Addressing PFAS Groundwater to Surface Water Discharge: Materials and Methods for Construction of In-Situ Permeable Reactive Barriers (PRB) to Limit Migration

John Collins and John Hull (AquaBlok, Ltd.)
Richard Stewart (Ziltek Pty Ltd),
Conceptual Site Model:

Use of a Permeable Reactive Barrier (PRB) to Address Groundwater to Surface Water Discharge

Benefits of PRB Approach:

- Immediate Removal of Contamination Impacting Groundwater
- Passive Approach Does Not Rely on Pumping and Ex-Situ Treatment
- Known Location of Treatment Media – Can be Removed or Addressed at a Later Date
- Allows for Ease of Confirmation Sampling – Immediately Up-Stream and Down-Stream of the PRB
Example Installations

Permeable Reactive Barrier at Groundwater/Surface Water Interface (Shoreline):

- Limit Contaminant Migration to Surface Water
- Eliminate/Reduce Pump & Treat
Groundwater to Surface Water Permeable Reactive Barrier (PRB)
Permeable Reactive Barrier (PRB) to Address Dissolved-Phase PAHs & Metals in Groundwater from Entering Stream

Site Location: U.S. EPA Region 7 Confidential Project, Kansas

Products:
- AquaGate+Organoclay
- AquaGate+IRM
Permeable Reactive Barrier (PRB) to Address NAPL & Dissolved-Phase PAHs in Groundwater

Site Location: Vancouver, B.C.

Products:
- AquaGate+Organoclay
- AquaGate+PAC
- AquaBlok 2080FW
AquaBlok Ltd. Materials Platform

Uniform Delivery of
High-Value Materials in Low Quantities

- powder coating
- aggregate core
- AquaBlok “composite particle”

Aggregate Core Adds Ballast and Increases Surface Area
Coating Material Reacts/Removes Contaminants or Reduces Flux

Typical particle: 1/4” - 3/8” (dry)
Sequestration and/or Treatment

- Low Permeability Chemical Isolation Material
- Variable Particle Size & Densities
- High Shear Strength (Freshwater Erosion Resistance)
- Proven Long-Term Performance (U.S. Superfund)

AquaGATE+ PAC/Organoclay/RemBind®/Other

- Permeable (Variable)
- Powdered Treatment Amendments
  - Generally Increased Sorption Rate/Reduced Resident Time
  - Higher Surface Area
  - Uniform Distribution at Low Levels
  - Targeted Placement within a Composite Cap
Low-Permeability for Sub-Aqueous Capping & Sequestration

Applied through standing water or in the dry

Hydraulic Conductivity of $5 \times 10^{-7}$ cm/sec Without Compaction
Permeable Materials for In-Situ Treatment & Remediation Applications

- PCBs
- Dissolved Phase
- VOCs
- Petroleum
- NAPL
- Coal Tar
- PFAS
- PAHs
- Soil Fixation
- PCs
- Dissolved Phase
- VOCs
- Petroleum
- NAPL
- Coal Tar
- PFAS
- PAHs
- Soil Fixation

AquaGate+PAC

+ORGANOCLAY

AquaGate+RemBind

AquaGate Composite Particle System

ziltek
Materials Proven/Accepted

- EPA Superfund Innovative Technology Evaluation (SITE) Program Success
- Accepted as Final Remedies after CERCLA 5-year Reviews – Multiple Superfund Site Installations
- Multiple Navy and ESTCP Projects – Winner of 2016 Project of the Year

Over 200 Remediation Projects

Installed/Accepted in All US EPA Regions
RemBind® – A PFAS Immobilization Reagent

- A powdered reagent that binds PFAS in soil and water to prevent leaching or transport
- Developed with the Australian Government’s leading national R&D organization: Commonwealth Scientific Industrial Research Organization (CSIRO)
- Independently verified by government airport authorities, Defence & industry worldwide
- Applied commercially at full-scale in Australia, Sweden, and the USA
What is RemBind® - How does it work?
Extensive Testing & Independent Technical Evaluation

Known Binding Capability of Established Materials

- Al (OH)₃
- Kaolinite
- Carbon
Case Study 2015: treatment of PFAS in soil from 2 commercial airport sites in Australia

* Soil leachates prepared using the Toxicity Characteristic Leaching Procedure (TCLP)
How effective is RemBind at binding PFAS?

Leachability Characteristics of Per- and Polyfluoroalkyl Substances (PFAS) in 14 Soils from Airport Sites across Australia

Richard Stewart¹ and Ross McFarland²

<table>
<thead>
<tr>
<th>Site</th>
<th>Soil Type</th>
<th>Product</th>
<th>Product Addition Rate % (w/w)</th>
<th>PFAS Concentrations in Soil Leachate*</th>
<th>Below NSW EPA Landfill Criteria? 50 µg/L**</th>
<th>PFOS Reduction %</th>
<th>Passed USEPA Method 1320?</th>
<th>PFOS/Total PFAS*** %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Silty clay loam</td>
<td>RemBind Plus</td>
<td>5.0</td>
<td>PFOS mg/kg 0.74, PFOS µg/L 34, PFOS µg/L 0.65, PFOS µg/L 0.29, PFOS µg/L &lt;0.02</td>
<td>Yes</td>
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<td>7.6</td>
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<td>Yes</td>
<td>90.07</td>
<td>Yes</td>
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<td>3</td>
<td>Clay</td>
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<td>Yes</td>
<td>99.80</td>
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<td>99</td>
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<tr>
<td>4</td>
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<td>95.00</td>
<td>Yes</td>
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<td>5</td>
<td>Sand</td>
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<td>&gt;98.00</td>
<td>nt</td>
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<td>Yes</td>
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<td>nt</td>
<td>nt</td>
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<tr>
<td>7</td>
<td>Silty sand</td>
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<td>PFOS mg/kg 7.25, PFOS µg/L 190, PFOS µg/L 0.05, PFOS µg/L 0.05, PFOS µg/L &lt;0.02</td>
<td>Yes</td>
<td>99.97</td>
<td>Yes</td>
<td>99</td>
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<td>8</td>
<td>Clayey loam</td>
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<td>&gt;99.97</td>
<td>Yes</td>
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<td>Clay/gravel (spill)</td>
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<td>99.90</td>
<td>Yes</td>
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<td>99.50</td>
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<td>13</td>
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<td>99.90</td>
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<td>Yes</td>
<td>99.89</td>
<td>nt</td>
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</tr>
</tbody>
</table>

* As prepared by TCLP or ASLSP at pH 5
** NSW landfill guidelines stipulate a soil leachate criteria of 50 µg/L for PFOS + PFHxS for general solid waste
*** Ratio of total PFOS/total PFAS extended suite (20 analytes) run by Australian Laboratory Services

TCLP = Toxicity Characteristic Leaching Procedure
ASLSP = Australian Standard Leaching Procedure
nt = not tested
How stable is the binding reaction?

- Because RemBind doesn’t destroy the contaminants, it is critical to prove the long term stability of the binding
- Multiple Extraction Procedure (USEPA 1320) simulates 1,000 yrs of acid rain conditions in an improperly designed landfill

<table>
<thead>
<tr>
<th>Site 1 - RemBind Plus Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leach</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>PFOS</td>
</tr>
<tr>
<td>pH</td>
</tr>
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</table>
# Comparison with Activated Carbon

<table>
<thead>
<tr>
<th></th>
<th>RemBind</th>
<th>Activated Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bind short chain PFAS?</td>
<td>High efficiency</td>
<td>Low efficiency ¹, ²</td>
</tr>
<tr>
<td>Easy to apply in field for soil treatment</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Availability of large volumes</td>
<td>1-2 weeks</td>
<td>1-2 Months</td>
</tr>
<tr>
<td>PFOS adsorption capacity</td>
<td>2,000 ug/g</td>
<td>~1,500 ug/g</td>
</tr>
</tbody>
</table>

¹ *Treatment of poly- and perfluoroalkyl substances in US full-scale water treatment systems.*
Appleman et al. (2014) *Water Research* 51 pp. 246-255

² *Sorption of Poly- and Perfluoroalkyl Substances (PFASs) Relevant to Aqueous Film-Forming Foam (AFFF)-Impacted Groundwater by Biochars and Activated Carbon*
Xinxiao et al. (2017) *Environmental Science and Technology* 51 pp. 6342-6351
Extending Applications to Groundwater and Sediment PFAS Immobilization

- RemBind® and AquaGate® have been combined to produce a unique product for removing PFAS from groundwater or pore water.
- Applications include permeable reactive barriers, surface water drains, sediment in ponds/rivers, landfills, and soil stockpile liners.
- Goal – Ease of Practical Application
- Proven long-term stability – US EPA 1320
- Independently validated by industry.
- Raw Materials Sourced in Australia (i.e. Attapulgite, Bentonite, etc.)
- Wollongong NSW Based Manufacturing Location
- On-Site Production for Larger Production Projects
- Inventory of Available Products
- Experienced Construction Operations with Wide Range of Licensure
Advantages of AquaGate Approach

Uniform Delivery of Permeable Reactive Barrier (PRB)

Placement from Bulk Bag

Uniform Installed Distribution

Benefits of AquaGate+ Approach:
- Uniform distribution of sorptive material
- Maintain and limit reduction in permeability
- Higher rate of sorption than granular material
Design Approach for Surface Water (PRB)
On-Site Production & Operations

Full-Scale Remote Manufacturing Performed at Multiple Locations
Summary – Q&A

AquaBlok as a Low-Permeability Material for Remediation & Geotechnical Applications

- Permeable Treatment Material for Remediation Applications
- Permeable Treatment Material for Groundwater & Sediment Remediation Applications
- Rapid Installation – Using Conventional Equipment
- Proven Full-Scale Production – On-Site Manufacturing

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Thebarton SA 5031, Australia
Machado Lake – 45 Acre Lake Capping Project

Dredge & Cap Approach to Restoration

Machado Lake is located in Harbor City, CA. The lake was identified as an impaired water body as a result of pollution in storm water and urban runoff flowing from its 15,553-acre watershed.

The approach involved dredging approximately 239,000 cubic yards of sediment and capping the lake bottom with AquaBlok. The City of Los Angeles Department of Public Works managed the project with OHL, Inc. acting as the prime contractor.