REGENESIS

# PlumeStop™

COLLOIDAL BIOMATRIX

securing rapid risk reduction and accelerated bioremediation
using a dispersive injectable reagent

# PlumeStop™ Colloidal Biomatrix

- What it is
- What's novel
- How it works
- Performance – lab / field
- Usage

# PlumeStop™ – what it is

*"A highly dispersive, injectable sorbent and microbial growth matrix"*


- Colloidal activated carbon (1 – 2 µm)
  - Size of a bacterium – suspends as 'liquid'
  - Huge surface area – extremely fast sorption
- Proprietary anti-clumping / distribution supporting surface treatment (patent applied for)
  - Core innovation
  - Enables wide-area distribution through the soil matrix without clogging

# PlumeStop™ – what's novel

- **The ability to widely disperse a sorptive medium through the subsurface**
  - no fracture-emplacement – no soil-mixing – no well-blockage – no patchy treatment
- **Fast Groundwater Reductions (hydrocarbons, solvents, MTBE…if it sorbs it will likely degrade)**
  - Risk-reduction secured through sorption
  - Sorbed contaminants then rapidly biodegraded through in-matrix biodegradation
  - Total removal…not just sorption…of contaminant mass.

# PlumeStop™ – what's novel

- **Improved *in situ* bioremediation performance**
  - Contaminants and bacteria concentrated together – faster net degradation rate
  - No diminishing returns – ability to pursue degradation to very low concentrations
- **A means of addressing matrix back-diffusion** (remediation tailing / rebound)
  - Maintains a diffusion gradient out of the immobile porosity while protecting groundwater
  - Will theoretically remain active for decades – not consumed in process – bio-regenerates

## Critical Questions for the Technology

- Can it effectively distribute in situ?
- How effective is contaminant sorption?
- What happens to sorbed contaminants?
- How does it perform in the field?

# PlumeStop™ Distributes Easily…Low Pressure With High Volume

This feature allows for wider spacing, multiple delivery options, less concern about infrastructure impacts

- Column Study – 50 mm x 600 mm (2” x 2’)
- Loamy Coarse Sand (48% coarse grain; 31% medium; 8% fine; 2% very fine; 11% fines)
- PlumeStop™ versus Powdered Activated Carbon (PAC)
  - 25 g of 0.6% PlumeStop – equal mass and conc. of PAC
- Gravity Feed – equal flow
- Total of three pore volumes

# PlumeStop™: reagent distribution

Plume Stop

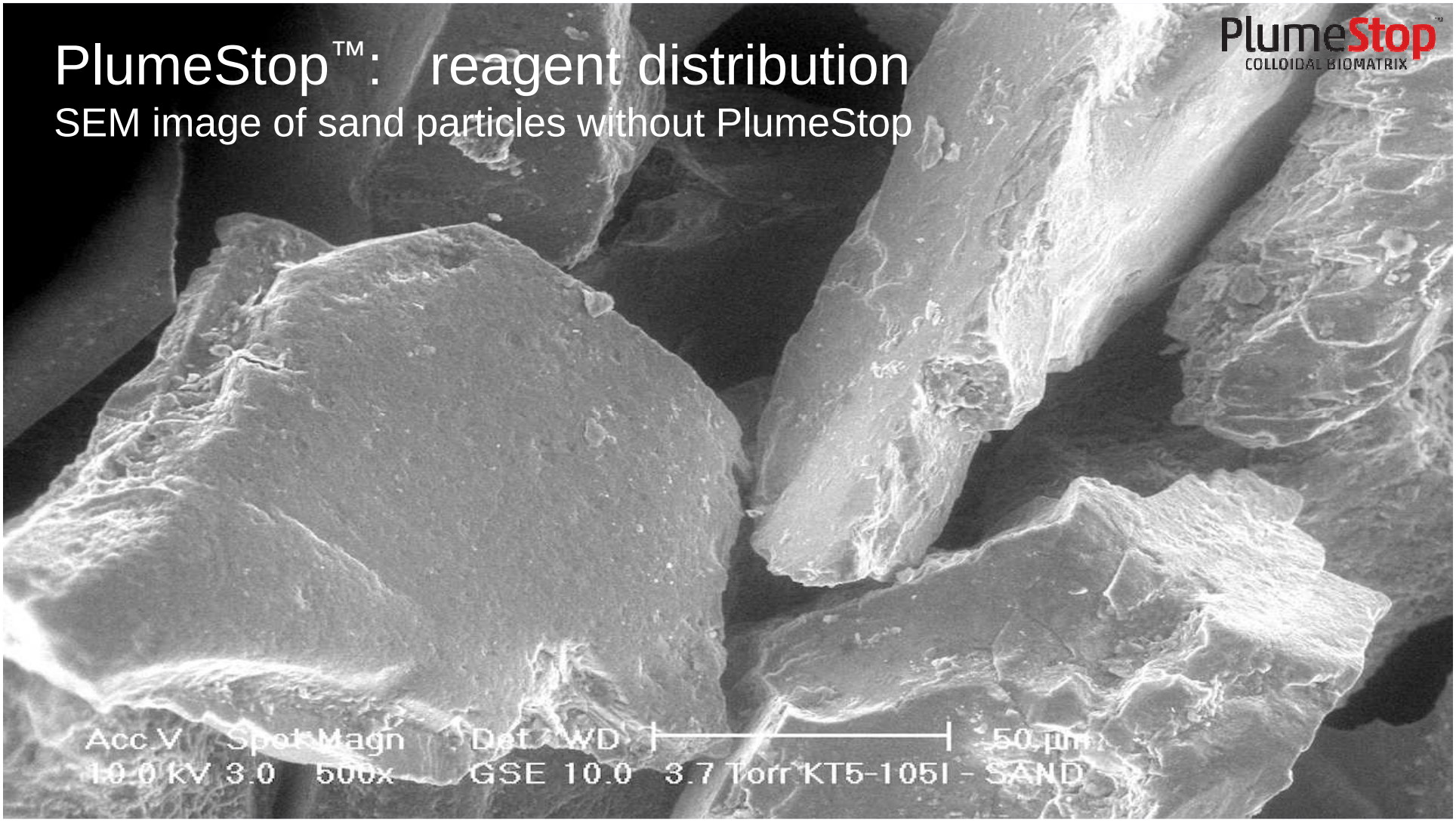
Powdered Activated Carbon

repeat

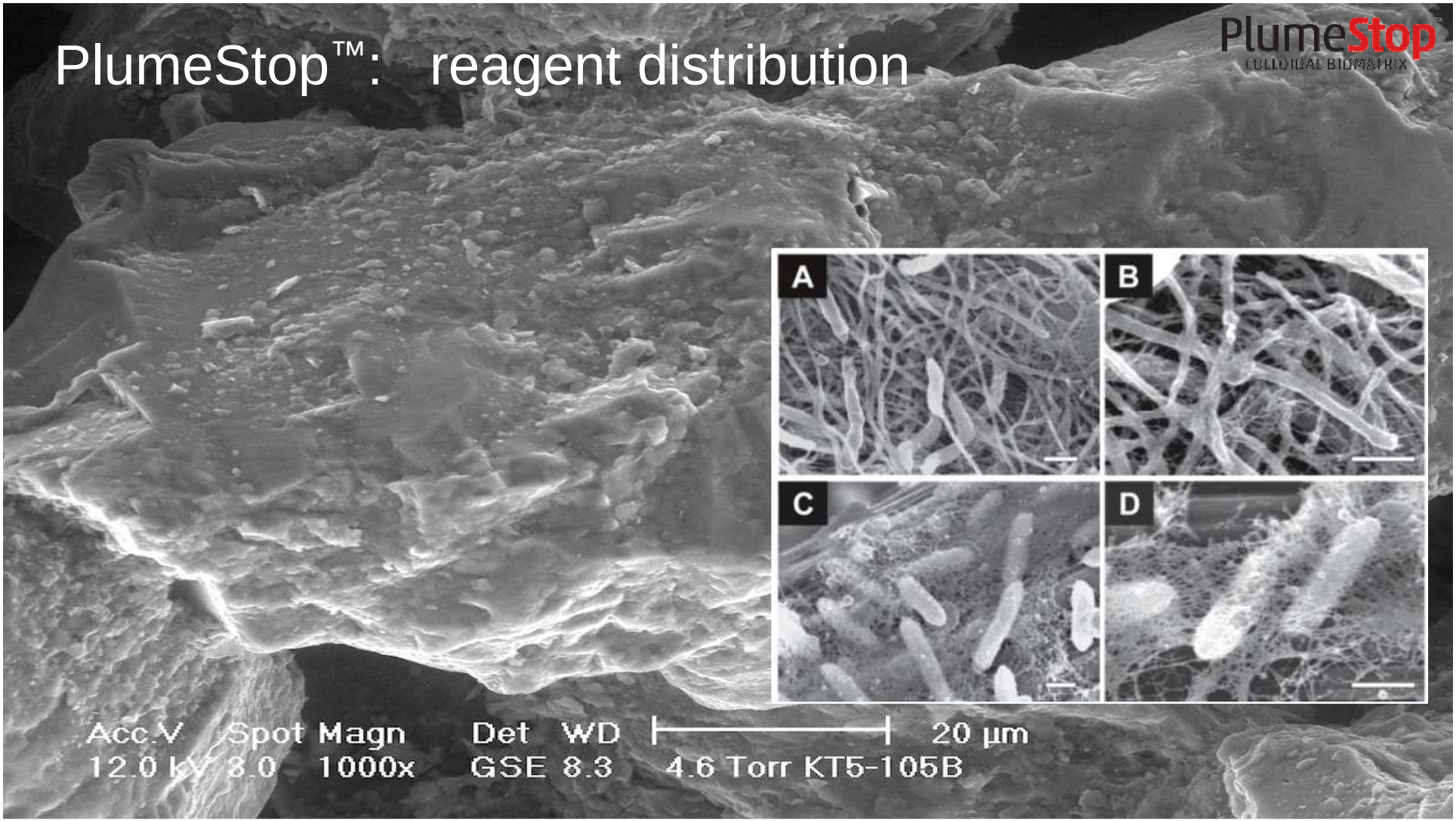
long column vid

# PlumeStop™: reagent distribution

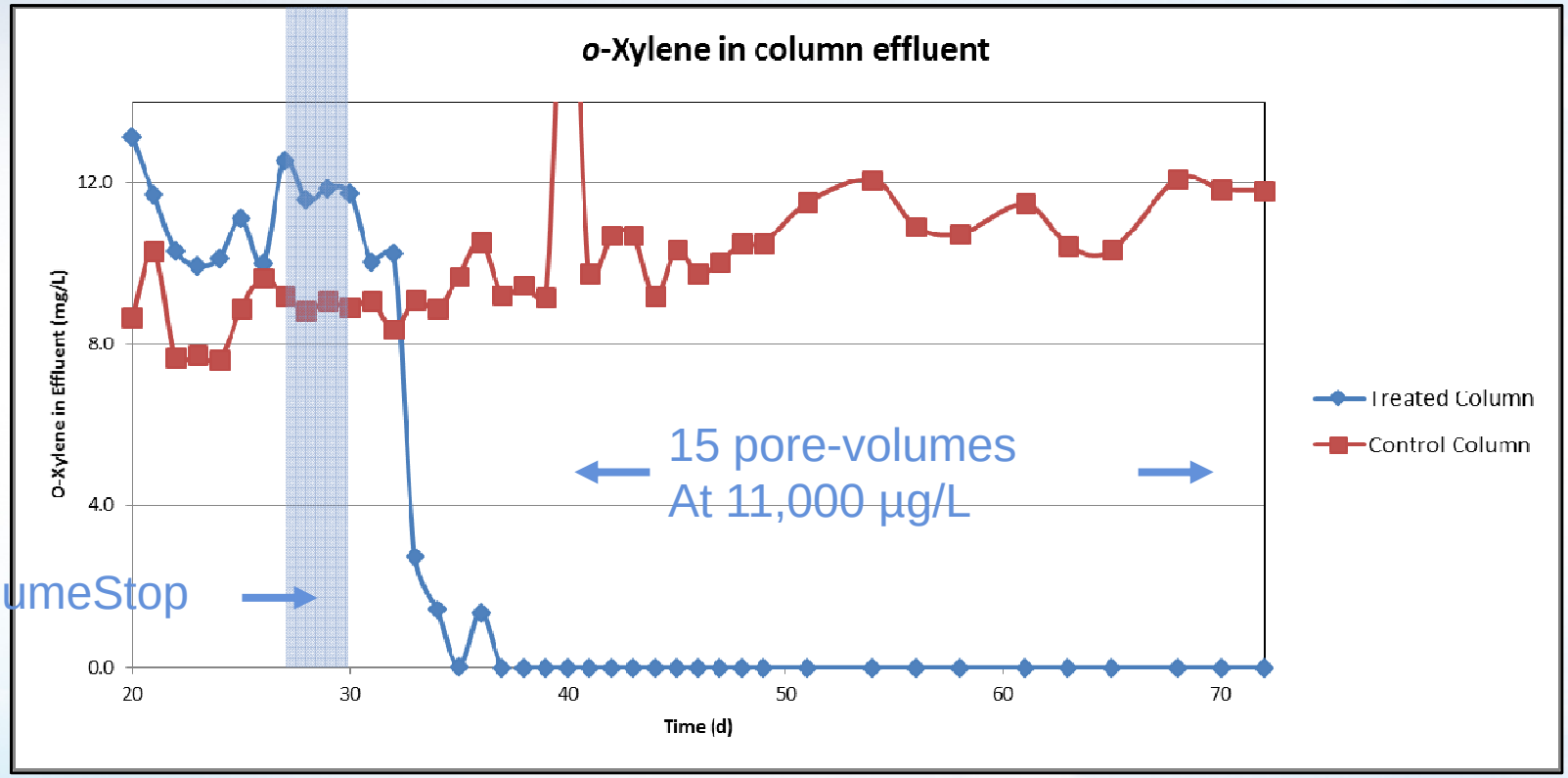
SEM image of sand particles without PlumeStop



# PlumeStop™: reagent distribution



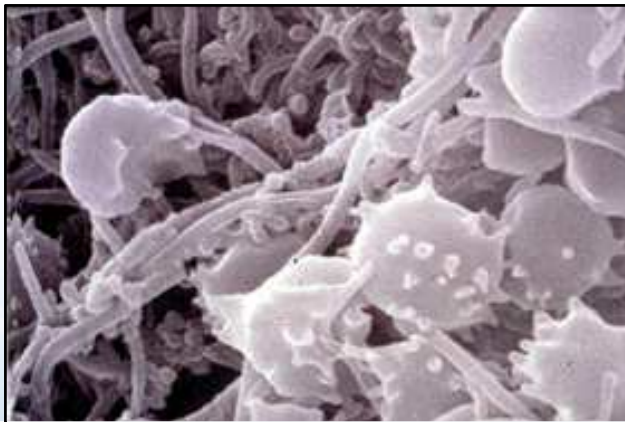
# PlumeStop™: Sorption Capacity



# PlumeStop™ – how it works

- **Concentrating bacteria and growth substrate together increases degradation rate**
  - Microbe and substrate are brought together – availability limitations are removed –activity increases

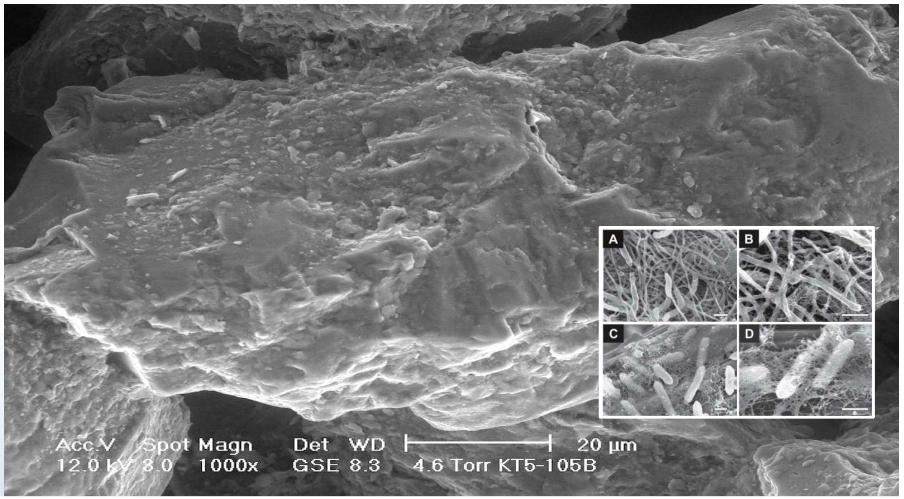
- **Upon injection, PlumeStop quickly sorbs contaminants from the dissolved-phase**
  - Multiple-order-of-magnitude decrease in days to weeks
  - High surface area (colloidal material) – high sorption capacity ($K_d$) – high distribution



# PlumeStop™ – how it works

- **Bacteria colonise the PlumeStop surface creating a bio-matrix**
  - Virgin matrix – no previous microbial colonisation – replete with substrate
  - Which bacteria will colonise and grow? The ones that live off the sorbed substrate

- **The interaction between the bacteria and the PlumeStop is synergistic**
  - The PlumeStop provides a substrate reservoir for the bacteria
  - The bacteria bio-regenerate the PlumeStop's sorptive capacity



# PlumeStop™: post-sorption biodegradation

**Benzene** Degradation Batch-Equilibrium Study #1

- Soil-water slurry microcosms
  - Treatment 1: **with PlumeStop (live)**
  - Treatment 2: **with PlumeStop (sterile)**
  - Treatment 3: **no PlumeStop (sterile)**
- Sampled destructively in triplicate
  - Days 1, 7, 14, 21

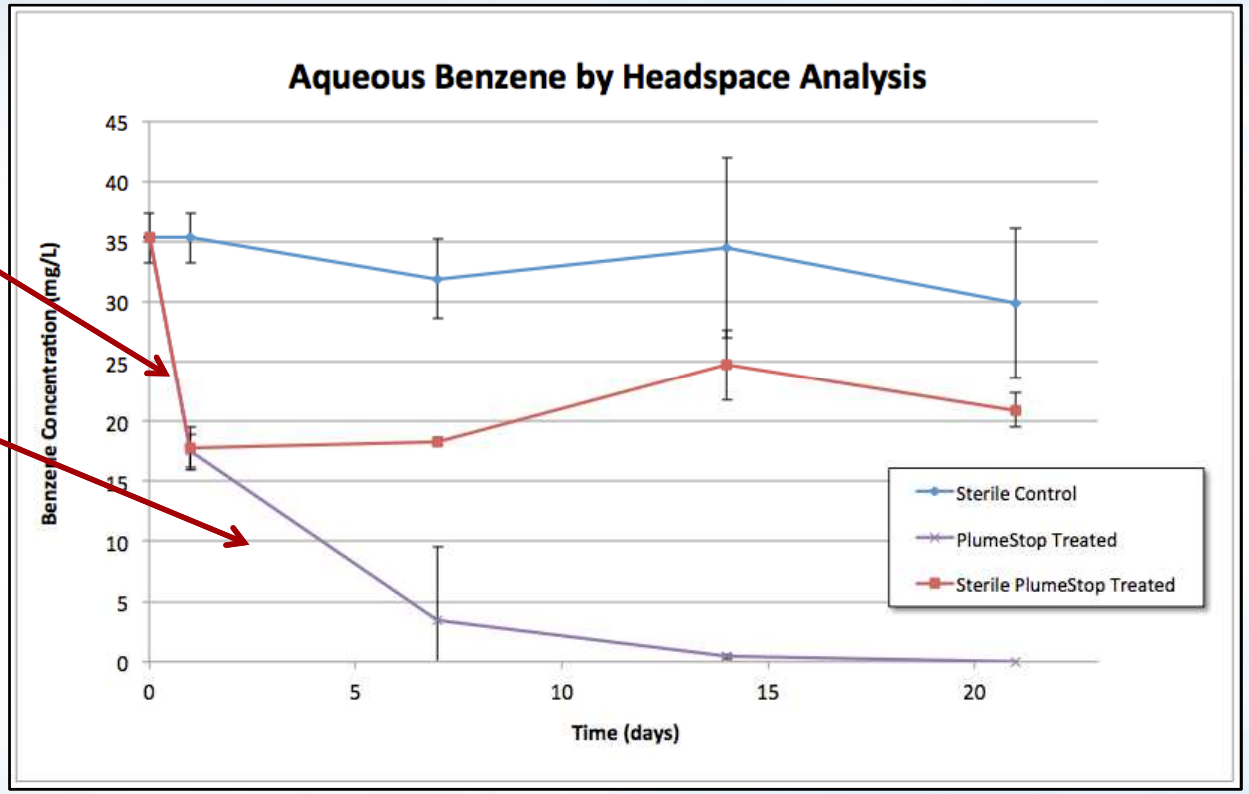
- **Water concentration** monitored by head-space analysis
- **Total benzene mass** monitored by whole-system extraction

# PlumeStop™: post-sorption biodegradation

PlumeStop COLLOIDAL BIOMATRIX

Equal sorption in both PlumeStop treatments <1 day

Ongoing drop in live PlumeStop treatment vs. sterile PlumeStop

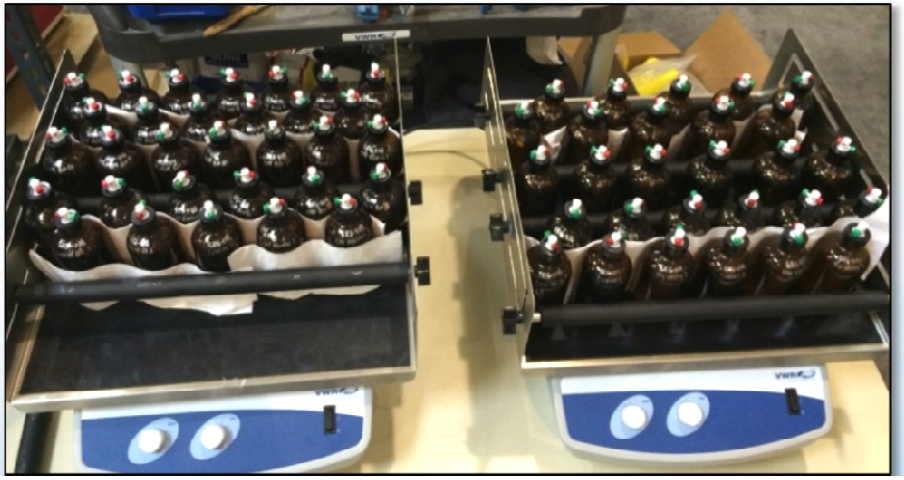


# PlumeStop™: Yes…bioremediation continues, but does PlumeStop accelerate it?

Benzene Degradation Batch-Equilibrium Study #2

- Soil-water slurry microcosms
  - Treatment 1: **with PlumeStop (live)**
  - Treatment 2: **with PlumeStop (sterile)**
  - Treatment 3: **no PlumeStop (sterile)**
  - Treatment 4: **no PlumeStop (live)**

- Sampled destructively in triplicate
  - Days 1, 7, 14, 21, 28
- Whole-system extraction



# PlumeStop™ ACCELERATES biodegradation

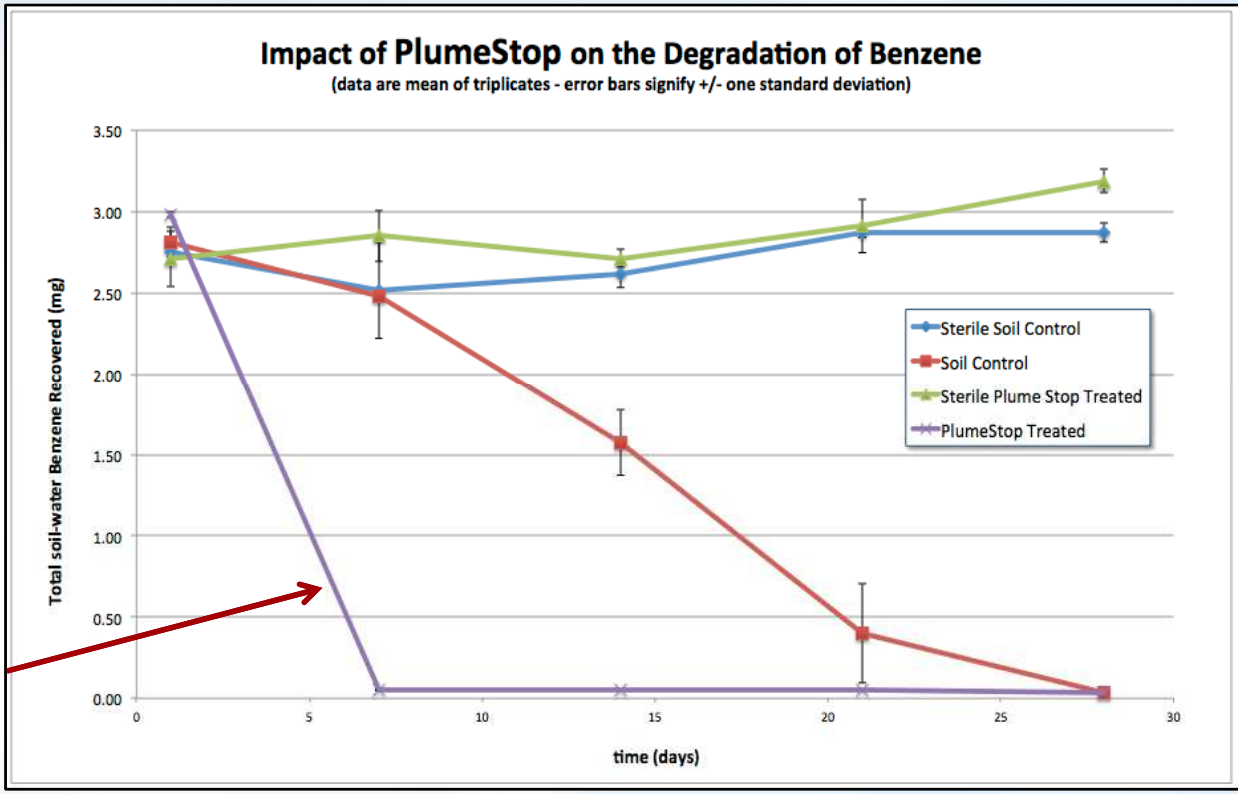
PlumeStop COLLOIDAL BIOMATRIX

Total system extract – soil and water

No net loss in either sterile system, with or without PlumeStop

Both non-sterile systems show benzene reduction

Degradation much faster in the PlumeStop system
>1 order-of-mag increase




**Howard et al (1991)** *"Handbook of Environmental Degradation Rates."* Lewis Publishers Inc. ISBN 0-87371-358-3

PlumeStop™
COLLOIDAL BIOMATRIX

# –performance –

## hydrocarbon site


REGENESIS

# PlumeStop™ - Performance - Field

- Historical underground storage tank leak
  - Gasoline-range petroleum hydrocarbons (TPH-g): 14,000 – 16,000 µg/L
  - Benzene, toluene, ethylbenzene, xylenes (BTEX): 7,000 – 9,000 µg/L
- Sandy silt with gravelly interbeds underlain by hard silt layer
- Adjacent hydraulic control system
  - Artificial high seepage velocity 200 – 280 m/year (650-900 ft/yr) to SW
  - Depth to water 2.5 m (7.5 – 8 ft)

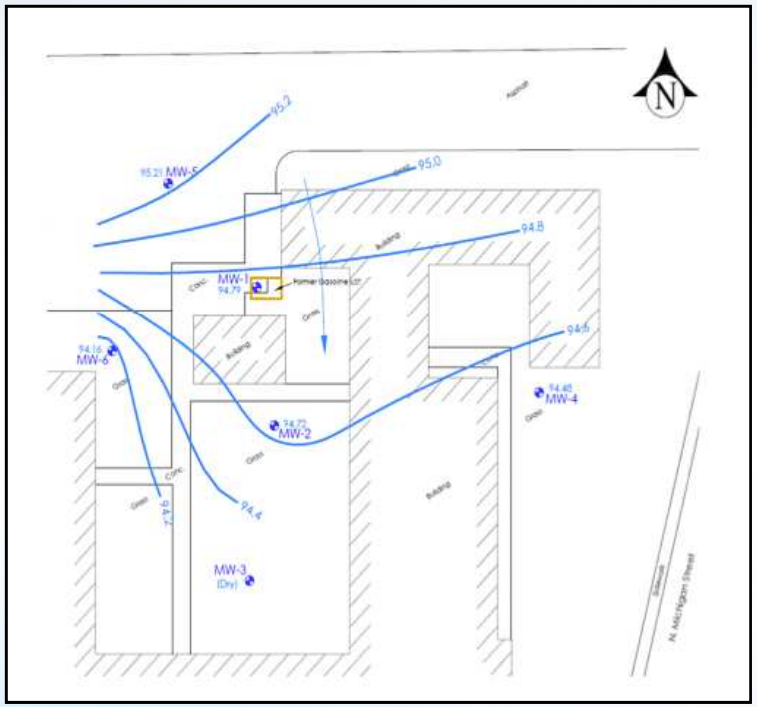
# PlumeStop™ - Performance - Field

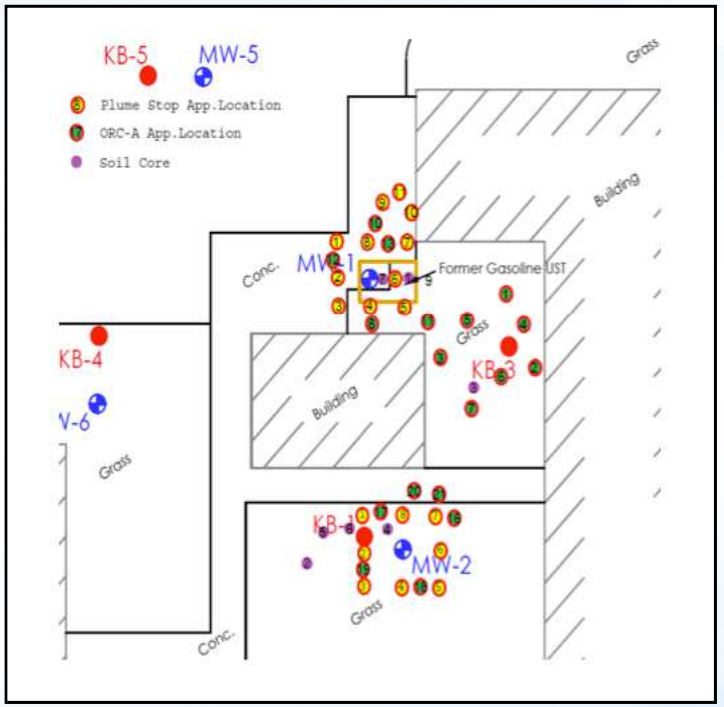
- Two test areas
  - MW1 – former source area
  - MW2 – plume area – 14 m (46 ft) down-gradient from source
- PlumeStop application by direct push injection
  - 11 point grid array (8 point MW2) at 1.5 m (5 ft) spacing
- ORC-Advanced® applied up-gradient and between points
  - Creates aerobic conditions appropriate for microbial colonisation and activity

Soil cores pre and post PlumeStop application

- Distribution evaluation

# PlumeStop™ - Performance - Field

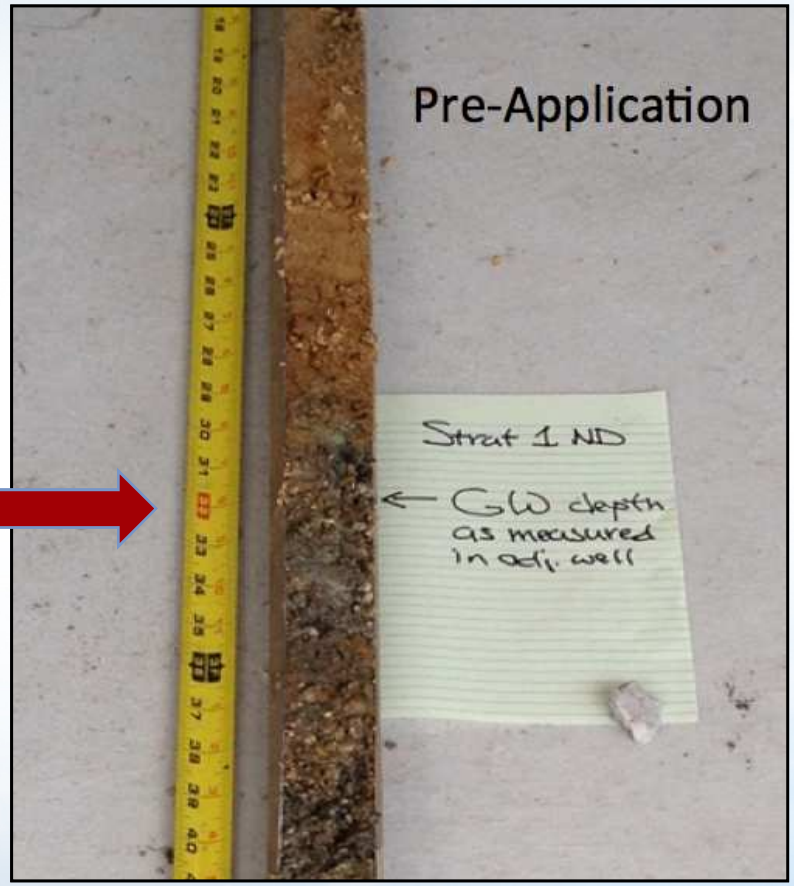


# PlumeStop™ - Performance - Field

Pre-application soil cores

Significant smear-zone contamination in gravelly stratum at saturated interface

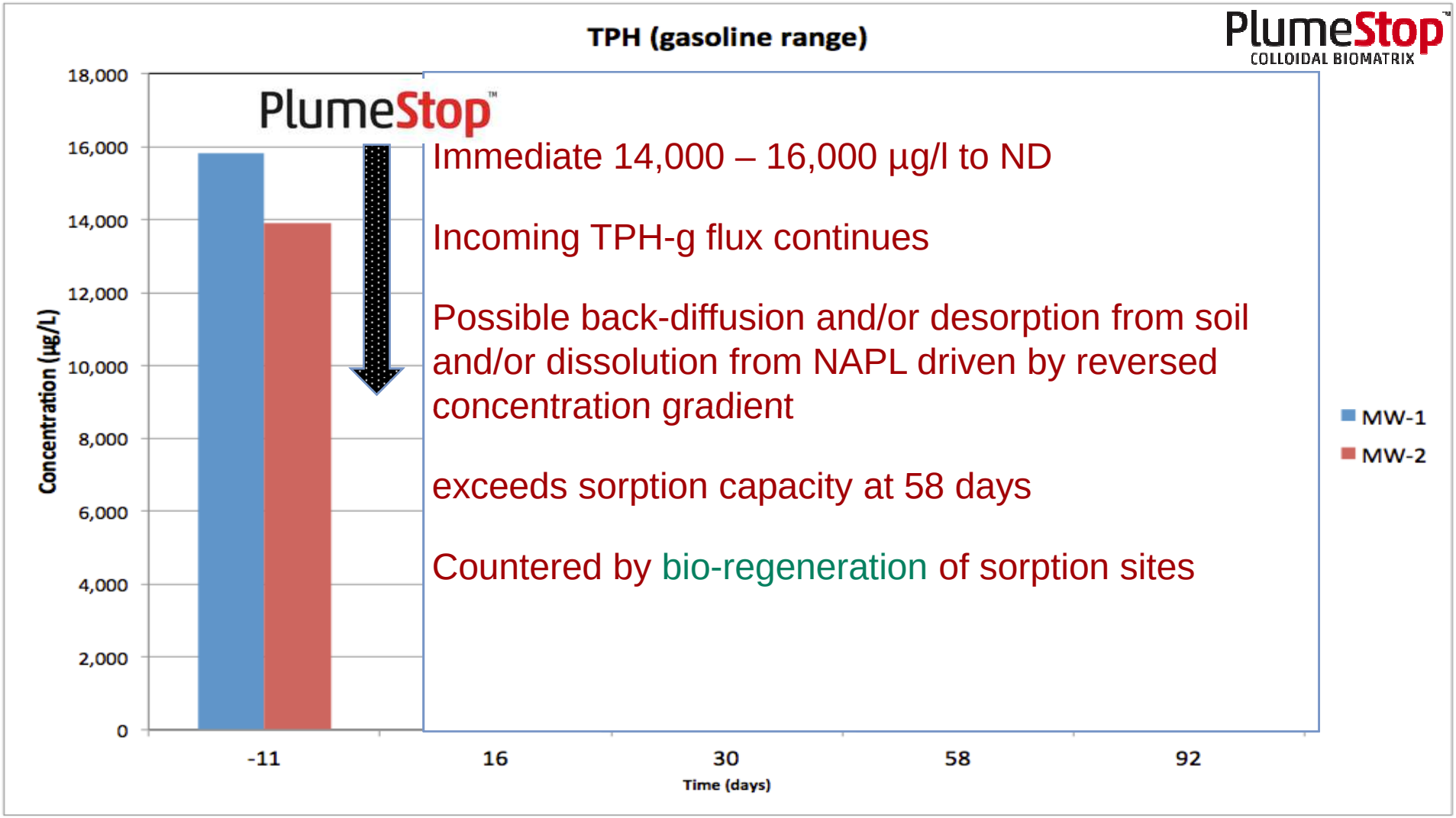


# PlumeStop™ - Performance - Field

## Post-application soil cores

Distribution of PlumStop through target zone visually apparent

Even dispersion evident through permeable strata


TPH (gasoline range)
PlumeStop
COLLOIDAL BIOMATRIX
PlumeStop
Immediate 14,000 – 16,000 µg/l to ND
Incoming TPH-g flux continues
Possible back-diffusion and/or desorption from soil and/or dissolution from NAPL driven by reversed concentration gradient
exceeds sorption capacity at 58 days
Countered by bio-regeneration of sorption sites
Concentration (µg/L)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
-11
16
30
58
92
Time (days)
MW-1
MW-2

# Summary – Hydrocarbon Site

- Good reagent distribution easily secured with simple pumps
  - 2 m (6’6”) radius – full distance tested – actual radius may be greater
- > 99% (two OOM) concentration reduction within 14 days
  - 14,000 – 16,000 µg/L to non detect (< 100 µg/L)
- Data trends consistent with post-sorption biodegradation
  - Suggestions of sorptive saturation followed by sorptive regeneration
  - Tentative only – but consistent with hypothesis and laboratory performance

PlumeStop™
COLLOIDAL BIOMATRIX

# –performance –

## chlorinated solvent site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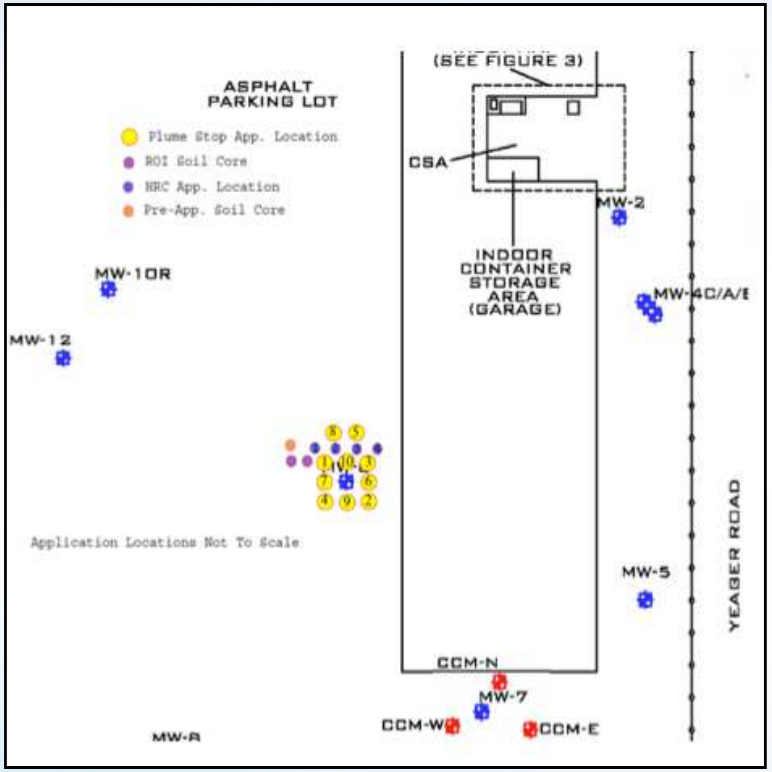
# PlumeStop™ - Performance - Field

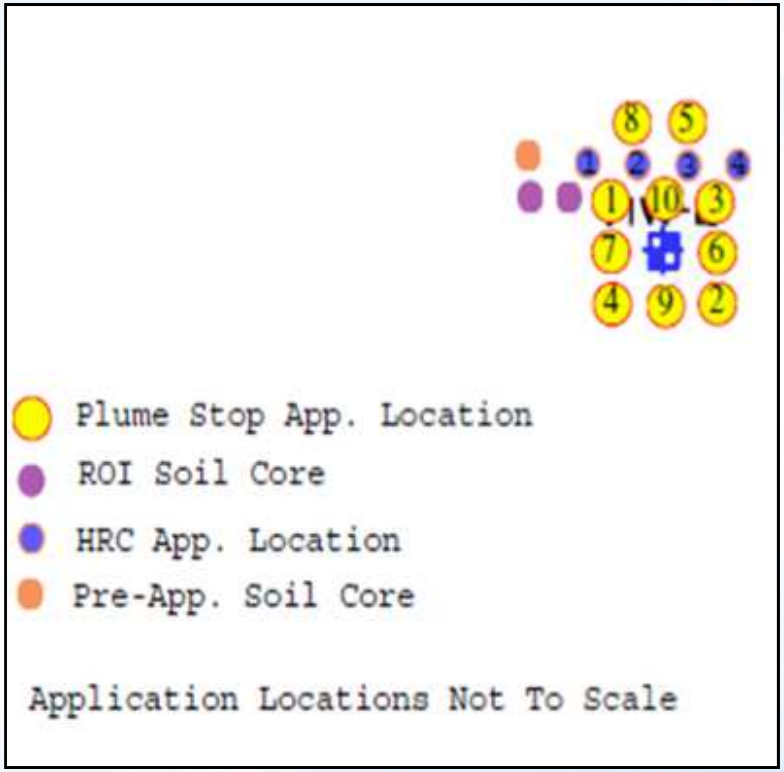
- Former electronics facility
  - TCE 1,390 µg/L
  - TCA 3,550 µg/L
- Sand to silty-sand
- Depth to groundwater 3 – 4 m (10 – 13 feet)
- Seepage velocity 3.7 m/yr (12 ft/yr) to the southwest

# PlumeStop™ - Performance - Field

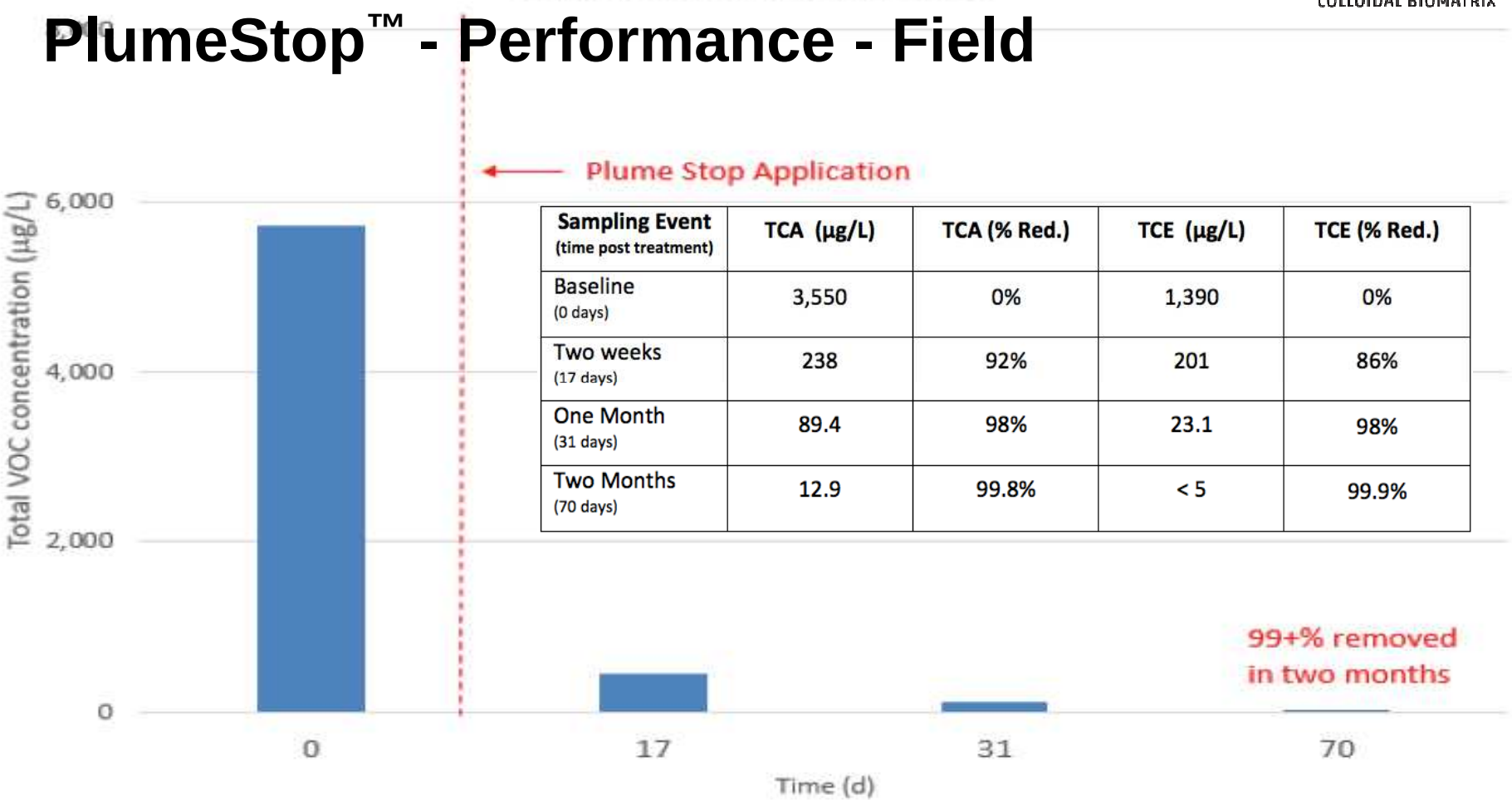
- One test area, down-gradient of sources
  - Plume only – no NAPL
- PlumeStop application by direct push injection
  - 10 point grid array at 1.5 – 2 m spacing (5 – 6.5 ft)
  - Target interval 2.75 – 6.5 m (9 – 21 feet) below ground surface
- HRC® applied up-gradient and between points
  - Creates conditions appropriate for microbial colonisation and activity
- Soil cores pre and post PlumeStop application
  - Distribution evaluation

# PlumeStop™ - Performance - Field



# PlumeStop™ - Performance - Field




| Sampling Event (time post treatment) | TCA (µg/L) | TCA (% Red.) | TCE (µg/L) | TCE (% Red.) |
|---|---|---|---|---|
| Baseline (0 days) | 3,550 | 0% | 1,390 | 0% |
| Two weeks (17 days) | 238 | 92% | 201 | 86% |
| One Month (31 days) | 89.4 | 98% | 23.1 | 98% |
| Two Months (70 days) | 12.9 | 99.8% | < 5 | 99.9% |

PlumeStop™
COLLOIDAL BIOMATRIX

# Summary – Chlorinated Solvent Site

- > 90% (one OOM) concentration reduction within 14 days
  - TCA 3,550 to 238 µg/L
  - TCE 1,390 to 201 µg/L
- 99.9% (three OOM) concentration reduction within 70 days
  - TCA 3,550 to 12.9 µg/L
  - TCE 1,390 to <5 µg/L
- Conditions conducive to bio establishing but still early days
  - Daughter products not observed at time of study

# PlumeStop™ – When To Use?

1. When time is critical
2. For control of migrating contamination
3. To secure stringent clean-up targets
4. As a long–term means of addressing matrix back-diffusion
5. When remediation performance is flat-lining

(skip detail)

PlumeStop™
COLLOIDAL BIOMATRIX

# Thank You


**Todd Herrington**

MS, PE

West Region Manager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## Questions?