



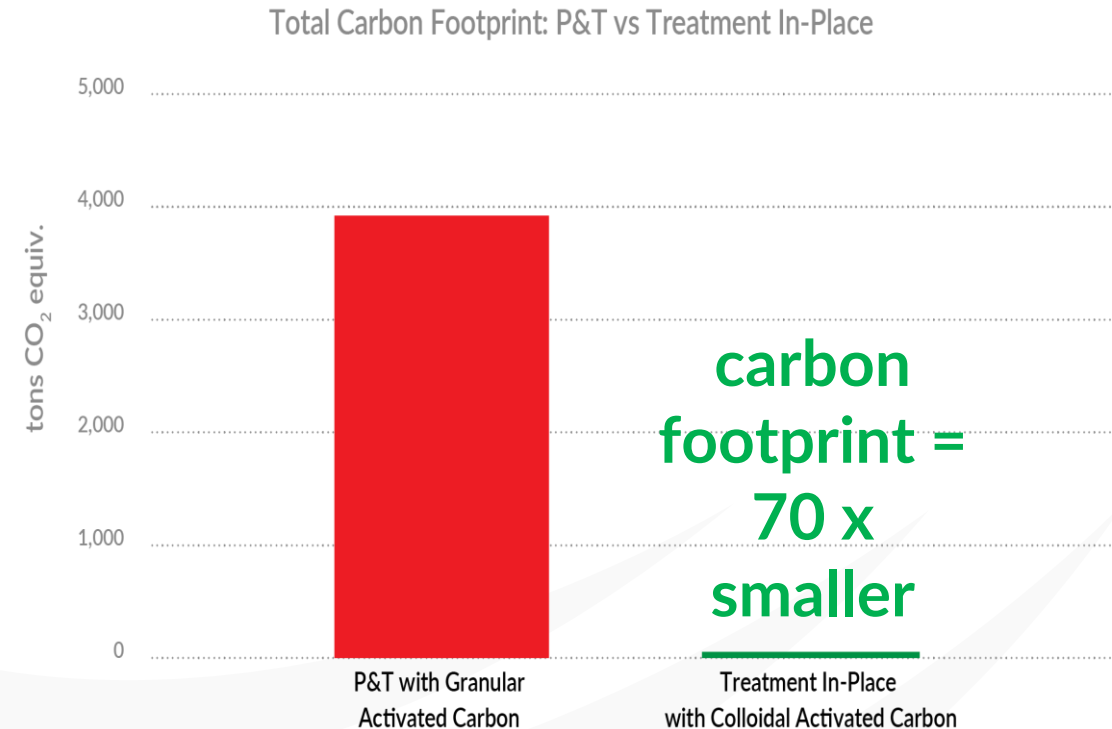
REGENESIS[®]

Implementing Effective *In-Situ* Permeable Colloidal Activated Carbon (CAC) Barriers to Stop Hydrocarbon Plume Migration

Katarina Seymour
Mid-Atlantic District Manager, REGENESIS

Social and Environmental Impact of CAC Barriers

- >95% reduction in greenhouse gas emissions vs P&T¹
- Highly resilient (no electricity or moving parts)
- No contamination brought to surface
- Green – No O&M



1. Ramboll 2023 [Sustainability-Case-study-PlumeStop-vs-PT-Final.pdf](#)

Design Considerations For Colloidal Barriers

- Colloidal Advantages
- Mass Flux
- Distribution
- Monitoring
- Case Studies

TEMPORARY
INJECTION RIG



What Is A Colloid?

A colloid is a mixture in which particles of one substance are distributed evenly throughout another substance. Paints, milk, and fog are colloids.

CAC (left image) is a 1-2 micron activated carbon colloid dispersed in water.

A non-dispersed, non-colloidal activated carbon solution is shown on the right.



Stabilized Micro-Scale AC
(Colloidal)



De-Stabilized Micro-Scale AC
(Non-Colloidal)

Does Colloidal Carbon Improve Distribution?

Colloidal Activated Carbon (CAC)

Carbon Type	Particle Size (mm)
Granular Activated Carbon	400-1,000
Powdered Activated Carbon	50-250
Micron-Scale Activated Carbon	1-2

Powdered Activated Carbon (PAC)

Grain Size	Pore Throat Diameter (mm)
Medium Sand	8-50
Fine Sand	5-20
Silt	3-8




CAC vs. PAC moving through the columns in 12 minutes

Colloidal activated carbon will move through soil and all other forms of non-colloidal carbon (CAC vs PAC) will not

Field Distribution Research (Third Party)

McGregor, R.(2020) Distribution of Colloidal and Powdered Activated Carbon for the in Situ Treatment of Groundwater. **Journal of Water Resource and Protection**, 12, 1001-1018.



Journal of Water Resource and Protection, 2020, 12, 1001-1018
<https://www.scirp.org/journal/jwarp>
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ISSN Print: 1945-3094


Distribution of Colloidal and Powdered Activated Carbon for the *in Situ* Treatment of Groundwater

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Abstract

The use of *in situ* technologies for the treatment of groundwater containing various compounds of concern are widely accepted. These technologies include chemical reduction, chemical oxidation, anaerobic and aerobic bioremediation, and adsorption, among others. One requirement for the successful application of these technologies is the delivery of the remedial reagent(s) to the compounds of concern. A rapidly evolving *in situ* technology is the injection of adsorptive media such as activated carbon and ion-exchange resin including powdered or colloidal activated carbon. Activated carbon has a long-demonstrated history of effectiveness for the removal of various organic and inorganic compounds in above ground water treatment systems. However, due to constraints related to the particle size and physical properties of the activated carbon, the *in situ* application of activated carbon has been limited. Recent developments in the manufacturing of activated carbon have created a smaller particle size allowing activated carbon to be applied *in situ*. To evaluate if powdered and colloidal activated carbon can be effectively distributed in aquifers, the two types of carbon were injected using direct push technology adjacent to each other at four sites with varying geology. Evaluation of distribution was completed by sampling the aquifer prior to and post-injection for total organic carbon. The results of the studies indicated that both forms of activated carbon were effectively delivered to the targeted injection zones with both carbon types being detected at least seven meters away from the point of injection. The colloidal form of the activated carbon showed good distribution throughout the four targeted zones of injection with 93 percent of the samples collected having colloidal activated carbon present within them whereas the powdered activated carbon cells were more susceptible to aquifer heterogeneity with only 67 percent of the samples collected having activated carbon present. Preferential accumulation of activated carbon was

DOI: 10.4236/jwarp.2020.1212060 Dec. 10, 2020 1001 Journal of Water Resource and Protection

CAC vs PAC Distribution Study

- **4 Sites: 1 CAC and PAC per site (8 plots total)**
- **Geology: Fine sand, glacial till, glacial, fluvial deposit, find sand + silt**
- **10m x 10m test cells, 3m spacing**

Field Distribution Research

Method

- 520 soil samples taken from soil cores (~65 per cell)
- Measure for total organic carbon (TOC) to determine presence of AC

Horizontal Detections

- **CAC** - detected in **94.4%** of samples
- **PAC** - detected in **42.4%** of samples

Vertical Detections

- **CAC** - **homogeneous** distribution
- **PAC** - **thin fracture** distribution

McGregor, R.(2020) Distribution of Colloidal and Powdered Activated Carbon for the in Situ Treatment of Groundwater. Journal of Water Resource and Protection, 12, 1001-1018.

Horizontal Detection

CAC

PAC

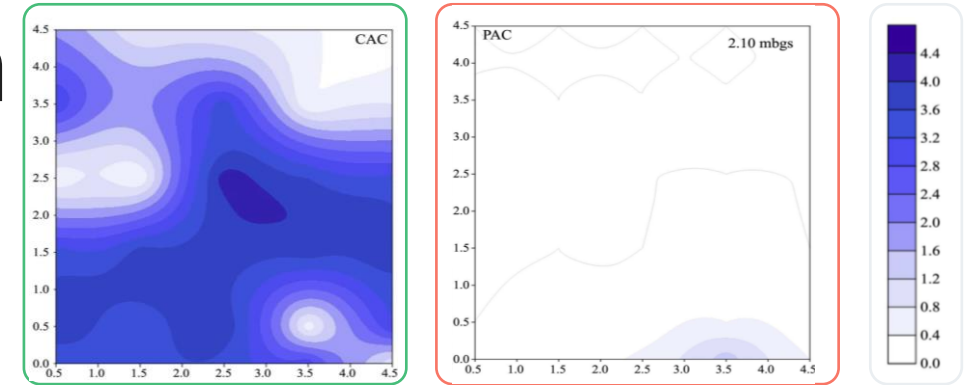
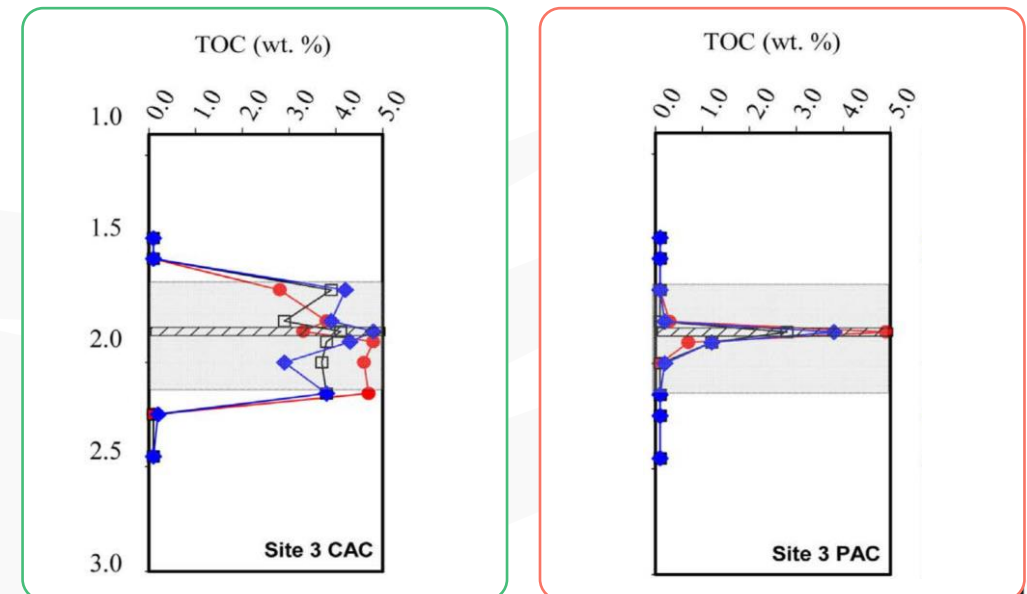


Figure 5. Total organic carbon (TOC) plots for the PAC and CAC test cells at Site 3 following the injection of the CAC and PAC at various depths (1.70, 1.85 and 2.10 mbgs).

Vertical Detection

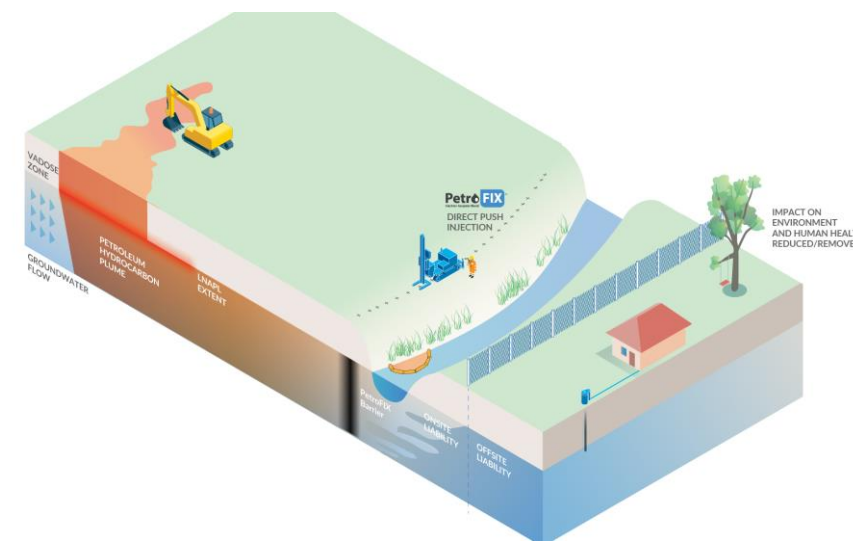
CAC

PAC



Benefits of In Situ Permeable Reactive Barriers (PRBs)

- Contain plume during source remediation
- Reduce treatment scope (reduced grid size)
- Reduce mass discharge to accelerate natural attenuation
- Applicable to a wide range of contaminants
- Green – no O&M, low footprint



Design Considerations For Colloidal Barriers

- Colloidal Advantages
- Mass Flux
- Distribution
- Monitoring
- Case Studies

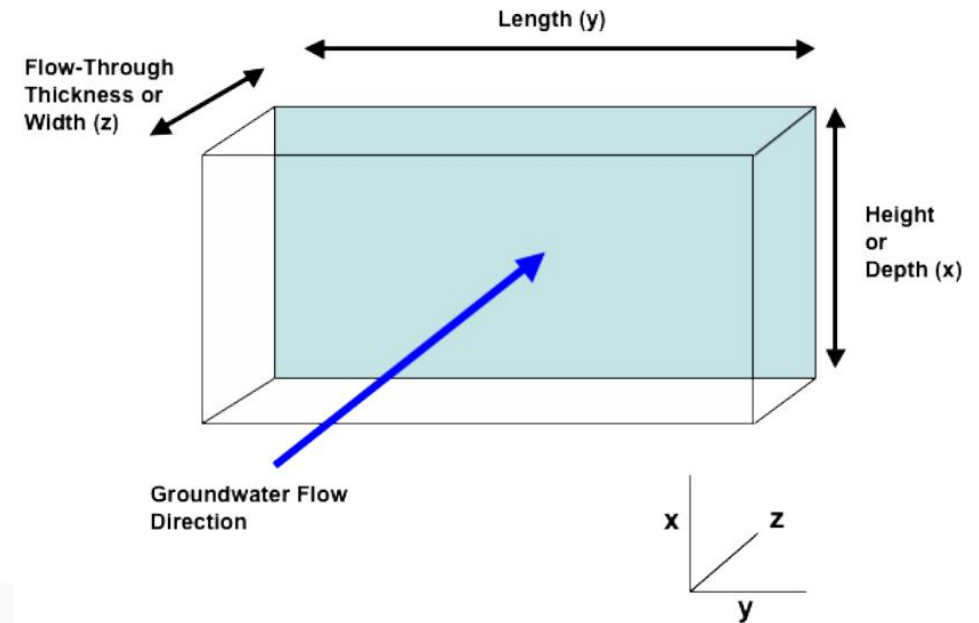
TEMPORARY
INJECTION RIG



Design and Construction of Colloidal iPRBs

A competent barrier requires:

- Good remedial conceptual model
- Appropriate reactive reagent
- Gapless placement of reagent
- Proper reagent dose and dimension



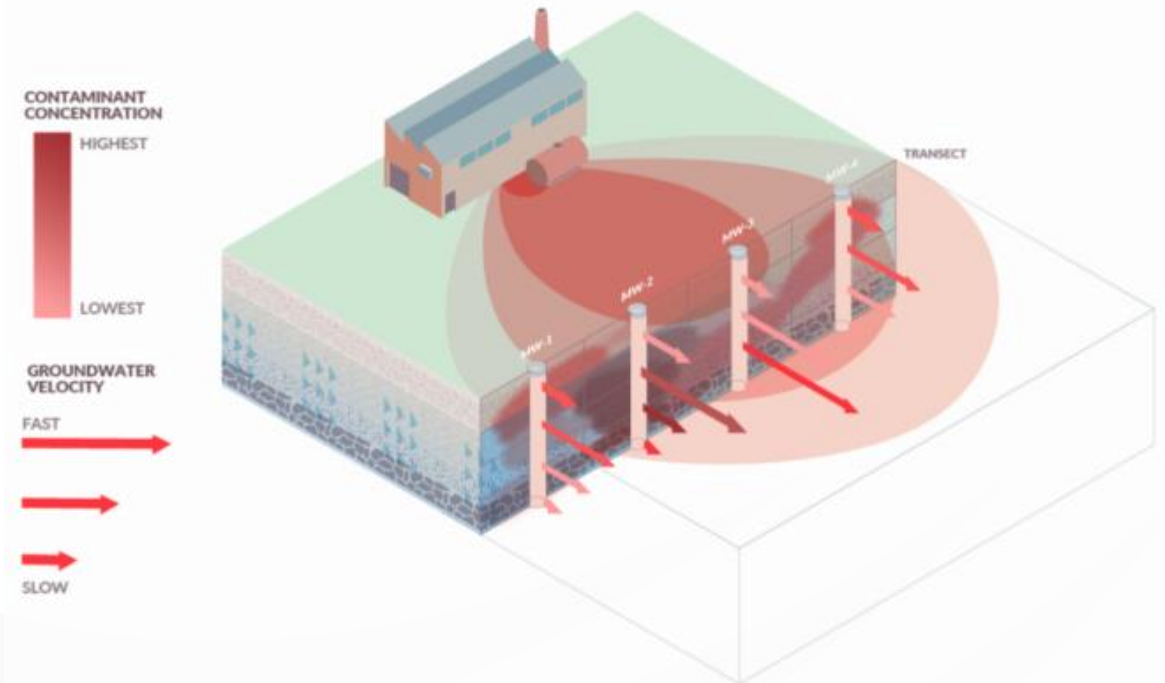
Idealized Barrier Cross Section and Average Mass Flux

Design and Construction of Colloidal iPRBs

Mass Flux = Contaminant mass moving across a unit area (aquifer) perpendicular to the groundwater flow direction (mg/m/day)

Determines:

- Spacing, dose, number of points, number of rows
- Allows for strategic, accurate loading rates

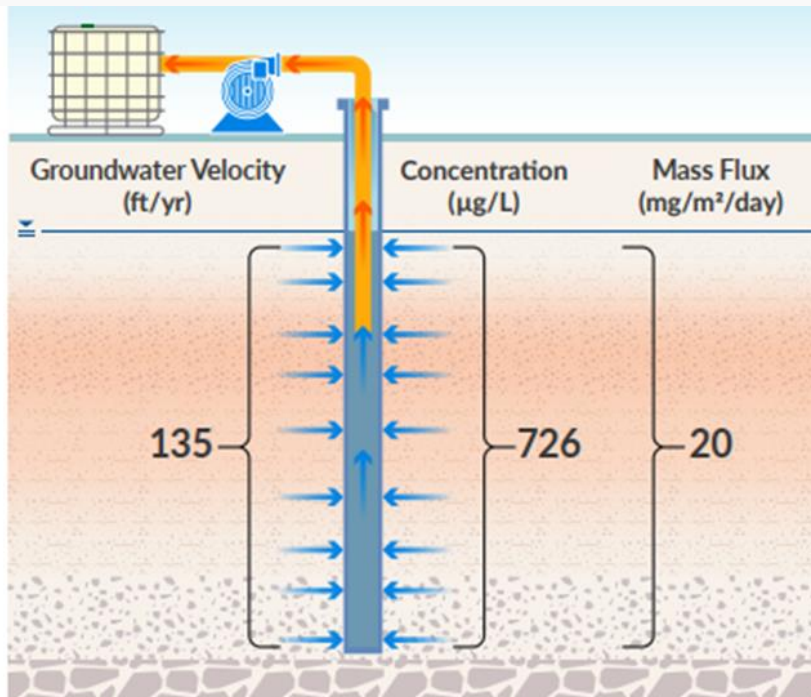


Actual Barrier Cross Section and Variable Mass Flux

Why is Mass Flux Important For Barriers?

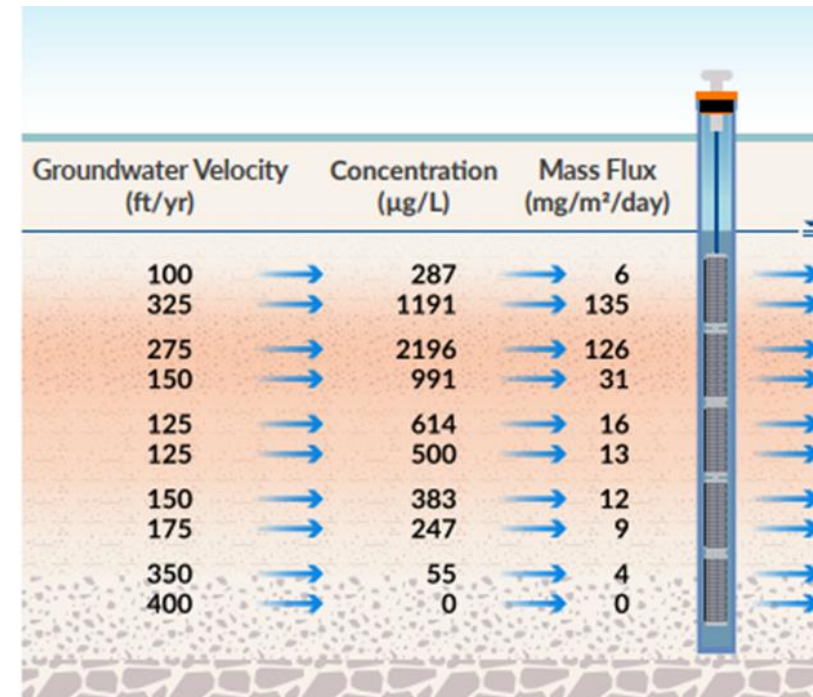
Bulk Average Methods (Pump/Slug Test)

- Does NOT delineate velocity and mass flux
- No data resolution
- Not ideal for in-situ remediation designs

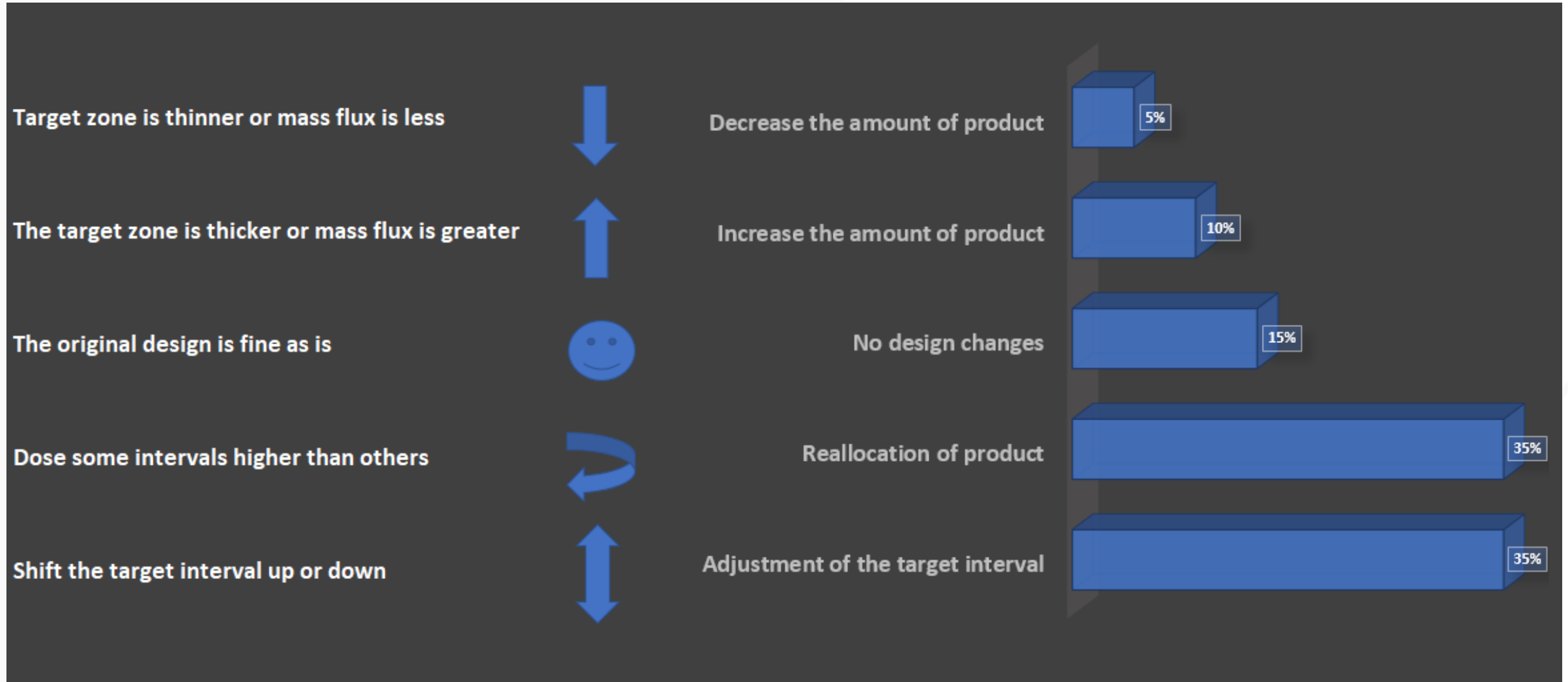


Higher Resolution Methods (FluxTracer)

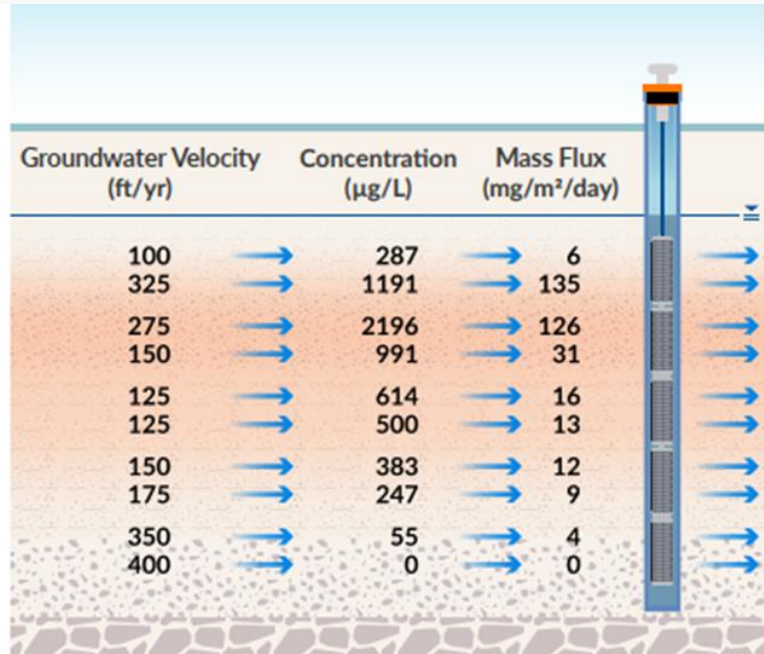
- Identifies zones with highest flux
- Optimize product placement
- More accurate insight into PRB longevity



How Flux Data Informs on Remedial Designs



Measuring Mass Flux?



90% of the mass may be flowing through as little as 10% of the screened interval



EnviroFlux™ Passive Flux Meter (www.enviroflux.com)



Scan QR code for Mass Flux Webinar
(not EnviroFlux related)



Wednesday Poster Session

A Modern View and Approach to Measuring, Reporting, and Designing With Mass Flux Data

A MODERN VIEW AND APPROACH TO MEASURING, REPORTING, AND DESIGNING WITH MASS FLUX DATA

Elliot Maker (REGENESIS, San Clemente, CA, USA)
Chris Lee (REGENESIS, San Clemente, CA, USA)



INTRODUCTION

The in situ remediation of contaminated aquifers continues to be one of the most cost and energy-efficient means of restoring and protecting natural water resources. To properly implement any in situ remedy, the extent and magnitude of contamination must be well understood as well as the site's geology and hydrogeology.

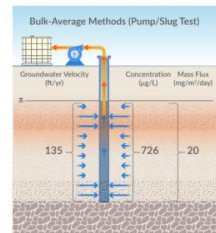
WHAT IS MASS FLUX?

- Mass flux refers to the rate at which mass flows through a specific unit area
- Mass flux is proportional to flow, and is the quantity of something that is moving through a unit area defined by a function of time

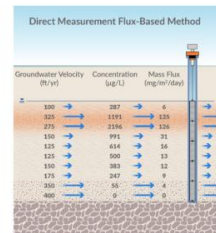
WHY IS MEASURING MASS FLUX IMPORTANT?

- When designing an in situ permeable reactive barrier, accuracy down to the foot matters.
- Oftentimes, 80% of the contaminant mass can be flowing through only 20% of the aquifer.
- FluxTracers provide accurate "direct measurements" of the contaminant mass flux and groundwater velocity rather than bulk average calculations across well screens using traditional methods.
- Virtually all barrier-type designs use contaminant mass flux and groundwater velocity when formulating a dose; therefore, it is necessary to have accurate input parameters.
- Mass flux measurements provide accurate means of design model calibration.

TEST METHOD COMPARISON



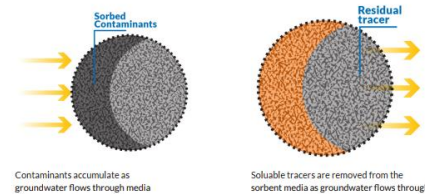
Low Resolution



High Resolution

APPROACH/ACTIVITIES

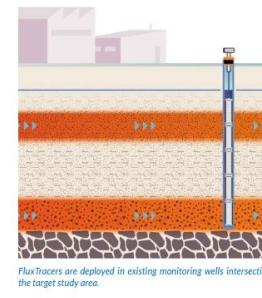
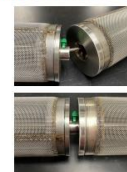
TECHNOLOGY BEHIND PERMEABLE SORBENT MEDIA



REGENESIS'S FLUXTRACER FLUX MAPPING TOOL



FluxTracers are easy-to-use devices that vertically delineate contaminant mass flux and groundwater speed within an existing monitoring well to aid in site characterization and remedial designs. FluxTracers are pre-assembled, stainless steel construction with sealed and tamper-resistant fittings. Canisters are self-centering to allow for seamless installation through a monitoring well. Junctions allow "train car" motion.



FluxTracers are deployed in existing monitoring wells intersecting the target study area.

EXAMPLE PROJECT: MARTHA'S VINEYARD AIRPORT

ABOUT MARTHA'S VINEYARD AIRPORT

- Centrally located on an island off the coast of Massachusetts
- AFFF leached into the underlying groundwater impacting it with PFAS and plume extends beyond airport property boundaries
- Private water wells supplying drinking water to residents at risk

REMEDATION GOALS

- Prevent further PFAS movement from the site
- Reduce PFAS migration to downgradient residents
- Achieve regulatory standard
- 22 ppt sum of MA PFAS 6
- PFOA, PFOS, PFHxS, PFHpA, PFDA

FLUXTRACER INSTALLATION

The summer before installation of the CAC barrier, two FluxTracer Flux Mapping Tools were deployed to delineate the zone containing PFAS contaminants and measure the rate of PFAS moving (i.e., PFAS flux) into the proposed barrier location.

The original design proposed a 20-ft vertical treatment interval, but according to this analysis, we determined that PFAS moved through a more discrete zone than previously estimated. This more precise understanding of the contaminant flux was instrumental in improving the accuracy and placement of the barrier.

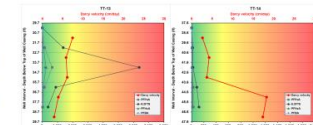
RESULTS

The first performance monitoring sampling event was conducted 103 days post-injection, showing the CAC barrier reducing PFAS by 99.8%. Notably, the PFAS concentrations coming into the barrier increased over this time frame, documented by an upgradient monitoring well.

PFAS were also significantly reduced in wells further away (>25 feet downgradient) from the barrier. This trend should continue as the clean water discharging from the barrier moves downstream.



Map showing CAC pilot test barrier location with yellow star highlighting where FluxTracer was deployed.



- Bulk of the mass flux is between 32-36 feet
- A target zone of 30 to 40 feet is appropriate for the site
- Darcy velocity decreases with depth
- Bulk of the mass flux is between 32-36 feet
- A target zone of 30 to 40 feet is appropriate for the site
- Darcy velocity decreases with depth



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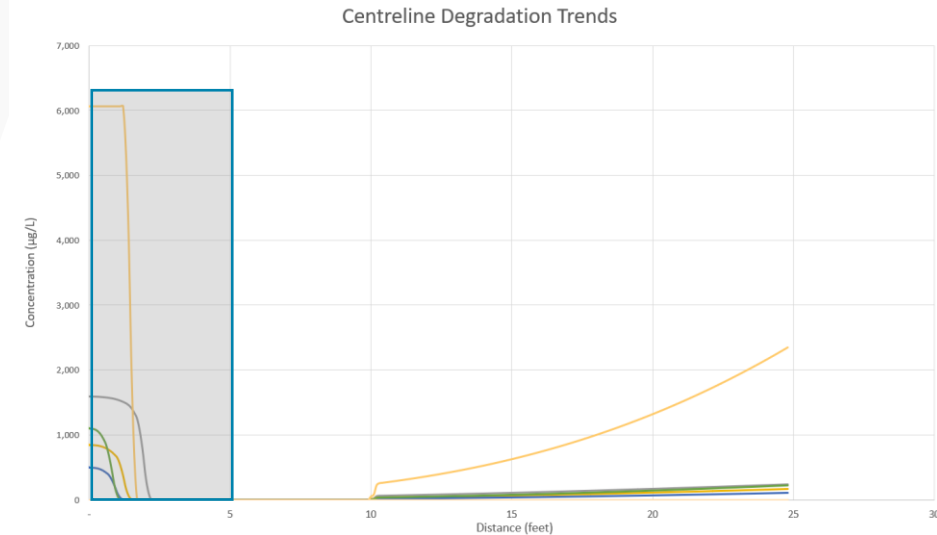
In Situ Remediation

Designing the Treatment

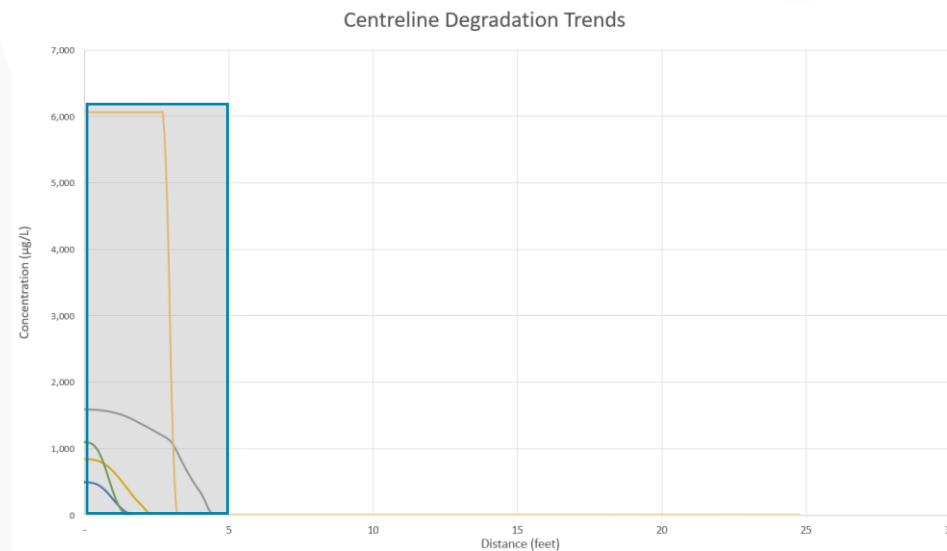
Barrier lifespan modeled on isotherms, dynamic sorption

Dose based on:

- Contaminant flux
- 1st Order Bio Rates
- Dimensions (length, width)
- Competitive Sorption
- Back Diffusion
- Time



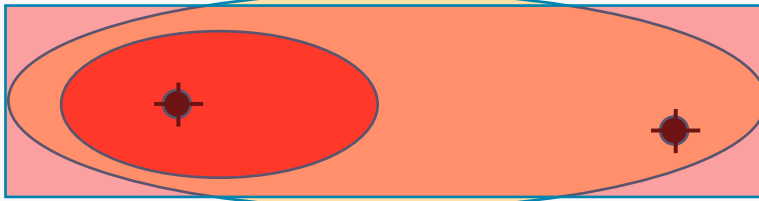
1 Year



5 Year

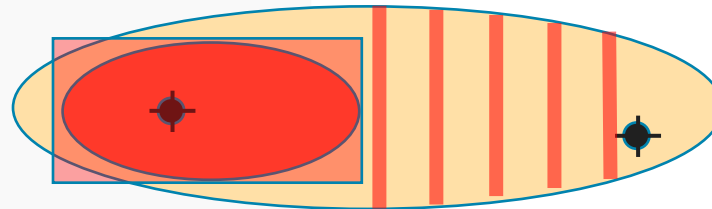
Optimization With Strategic Barriers

20,000 SF Plume, Grid Spacing 6.5'-on-center

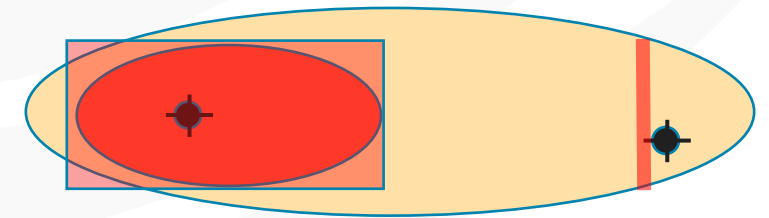


470 injection points; 105,000 gallons water, 35 days in field

Groundwater flow direction



300 injection points; 65,000 gallons water
22 days in field



200 injection points; 50,000 gallons water
17 days in field



Monitoring well

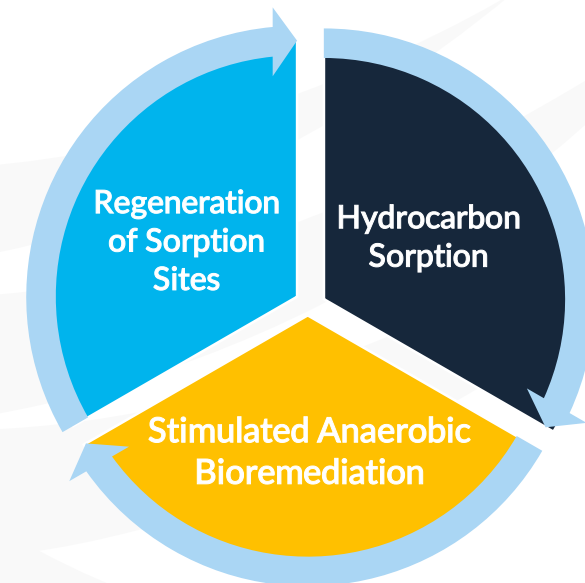
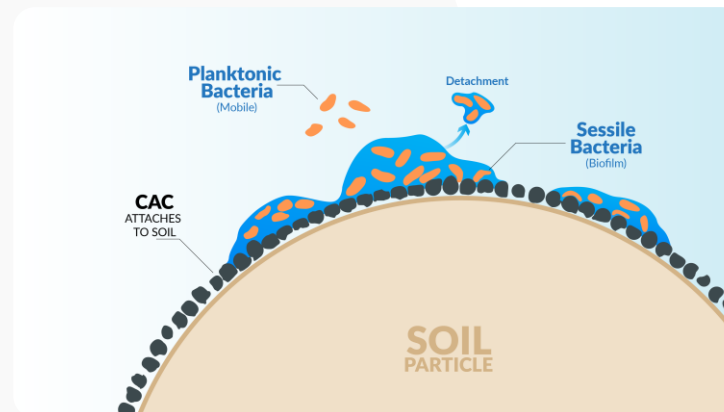
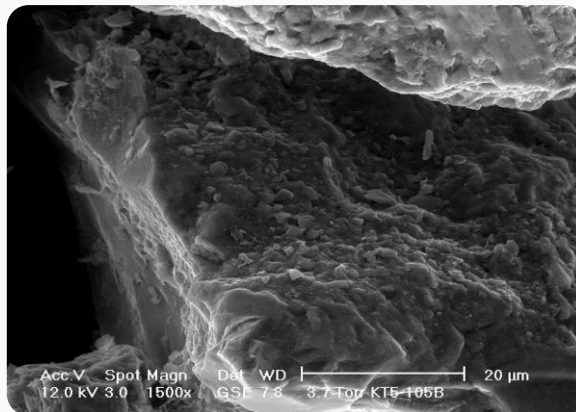


Injection grid

Does PetroFix Increase Longevity?



- PetroFix coats soils in flux zones with a micrometer-thick layer – contaminants adsorb
- Contaminant flux from advection or back-diffusion captured
- **$\text{NO}_3 + \text{SO}_4$ kick-start bioremediation = biofilm formation**
- **YES** - *In situ* carbon regeneration = contaminant destruction and multi-year longevity



Design Considerations For Colloidal Barriers

- Colloidal Advantages
- Mass Flux
- **Distribution**
- Monitoring
- Case Studies

TEMPORARY
INJECTION RIG

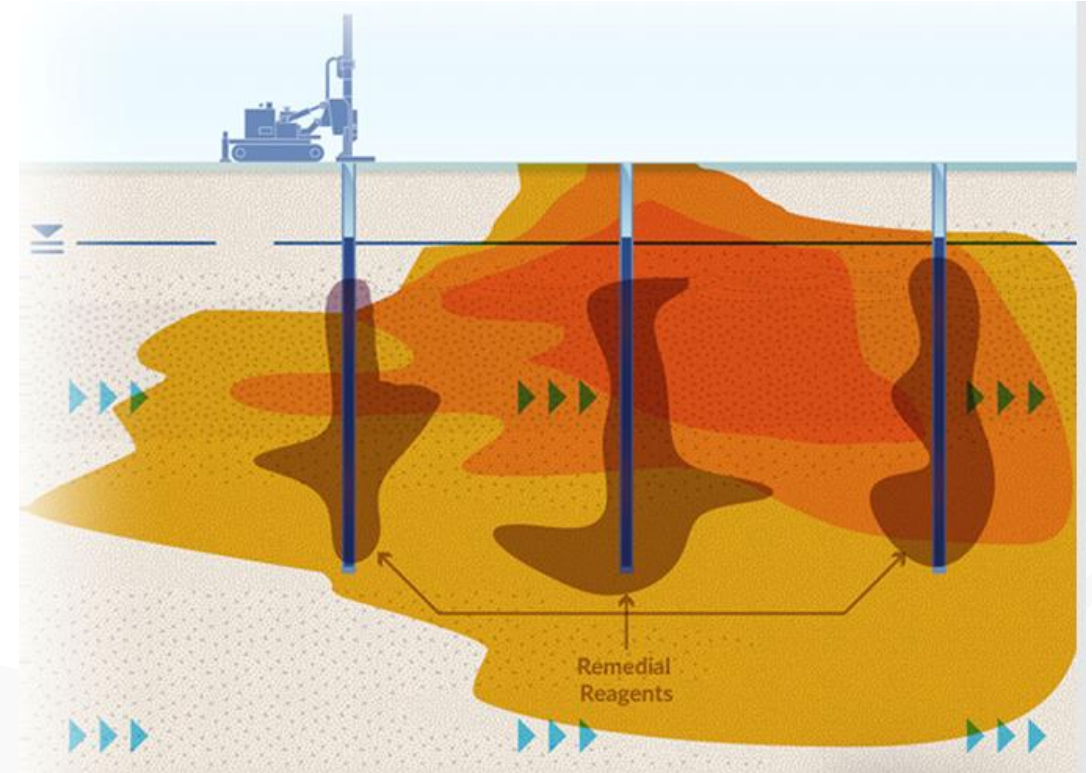


Construction

Distribution and Contact

Poor remediation amendment distribution is a principal limiting factor of performance for in situ remediation¹

Monitoring of injection subsurface conditions should inform real-time adaptation of the delivery approach²



1. Battelle/NAVFAC, 2013 – Injection and Distribution of Amendments
2. ITRC, 2020 – Optimizing Injection Strategies

Construction

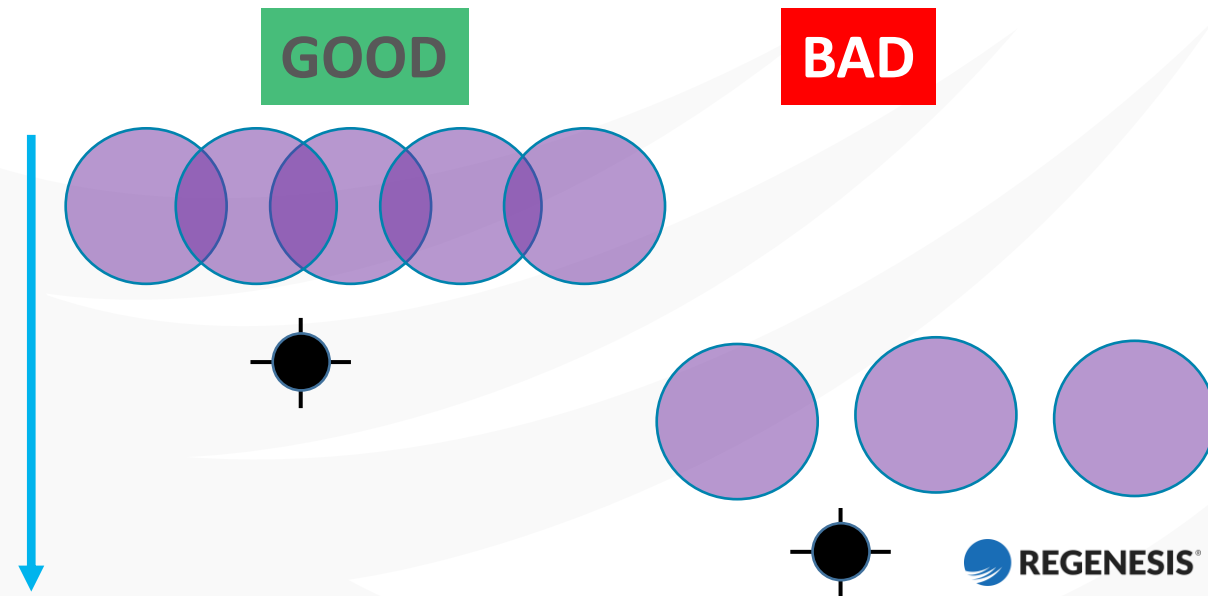
Distribution Verification?

- Don't let economic pressure necessarily dictate spacing for you
- Field test if you feel differently

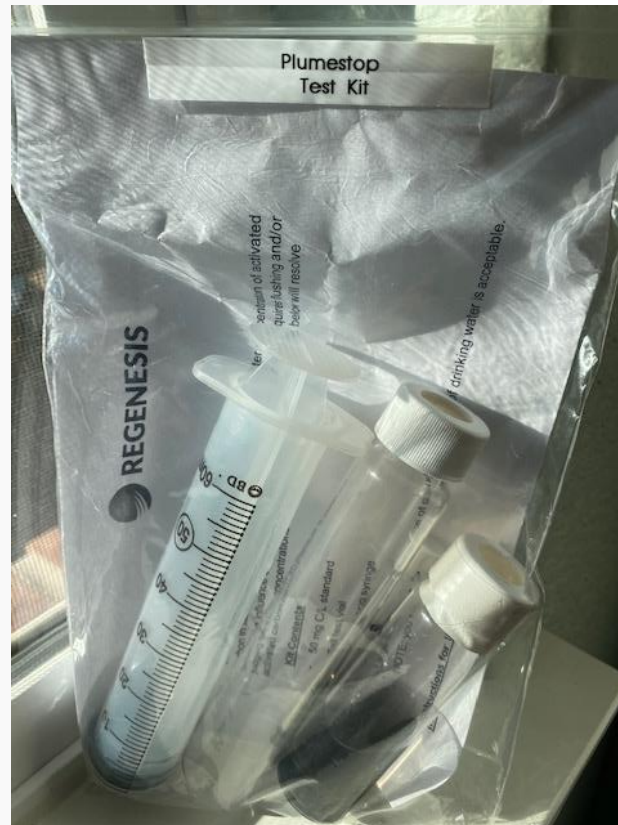


SOIL TYPE	DIRECT PUSH INJECTION POINT SPACING (feet on center)	MINIMUM EPVF %*
COARSE >75% SAND/GRAVEL	6.5	60%
FINE >75% SILT/CLAY	5.0	40%
MIX OF COARSE AND FINE	6.0	50%
BEDROCK	6.0	40%

* EPVF % = Effective Pore Volume Fill Percentage



CAC-Distribution Confirmation



Does CAC Stop Moving or Does it Wash Out?

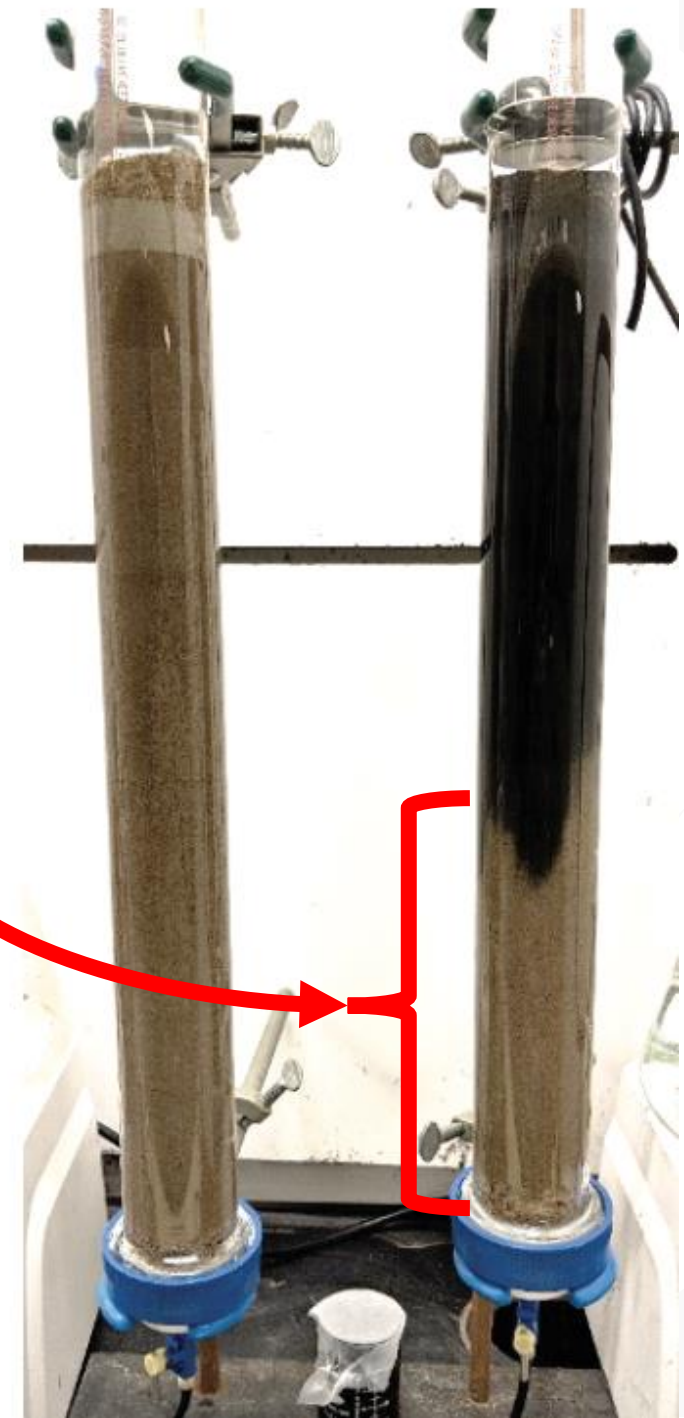
Right column: CAC solution applied and fed tap water for 24 hours.

NO CAC elution from the column

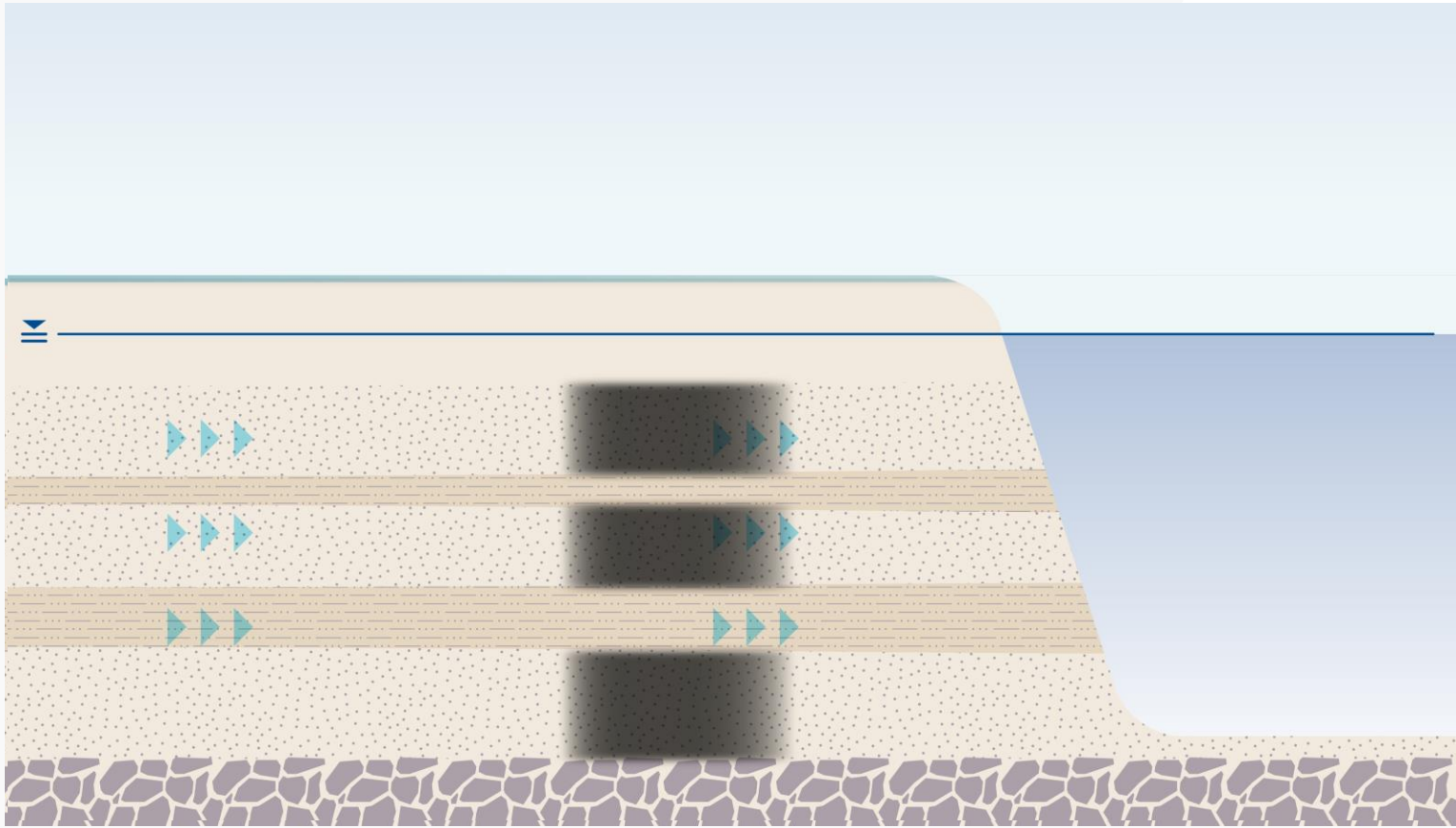
Higher surface area correlates to faster attachment

Post application movement is minor

The control (left) and CAC-treated (right) columns used in the study to demonstrate the ability of CAC to capture small diesel spills.



CAC Can Be Park if Needed

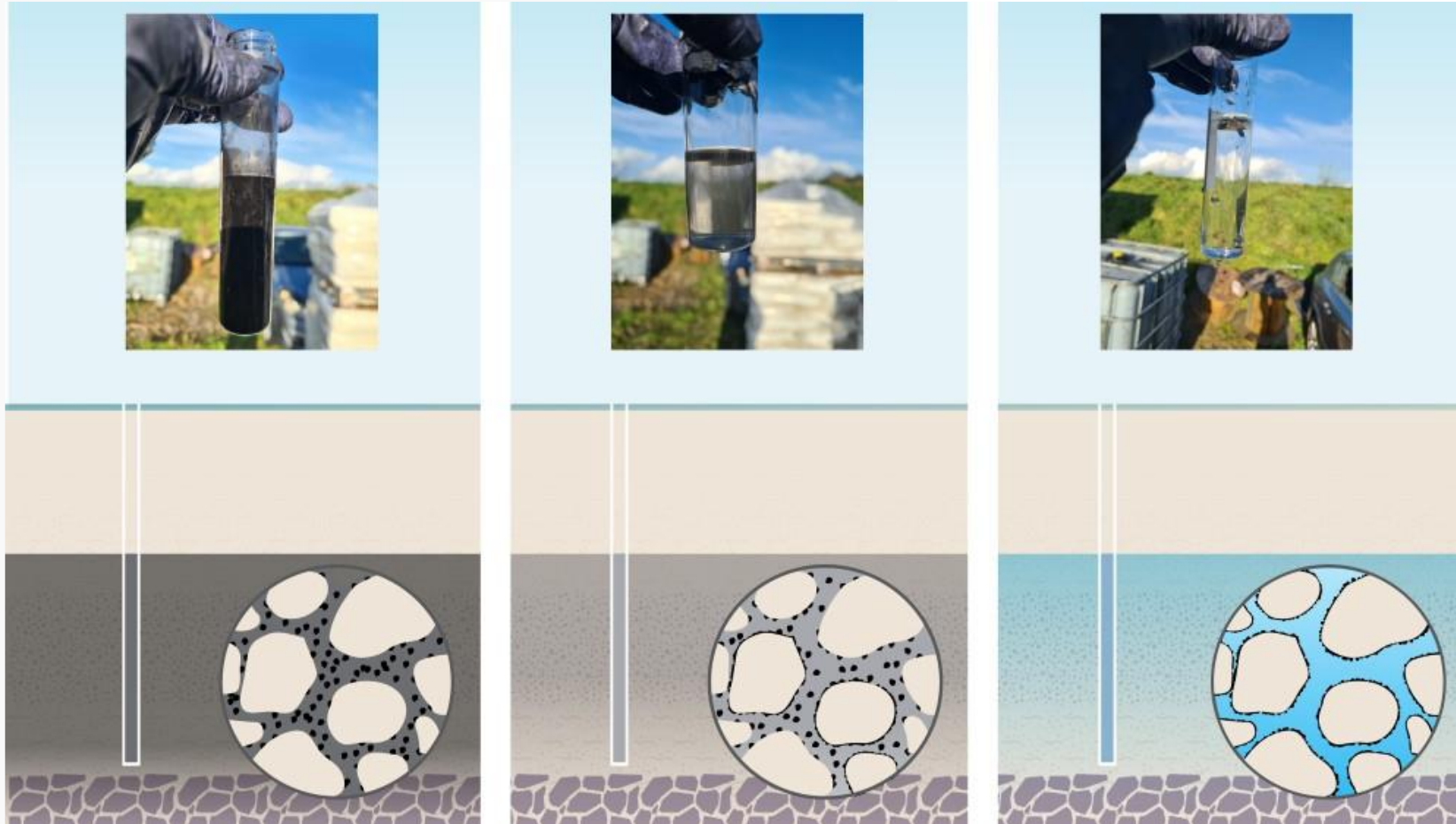


- CAC usually adsorbs to soil before moving out of the injection area
- <0.5% of injection mass to turn water very black

Option:

For High flow and/or low surface area (i.e. gravel/coarse sand)
“Parking” is a solution

What Is Exactly “Parking”?



Applying Chemistry To Break the Colloidal Nature of CAC
and Accelerate Flocculation

Di-Valent Cationic Salts such as Calcium Chloride (CaCl_2)

Design Considerations For Colloidal Barriers

- Colloidal Advantages
- Mass Flux
- Distribution
- **Monitoring**
- Case Studies

TEMPORARY
INJECTION RIG



Injection Monitoring

Upgradient & Downgradient Wells
In Barrier (Distribution)

Visual changes

Measurable geochemistry

- SO₄, NO₃, EC, Sodium

Contaminants

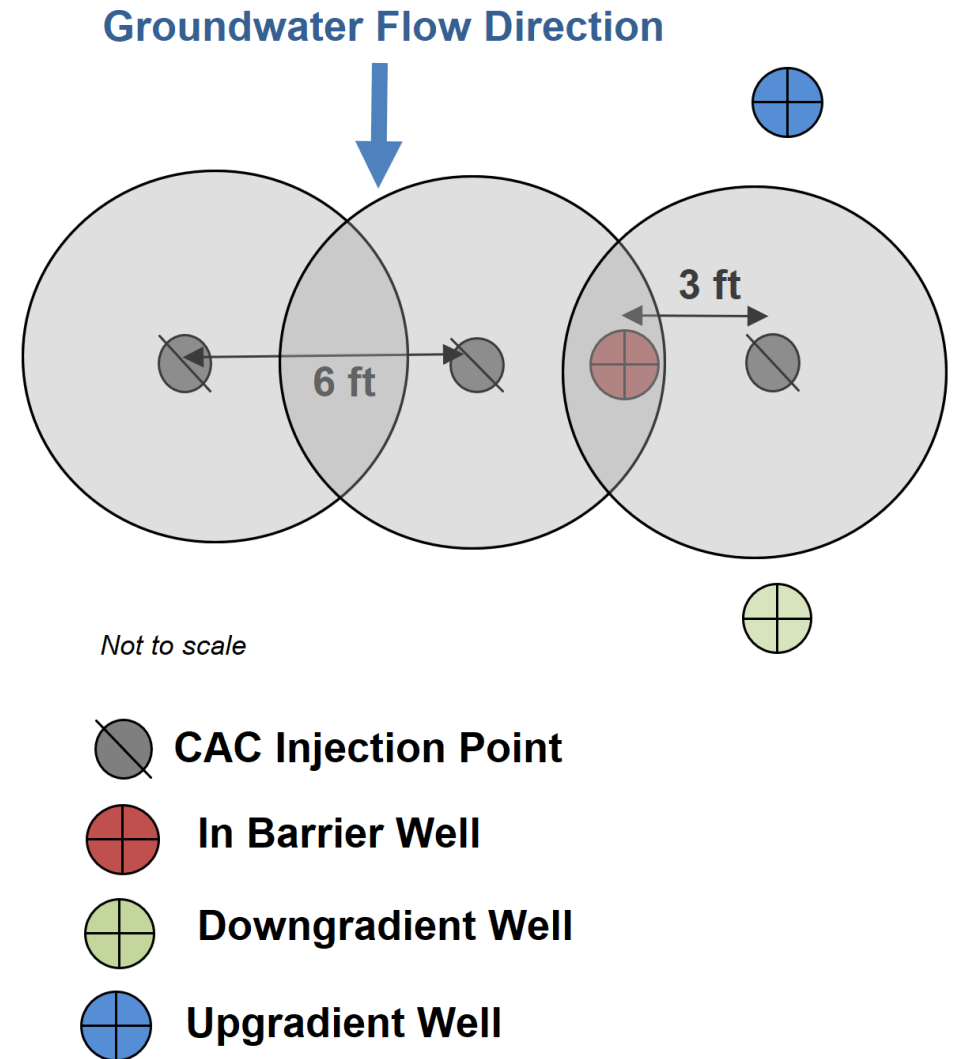
Microbial Indicators

- QuantArray Petro

Methane

UIC parameters

Any required



Post Injection Sampling

- Avoid collecting groundwater samples still black with PetroFix
- PetroFix clarifies in weeks to months to clear or light grey
- If you can see through a VOA and color is light grey, good for sampling
- Post Sampling Technical Bulletins at www.petrofix.com/resources



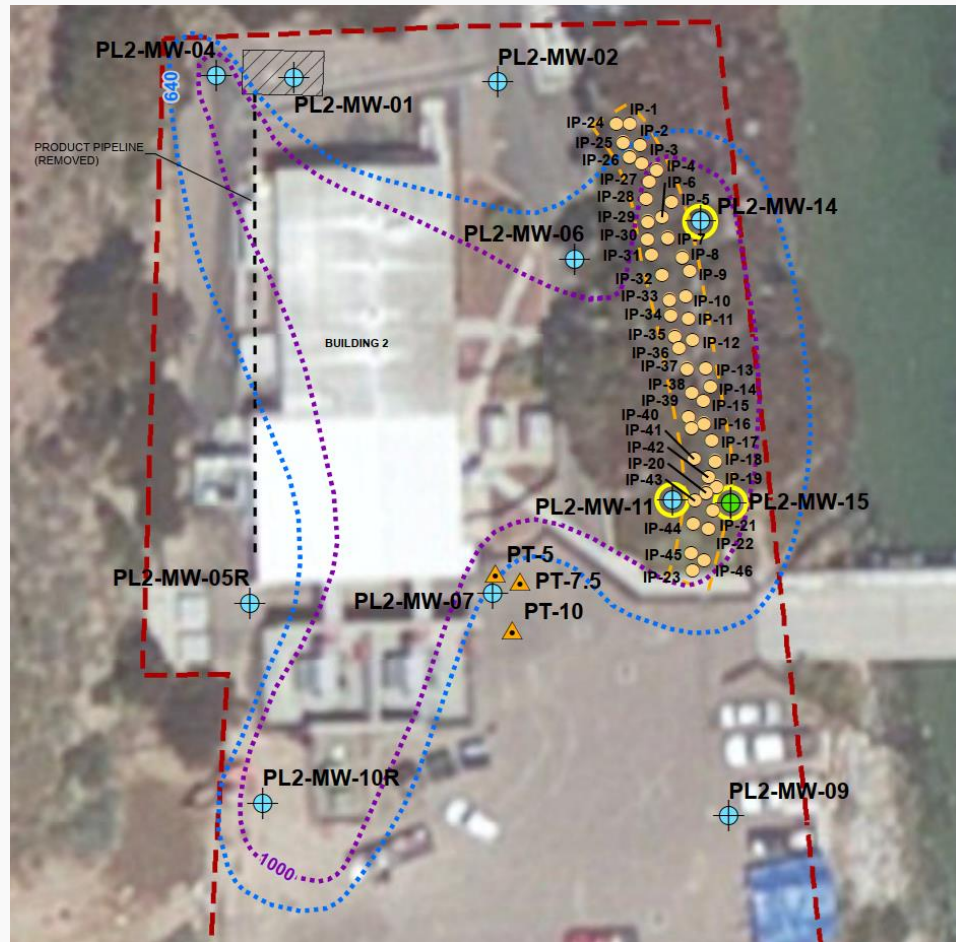
Design Considerations For Colloidal Barriers

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TEMPORARY
INJECTION RIG



Barrier Protects San Diego Bay



Naval Base Point Loma, San Diego

- Diesel-range plume migrating from fuel storage UST to San Diego Bay
- Install a barrier to intercept TPH-d plume
- January 2021 – 3 injection points to verify distribution in flux zones
- Immediately followed full scale:
 - 46 points
 - Double row, staggered
 - 8 to 18' bgs
 - 281 gallons per point

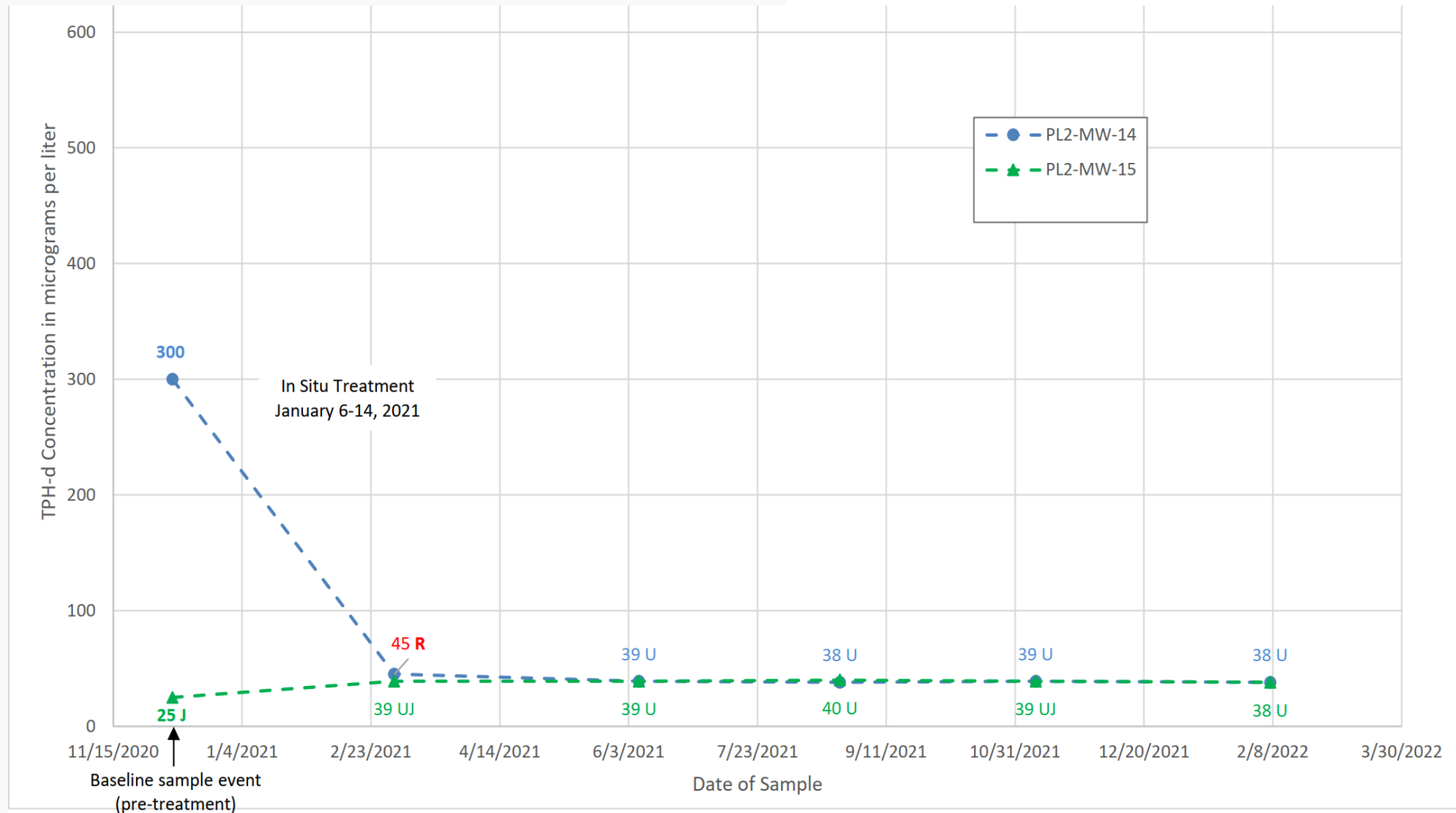
Barrier Protects San Diego Bay

- **Groundwater quality was protected.** TPH-d concentrations decreased to ND in the sentry wells adjacent to San Diego Bay for all 5 post-injection monitoring events (14 months)
- **Nitrate and sulfate concentrations increased** in some wells, stabilized and then decreased to meet water quality parameters for waste discharge compliance within acceptable ranges.
- **Methane concentrations increased** in wells, which provides evidence of the biostimulation of anaerobic hydrocarbon biodegradation.



UST 105 corrective action implementation

Barrier Protects San Diego Bay



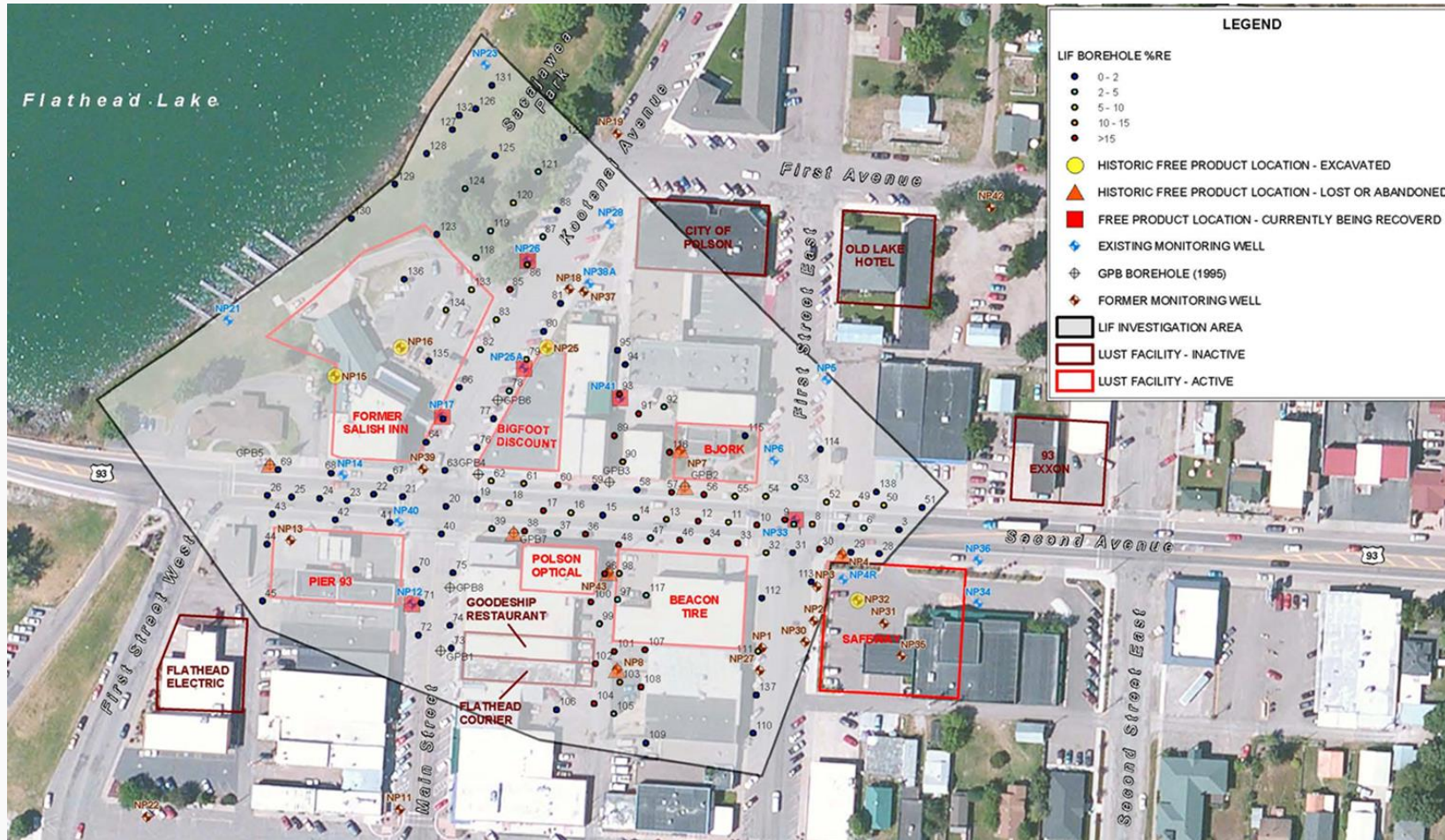
CAC Barrier Protects Flathead Lake, MT

Project Background

- Legacy petroleum release site in downtown Polson, initial investigation in early 1990s
- 13 facilities with releases and individual PRP ownership
- Large undefined LNAPL plume, LNAPL present in various monitoring wells across the site
- Complex lithology consisting of fine-grained, varved lakebed sediments
- Sensitive surface water receptor (Flathead Lake)

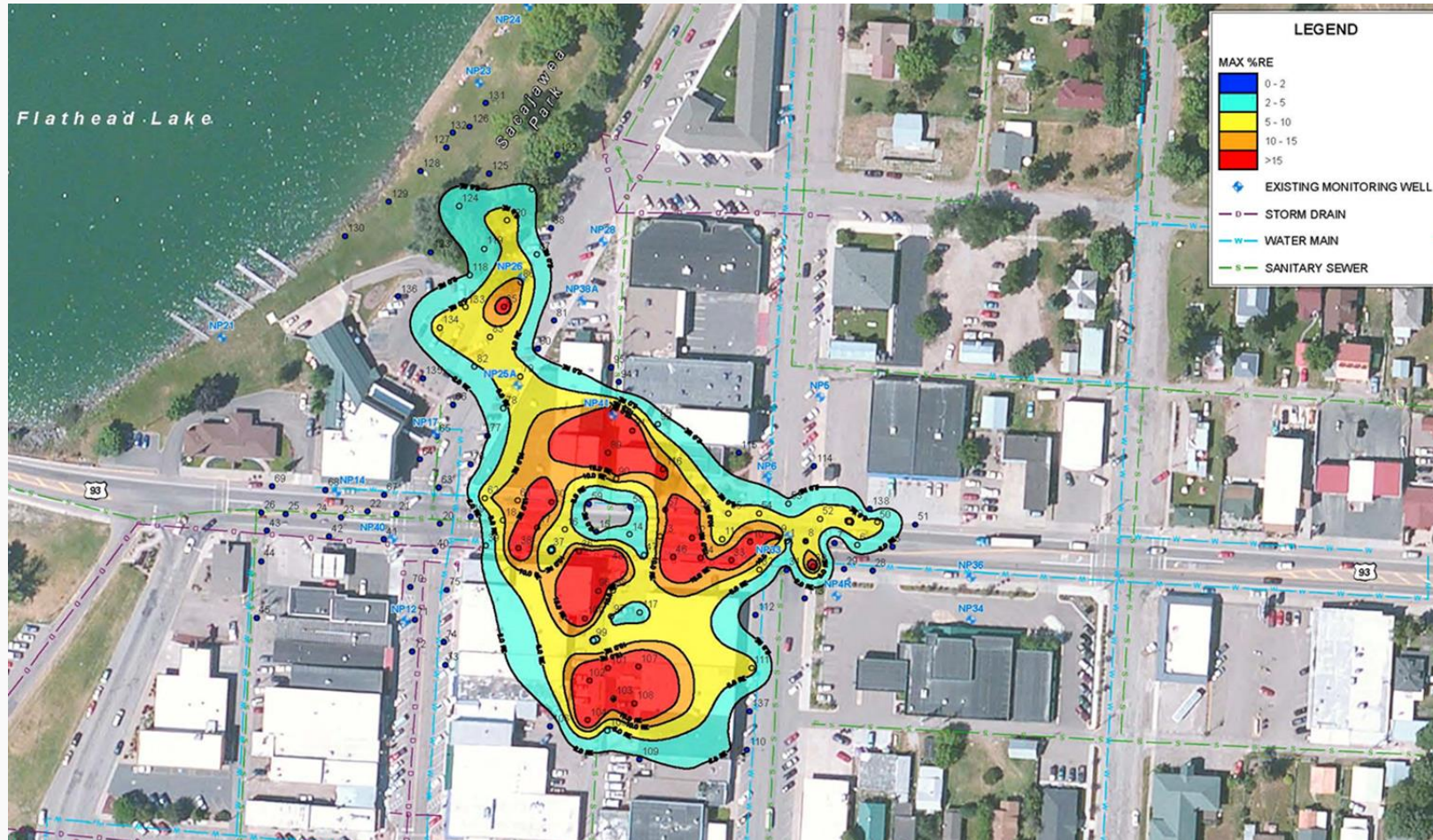
Flathead Lake Reactive CAC Barrier

CSM Development – High Resolution Site Characterization (HRSC)



Flathead Lake Reactive CAC Barrier

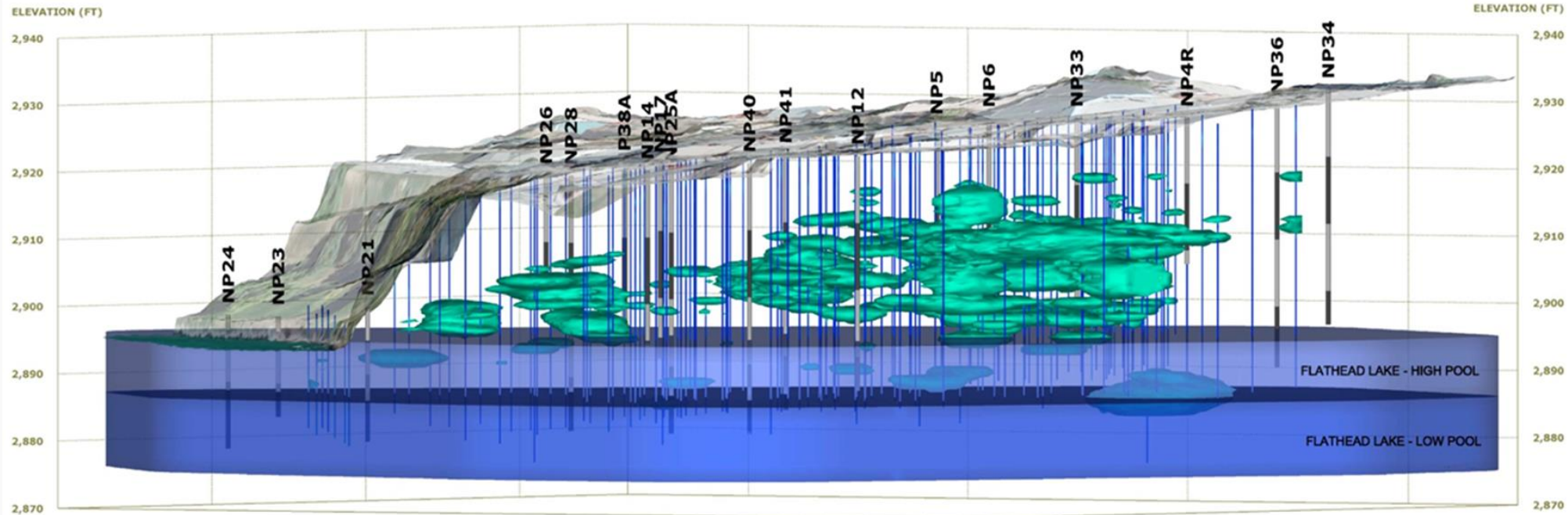
CSM Development – HRSC Investigation



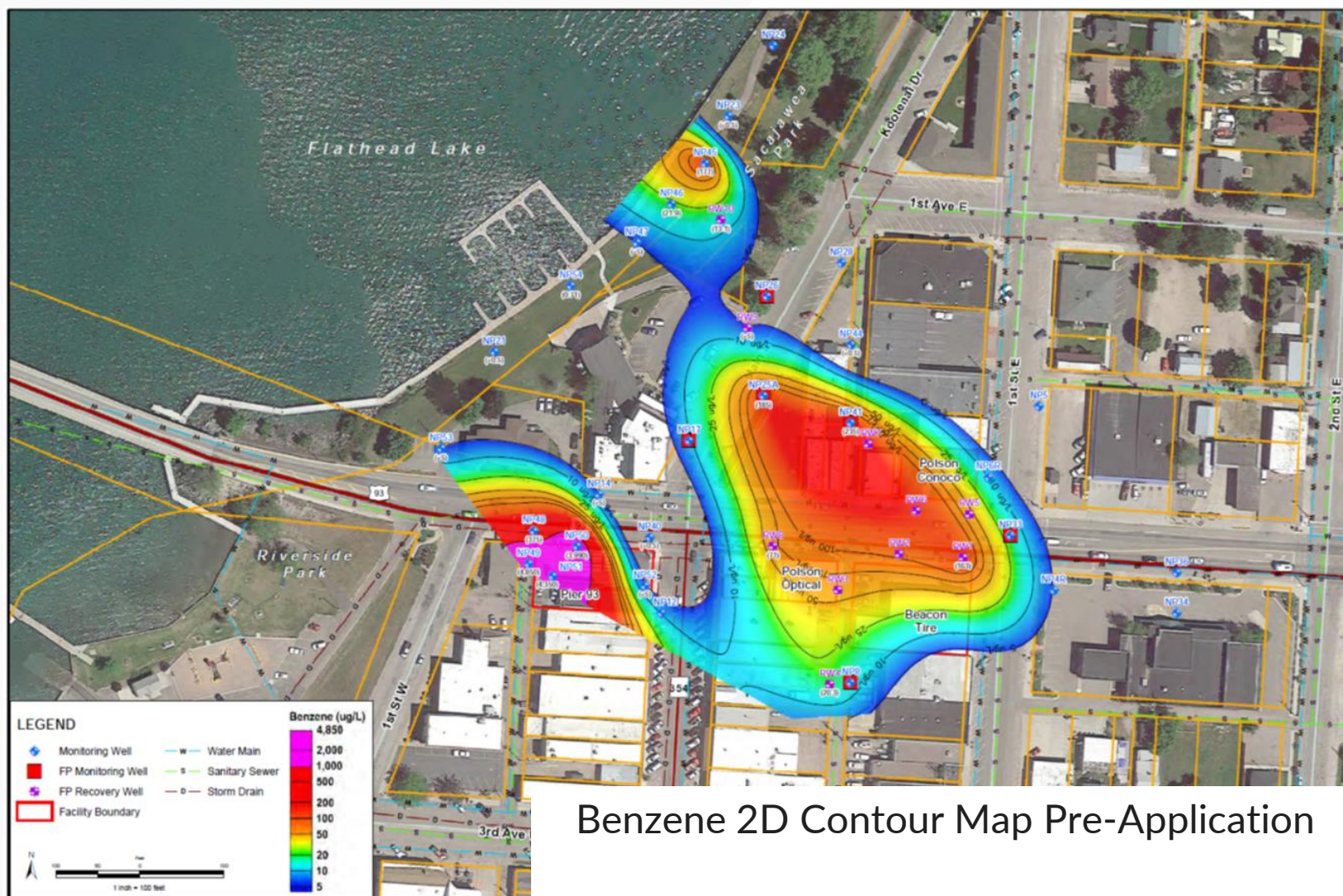
Flathead Lake Reactive CAC Barrier

CSM Development – HRSC Investigation

3D LNAPL Plume Depicting 1 %RE
Four Corners Release Sites
Polson, MT
(Vertical Exaggeration = 5:1)

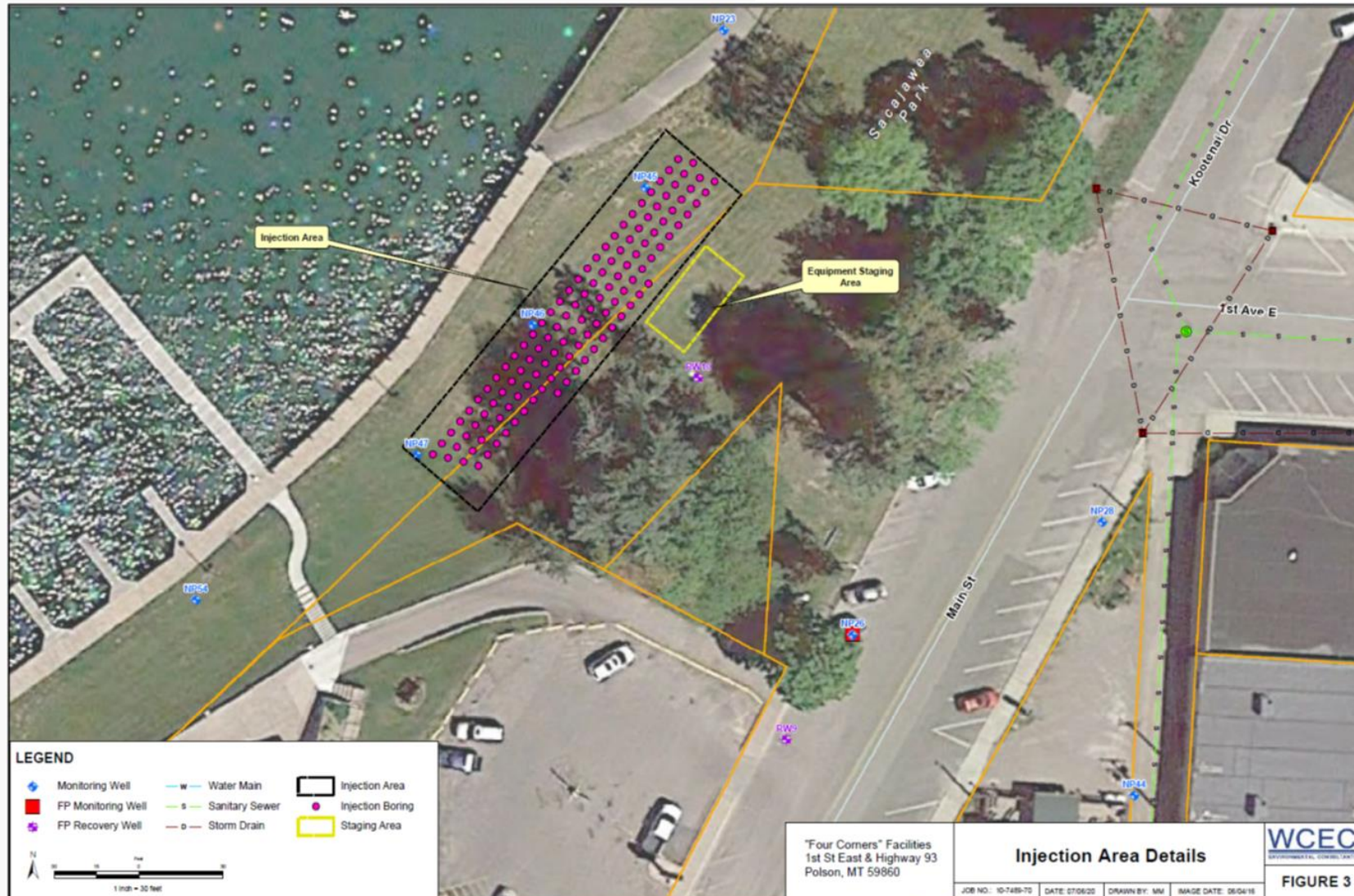


Flathead Lake Reactive CAC Barrier

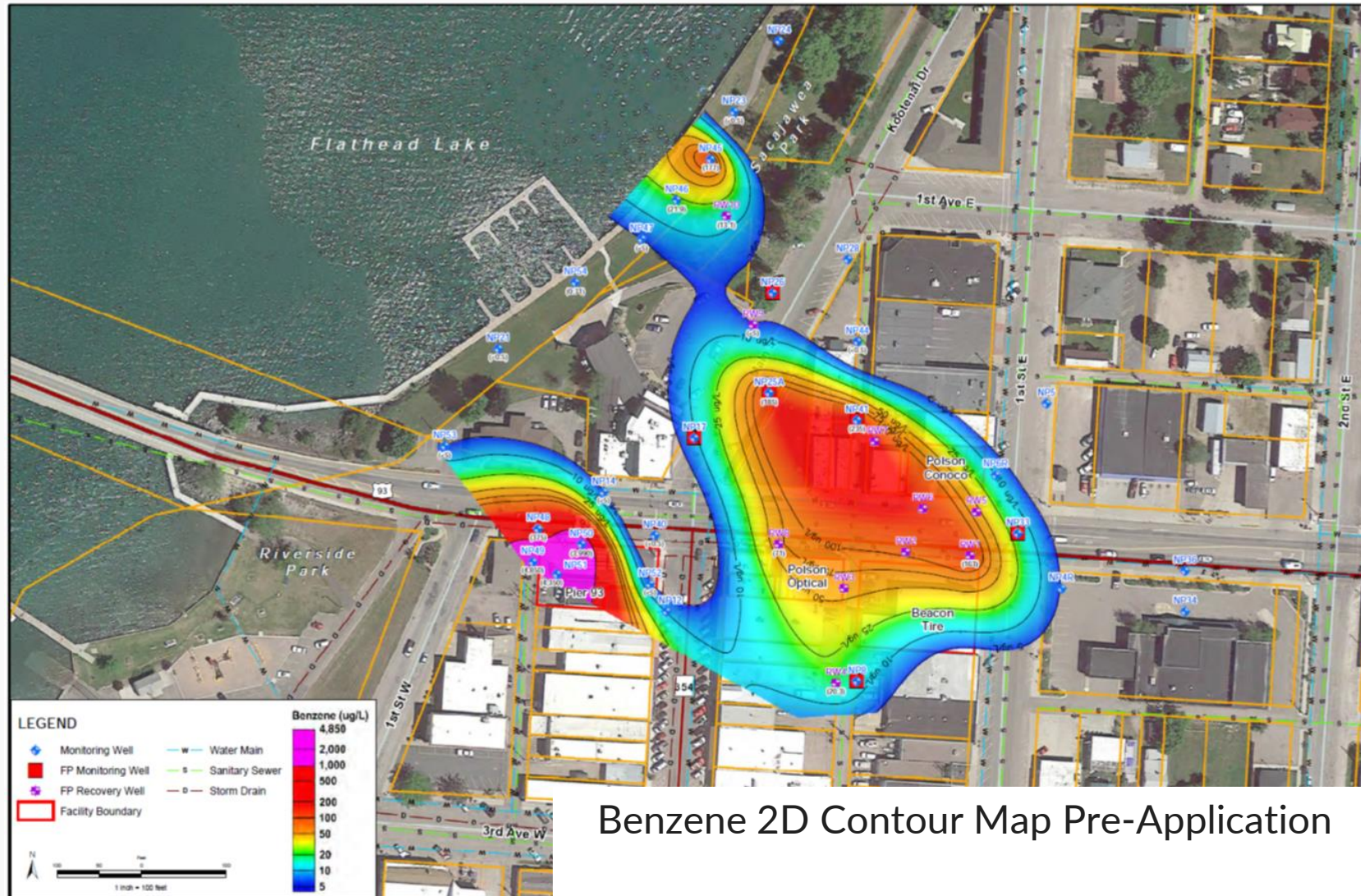


Benzene 2D Contour Map Pre-Application

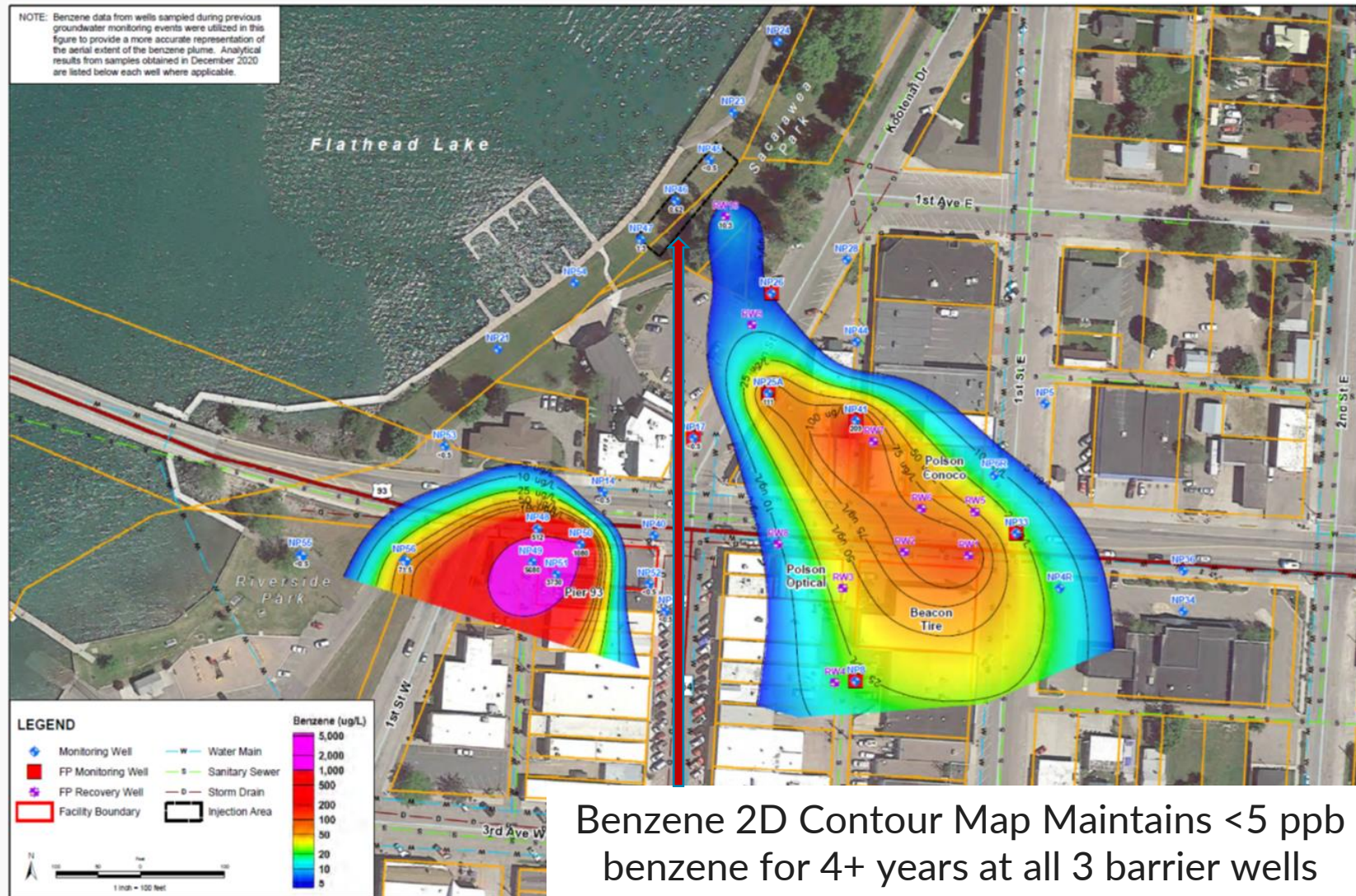
Flathead Lake Reactive CAC Barrier



Flathead Lake Reactive CAC Barrier



Flathead Lake Reactive CAC Barrier



Benzene 2D Contour Map Maintains <5 ppb benzene for 4+ years at all 3 barrier wells

Colloidal Barrier Conclusions

Results:

- CAC can form long-term bio-regenerative barriers
- Mass flux is important for the Remedial Conceptual Model (RCM)
- Field distribution verification is key
- Rapidly effective
- Low concentrations can be achieved (to ND)
- Safe for wells

Questions?

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