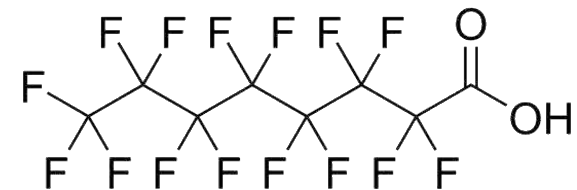
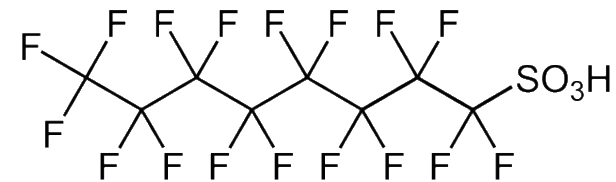


Summary of Four Applications of Colloidal Activated Carbon for the In Situ Treatment of PFAS in Groundwater

R. McGregor, L. Benevenuto, A. Zhou
InSitu Remediation Services

Background

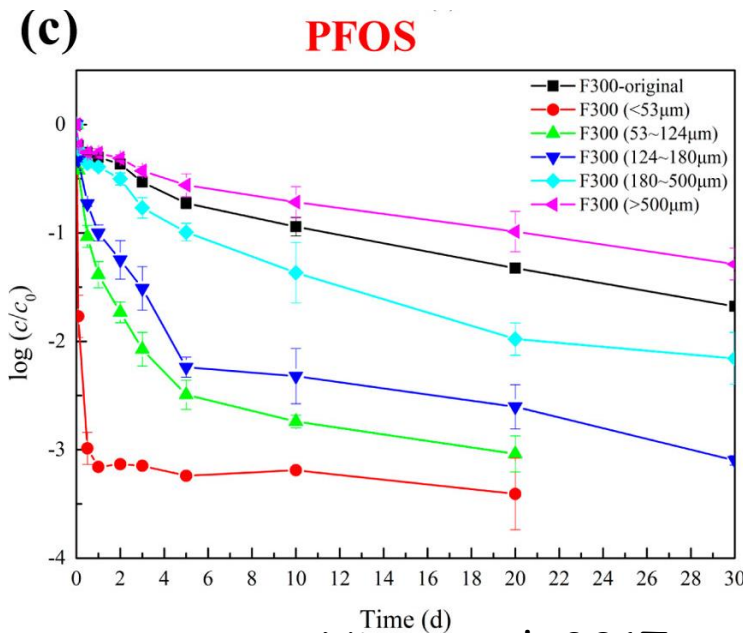
- Per & Polyfluoroalkyl Substances (PFAS)
- Emerging Compounds of Concern
 - Perfluorooctane Sulfonate (PFOS)
 - Perfluorooctanic acid (PFOA)
- Thousands of compounds
- Carbon-fluoride bond strong
- Shown to bioaccumulate
- Analytical challenges
- Health Advisory Levels 10s of ng/L (ppt)
- Fate & transport not well understood



Background

In Situ Current Approaches

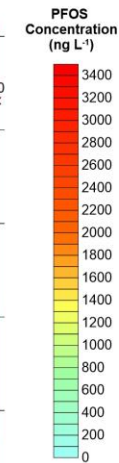
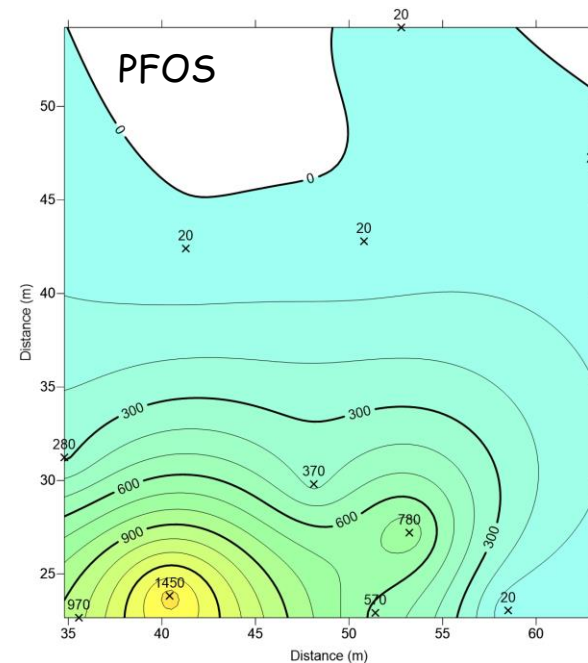
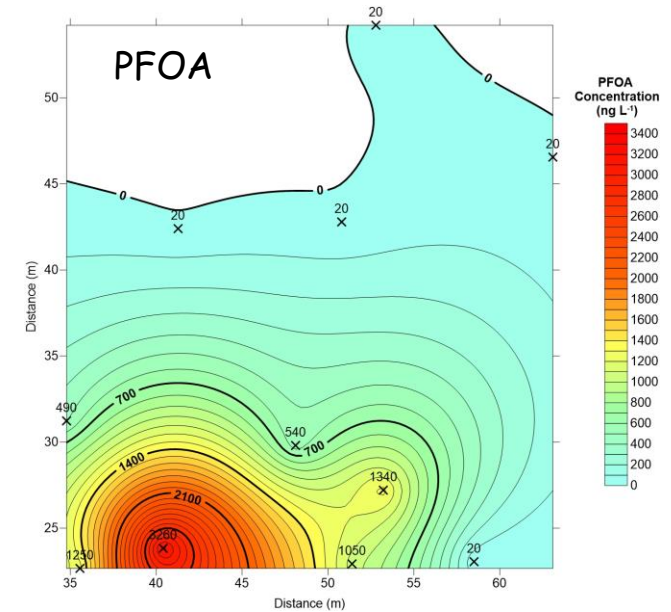
- Proven
 - Colloidal activated carbon
- Development
 - Ion exchange resin
 - Biochar
 - Powdered activated carbon
 - Sonochemical
 - Foam Fractionization
 - Oxidants



Source: Xiao et al., 2017

Study Site #1

- Petroleum Hydrocarbon Spill
 - Source excavated
 - Residue PHCs in soil and groundwater
 - BTEX < 300 ug/L
 - F1 < 2,000 ug/L
 - F2 < 3,500 ug/L
- PFAS
 - PFOS up to 1,450 ng/L
 - PFOA up to 3,260 ng/L
- Geology & Hydrogeology
 - Silty sand with sand lens
 - Unconfined
 - $K \sim 2.6$ m/day
 - $V \sim 1$ m/day



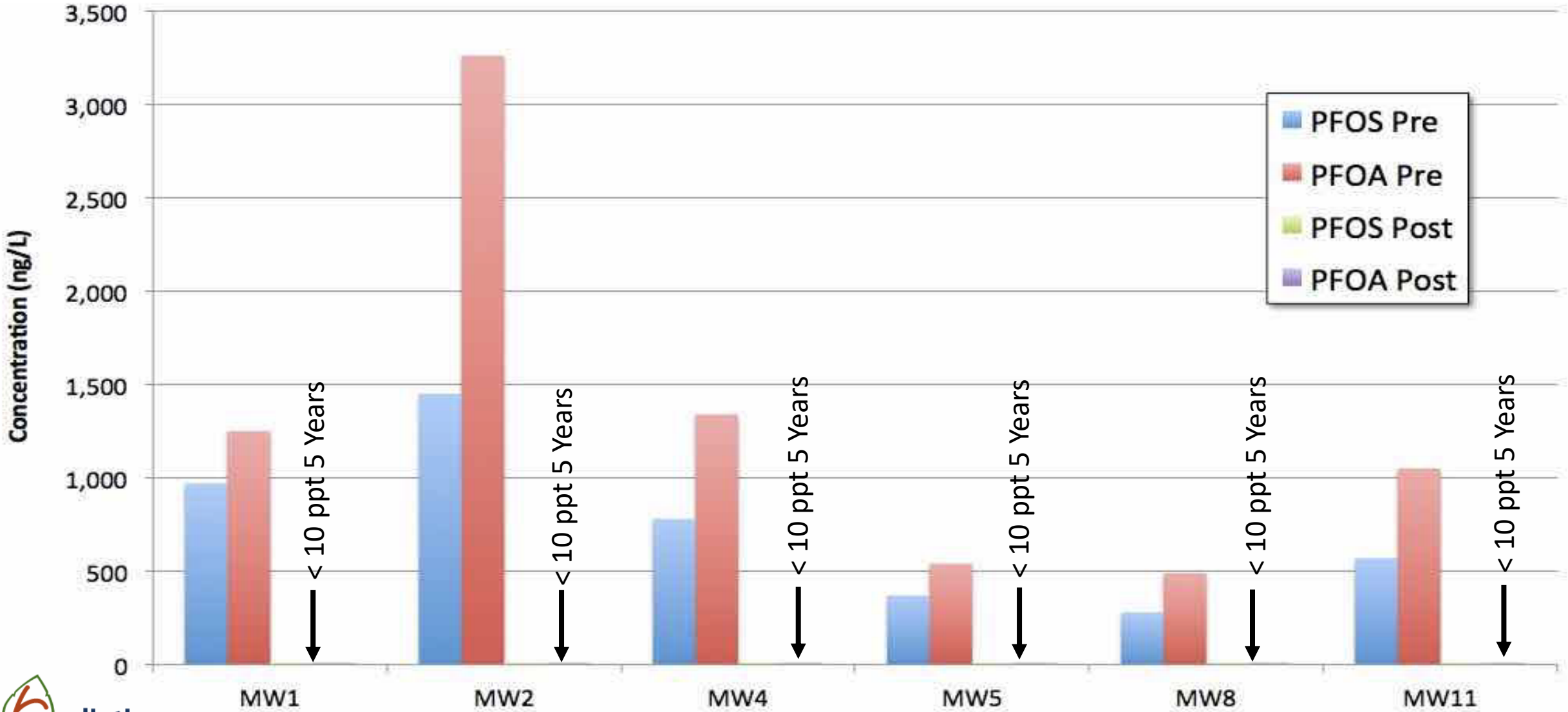
←
Groundwater Flow

Study Site #1

- Based on Pore Volume
 - One event
- Direct Push
- Geology Specific Tools
- Multiple Locations
- Multiple Intervals
- Low Pressure
 - <25 psi
- Low Volume
 - ~100 to 200 litres/location



Study Site #1



Study Site #2

- Large Petroleum Hydrocarbon Facility
 - Large BTEX plume with PFAS present
 - BTEX ~ 680 ug/L
 - GRO ~ 3,500 ug/L
 - 22 PFAS analyzed, 6 detected
 - PFBA up to 6,200 ng/L
 - PFHxA up to 16,100 ng/L
 - PFHpA up to 6,080 ng/L
 - PFNA up to 140 ng/L
 - PFOA up to 450 ng/L
 - PFPeA up to 24,000 ng/L



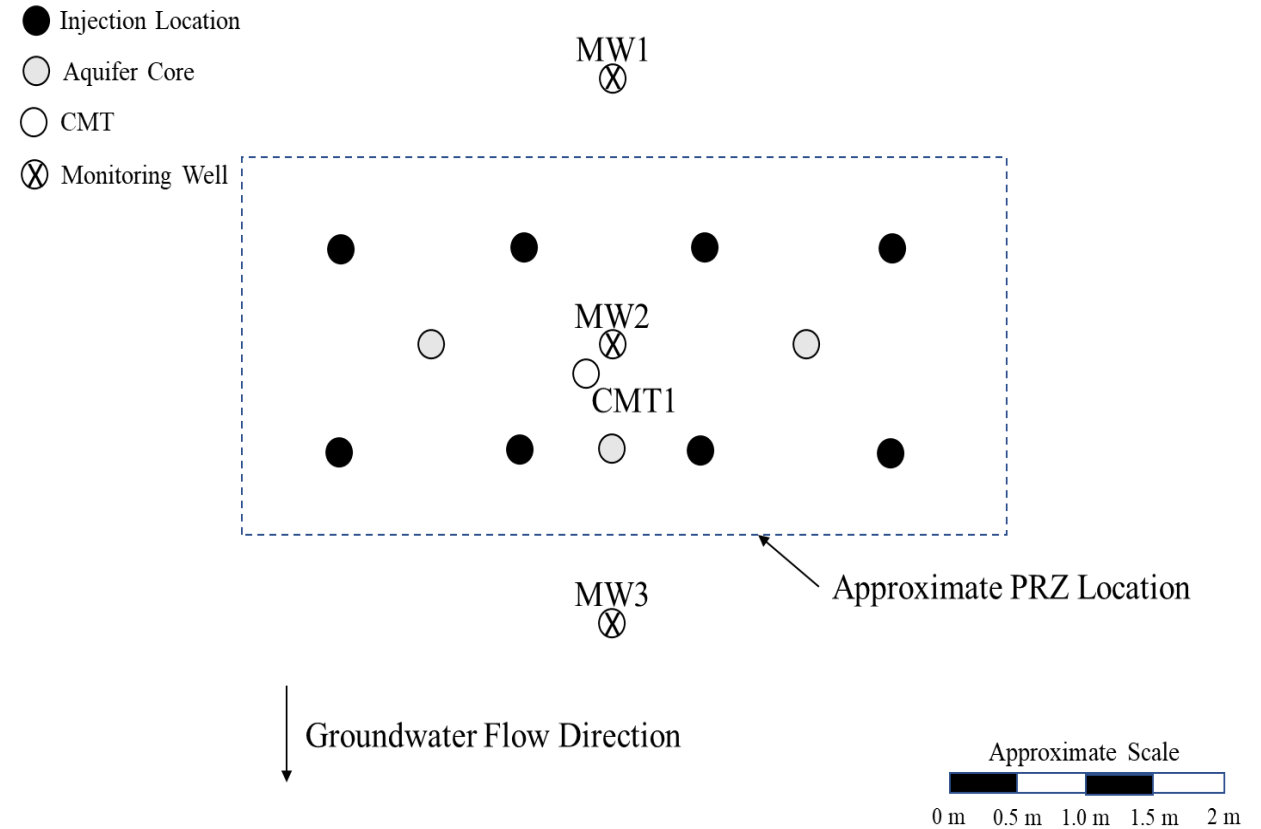
Study Site # 2

- Geology
 - Fine-grained sand
 - Zone of medium grained sand (~1 inch thick)
- Hydrogeology
 - Unconfined aquifer
 - Water table ~17 ft below surface
 - Mean K 5×10^{-5} m/sec
 - Groundwater velocity ~ 200 ft/year
- Geochemistry
 - Iron & sulfate reducing



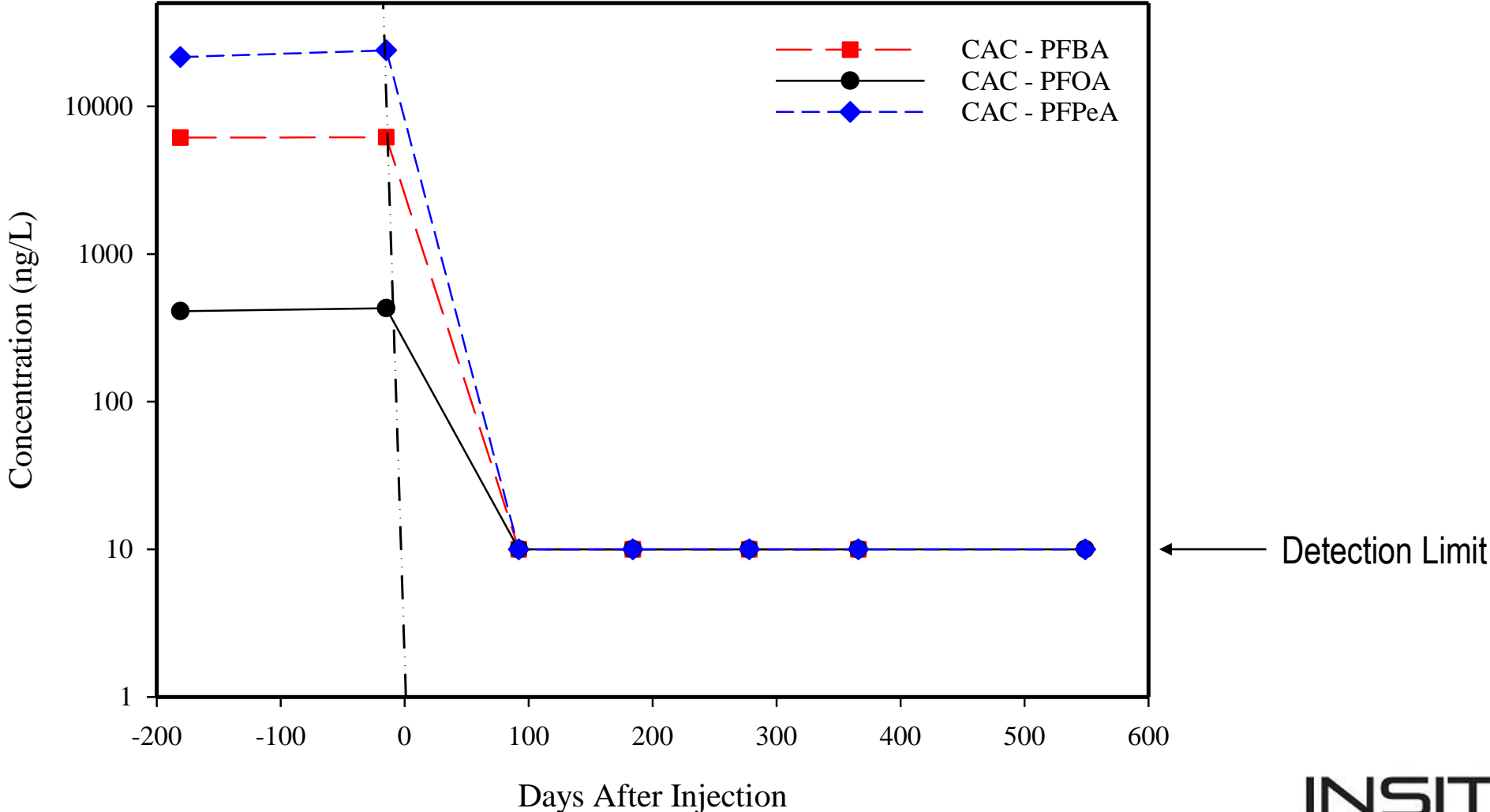
Study Site # 2

- Six permeable reactive barriers/zones created using:
 - Colloidal activated carbon
 - Powdered activated carbon
 - Biochar
 - Ion exchange resin
 - Sodium persulfate- unactivated
 - Hydrogen peroxide
- Injection
 - Grid - 1.5 m spacing
 - Direct push technology
 - Multiple vertical intervals



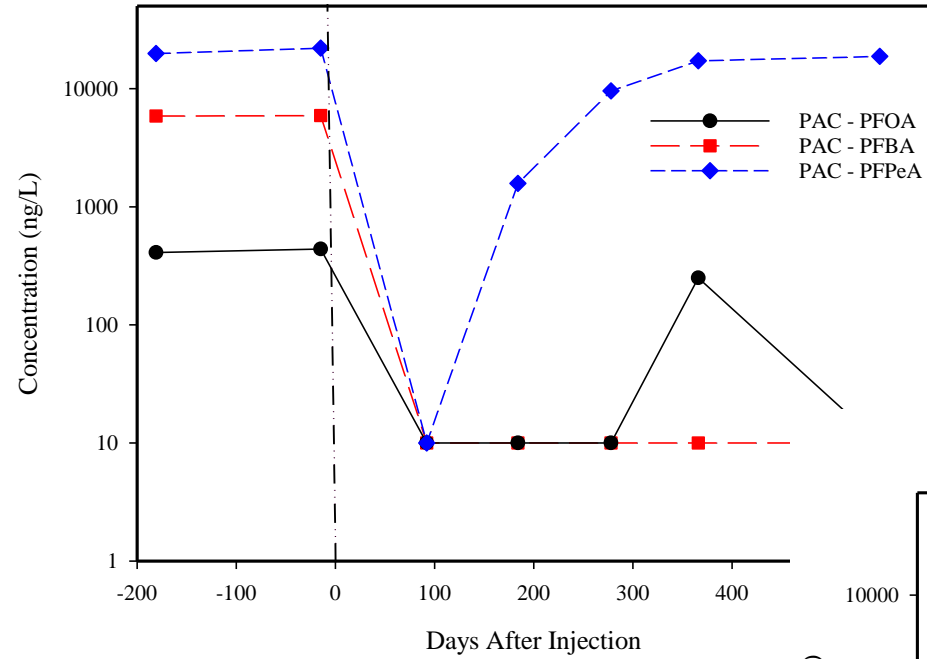
Study Site # 2

Colloidal Activated Carbon

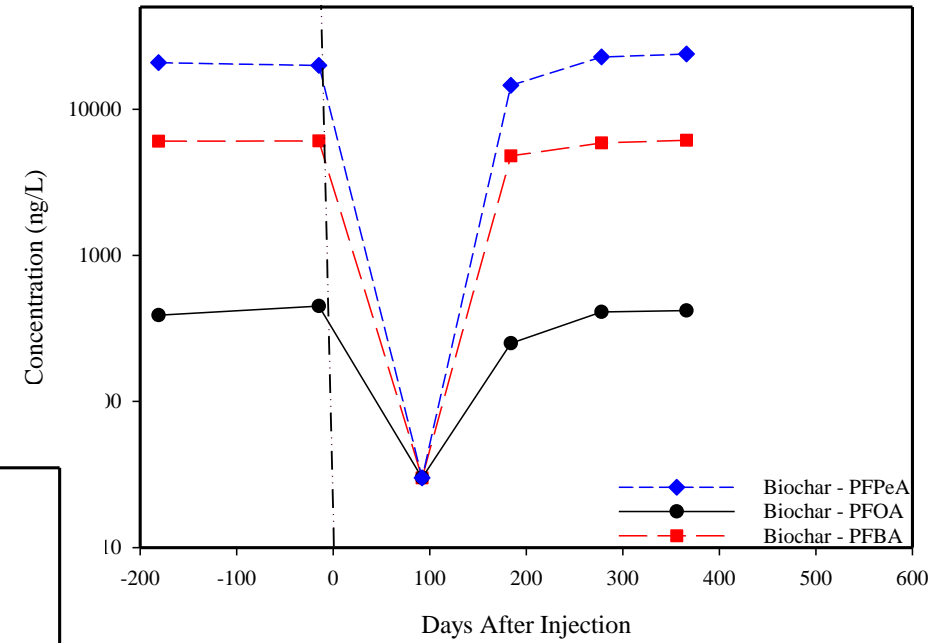


Study Site # 2

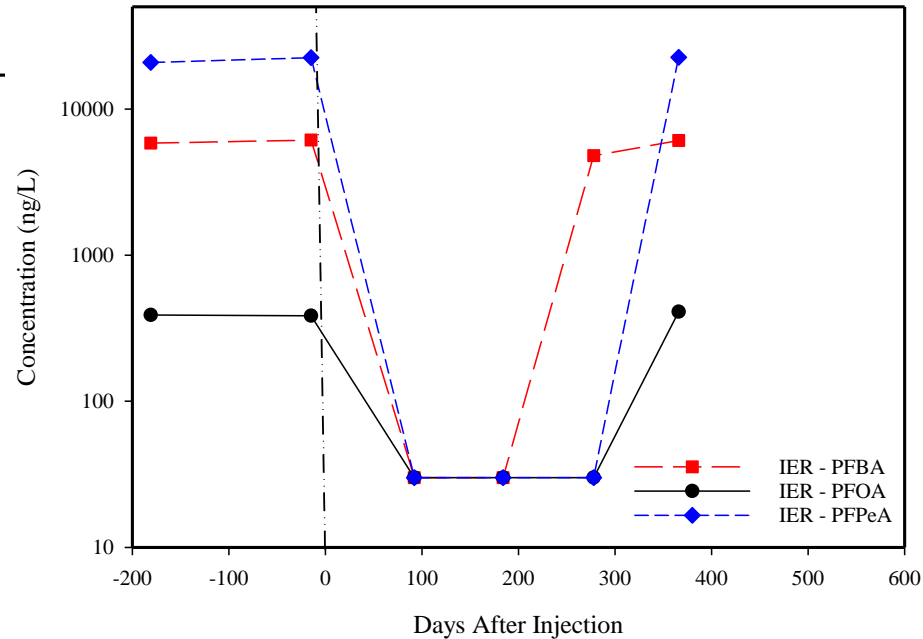
PAC



Biochar



IER



Study Site # 2

- Breakthrough observed throughout target zone
 - Except for CAC
 - Hydrogen peroxide & persulfate breakthrough in 90 days
- High C > Low C PFAS
- Sulphonates > Carboxylates
- CAC > PAC > IER > Biochar > Hydrogen peroxide = persulfate



DOI: 10.1002/rem.21653

RESEARCH ARTICLE

WILEY

Six pilot-scale studies evaluating the in situ treatment of PFAS in groundwater

Rick McGregor

InSitu Remediation Services Ltd., St. George,
Canada

Correspondence
Rick McGregor, InSitu Remediation Services
Ltd., PO Box 324, St. George, ON N0E 1N0,
Canada.
Email: rickm@insl.ca

Abstract

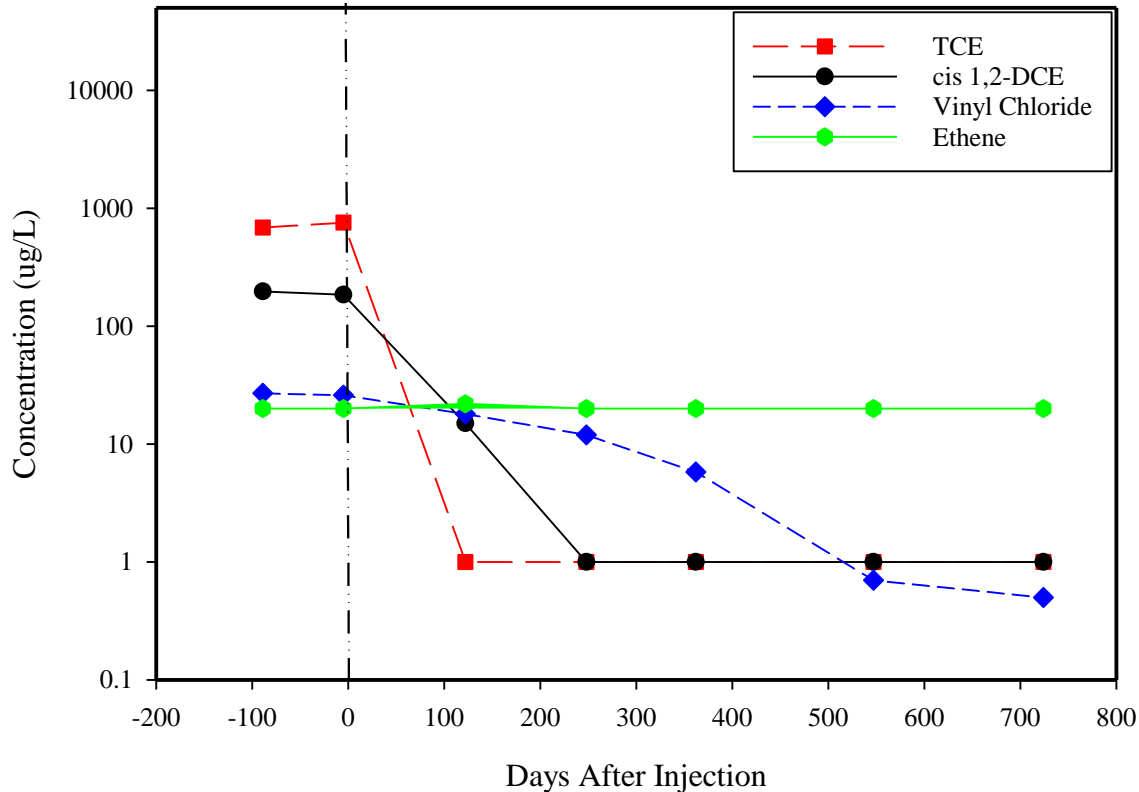
Per- and polyfluoroalkyl substances (PFAS) have been identified by many regulatory agencies as emerging contaminants of concern in a variety of media including groundwater. Currently, there are limited technologies available to treat PFAS in groundwater with the most frequently applied approach being extraction (i.e., pump and treat). While this approach can be effective in containing PFAS plumes, previous studies of pump and treat programs have met with limited remedial success. In situ treatment studies of PFAS have been limited to laboratory and a few field studies. Six pilot-scale field studies were conducted in an unconfined sand aquifer compacted by petroleum hydrocarbon along with PFAS to determine if a variety of reagents could be used to attenuate dissolved phase PFAS in the presence of petroleum hydrocarbons. The six reagents consisted of two chemical oxidants, hydrogen peroxide (H₂O₂) and sodium persulfate (Na₂S₂O₈), and four adsorbents, powdered activated carbon (PAC), colloidal activated carbon (CAC), ion-exchange resin (IER), and biochar. The reagents were injected using direct push technology in six permeable reactive zone (PRZ) configurations. Groundwater concentrations of various PFAS entering the PRZs ranged up to 24,000 ng/L perfluoropentanoic acid, up to 6,200 ng/L perfluorobutanoic acid, up to 16,100 ng/L perfluorohexanoic acid, up to 6,080 ng/L perfluoroheptanoic acid, up to 450 ng/L perfluorooctanoic acid, and up to 140 ng/L perfluorononanoic acid. Performance groundwater sampling within and downgradient of the PRZs occurred for up to 18 months using single and multilevel monitoring wells. Results of groundwater sampling indicated that the PFAS were not treated by either the persulfate nor the peroxide and, in some cases, the PFAS increased in concentration immediately following the injection of peroxide and persulfate. Concentrations of PFAS in groundwater sampled within the PAC, CAC, IER, and biochar PRZs immediately after the injection were determined to be less than the method detection limits. Analyses of groundwater samples over the 18-month monitoring period, indicated that all the PRZs exhibited partial or complete breakthrough of the PFAS over the 18-month monitoring period, except for the CAC PRZ which showed no PFAS breakthrough. Analysis of cores for the CAC, PAC, and biochar PRZs suggested that the CAC was uniformly distributed within the target injection zone, whereas the PAC and biochar showed preferential injection into a thin coarse-sand seam. Similarly, analysis of the sand packs of monitoring wells installed before the injection of the

Study Site #3

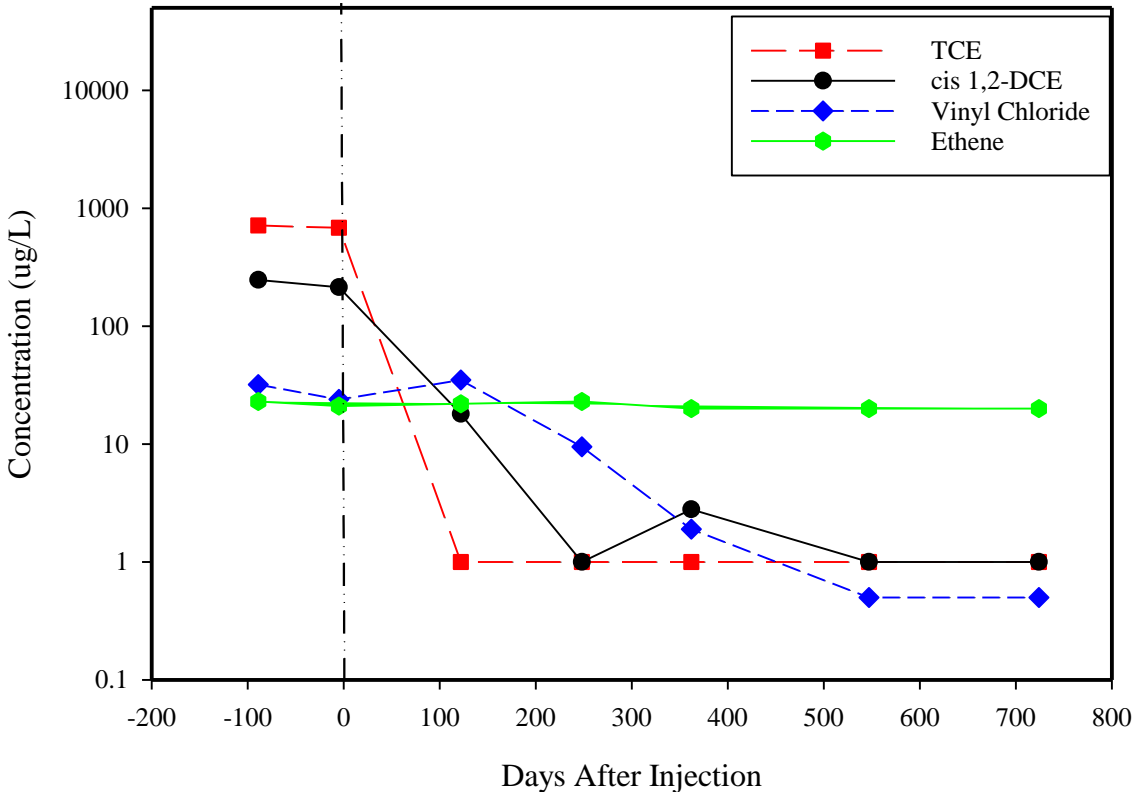
- Industrial Facility - China
 - Comingled
 - TCE up to 985 ug/L
 - 1,2 cis DCE up to 258 ug/L
 - Vinyl chloride up to 54 ug/L
 - 5 PFAS detected
 - PFBA up to 795 ng/L
 - PFHxA up to 3,240 ng/L
 - PFOA up to 420 ng/L
 - PFPeA up to 12,800 ng/L
 - PFOS up to 2,140 ng/L
- Geology
 - Silty sand
- Hydrogeology
 - Unconfined aquifer
 - Water table ~3.2 m below surface
 - K: 5×10^{-6} to 6.3×10^{-4} m/sec
 - Groundwater velocity ~ 9 m/year
- Geochemistry
 - Iron & sulfate reducing

Study Site #3

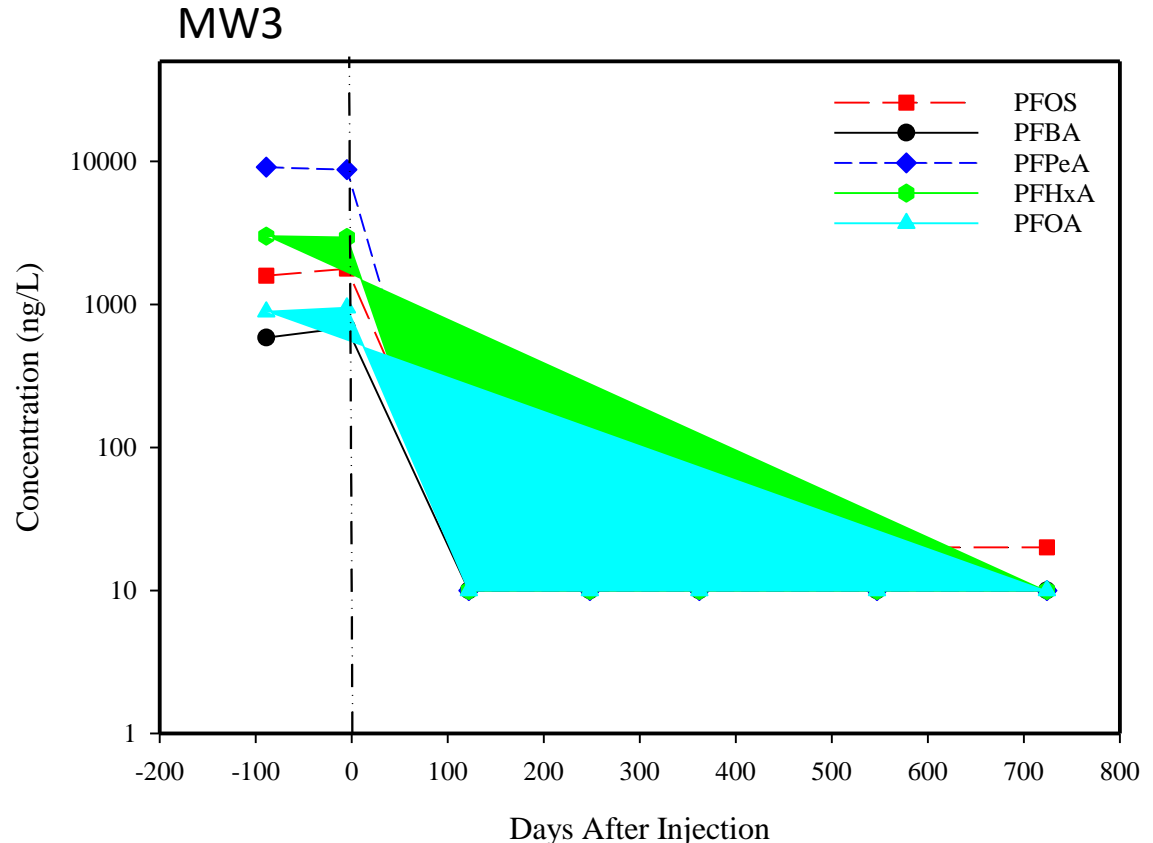
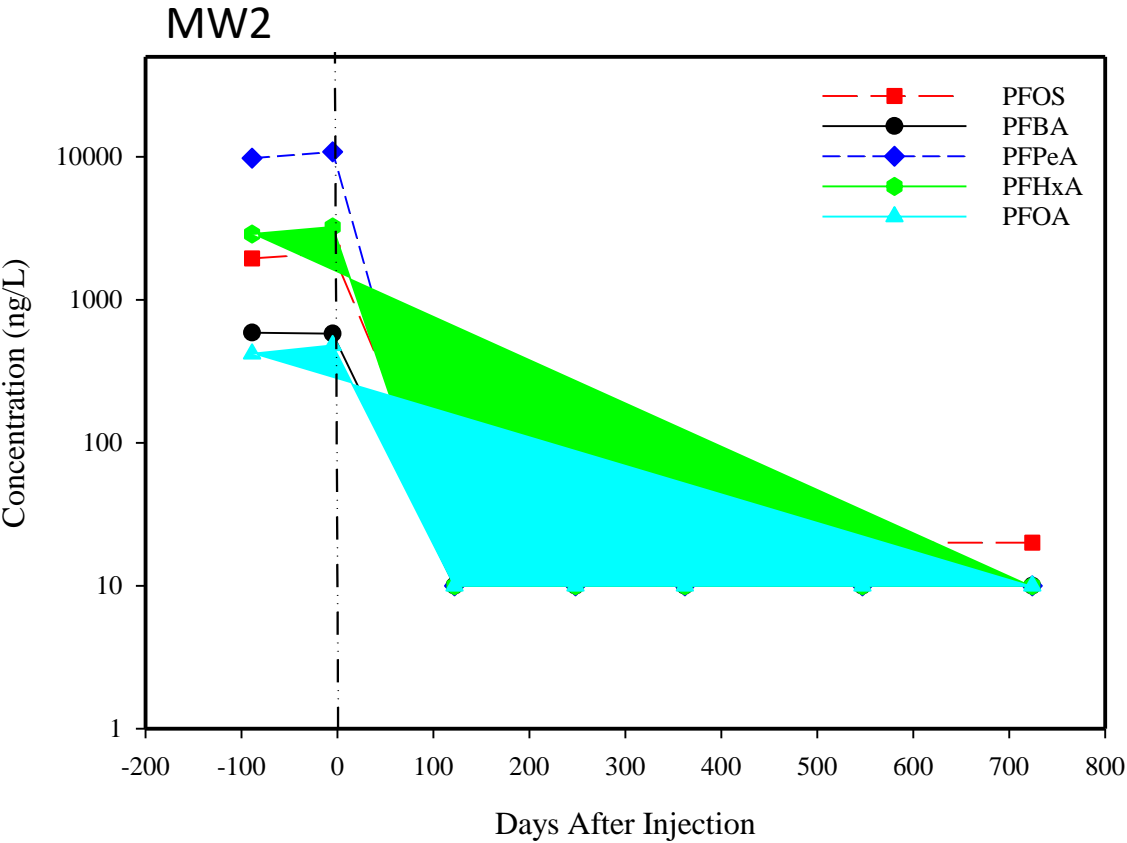
MW2



MW3



Study Site #3



Study Site # 3

- Treatment with 3 months of application
 - Comingled with TCE, 1,2 DCE and vinyl chloride
- Strong reduction conditions, dichlorination of TCE noted, treatment for greater than 2 years
- Removal of PFAS to below 10 ng/L for greater than 2 years
- Greater than 99% of samples within target injection zone had CAC present

Check for updates

DOI: 10.1002/rem.21675

RESEARCH ARTICLE

WILEY

The in situ treatment of TCE and PFAS in groundwater within a silty sand aquifer

Rick McGregor | Ye Zhao

InSitu Remediation Services Ltd, St George, Ontario, Canada

Correspondence
Rick McGregor, InSitu Remediation Services Ltd, PO Box 324, St George, ON N0E 1N0, Canada.
Email: rickm@rsi.ca

Abstract

Chlorinated ethenes such as trichloroethene (TCE), *cis*-1,2-dichloroethene (*cis*-1,2-DCE), and vinyl chloride along with per- and polyfluoroalkyl substances (PFAS) have been identified as chemicals of concern in groundwater; with many of the compounds being confirmed as being carcinogens or suspected carcinogens. While there are a variety of demonstrated in-situ technologies for the treatment of chlorinated ethenes, there are limited technologies available to treat PFAS in groundwater. At a former industrial site shallow groundwater was impacted with TCE, *cis*-1,2-DCE, and vinyl chloride at concentrations up to 985, 258, and 54 µg/L, respectively. The groundwater also contained maximum concentrations of the following PFAS: 12,800 ng/L of perfluoropentanoic acid, 3240 ng/L of perfluorohexanoic acid, 795 ng/L of perfluorobutanoic acid, 950 ng/L of perfluorooctanoic acid, and 2140 ng/L of perfluorooctanesulfonic acid. Using a combination of adsorption, biotic, and abiotic degradation in situ remedial approaches, the chemicals of concern were targeted for removal from the groundwater with adsorption being utilized for PFAS whereas adsorption, chemical reduction, and anaerobic biodegradation were used for the chlorinated ethenes. Sampling of the groundwater over a 24-month period indicated that the detected PFAS were treated to either their detection, or below the analytical detection limit over the monitoring period. Postinjection results for TCE, *cis*-1,2-DCE, and vinyl chloride indicated that the concentrations of the three compounds decreased by an order of magnitude within 4 months of injection, with TCE decreasing to below the analytical detection limit over the 24-month monitoring period. *Cis*-1,2-DCE, and vinyl chloride concentrations decreased by over 99% within 8 months of injections, remaining at or below these concentrations during the 24-month monitoring period. Analyses of Dehalococcioides, ethene, and acetylene over time suggest that microbiological and reductive dechlorination were occurring in conjunction with adsorption to attenuate the chlorinated ethenes and PFAS within the aquifer. Analysis of soil cores collected pre- and post-injection, indicated that the distribution of the colloidal activated carbon was influenced by small scale heterogeneities within the aquifer. However, all aquifer samples collected within the targeted injection zone contained total organic carbon at concentrations at least one order of magnitude greater than the preinjection total organic carbon concentrations.

KEYWORDS

colloidal activated carbon, in situ, PFAS, synthetic dye, trichloroethene

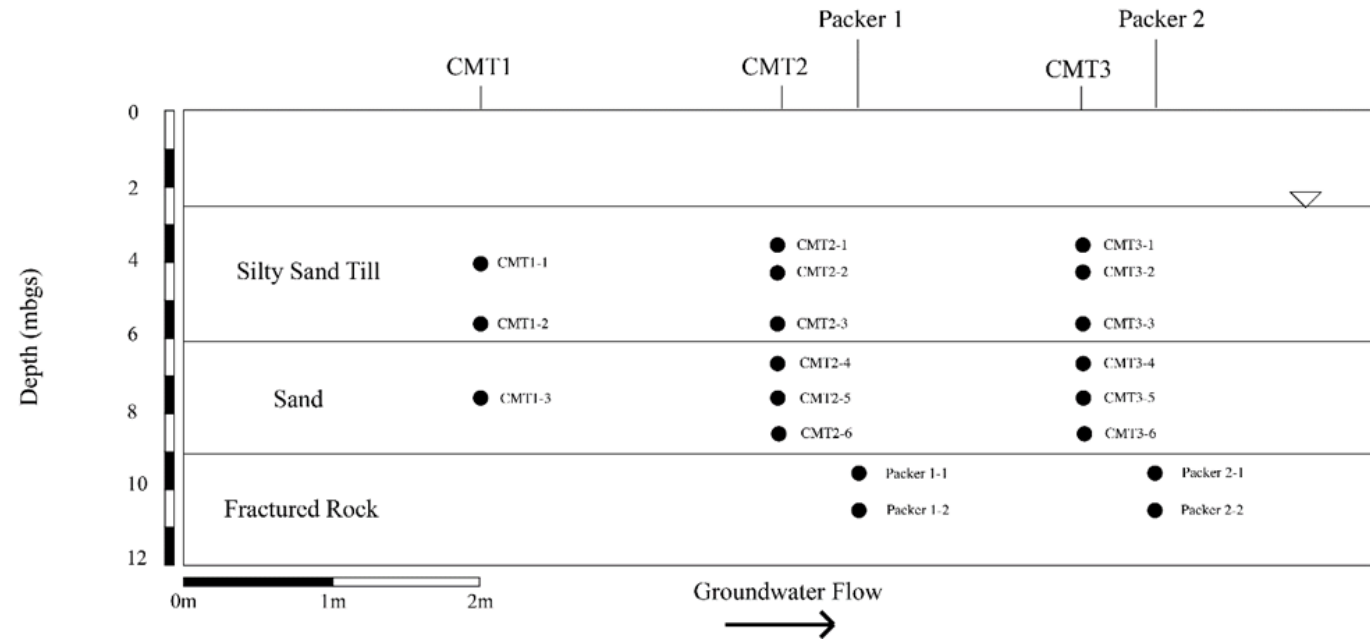
Remediation, 2021, 1-11.

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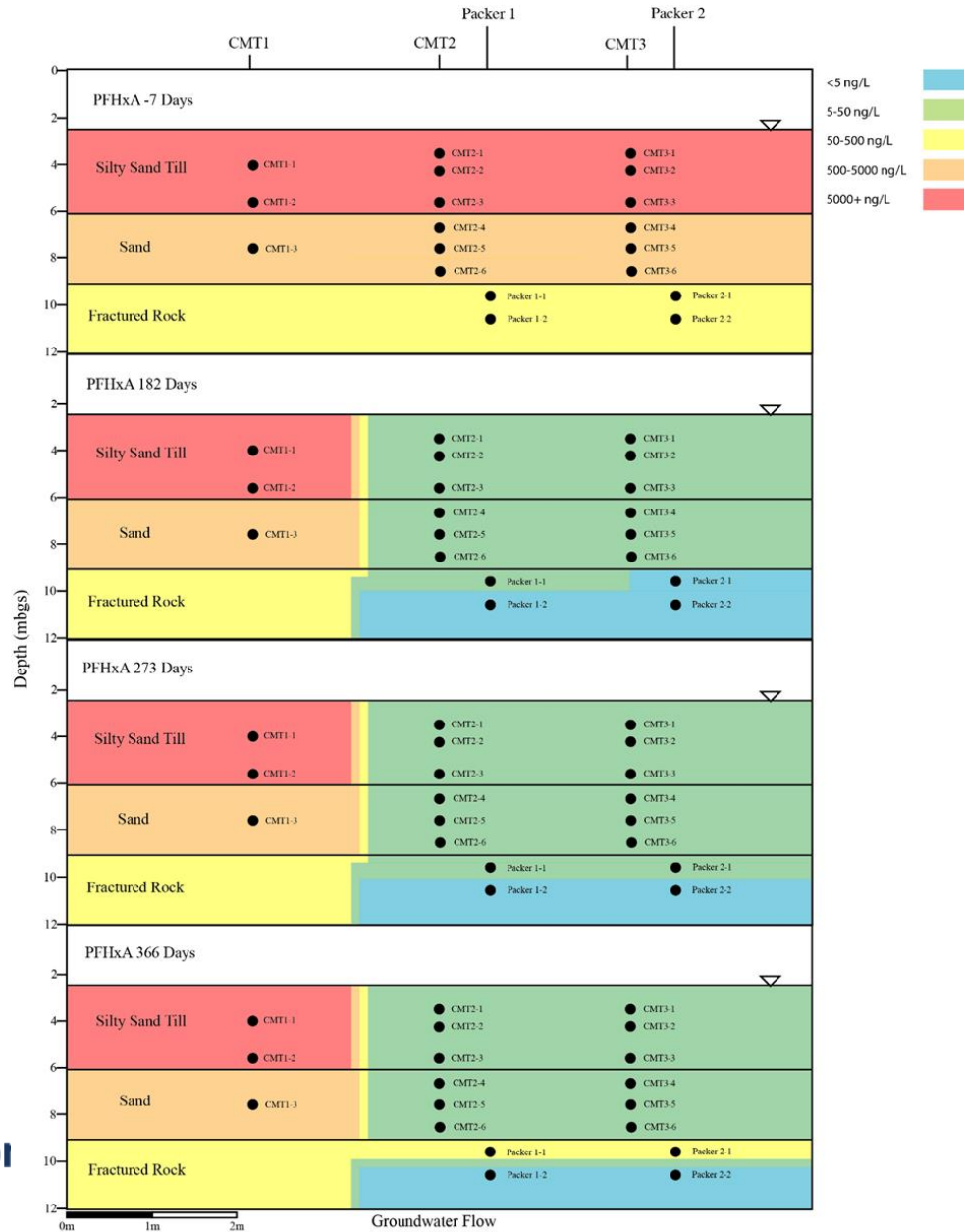
Study Site #4

- Residential/Small Industrial
 - Complex geology
 - Silty sand
 - Sand
 - Fractured rock
 - 5 PFAS detected within the 3 aquifers
 - PFBA up to 795 ng/L
 - PFHxA up to 3,240 ng/L
 - PFOA up to 420 ng/L
 - PFPeA up to 12,800 ng/L
 - PFOS up to 2,140 ng/L

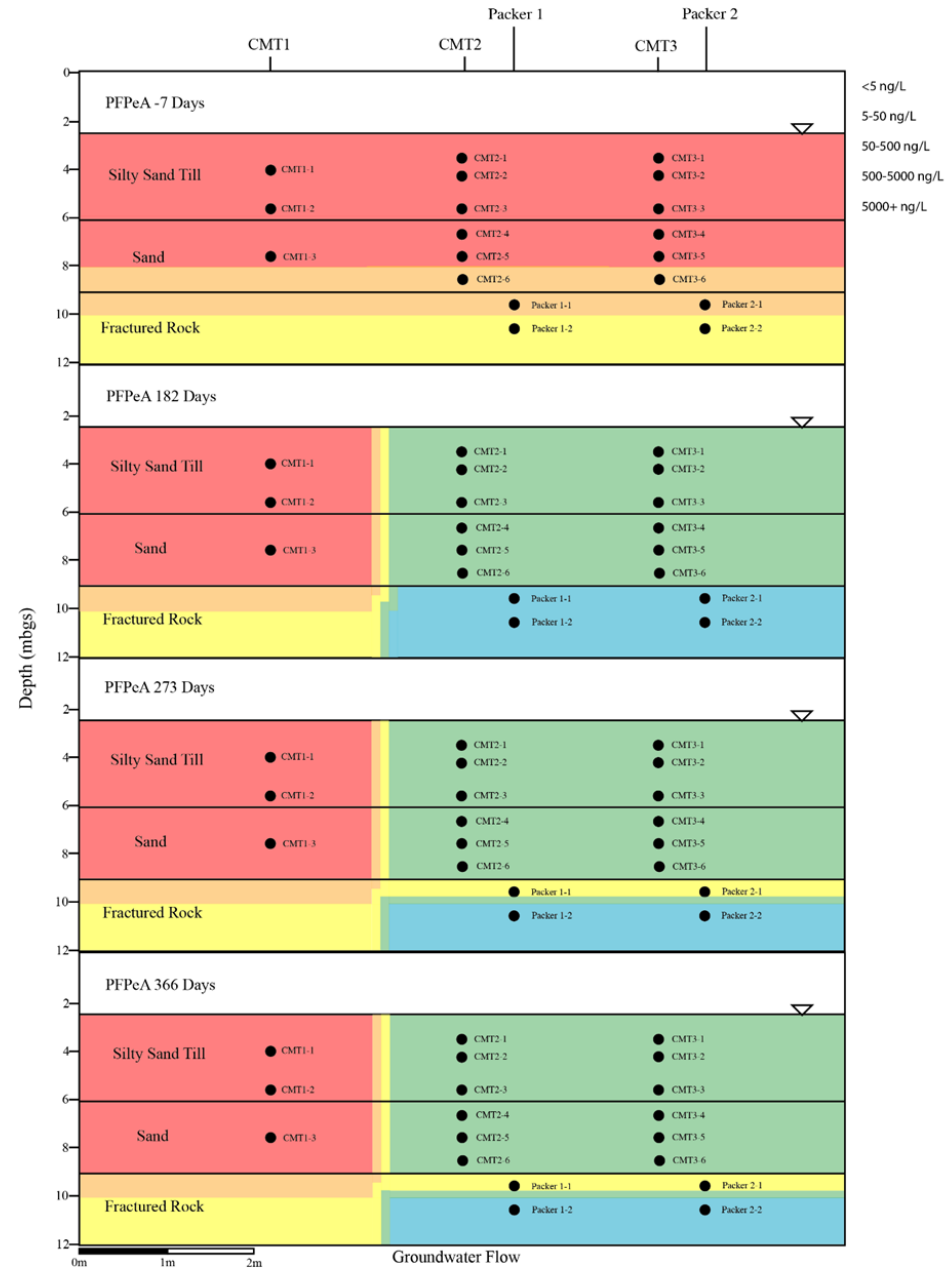


Study Site #4

PFHxA

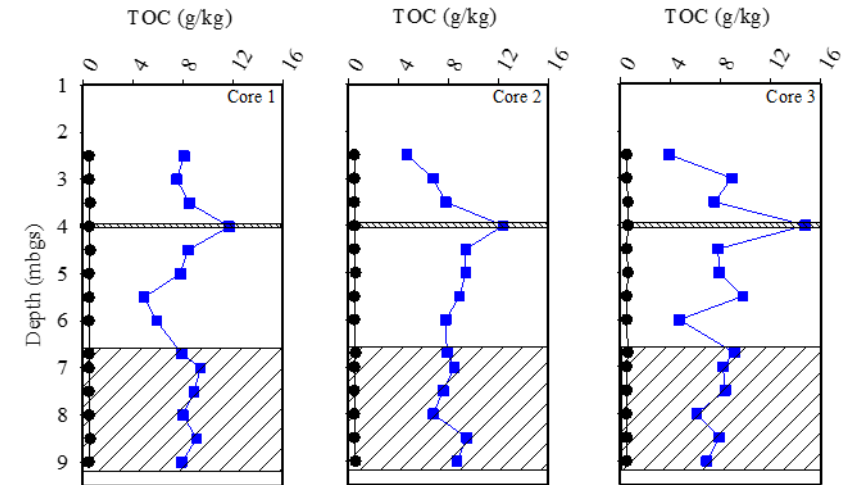


PFPeA



Study Site # 4

- Removal of PFAS within unconsolidated aquifers within 3 months to below 10 ng/L for greater than 1.5 years
- Greater than 99% of samples within target injection zone had CAC present within consolidation aquifers
- Breakthrough of C4-C5 carboxylic acids within fractured rock aquifer before sulfonic acids



PFAS Remediation Research Group

Academic Partners



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