Technology-Based Solutions for the Environment

Engineered Retardation Factor Manipulation

using **PlumeStop® Liquid Activated Carbon™**
for Passive Management of Plume Dynamics

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Framing the Problem

Monitored Natural Attenuation (MNA)

- Pragmatic and efficient strategy – *within* its operating window
  - low cost – low resource use – low disturbance

- But in other cases:
  - Too slow – (whole plume attenuation or expansion mitigation)
  - Insufficient space / excessive groundwater velocity

plume will reach compliance point before attenuating

Modelling Perspective

Groundwater Modelling

- Frequently employed in the more significant MNA projects
- Provides a focused and objective conceptual platform

Modelling Perspective

Options when plume will reach receptor before attenuating:

- Reduce the source term C_0 – (physical removal, ISCO, etc.)
- Increase the degradation term k – (bio amendments, etc.)
- Manipulate the advection term – (hydraulic control, P&T)

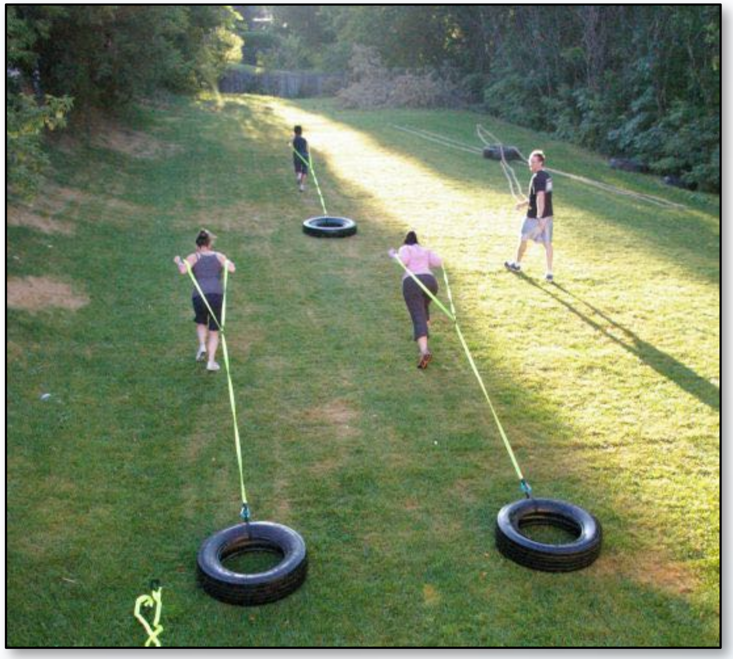
Modelling Perspective

New strategy: (theme of this talk)

- Rather than *actively* manage advection through V (GW velocity)
- ***Passively*** manage advection through $\boldsymbol{R}$ (retardation factor)

low cost - low resource use - low disturbance

What is a Retardation Factor?



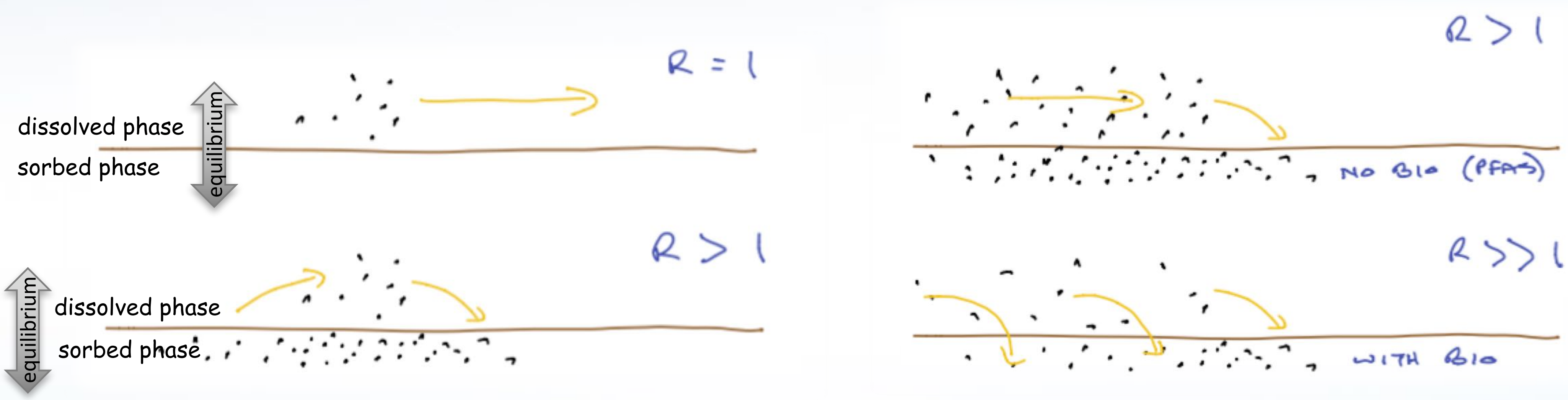
Managing plumes via the retardation factor *R*

- The Retardation Factor (*R*) determines how fast a contaminant moves relative to the groundwater.
    - An *R* of 1.0 means the contaminant moves at the groundwater velocity
    - An *R* of 2.0 means the contaminant moves at half of the groundwater velocity
    - An *R* of 10 means the contaminant moves at 1/10th of the groundwater velocity

    - For VOCs in natural soil, *R* is typically in the range of 1 – 3.

Basis of the retardation factor *R*

Plume Velocity = GW Velocity / *R* (the bigger the *R*, the slower the plume)



Sorption confers retardation
Bio increases retardation – plume may be consumed before it breaks through

Retardation Factor Manipulation Strategy for MNA

'Splice in' extra degradation time into a shorter distance

- What if the attenuation achieved over 300 yds could be obtained over 3 yds?
  - Implications to expanding plumes?
  - Ability to achieve MNA within site boundaries?

- Groundwater flow unchanged
- Incoming natural donor / acceptor supply unchanged
  - These may be sufficient given the extra degradation time
  - Ongoing donor / acceptor reapplications may be unnecessary
    (significant cost and engineering savings)

Key Questions

- **How do you engineer the retardation factor?**
- What scale of change can be achieved?
- What will this do to the bio rate?

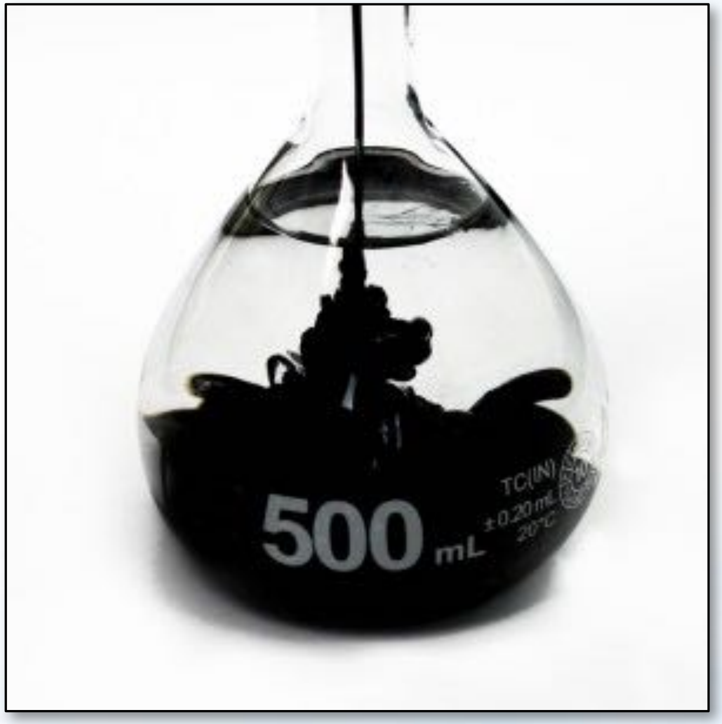
- How is this designed?
- How is performance tracked?
- What are the cost / engineering / resource implications?

PlumeStop®

PLUME STOP™
Liquid Activated Carbon

- a.k.a. **Liquid Activated Carbon™**
- Injectable at low pressure
  - flows like ink
  - coats flux channels
  - does not impede groundwater flow
- Commonly used for:
  - rapid compliance achievement
  - coupled sorption and bio
    - takes bio out of the dissolved-phase
    - daughter products contained during degradation
- This use:

Engineered retardation factor manipulation

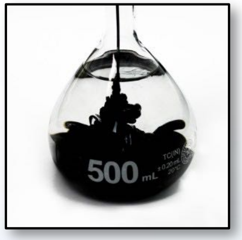


PlumeStop® : Engineered Retardation Factor Manipulation

Material attributes key to this:

- Must provide a even, thin-layer, flux channel coating
  - No gaps! – flux interception criticality
  - No permeability change – groundwater must not divert around barrier

PLUME STOP™
Liquid Activated Carbon



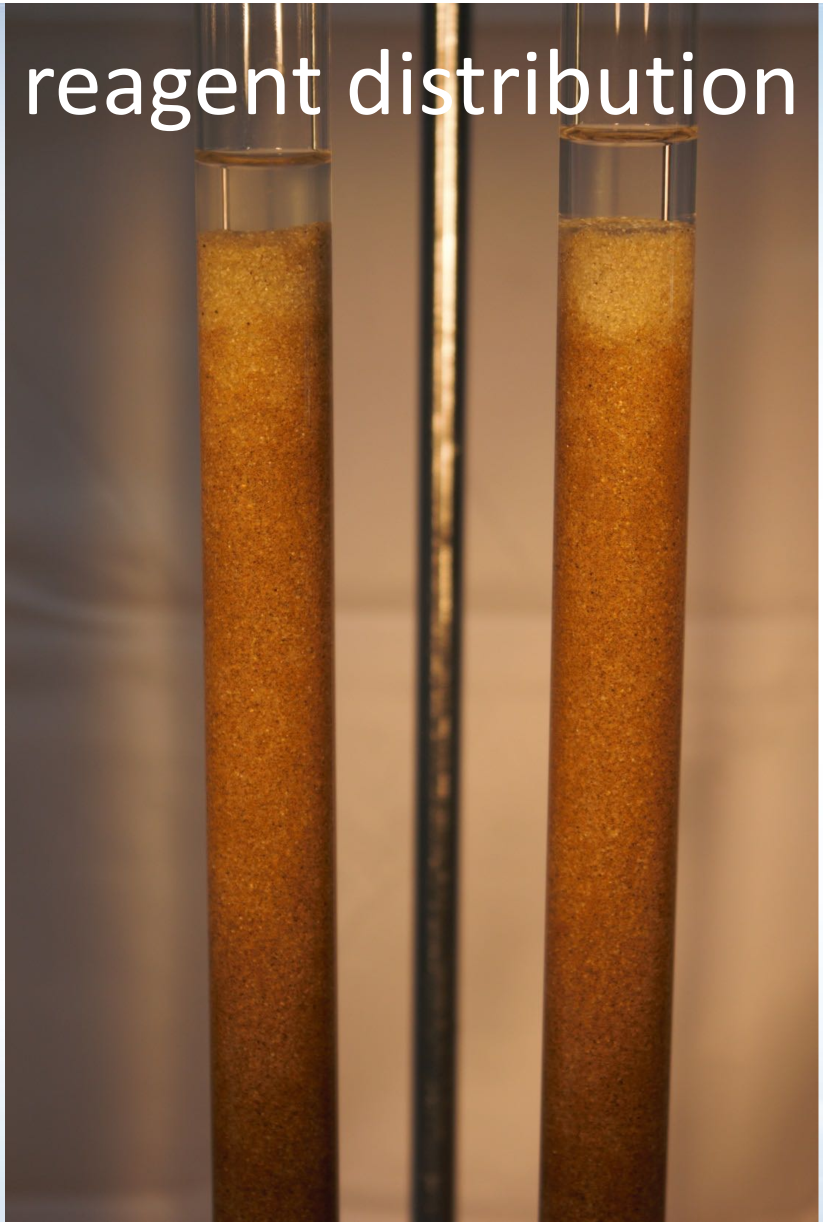
PlumeStop® – what it is

PLUME STOP™
Liquid Activated Carbon

- 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 (patented – plus three additional patents pending)
    - Core innovation
    - Enables wide-area, low-pressure distribution through the soil matrix without clogging

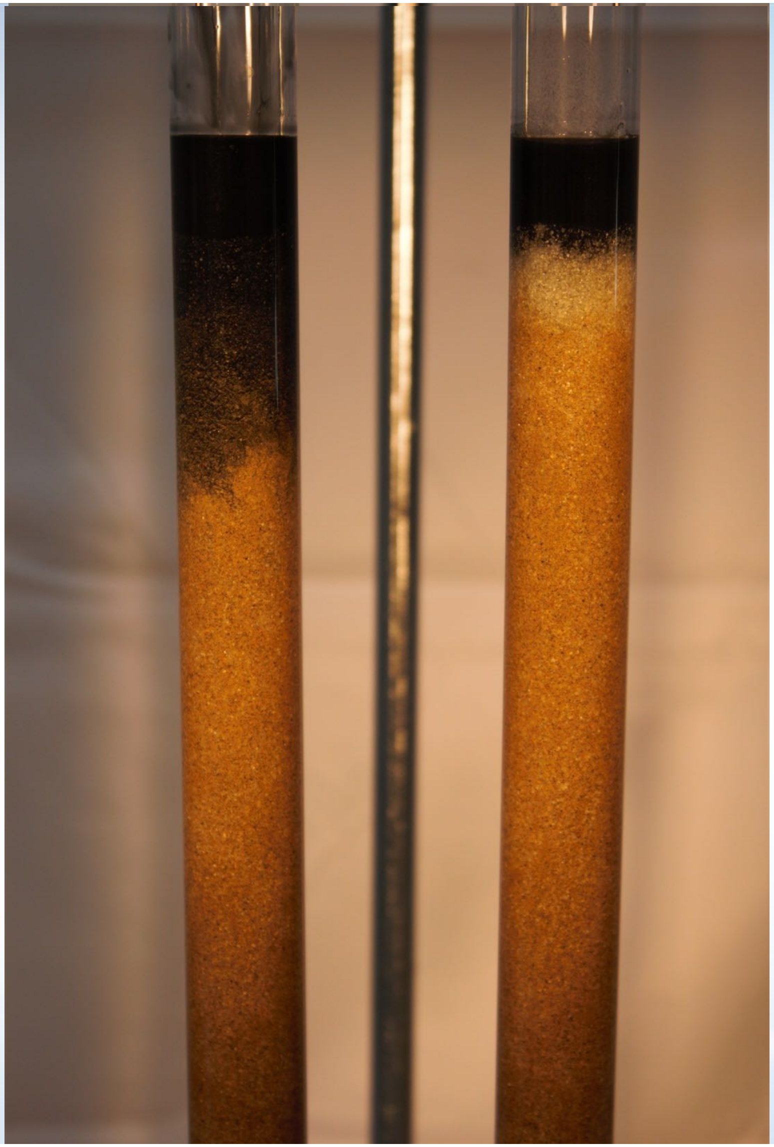
PlumeStop®: reagent distribution



PlumeStop

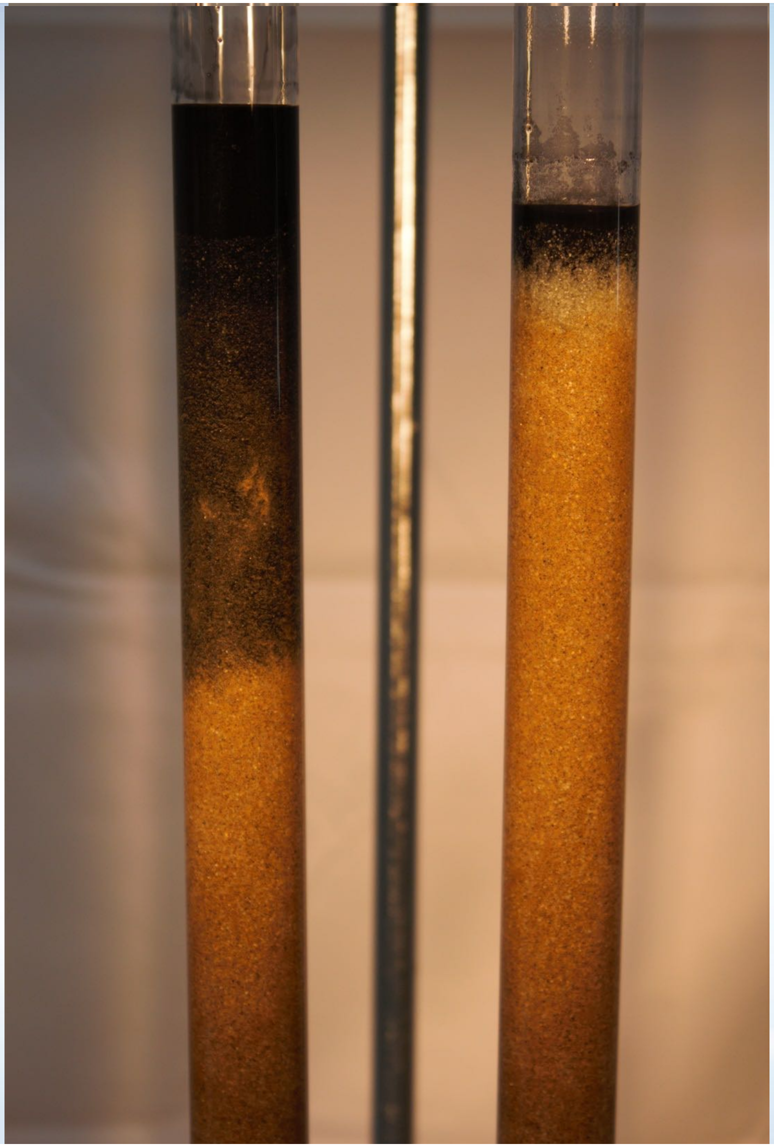
Powdered Activated Carbon

PlumeStop



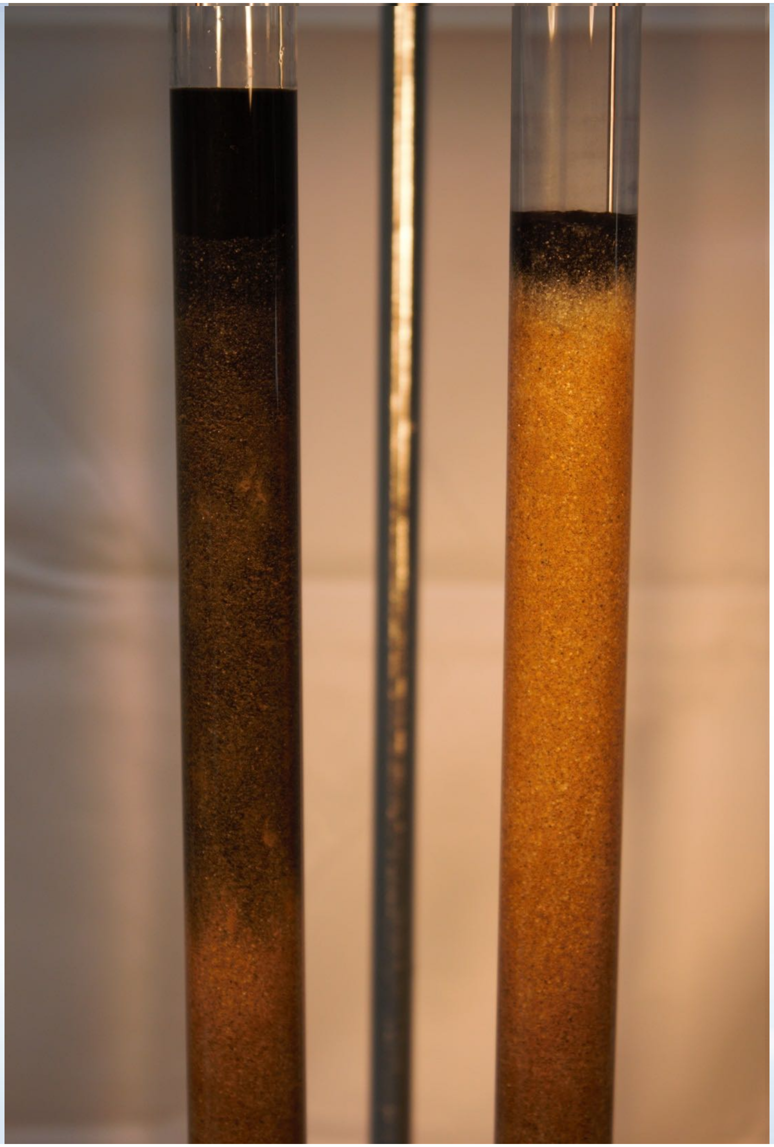
Powdered Activated Carbon

PlumeStop



Powdered Activated Carbon

PlumeStop

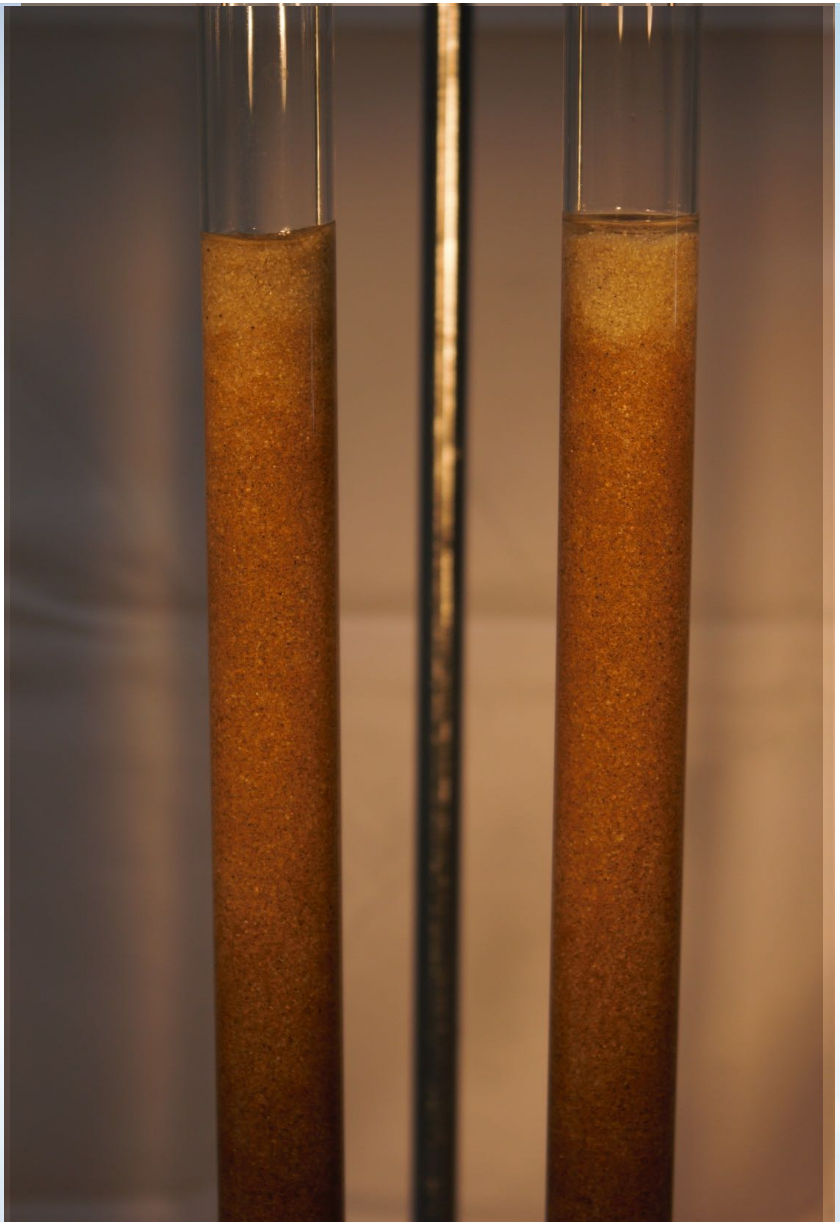


Powdered Activated Carbon

PlumeStop

PLUME STOP
Liquid Activated Carbon

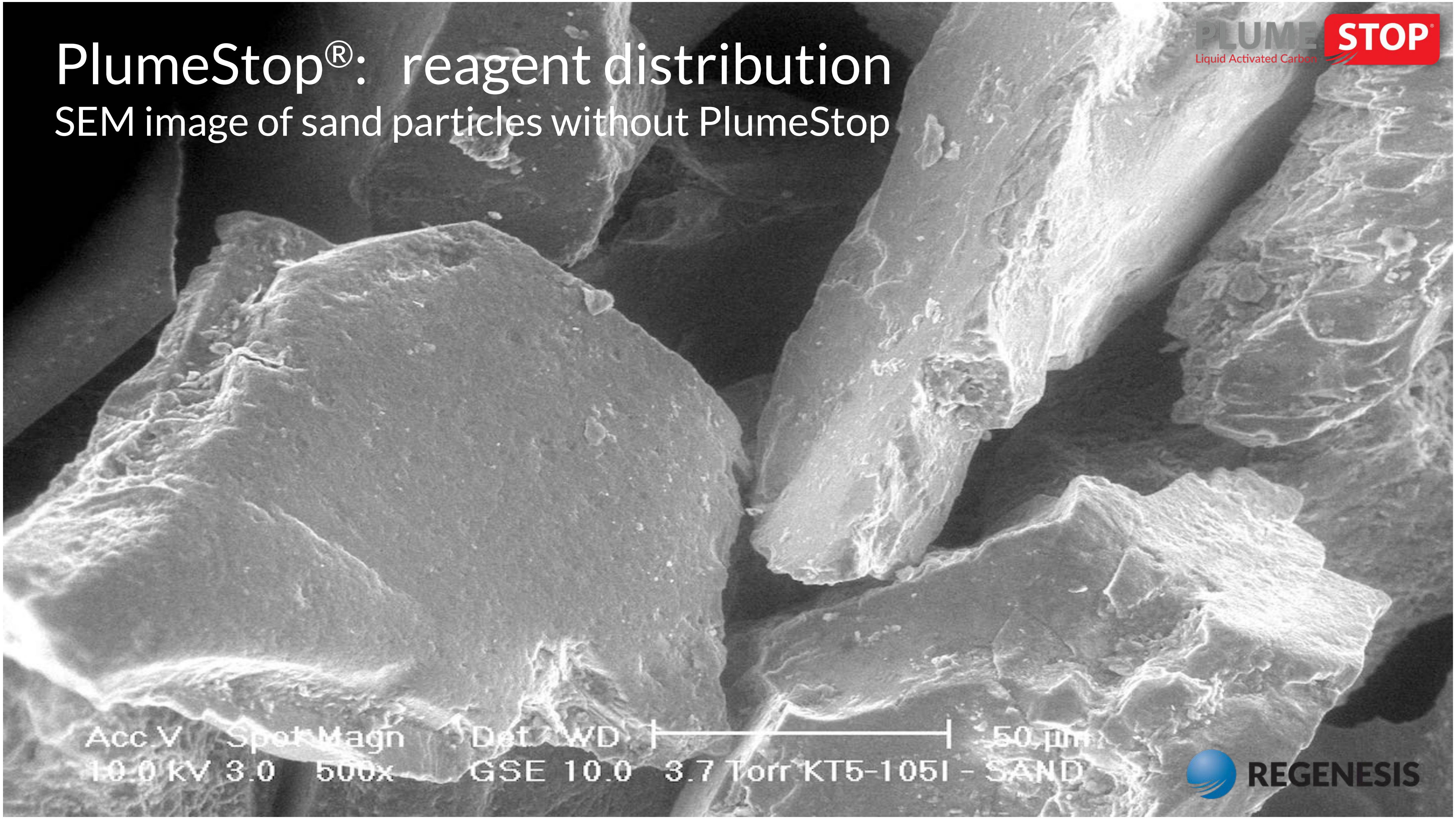
repeat



Powdered Activated Carbon

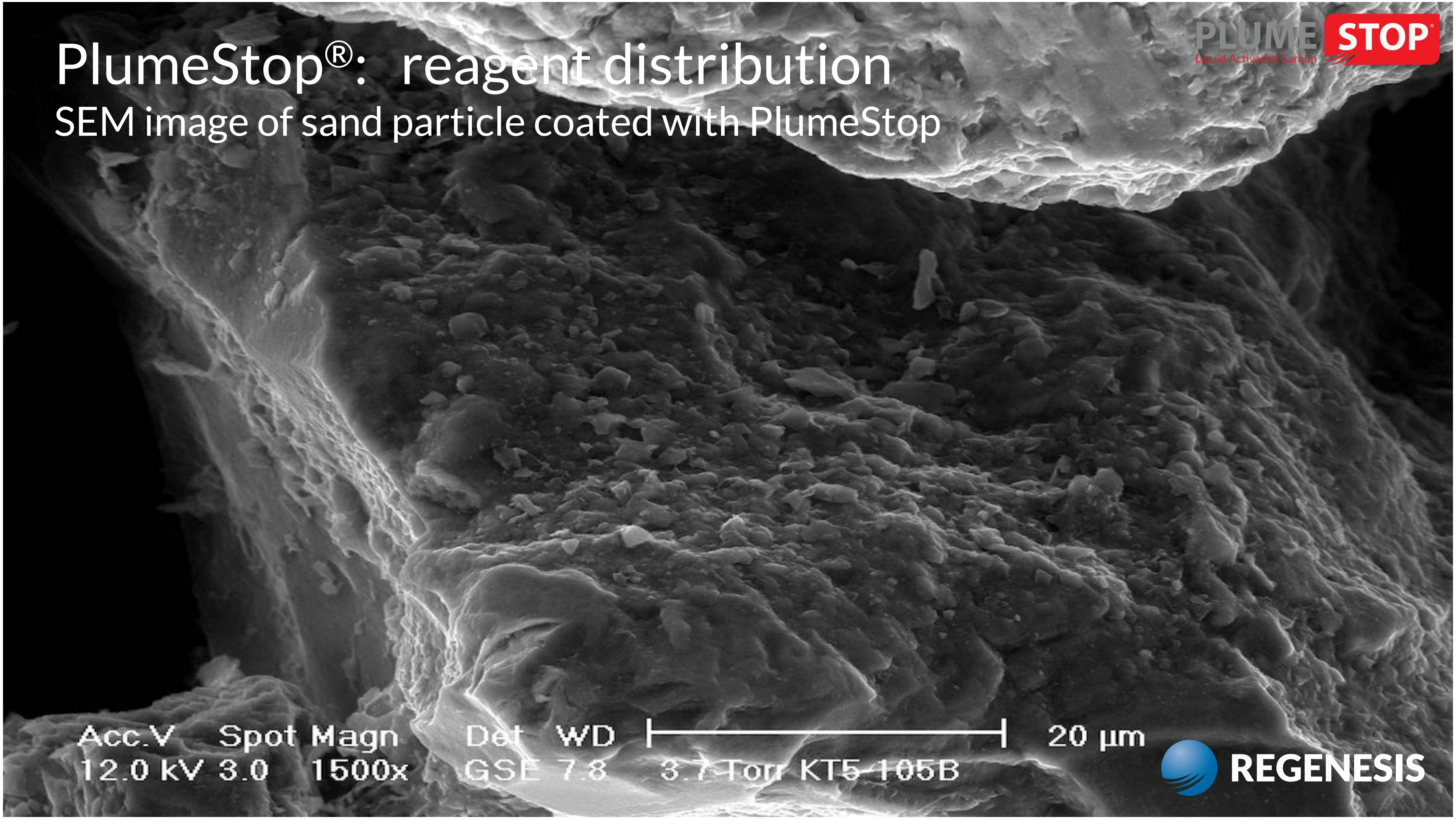
PlumeStop®: reagent distribution

SEM image of sand particles without PlumeStop



PlumeStop®: reagent distribution

SEM image of sand particle coated with PlumeStop



PLUME STOP
Liquid Activated Carbon

REGENESIS

Key Questions

- How do you engineer the retardation factor?
- **What scale of change can be achieved?**
- What will this do to the bio rate?

- How is this designed?
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Baseline Condition

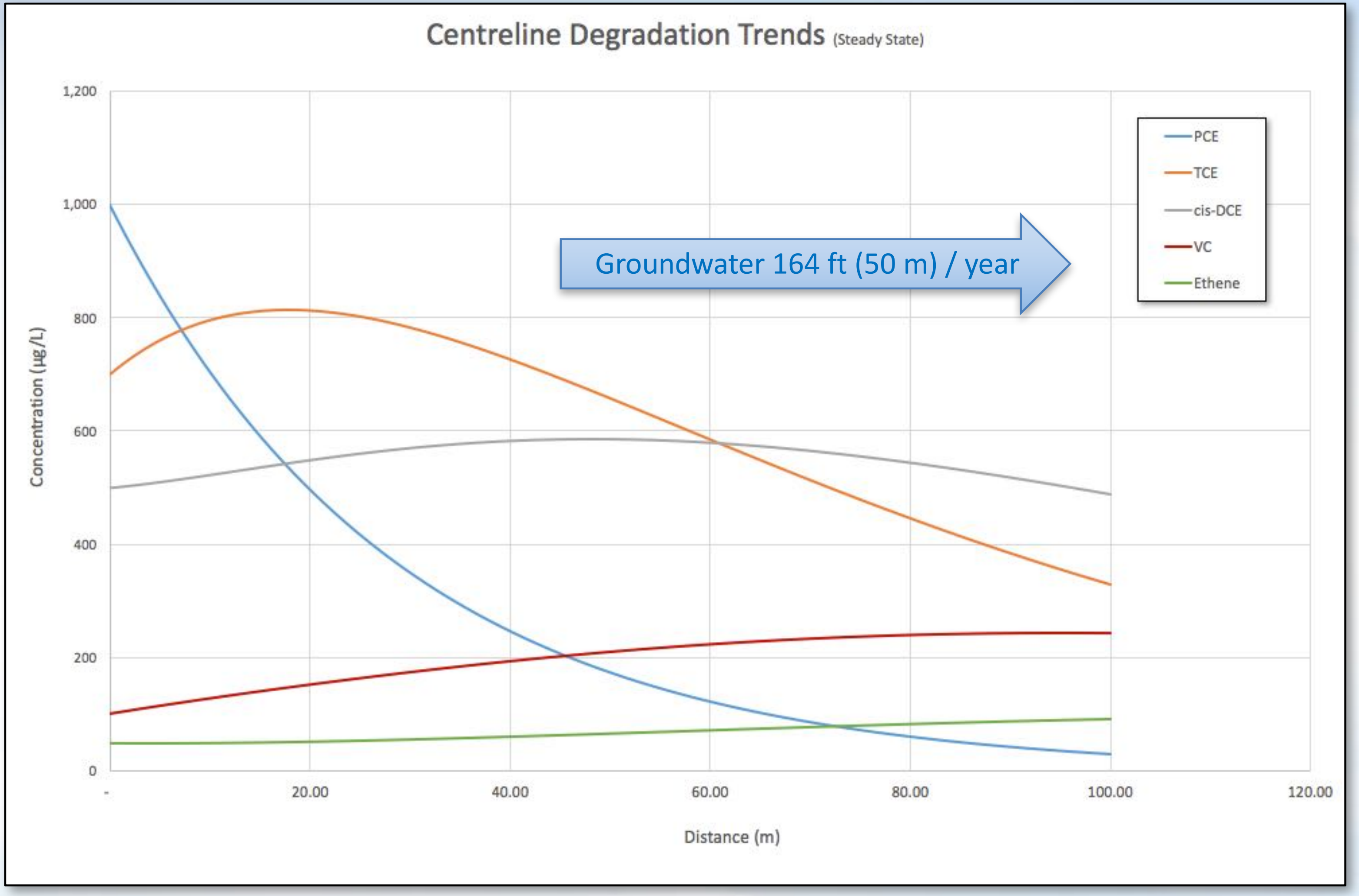
(i.e. ambient background)

Deg. Rates *k* (as $t_{\frac{1}{2}}$)
500 days (PCE, TCE, DCE)
250 days (VC, ethene)

Retardation Factors (*R*)
PCE = 3.45
TCE = 1.81
DCE = 1.53
VC = 1.02

R = 1.00 = GW velocity
R = 2.00 = $\frac{1}{2}$ GW velocity

f_{oc} 0.001



REGENESIS

Enhanced Natural Attenuation Barrier

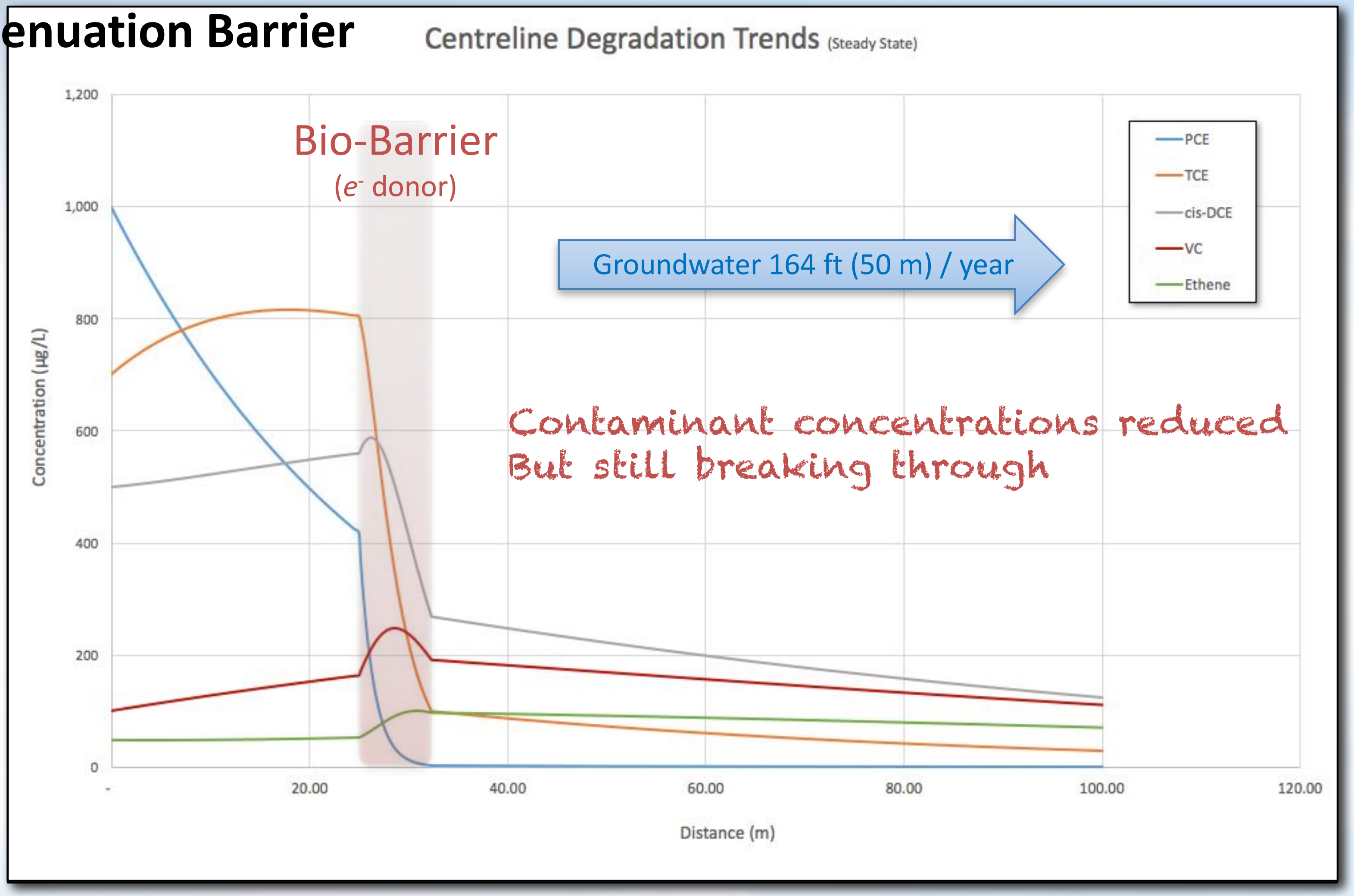
(i.e. electron donor addition)

Deg. Rates k (as $t_{\frac{1}{2}}$)
25 days (PCE, TCE, DCE)
12.5 days (VC, ethene)

(all reduced by 95%)
(i.e. 20 x faster in barrier)

Ret. factors (unchanged)
PCE = 3.45
TCE = 1.81
DCE = 1.53
VC = 1.02

Barrier width = 24 ft.
(7.3m)



Bio-Barrier
(e^- donor)

Groundwater 164 ft (50 m) / year

Contaminant concentrations reduced
But still breaking through

Enhanced Natural Attenuation Barrier

(i.e. electron donor addition)

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12.5 days (VC, ethene)

(all reduced by 95%)
(i.e. 20 x faster in barrier)

Ret. factors (unchanged)
PCE = 3.45
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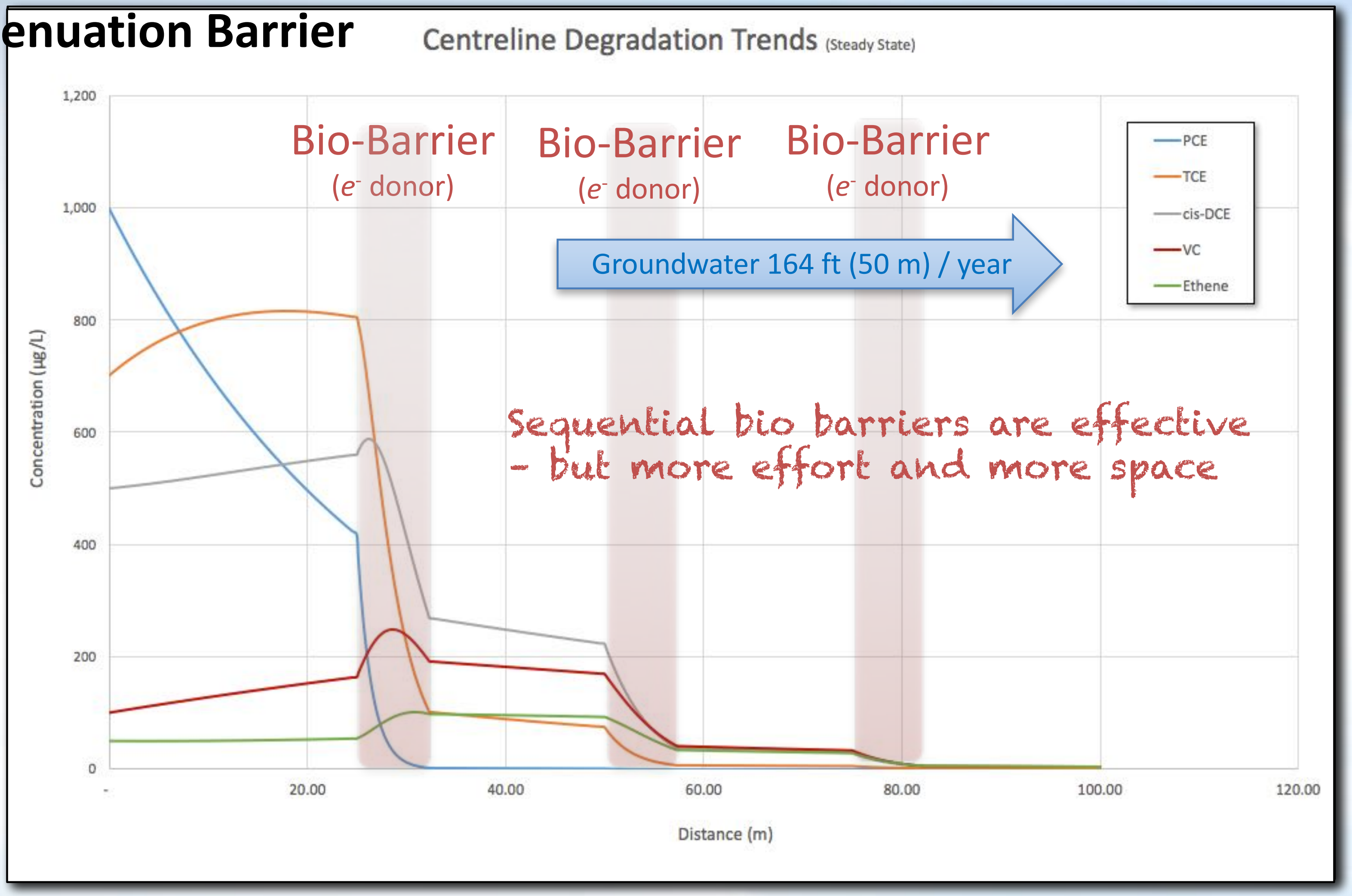
DCE = 1.53
VC = 1.02

Barrier width = 24 ft. x 3
(7.3m each)



Sequential bio barriers are effective
– but more effort and more space

Engineered Retardation Factor

(i.e. Post LAC™ Application)

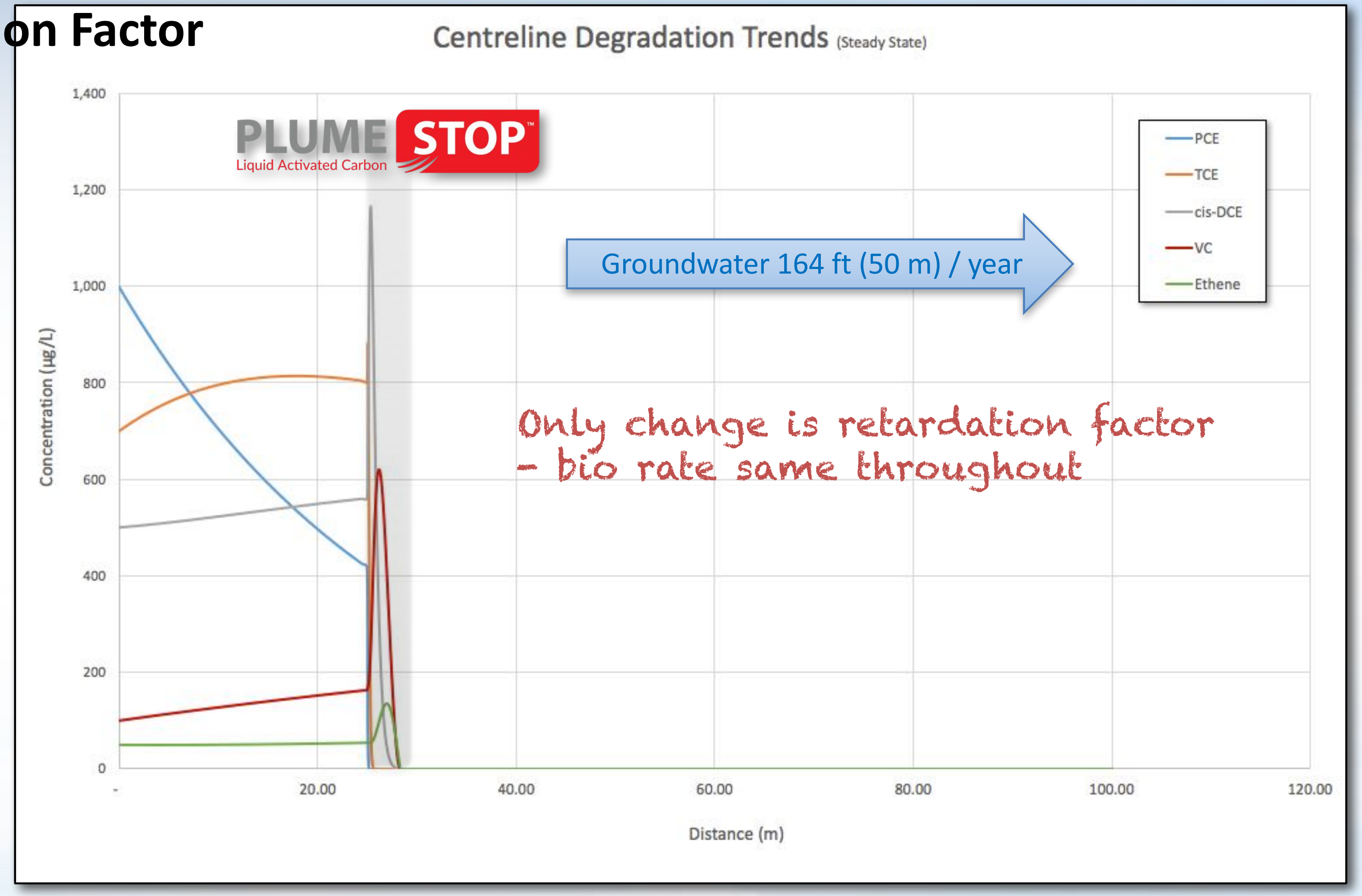
Deg. Rates k (as $t_{\frac{1}{2}}$)
500 days (PCE, TCE, DCE)
250 days (VC, ethene)
(unchanged from background)

Retardation Factors (R)

- dynamically variable
  - convex isotherms
  - competitive sorption
  - range 10's to 1000's

f_{oc} = 0.001
$f_{PlumeStop}$ = 0.003

LAC™ Emplaceable Range:
~0.0001 – 0.02 (∴0.003 ≈ 15%)



Centreline Degradation Trends (Steady State)

Groundwater 164 ft (50 m) / year

Only change is retardation factor
– bio rate same throughout

Engineered Retardation Factor

(i.e. Post LAC™ Application)

Deg. Rates k (as $t_{\frac{1}{2}}$)
500 days (PCE, TCE, DCE)
250 days (VC, ethene)
(unchanged from background)

Retardation Factors (R)
- dynamically variable
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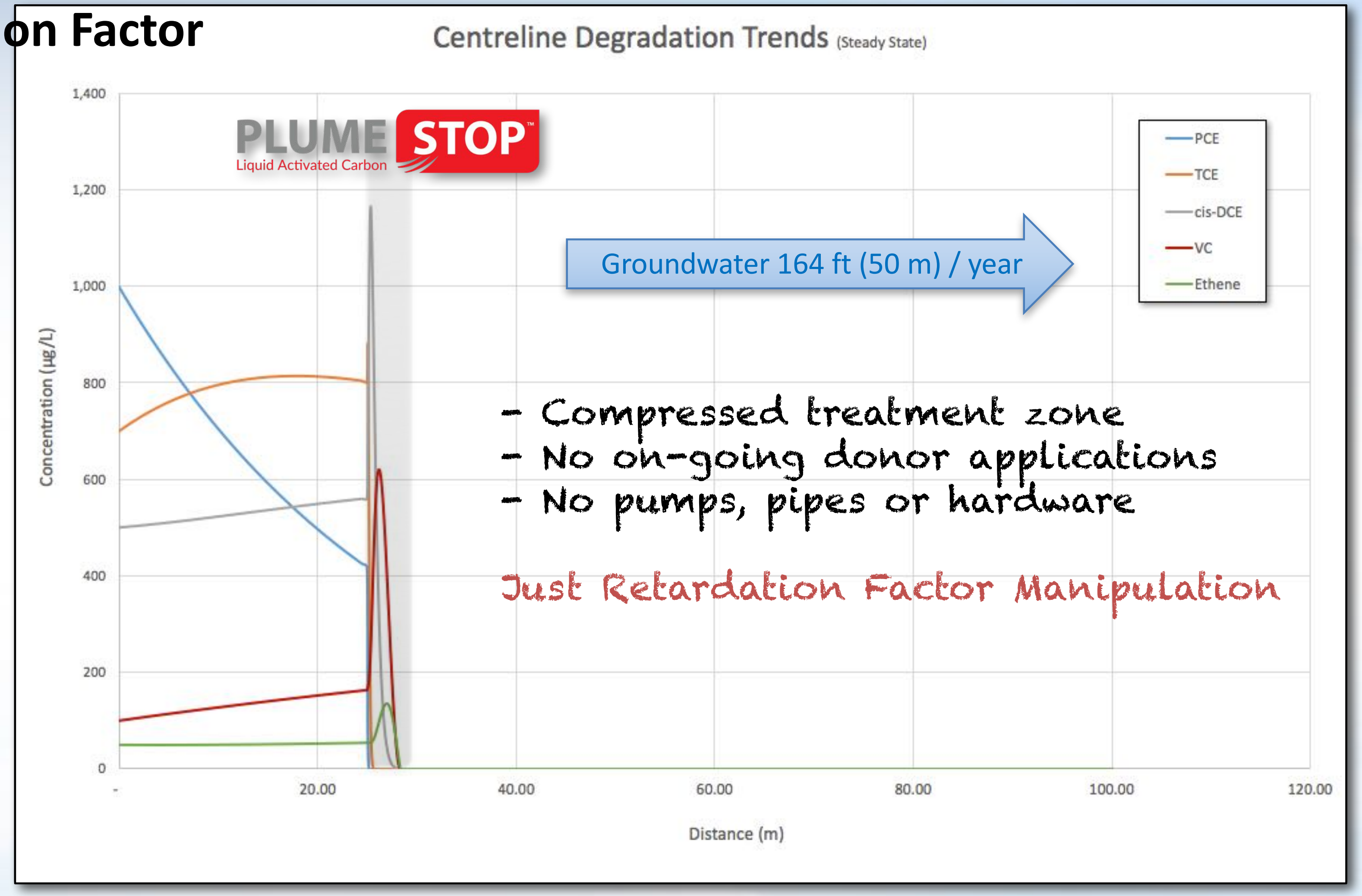

- Compressed treatment zone
- No on-going donor applications
- No pumps, pipes or hardware

Just Retardation Factor Manipulation

Key Questions

- How do you engineer the retardation factor?
- What scale of change can be achieved?
- **What will this do to the bio rate?**

- How is this designed?
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What will this do to the biodegradation rate?

Rate change will be a balance of stimulatory and inhibitory factors

Bio-stimulatory Factors

(increase rate)

- Increased contact time
  - as in wastewater treatment systems
- Higher local concentration
  - Increased local bio-availability
  - Overcome S_{min} limitation
- Higher microbial numbers
  - Conducive physical matrix?
- Stabilized substrate availability
  - Desorption rate equilibrates with bio

Bio-inhibitory Factors

(decrease rate)

- Irreversible sorption
  - High carbon / contaminant ratio
  - But further up the isotherm exchange occurs
  - If sorption is *truly* irreversible, what risk remains?
- Micropore bacterial inaccessibility
  - Microbe size exclusion

PlumeStop® particle diameter only 1 – 2 µm

- Higher accessible *outer* surface than GAC
- Short internal diffusion distances → faster exchange

∴ calibration and monitoring

Key Questions

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- **How is this designed?**
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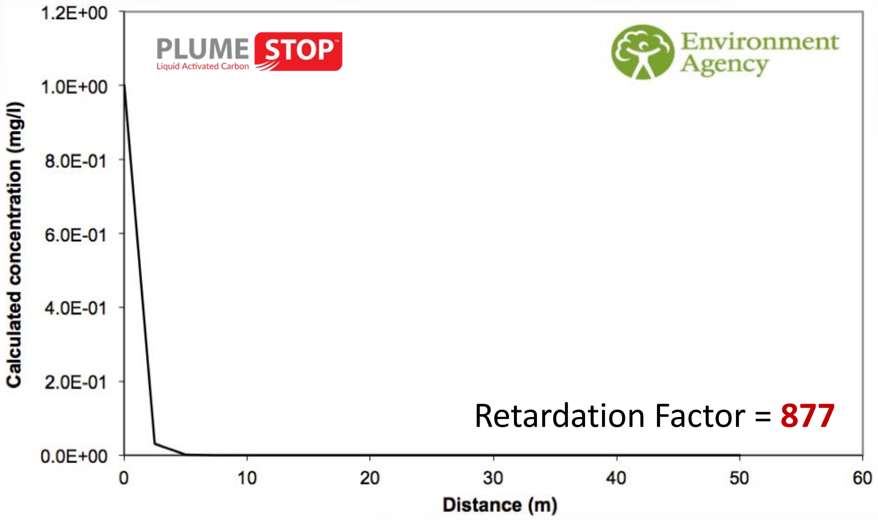
PlumeStop® - integration with off-the-shelf models *

- **TCE 1,000 µg/L**
- Groundwater velocity 39 m/year (128 ft/year)
- **Runtime 9E+99 days** (infinite, steady-state)
- TCE $t_{½}$ 500 days
- f_{oc} 0.001

→ **783 µg/L at 10 m** (33 ft) (283 µg/L at 50 m (164 ft))



- As before, with PlumeStop® ($f_{PlumeStop}$ 0.0015)
  - TCE conc. at 2.5 m (8') = 30 µg/L (97.0% reduction)
  - TCE conc. at 5.0 m (16') = <1µg/L (99.9% reduction)
- Required barrier thickness = **5.0 m** (16 ft) (at specified dose)

(based on single species – limitation of RTM Model)

* R&D Publication 20 Remedial Targets Worksheet, Release 3.2 (Level 3 Groundwater)

PlumeStop® - passive management of groundwater plumes

- **PlumeStop® projects can be designed using off-the-shelf models**
  - Direct integration into fate and transport / risk assessments
  - Ability to explore and refine design scenarios

- **Any model can be accessed via specific parameters influenced by PlumeStop®**
  - The preceding **fraction of organic carbon** (f_{oc}) entry point is just one example
  - There are other entry points too depending on the sophistication of the model

Conversion sheets exist for parameter translation to PlumeStop® equivalents

(close)

REGENESIS

Key Questions

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- How is this designed?
- **How is performance tracked?**
- What are the cost / engineering / resource implications?

(skip)

How is performance tracked?

- Conventional monitoring wells
  - Plume monitoring is no different
  - The contaminants are just moving more slowly

Benefit of well placement within / between barriers

How is performance tracked?

- **Directly** – it's all about the retardation factor
  - this can be measured – i.e. no need for emplaced-carbon measurement
  - dual tracer comparison – zero retardation tracer and mildly retarded tracer
- What about residual / ongoing capacity / bio?
  - same approach – if bio is keeping pace with sorption *R* will not decline
- Importance of tracer selection
  - Must have significantly weaker sorption than target contaminants
  - Risk of competitive displacement

(close)

Key Questions

- How do you engineer the retardation factor?
- What scale of change can be achieved?
- What will this do to the bio rate?

- How is this designed?
- How is performance tracked?
- **What are the cost / engineering / resource implications?**

What are the cost / engineering / resource implications?

- Pumps, Pipes and Perforations (less)

versus

- Modelling, Measurement and Management (more)

- Principal engineering components
    - Flux-channel identification
    - Pump tests, tracer tests
    - Modelling, monitoring and maintenance

So Higher on Hydro

Take Home

- This session: **MNA for Achieving Site Goals**
- This presentation: **retardation factor manipulation**

  'splicing in' extra attenuation time into a shorter distance
- Relevance:
  - achieve MNA targets within site boundaries on many more sites
  - achieve MNA plume expansion-limitation targets easily
  - **achieve this passively**: maintain the intrinsic benefits of MNA

The retardation factor is now an engineering variable

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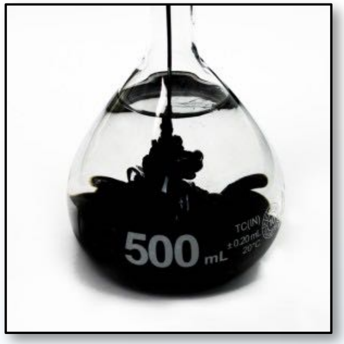
Thank You



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