained its performance for over five years, preventing further contribution to a regional chlorinated solvent plume and showcasing the long-term impact of PRBs for site cleanup. The sustained effectiveness of this PRB underscores the capability of advanced reactive amendments to provide enduring remediation in complex contaminant settings.



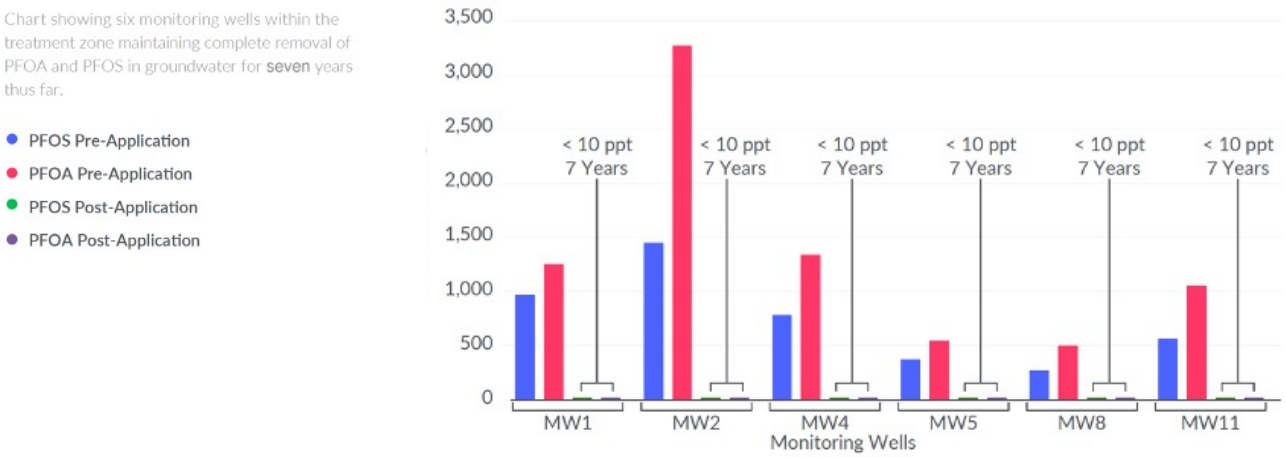


Case Study: World's First Full-Scale *In Situ* PFAS Treatment Shows 7+ Years of Sustained Results

In 2016, the world's first full-scale *in situ* PFAS treatment was completed at a manufacturing and former firefighting training site in Ontario, Canada.

The site had extensive PFAS contamination from the historical use of aqueous film-forming foams (AFFF). PlumeStop colloidal activated carbon was applied within the PFAS source zone, achieving a groundbreaking reduction to non-detectable PFAS levels within the first three months. For over seven years, these reductions have been maintained, effectively preventing exposure risks and minimizing liability for the site owner. Additionally, an independent modeling study suggests that the PlumeStop application will continue to function as a barrier to PFAS migration for more than 60 years , ensuring prolonged protection and demonstrating the potential for durable, sustainable PFAS remediation.

Chart showing six monitoring wells within the treatment zone maintaining complete removal of PFOA and PFOS in groundwater for seven years thus far.



#6

PRBs Reduce Risk and Liability

By containing and treating contaminants within the site boundaries, PRBs offer a powerful solution for reducing long-term risk and liability. This proactive approach prevents contaminants from migrating off-site, significantly lowering the legal and financial risks associated with impacts on nearby residential areas, waterways, and other sensitive locations.

For challenging contaminants such as PFAS, PlumeStop PRBs provide the only proven *in situ* solution to prevent the migration of high-risk PFAS compounds such as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) in groundwater. Unlike pump-and-treat systems, which generate waste requiring careful disposal, PRBs function *in situ*, eliminating the risk of creating additional PFAS exposure pathways. This is particularly critical as PFOA and PFOS are now classified as hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), leading to Joint and Several Liability concerns.

When employing a PRB, stakeholders manage contamination risks responsibly, minimize potential disruptions, and build trust with regulatory agencies and surrounding communities. With this approach, PRBs serve as a risk-mitigation tool, providing long-term environmental stewardship and liability protection.

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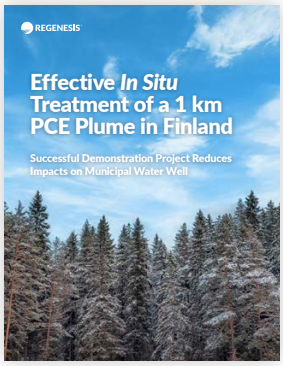
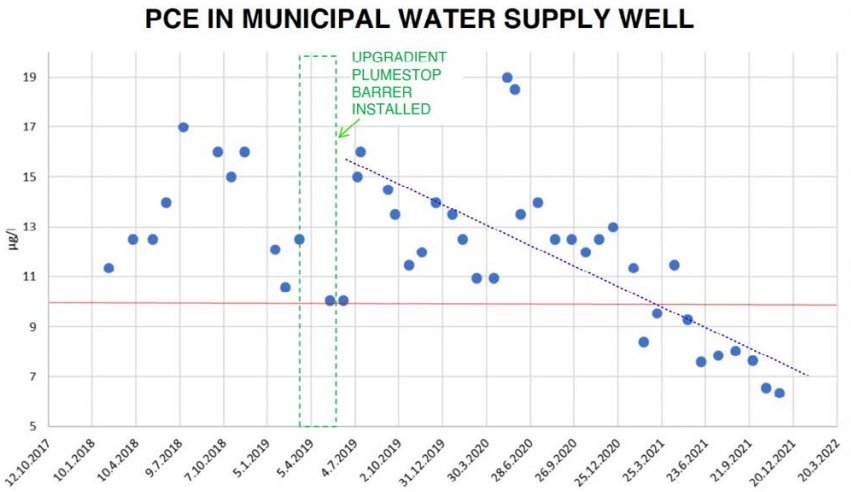


Case Study: PlumeStop Barrier Reduces PCE Below Drinking Water Limits in Municipal Water Well - Finland

Historical operations at a metal-processing site in Eastern Finland caused a PCE plume to migrate rapidly through a fast-moving aquifer and impact a municipal water source 1 km downstream. To address this, a colloidal electron donor and microbial consortium were injected into the source zone, while a PRB incorporating PlumeStop and a controlled-release electron donor was installed 700 meters downgradient.Within a few months, PCE concentrations in the municipal well began to drop, eventually falling below the 10 µg/L drinking water limit.

This project showcases the effectiveness of a sorption-enhanced bioremediation approach implemented as a PRB to protect public water wells and other sensitive receptors from chlorinated solvent contaminants. The approach demonstrated success, even in a cold, fast-moving Finland aquifer.



PCE Concentrations in municipal water supply well following installation of PlumeStop barrier.

#7

PRBs are Resilient and Sustainable

PRBs offer a resilient, sustainable alternative to conventional remediation systems by operating without continuous energy input. Unlike pump-and-treat systems that rely on power-intensive equipment, PRBs leverage natural groundwater flow, minimizing carbon emissions, energy use, and operational waste.

In addition to their low energy footprint, PRBs incorporate highly efficient amendments like PlumeStop and S-MicroZVI, which react with contaminants directly *in situ* over extended periods. This design significantly lowers the environmental impact of remediation efforts and leads to quicker site closures, preserving time, energy and resources. PRBs align with green remediation principles favored by regulatory agencies, supporting sustainable site restoration with minimal ecological disturbance.

By implementing PRBs, stakeholders can achieve remediation objectives while meeting sustainability goals, making PRBs an ideal choice for environmentally conscious projects.

"PRBs align with green remediation principles favored by regulatory agencies, supporting sustainable site restoration with minimal ecological disturbance."

Case Study: *In Situ* PFAS Treatment at UK Airport with PlumeStop Achieves 98% Reduction in Greenhouse Gas Emissions

At a commercial airport in the UK, PFAS contamination from fire training exercises created a groundwater plume posing a risk to the local community. To address this, PRB using PlumeStop was implemented, to contain PFAS *in situ*. A comprehensive 15-year life-cycle analysis demonstrated that the PlumeStop solution reduced greenhouse gas emissions by over 98% compared to the pump-and-treat alternatives. The approach avoided the discharge of more than 200 million gallons of water and prevented the generation of up to 790,000 pounds of PFAS-laden waste.

In addition to environmental benefits, the *in situ* solution reduced operational costs to one-third of those associated with pump-and-treat, offering a sustainable and economically viable approach to PFAS remediation.

15-Year Lifecycle Assessment Parameter (post-commissioning)	Belowground Filtration with PlumeStop CAC	Pump-and-Treat
Groundwater pumping and effluent discharge	0-gal	208,000,000-gal
Energy usage	0-kwH	960,000-kwH
Carbon dioxide emissions	0 tons	2,400 to 4,300 tons
Quarterly O&M inspections and reports	0	60
Permanent infrastructure, including eight extraction wells, pumps, tanks/vessels, piping and utilities	No	Yes
System operational downtime	0 percent	Estimated 5%

Life Cycle Assessment for PFAS Groundwater Plume Containment Options at a UK Airport Site. Note that Option 2 considers separation treatment with either GAC or foam fractionation.than 60 years , ensuring prolonged protection and demonstrating the potential for durable, sustainable PFAS remediation

Conclusion

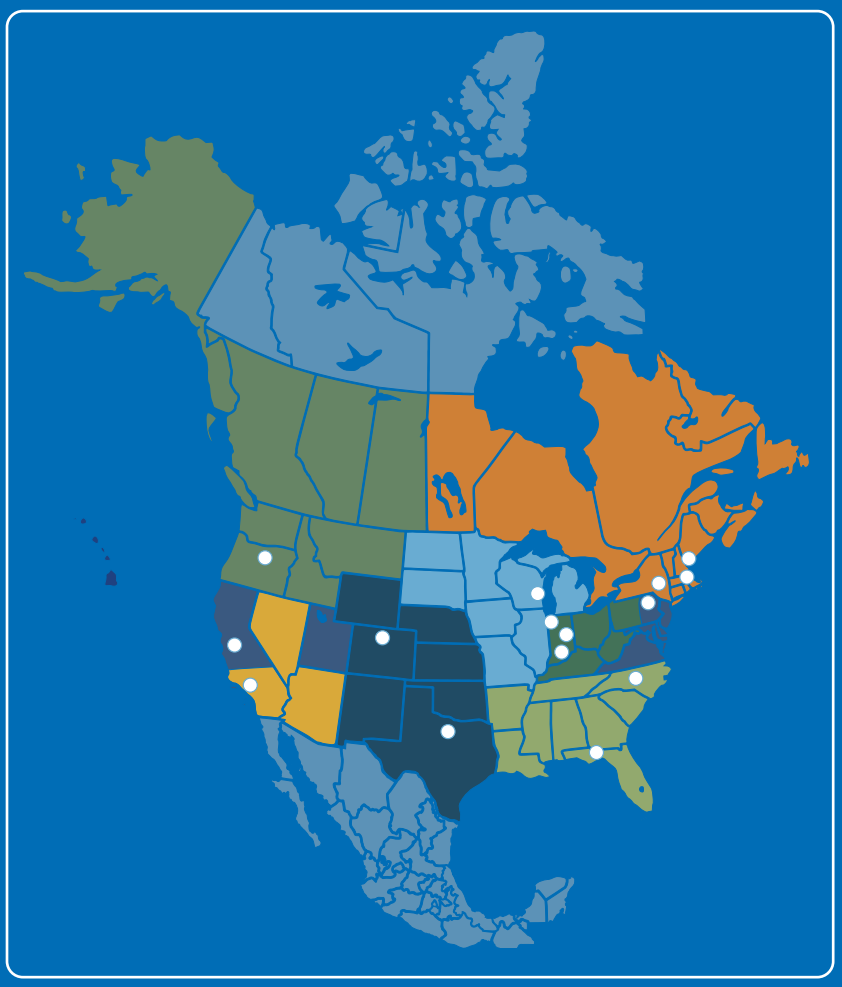
PRBs- represent a powerful, sustainable approach to groundwater remediation, providing a range of benefits that make them the optimal solution for complex contamination challenges. With the ability to treat a broad spectrum of contaminants—ranging from chlorinated solvents and petroleum hydrocarbons to persistent PFAS compounds—PRBs deliver both rapid, measurable results and sustained, long-term performance with minimal maintenance.

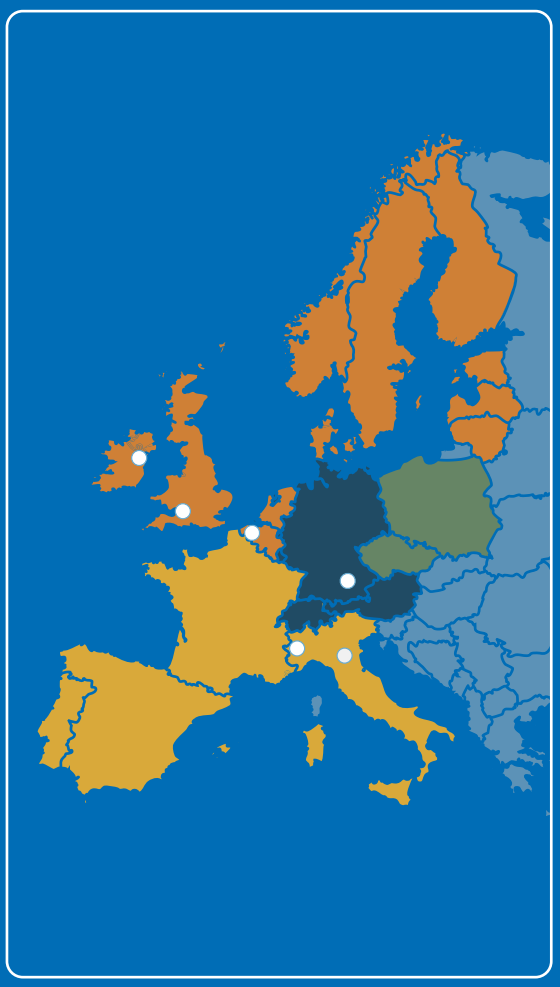
Recent advancements in PRB technology, including the development of materials like PlumeStop, S-MicroZVI, AquiFix, 3-D Microemulsion, and PetroFix, have significantly enhanced the effectiveness of PRBs. These materials offer superior reactivity, distribution, and treatment efficiency, achieving regulatory compliance faster and with greater efficiency than traditional methods.

Beyond technical performance, PRBs provide substantial economic and environmental benefits. Compared to pump-and-treat systems, PRBs minimize operational costs, reduce greenhouse gas emissions, and eliminate the generation of waste, all while preserving ecological health. Their *in situ*, low-impact design makes them ideal for developed sites, where they allow for seamless integration and support property redevelopment timelines by minimizing disruptions.

As regulatory standards tighten and communities increasingly seek responsible, eco-friendly solutions, PRBs emerge as a proactive choice for contamination management. By leveraging cutting-edge remediation technologies, PRBs empower industries, governments, and communities to restore contaminated sites with confidence—promoting environmental stewardship and sustainable progress for the future.

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





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