A Study of the Effectiveness of Colloidal Activated Carbon as an In-Situ Treatment to Mitigate PFAS Migration in Groundwater at a Michigan Army National Guard Site

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Problem Statement

- Multiple PFAS point sources
- Comingled with PCE plume
- Identified at the property boundary and migrating off-site
- Many potential downgradient receptors
- Limited budget for field testing of remedial technologies

- Question:

  Can CAC be used as a means to mitigate the risk of PFAS to the sensitive receptors?

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Grayling Army Airfield

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Site Description

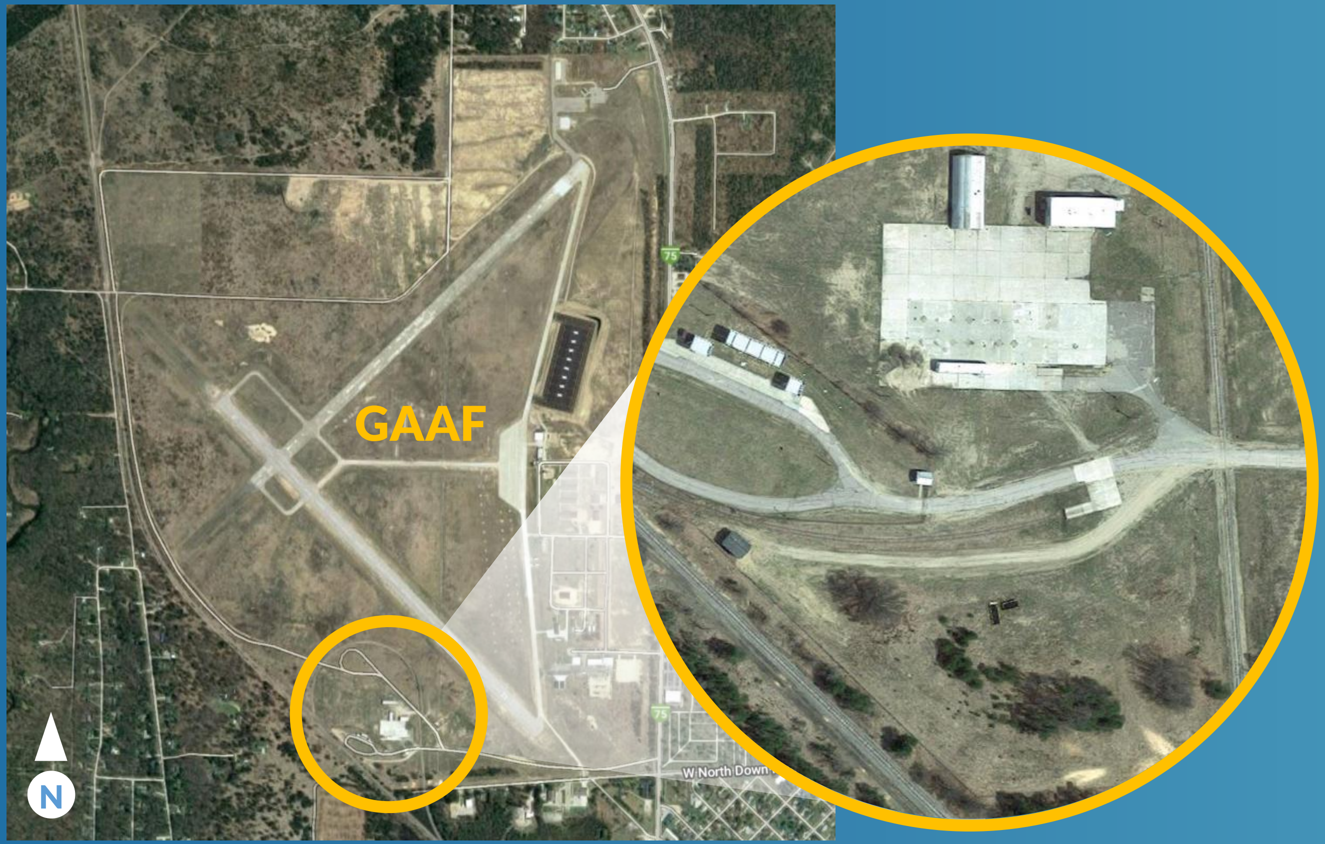
Site Location:
Camp Grayling Joint Maneuver Training Center

- Founded 1913
- 147,000 acres
- Largest National Guard training center in the country
- Training facility for military, emergency responders, and private-sector from all over the world
- Home to the Grayling Army Airfield

Grayling Army Airfield (GAAF)

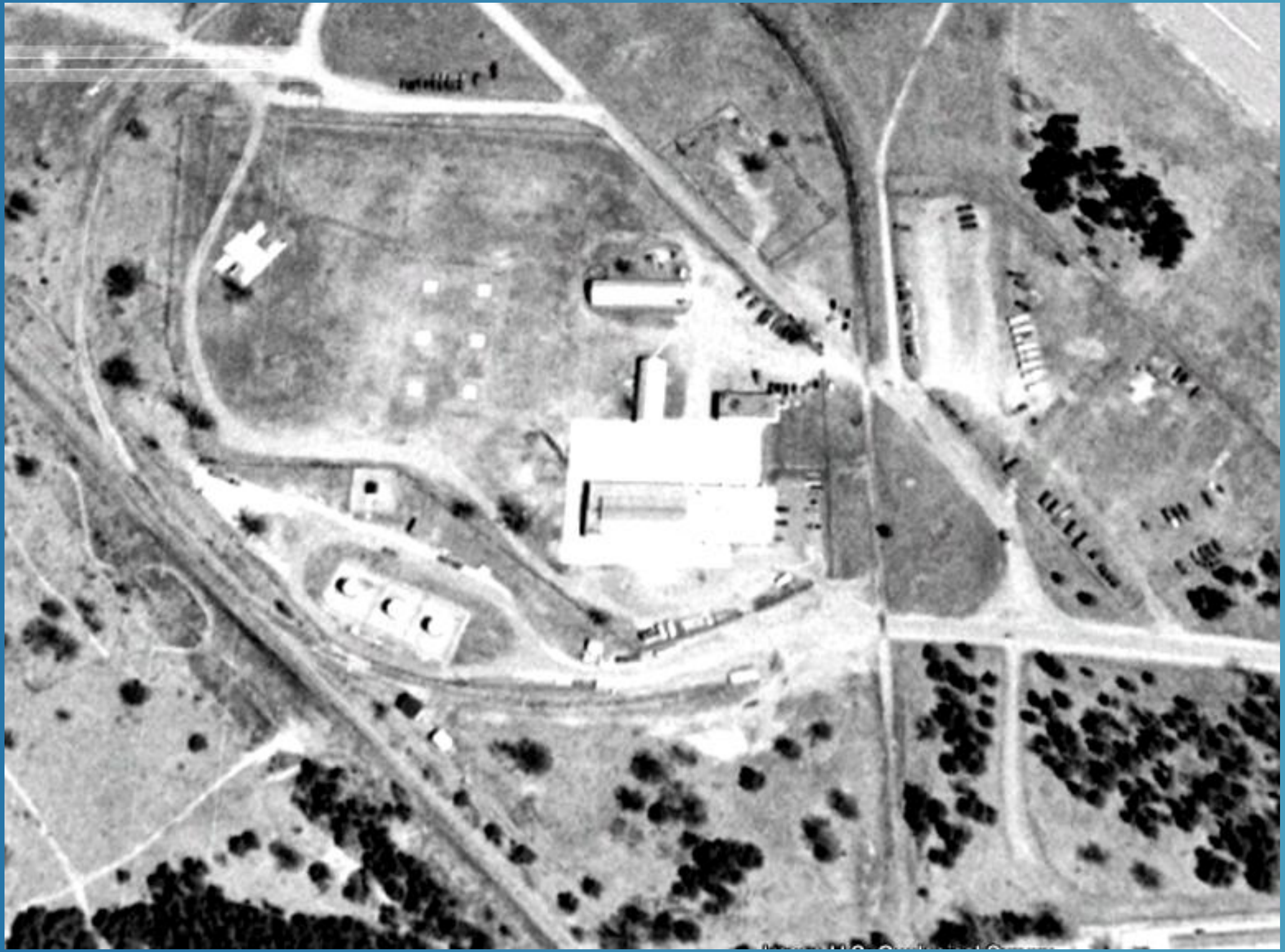
- 900-acre
- Built during World War II

Former Bulk Fuel Storage Area



- Generally flat, slight slope downward toward the south
- Surficial geology: sand and gravel
- Non-continuous clay layer at ~ 25-27 feet bgs
- 2nd deeper clay layer in some areas at ~45-60 feet bgs
- GW at ~ 17 feet bgs and flows south toward Au Sable River, ~4000 feet away

Former Bulk Fuel Storage Area



*1994 Photo

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What a long strange trip it's been…

1984-1988

- Diesel fuel release from buried feed line of bulk fuel tank.
- Soil excavation, removed leaking pipeline and
- Surficial pumping of free product and GW.
- GW treated using GAC, return- leach fields and injection wells.
- Free product recovery complete, but GW still contaminated with BTEX.

Remediation History

1988

- Enhanced GW bioremediation system installed
- Above ground bioreactors and reinjected
- PCE and TCE contamination discovered
- PCE/TCE distribution was not consistent with BTEX plume
- No defined PCE/TCE source identified
- Bioremediation successful on diesel fuel release

Remediation History

1992-1998

- Bioremediation not effective for remediation of PCE/TCE
- Bio system removed and replaced with liquid-phase GAC system.
- FS to identify remedial technology to reduce PCE/TCE in GW
- Modified GW extraction system in order to capture deeper PCE/TCE.
- Included network of recovery wells, GAC, and infiltration gallery.
- Additional investigation performed to determine source of PCE/TCE.
- Two areas with elevated concentrations of PCE/TCE identified.

Remediation History

1999-2001

- Air sparge/soil vapor extraction (AS/SVE) installed to remediate PCE/TCE source areas.
- Additional AS/SVE points added.
- Increasing levels of PCE observed in MW located on eastern boundary of GW plume.
- Investigation finds separate plume east of previously identified plume, suggesting another upgradient source.

Remediation History

- PCE/TCE sources??
- Degreasers used in cleaning/maintenance of tanks/vehicles
- Took place in and around buildings and helicopter landing area, tank cleaning conducted wherever tanks were staged
- Small quantities of used solvent likely dumped to ground
- Result: numerous, small, discrete and randomly distributed source areas

Remediation History

2002-2006

- Additional 3 separate PCE/TCE GW plumes identified
- HRC injected in GW near leading edge of PCE/TCE plume
- Investigations revealed PCE/TCE plume was larger/deeper
- GAC treatment system upgraded with additional wells
- With new wells, total pumping capacity of all recovery wells exceeded capacity of GAC system, but select recovery continued until the system was replaced by air stripping system
- Increased flow capacity of air stripper allowed use of all recovery wells simultaneously

Remediation History

2007-2016

- PCE was primary constituent detected in GW air stripper
- Air stripper system continually active
- PCE/TCE GW plumes remained delineated
- Existing recovery well network was effectively capturing and remediating GW
- PCE /TCE not detected in GW above residential drinking water criteria in MWs downgradient of recovery wells at toe of East and West Plumes

Remediation History

2016

- Due to growing concerns with PFAS at military sites, MIARNG proactively initiated an investigation for presence of PFAS in GW at GAAF…
- Bulk Fuel Area was chosen due to several existing shallow and deep monitoring wells and it is hydrogeologically downgradient of Airfield.
- PFOS detected in 6 GW samples

Remediation History

2017

- GW sampling along GAAF's western and southern fence lines to determine if PFAS migrated off-site.
- PFOS/PFOA identified in GW samples collected at 11 of 38 fence line VAP locations
- Subsequent off-site sampling of residential wells finds exceedances of PFAS criteria
- Alternative water supplied to impacted homes.
- NGB initiates CERCLA process at Camp Grayling beginning with Preliminary Assessment

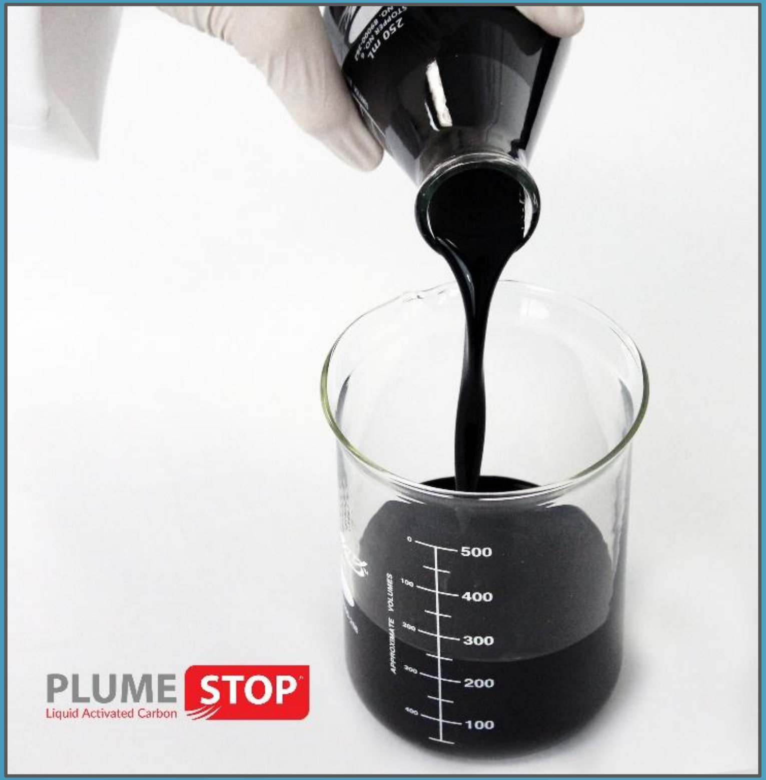
Remediation History

2018 MIARNG initiated Plumestop pilot project to evaluate:

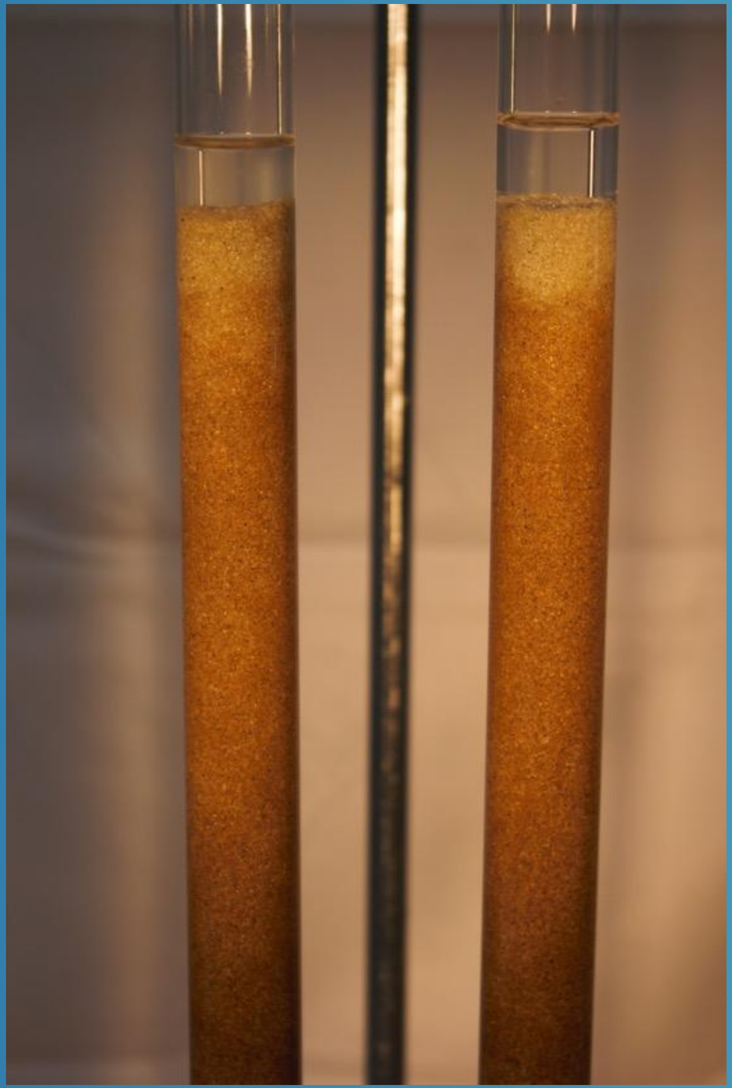
- Ability to polish GW for PCE/TCE to eliminate long-term O&M of air stripper system.
- Long-term ability to reduce concentration of PFAS compounds in GW under GAAF's in-situ hydrogeologic conditions.

Colloidal Activated Carbon

- Size: 1 – 2 µm
  - 2-3 OOM smaller than GAC (500-1,000 µm)
  - Size of a red blood cell
  - Suspended in water/polymer
  - Distributes widely at low pressure
  - Extremely fast sorption
  - Huge surface area
  - Converts polluted aquifer into purifying filter



PLUMESTOP – REAGENT DISTRIBUTION



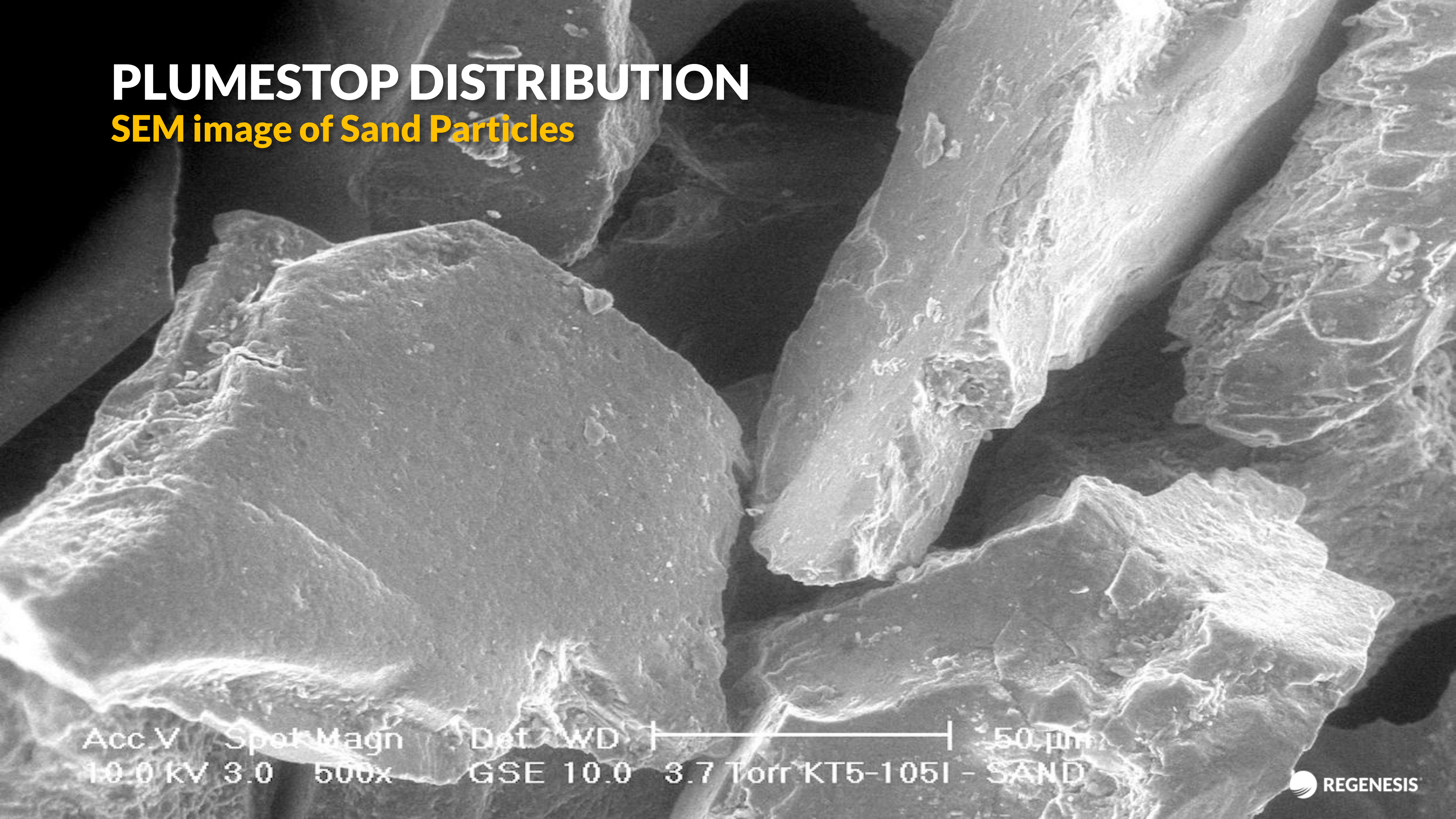
PLUMESTOP – REAGENT DISTRIBUTION

PLUME STOP®
Liquid Activated Carbon

Powdered
Activated Carbon

PLUMESTOP DISTRIBUTION

SEM image of Sand Particles



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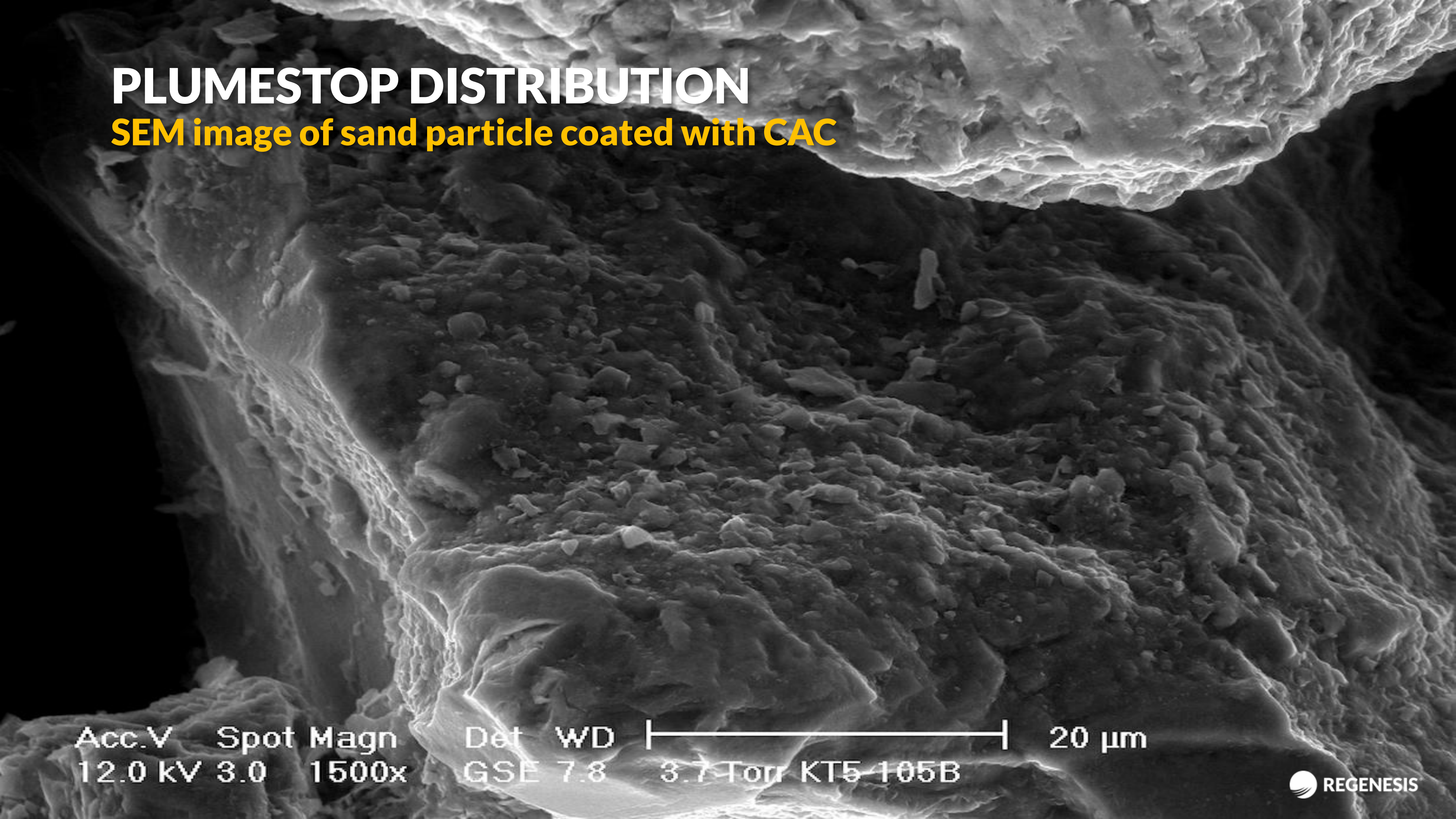
PLUMESTOP DISTRIBUTION

SEM image of sand particle coated with CAC



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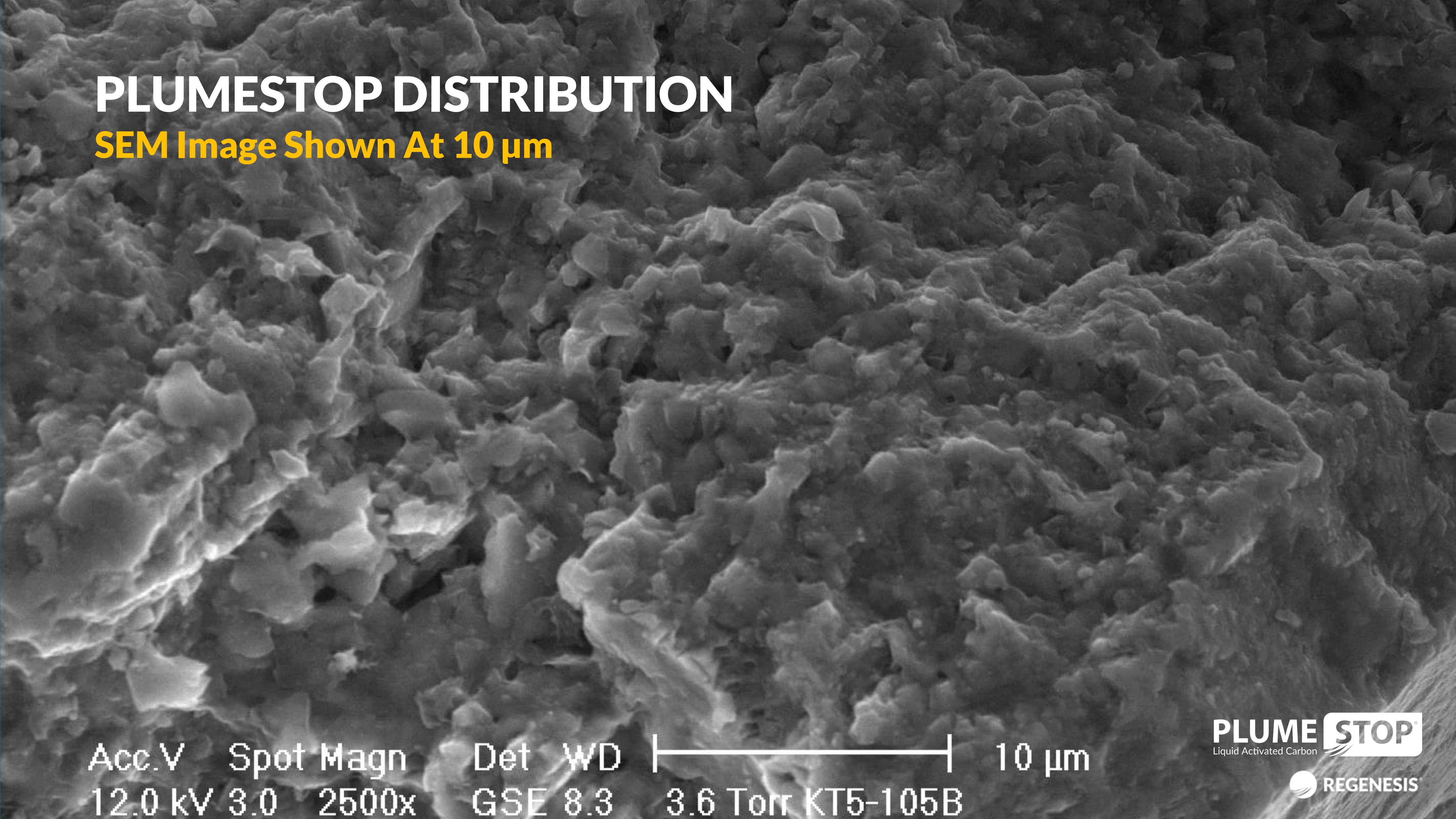
PLUMESTOP DISTRIBUTION

SEM Image Shown At 10 µm



PLUME STOP
Liquid Activated Carbon

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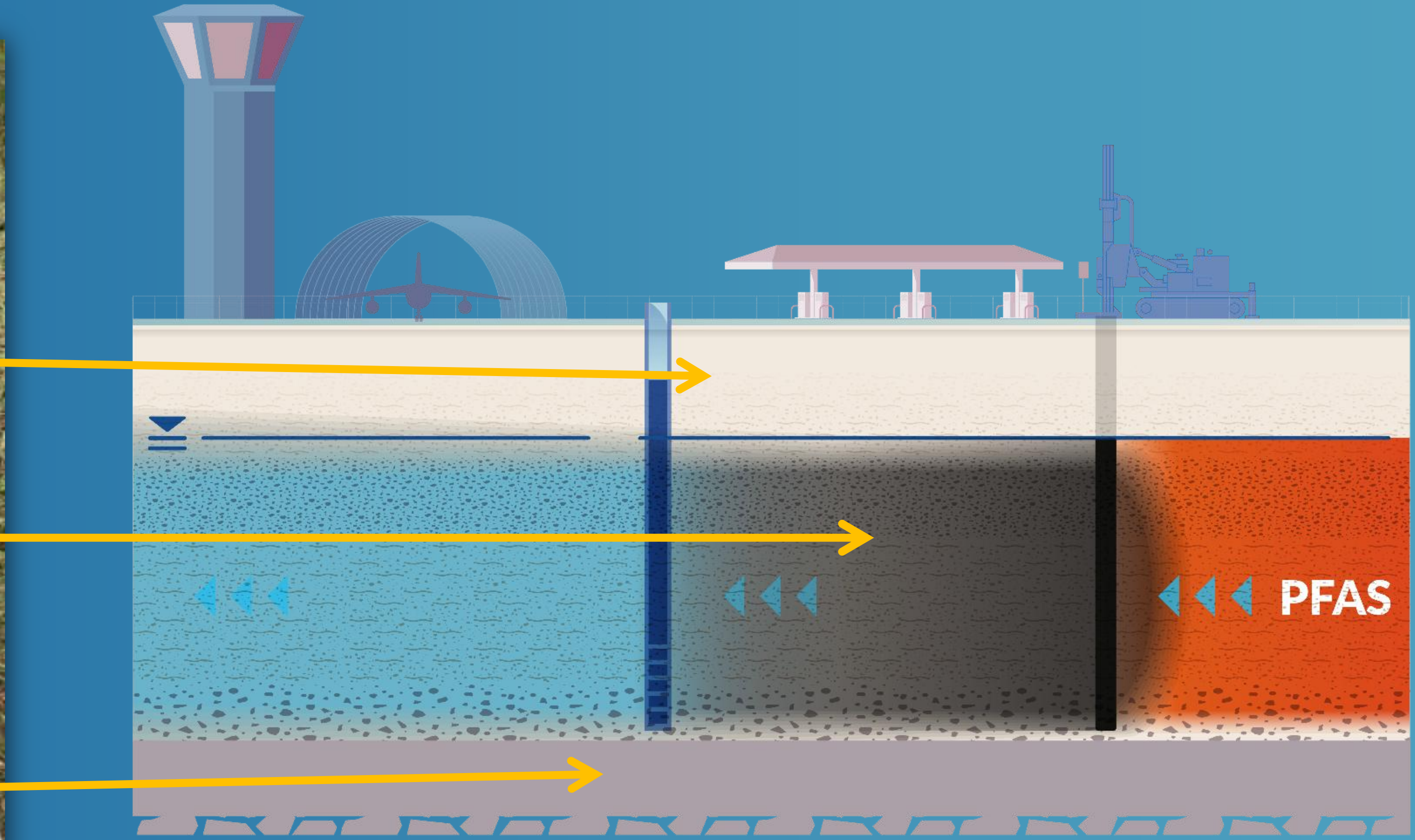
Treatment of Flux Zones and Control of Back Diffusion



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ENVIRONMENTAL RISK

Environmental RISK = (Hazard) X (Exposure)

Attributed to Dr. Frank Lawrence, ELD, Portland Maine

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ELIMINATE THE RISK FROM PFAS

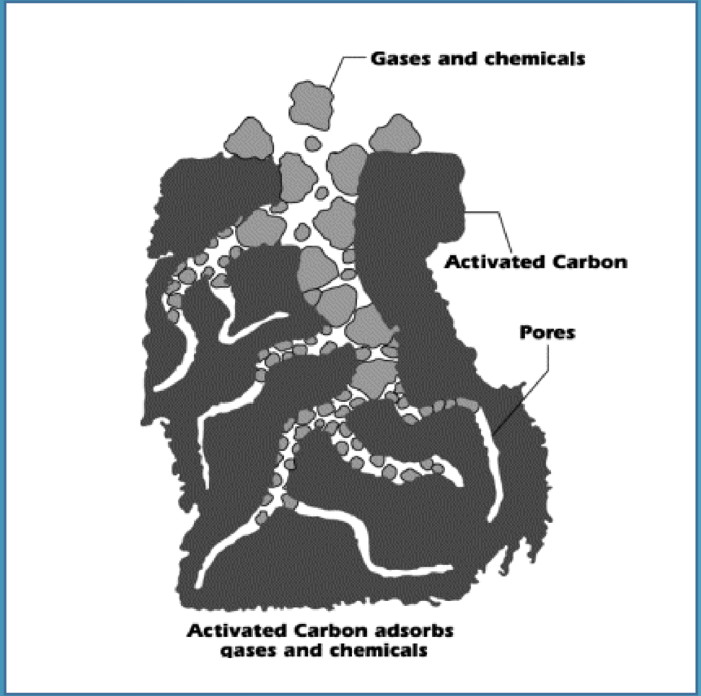
- Injection of colloidal activated carbon
- Sorbs PFAS out of solution
- Prohibits migration of plume

Environmental RISK = (Colloidal Activated Carbon) X (Exposure)

SMALLER PARTICLES = MUCH FASTER SORPTION

The reason can be attributed to kinetics:

- Intraparticle diffusion is the same regardless of size
- Smaller particles provide more exterior surface and shorter distance to all the sorption sites



[a]Xiao, Ulrich, Chen & Higgins. Environ. Sci. Technol. 2017, 51, 6342.

PARTICLE CROSS SECTION ILLUSTRATION

Granular Activated Carbon (>500µm):

Slow sorption due to limited surface area exposed to solute

Collodial Activated Carbon (1-2 µm):

Rapid sorption and more complete use of sorption sites

CAPTURE EFFICIENCY: PS + PFAS

So what happens over time?

- Won’t the barrier eventually fill up and breakthrough?
- As PFAS do not degrade, the answer is yes
- What’s important is how long this will take

RETARDATION FACTOR: PS + PFAS

A Retardation factor (R) of 1 means the contaminant is moving at the same rate of GW

R of 10 means the plume is traveling 1/10th the rate of GW

PFOA

- The R of a 100 µg/L plume is 570

PFOS

- The R of a 100 µg/L plume is 2,000

RETARDATION FACTOR: PS + PFAS

Example:

- 100 µg/L influent concentration
- PlumeStop barrier width 16’ (single application at mid-range dose)
- 160’ per year seepage velocity

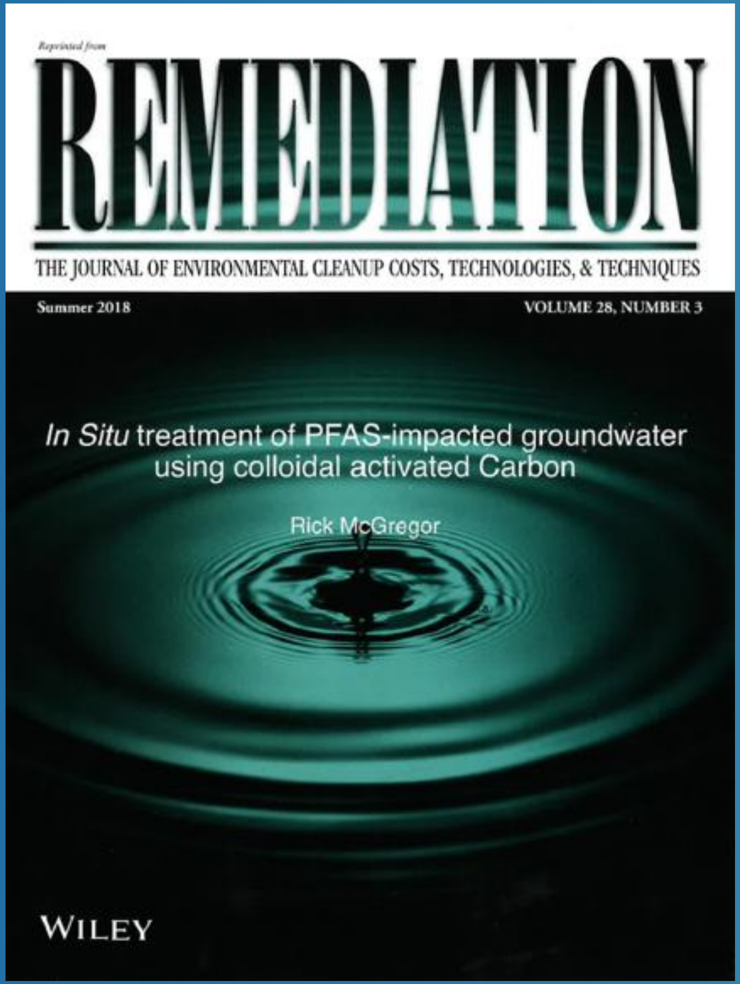
This is at 100 µg/L

At lower influent concentrations, the retardation quickly becomes much greater.

- GW transit time = 36.5 days
- PFOA transit time* = 20,800 days (57 years)
- PFOS transit time* = 73,000 days (200 years)

* transit time peak based on individual components

Longevity-Third Party Review



- University of Waterloo, Waterloo, Ontario, Canada
- University of Toronto, Toronto, Ontario, Canada
- Purewater Solutions, Ottawa, Ontario Canada
- In Situ Remediation Services Ltd., St. George, Ontario, Canada

Longevity Conclusions:

- Increased by CAC concentration injected
- Length of treatment area

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Field Test Location

Former Bulk Storage Tanks Location

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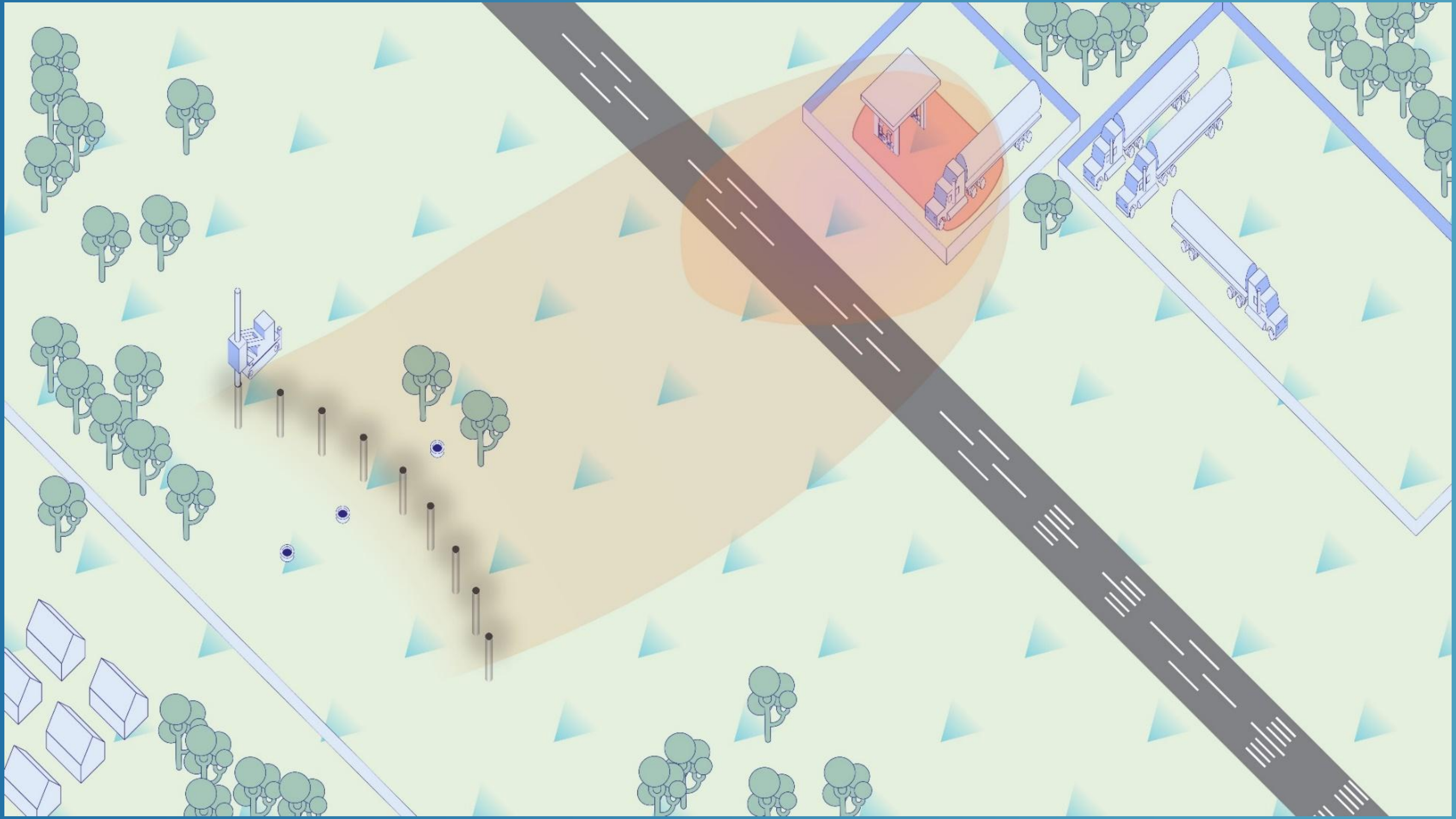
Simple Plume Cut-Off Barrier



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Modeling in the Design Process

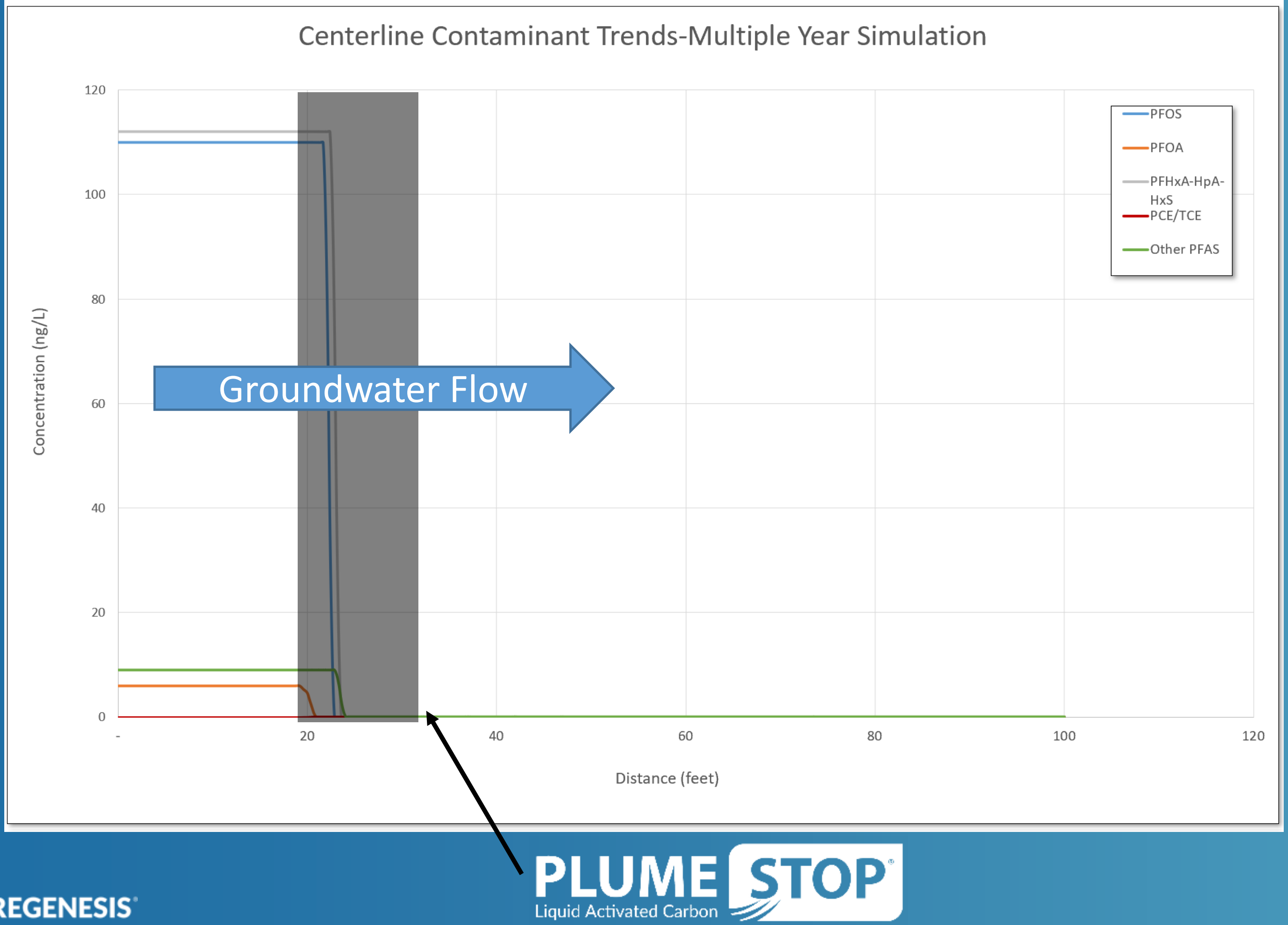
PlumeForce

- Long-Term Prediction Model
- Competitive Sorption and Degradation (if applicable)
- Compound Specific Isotherms
- VOCs, PFAS, etc.

Considerations

- Soil Type/Porosity
- Groundwater Seepage Velocity/Mass Flux
- Vertical Variations
- Barrier Thickness
- Carbon Demand
- Time

Modeling in the Design Process



Inputs

- GW 219 feet/year
- Infinite Source
- PFOS 110 ng/L
- PFOA 8 ng/L
- PFHxA -HpA – HxS 112 ng/L
- Other PFAS 9 ng/L
- PCE 10 ug/L
- No degradation of any PFAS compound or CVOC's

- Time (>75yrs)

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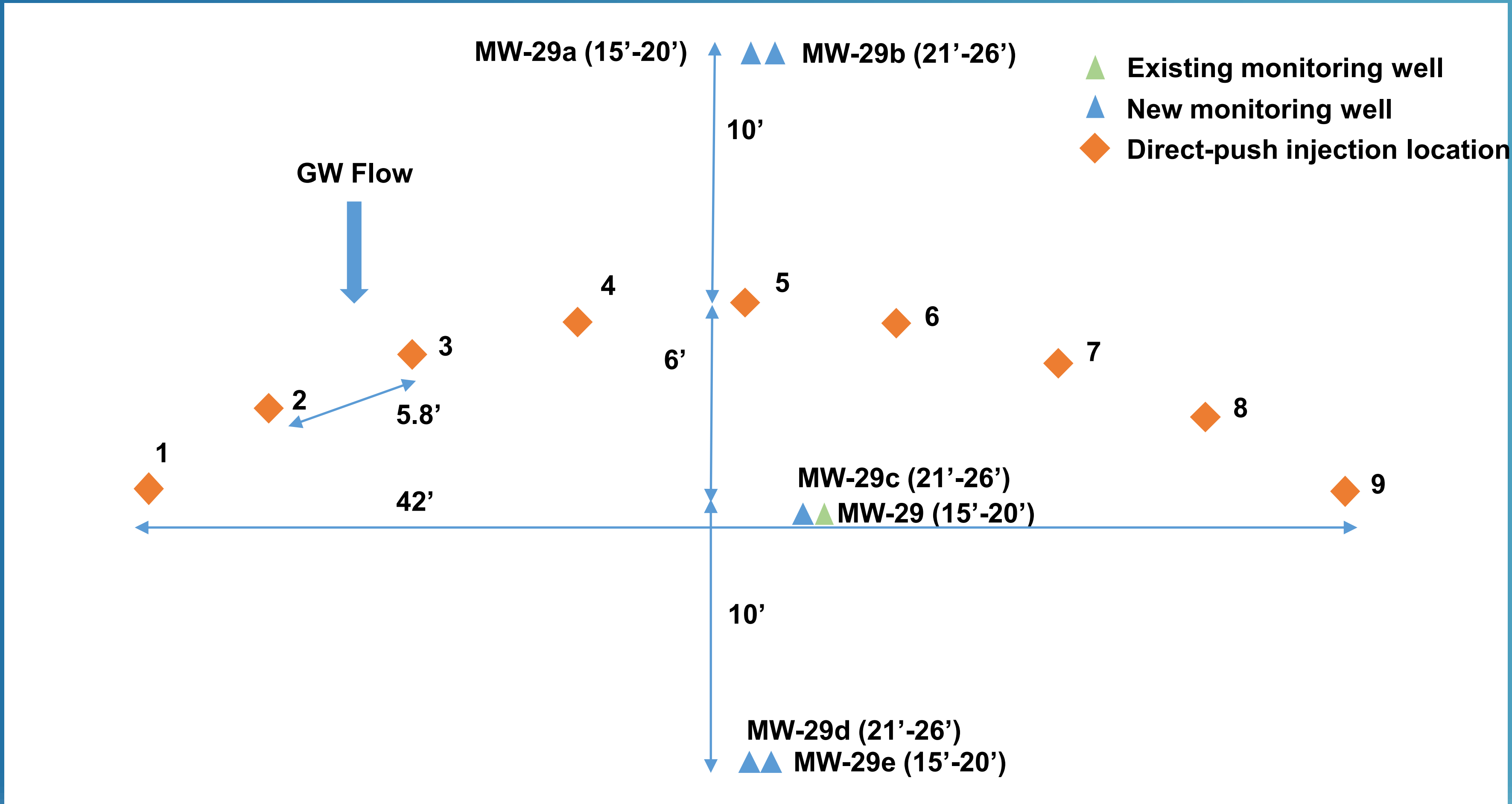
Field Test Layout



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Field Test Layout

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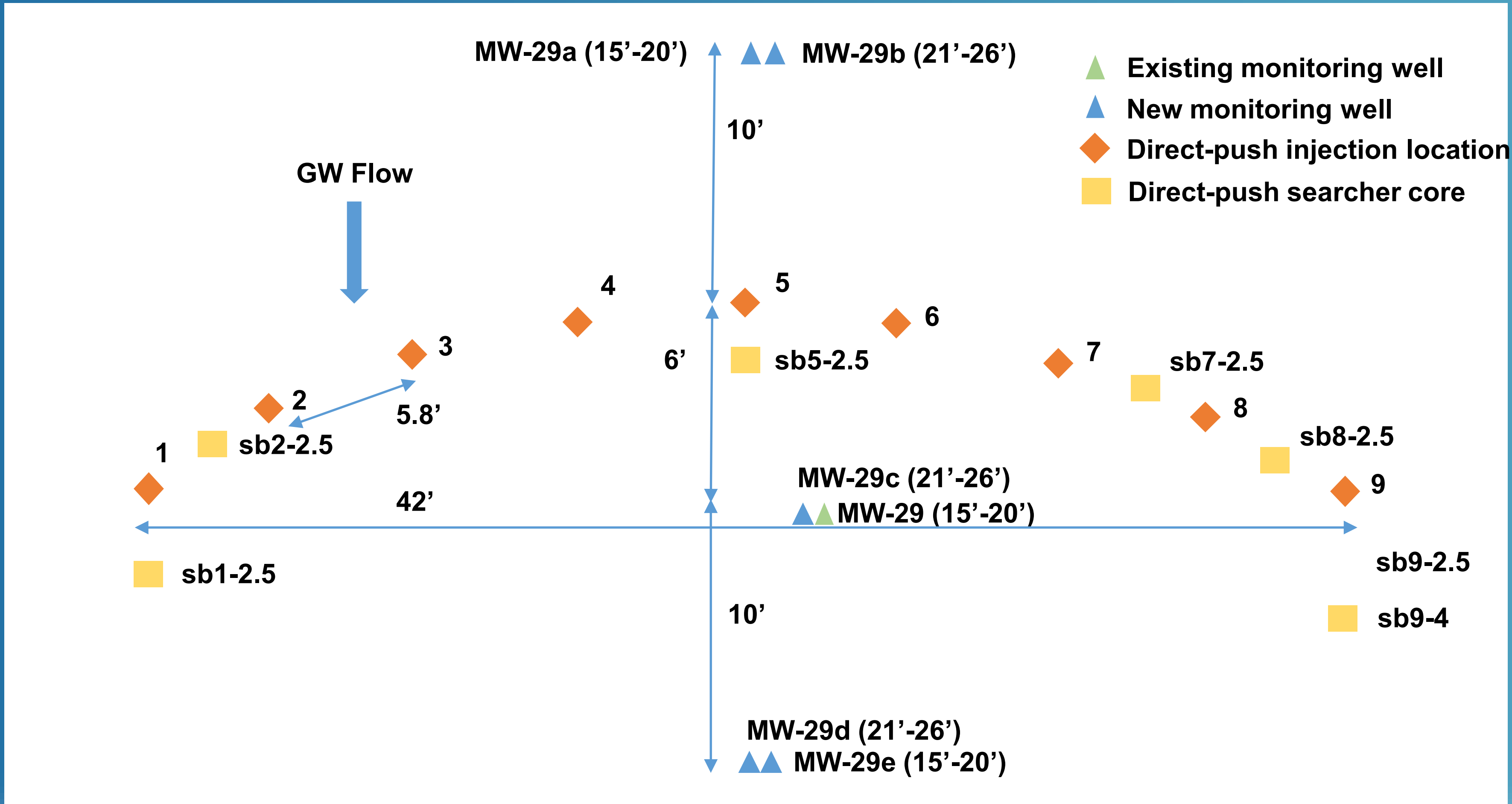
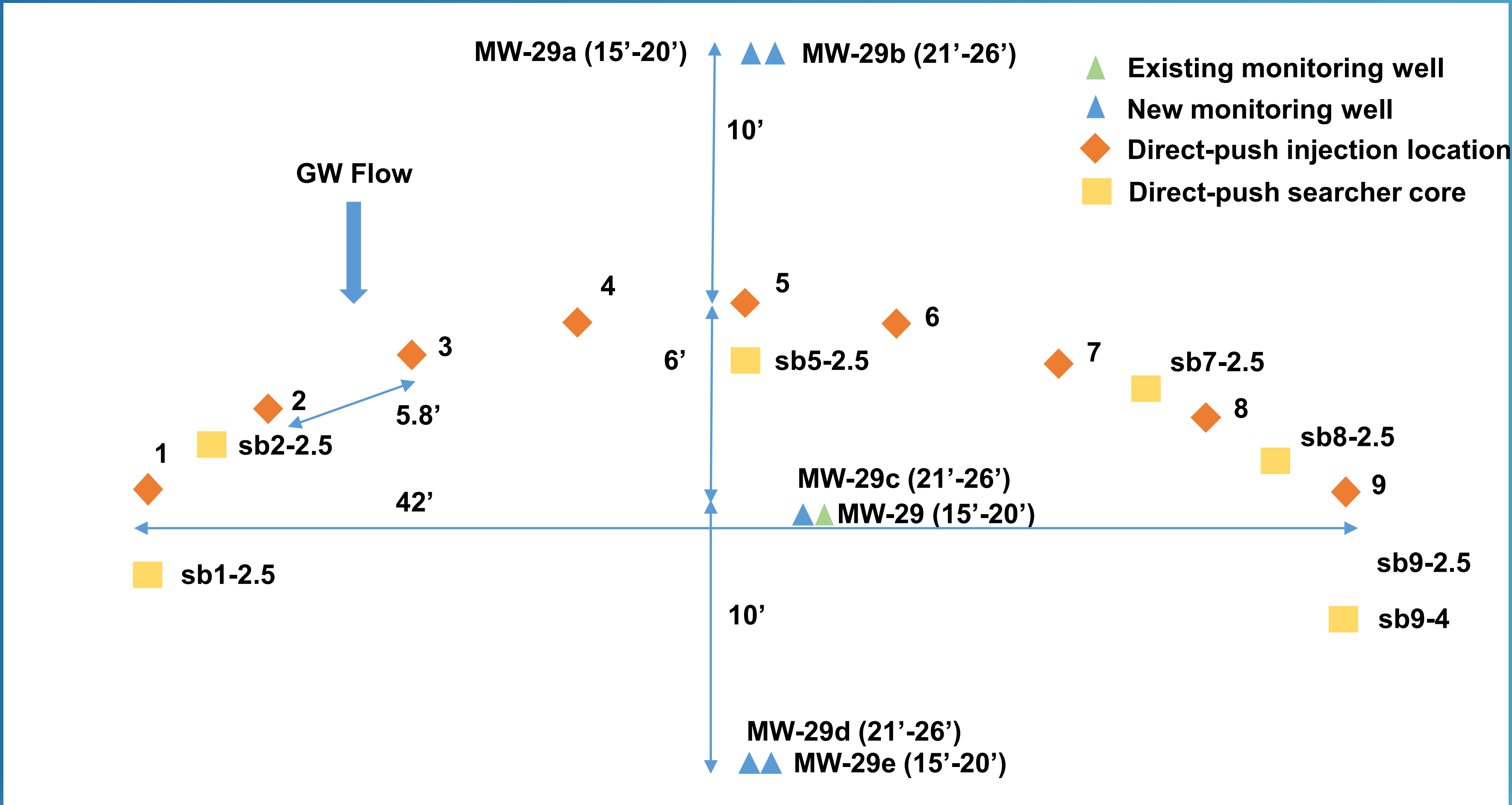
Field Test Layout



PS-Distribution Confirmation

Field Test Layout



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PS-Distribution Confirmation

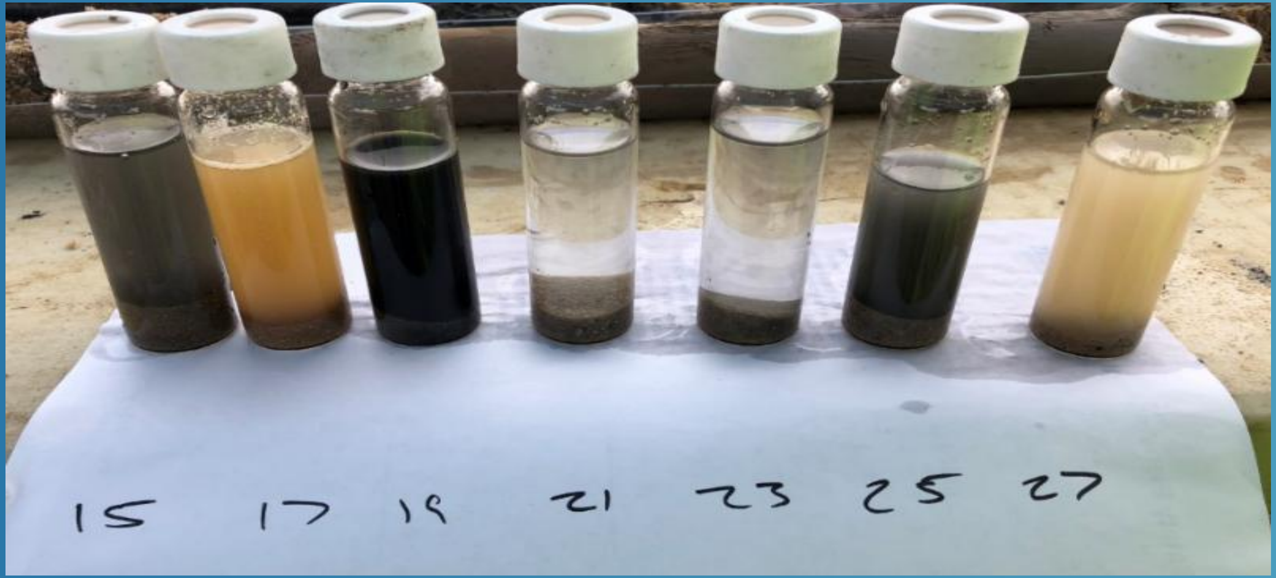
27 feet bgs

0 feet bgs

15 feet bgs

30 feet bgs

PS-Distribution Confirmation



Soil Vial Shake Test

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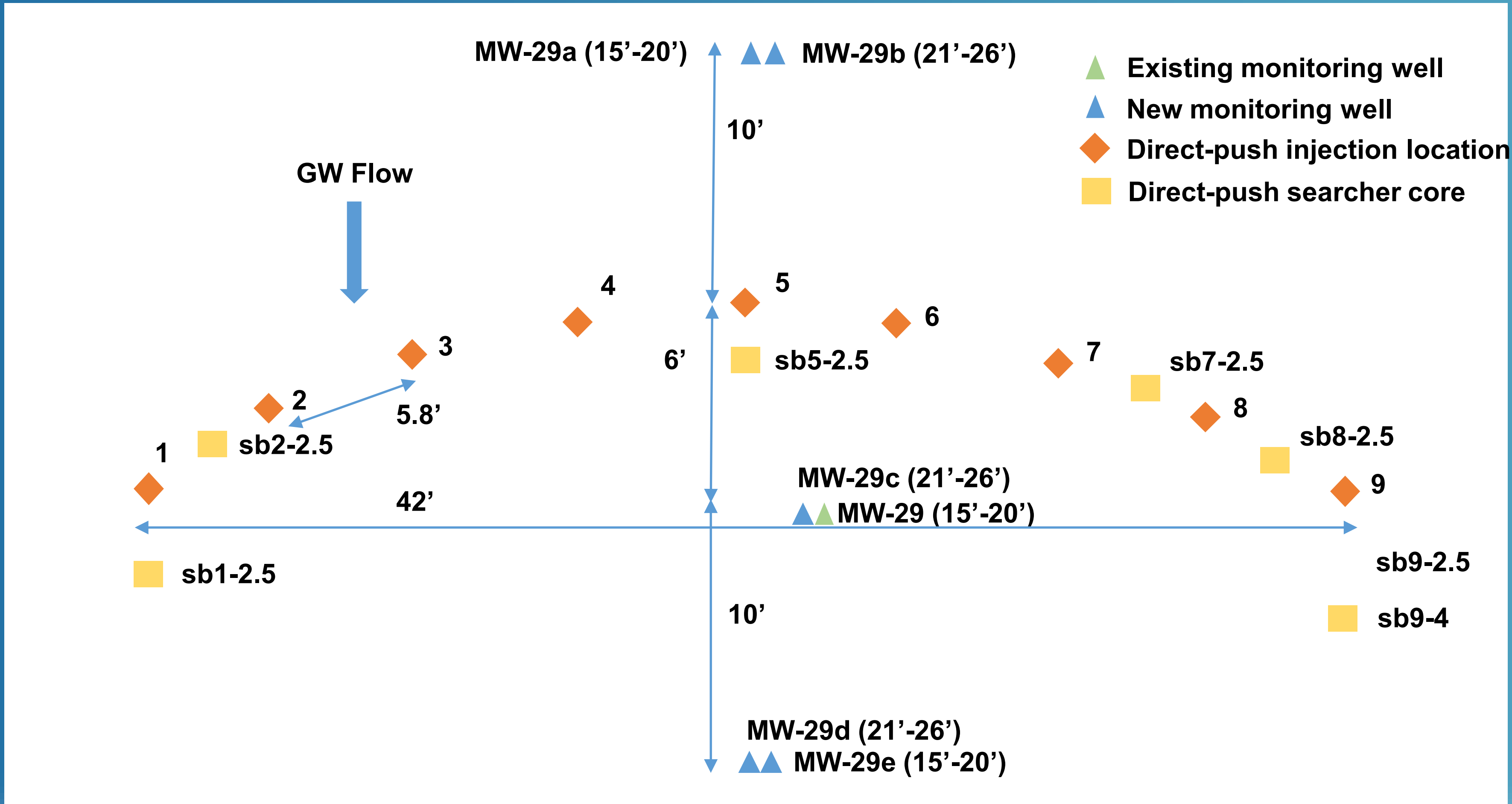
Field Test Layout



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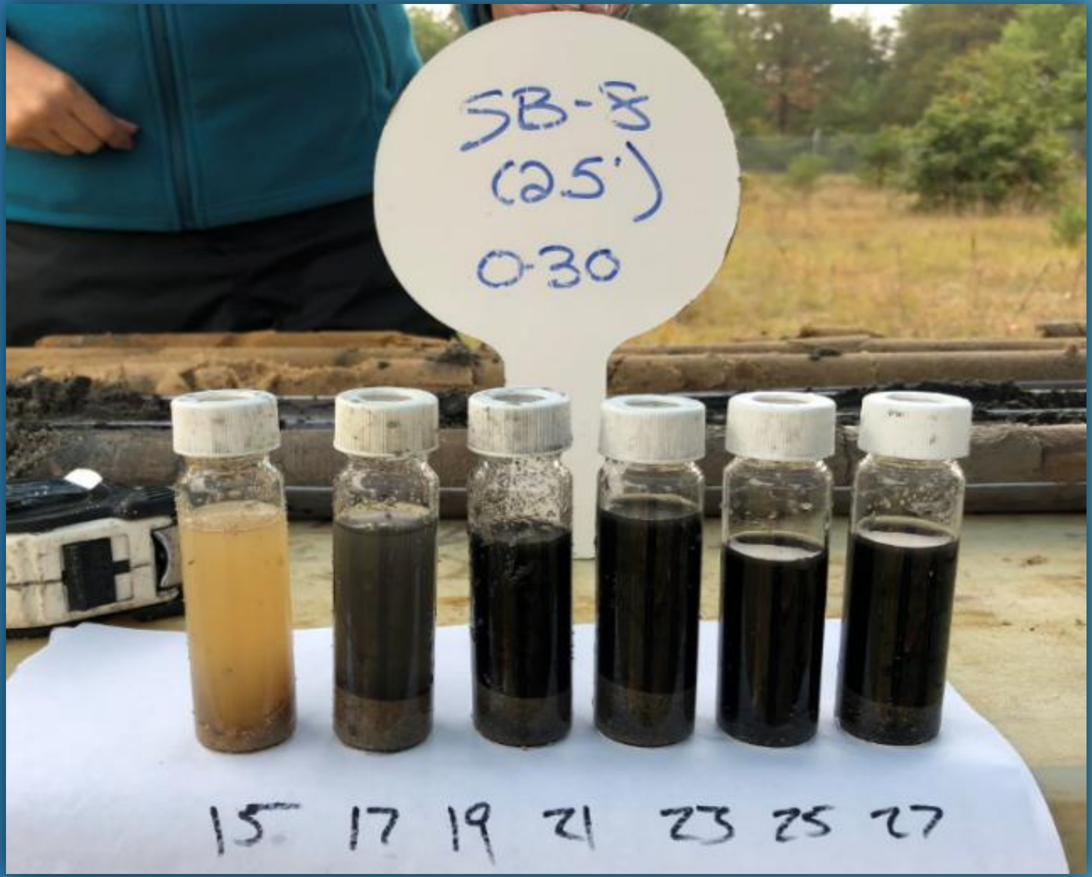


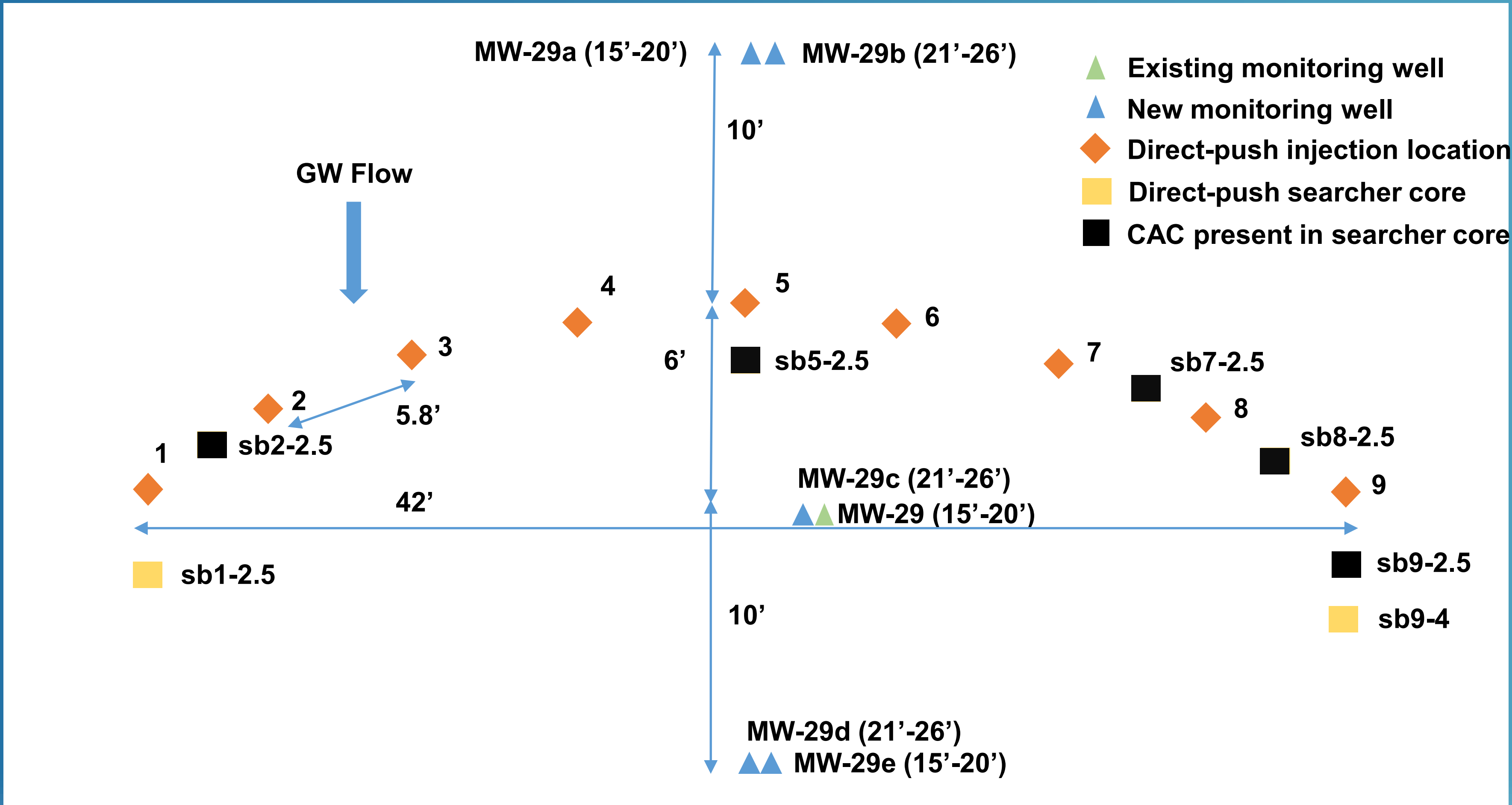
Soil Vial Shake Test

PS-Distribution Confirmation

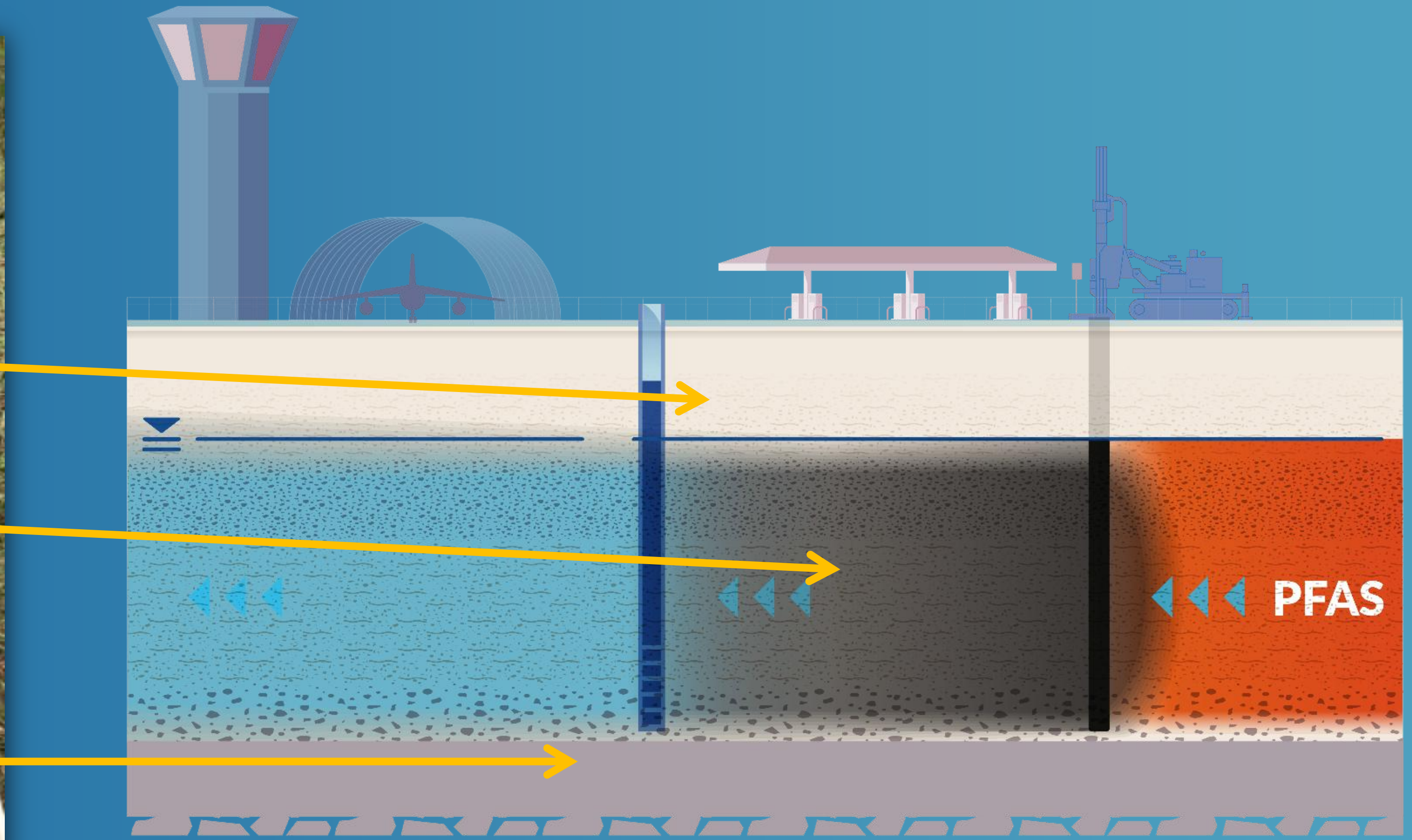
Sample MW-29c

Field Test Kit

Field Test Layout



PS-Distribution Confirmation



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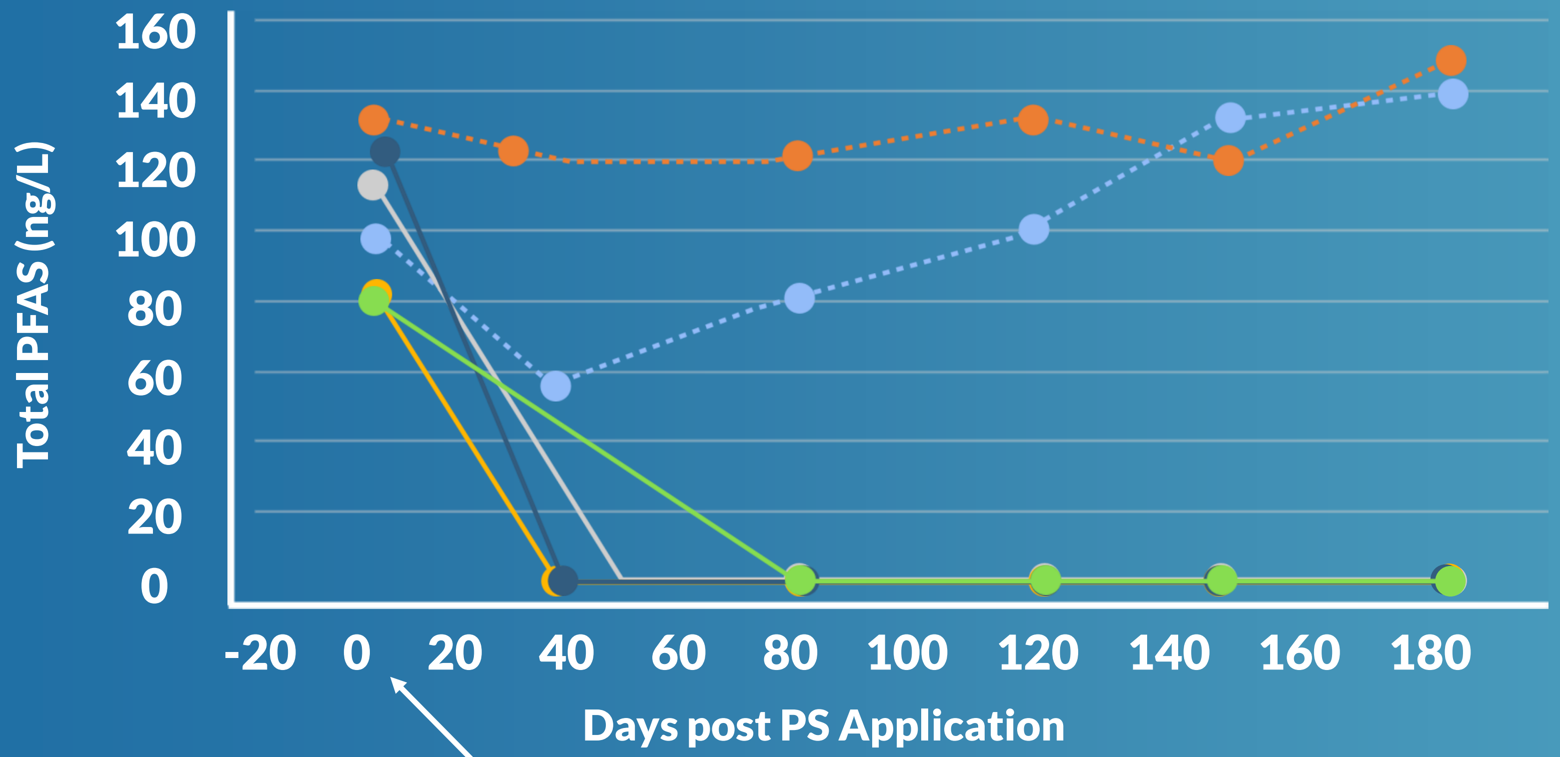
Total PFAS Results:
170 Days Post-application



Upgradient wells

- MW-29a (15-20')
- MW-29b (21-26')

6' Downgradient wells

- MW-29 (15-20')
- MW-29c (21-26')

16' Downgradient wells

- MW-29e (15-20')
- MW-29d (21-26')

PLUME STOP
Liquid Activated Carbon

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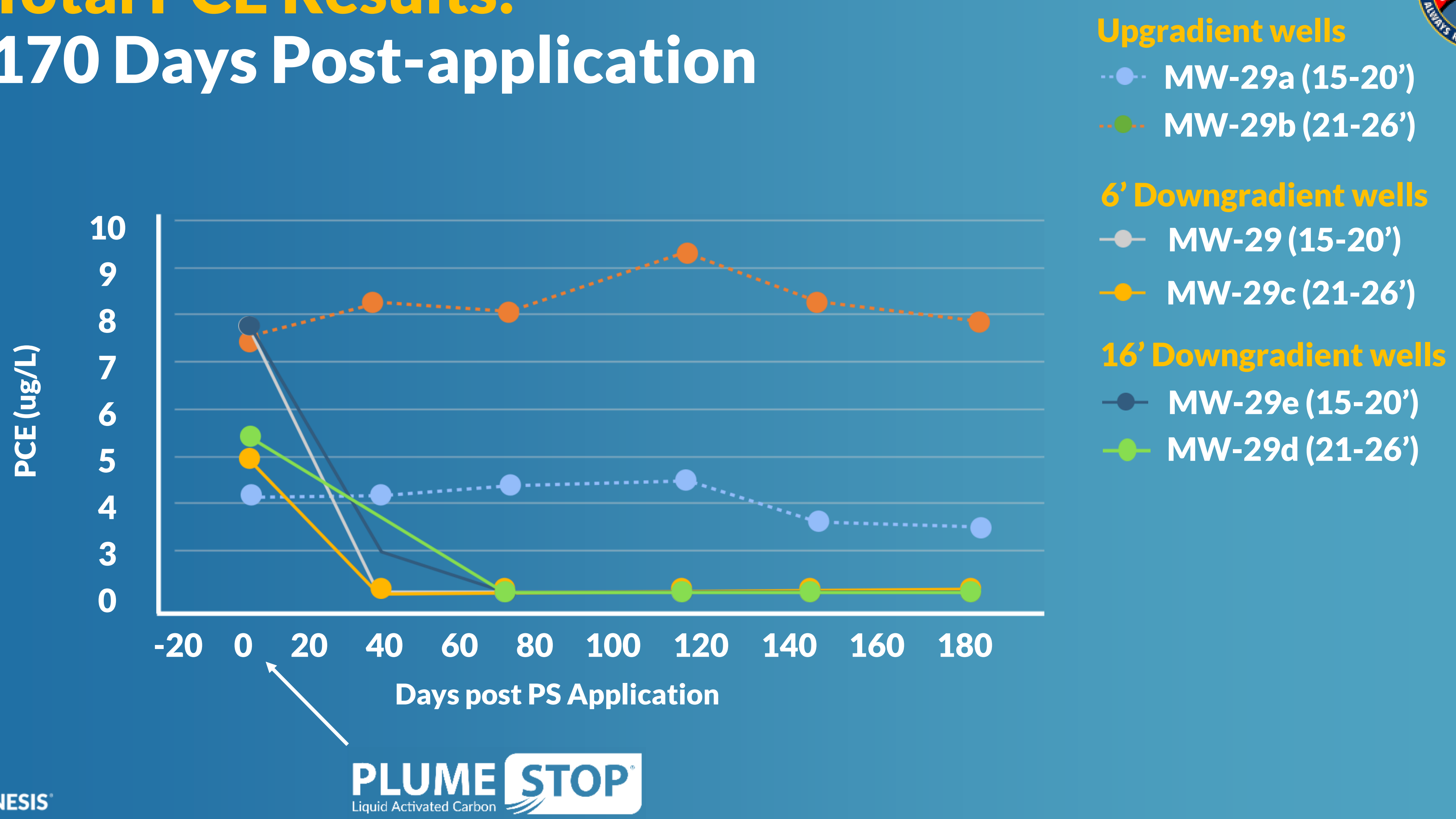
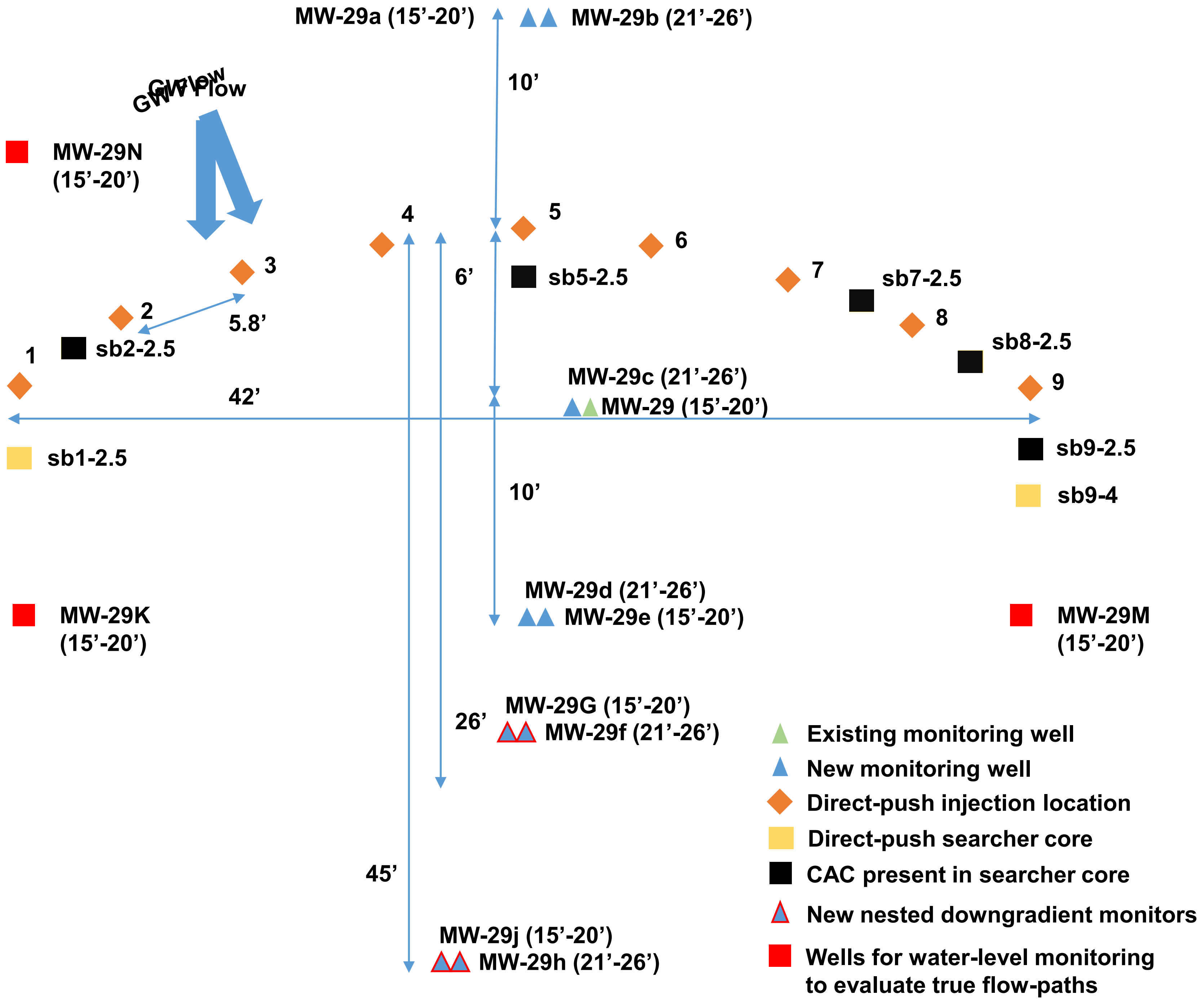
Total PCE Results:
170 Days Post-application



REGENESIS


MW-29a (15’-20’)
MW-29b (21’-26’)
10’
GW Flow
MW-29N
(15’-20’)
4
5
6
3
6’
sb5-2.5
7
sb7-2.5
2
5.8’
8
1
sb2-2.5
sb8-2.5
MW-29c (21’-26’)
9
42’
MW-29 (15’-20’)
sb1-2.5
sb9-2.5
10’
sb9-4
MW-29d (21’-26’)
MW-29e (15’-20’)
MW-29K
(15’-20’)
MW-29M
(15’-20’)
MW-29G (15’-20’)
26’
MW-29f (21’-26’)
45’
MW-29j (15’-20’)
MW-29h (21’-26’)
Existing monitoring well
New monitoring well
Direct-push injection location
Direct-push searcher core
CAC present in searcher core
New nested downgradient monitors
Wells for water-level monitoring
to evaluate true flow-paths

REGENESIS

Total PFAS Results:
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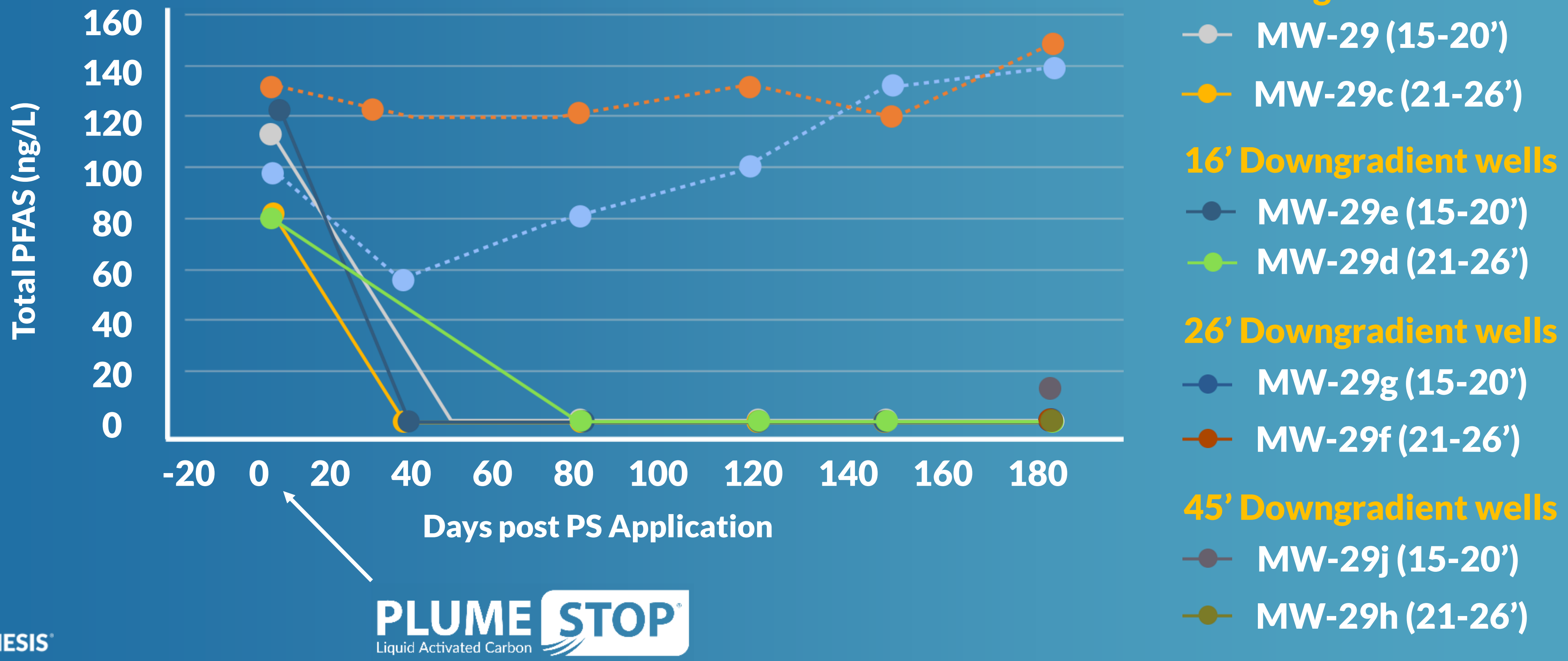

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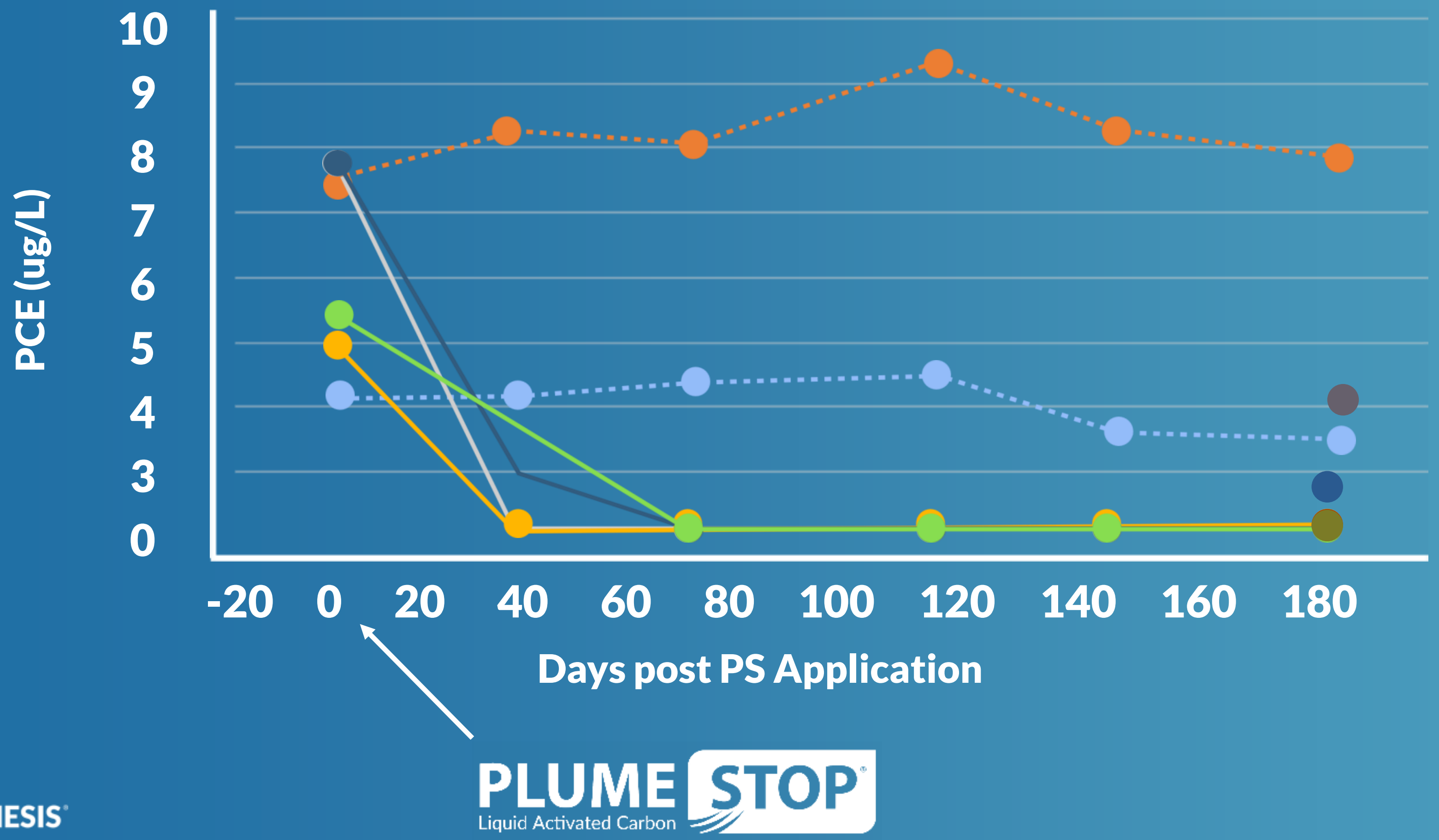

Upgradient wells
- MW-29a (15-20')
- MW-29b (21-26')

6' Downgradient wells
- MW-29 (15-20')
- MW-29c (21-26')

16' Downgradient wells
- MW-29e (15-20')
- MW-29d (21-26')

26' Downgradient wells
- MW-29g (15-20')
- MW-29f (21-26')

45' Downgradient wells
- MW-29j (15-20')
- MW-29h (21-26')

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Summary

- Very Successful Test
  - Verified distribution of CAC
  - Sustained reductions of PFAS and PCE over time
  - Anticipated to last for decades
  - Low cost alternative for possible remediation

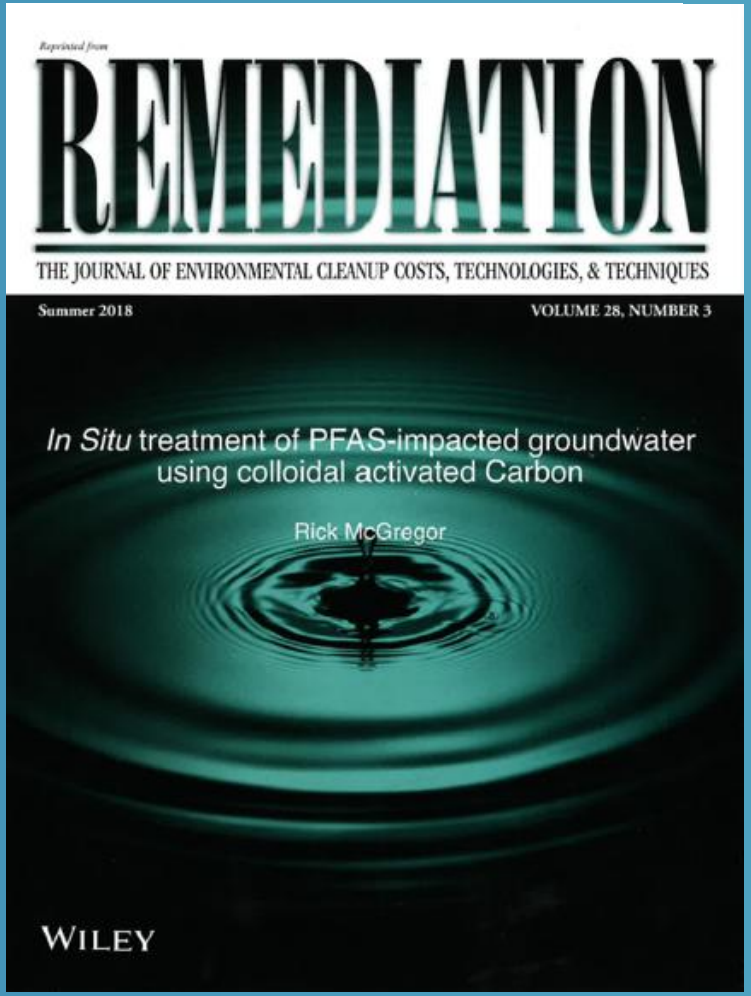
- ANSWER: Yes, CAC can be used to eliminated risk to potential multiple receptors!

Next Steps

- Pilot Test (2019)
  - Continue to monitor
- Remedial investigation (2019/2020)
- Develop Sitewide Remedial Strategies (2020/2022)

PFAS Research Articles

- **In-Situ treatment of PFAS-impacted groundwater using colloidal activated carbon**
- **http://www2.regenesis.com/pfas-wiley-article**
- **Evaluating the longevity of a PFAS *in situ* colloidal activated carbon remedy**
- **http://www2.regenesis.com/grant-carey-wiley-remediation-journal**



Thank you!
QUESTIONS?

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