In Situ Sediment Immobilization Treatment: From Demonstration to Full-scale Implementation

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Presentation Overview

• In situ treatment with amendments
  - Field pilot demonstrations
  - Bioavailability reductions
  - Potential ecological effects

• Demonstrated application methods
  - Direct application of amendments
  - Mixing amendments with sediment or sand
  - Placement of amendments below covers/caps

• Lessons learned on promising applications
  - Recommendations for moving forward
Variable $K_{oc}$ of Amendments and Sediment

$C_s = C_{aq} \cdot K_{oc} \cdot f_{oc}$

Need to identify sediment component(s) that have major influence on contaminant availability

Source: Ghosh et al. 2003
In Situ Treatment by Direct Amendment

- Laboratory studies (2000 - present)
  - Mixing activated carbon (AC) or biochar amendments with sediments reduces the bioavailability of PCBs, PAHs, DDx, dioxins/furans, chlorinated benzenes, TBT, and mercury
  - Bioavailability reductions improve over time

- Field pilot studies (2004 - present)
  - More than 25 field studies are now either completed or are underway in wide range of environments using a range of different application methods
  - Results continue to show success
Reduction in PCB Porewater Concentrations in Worms

Source: Ghosh 2012
## Completed AC and Biochar Field Pilots

<table>
<thead>
<tr>
<th>Year Initiated</th>
<th>Site</th>
<th>Contaminant</th>
<th>Key Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>Anacostia River, Washington, DC</td>
<td>PAHs</td>
<td>Placed coke breeze in geotextile to control long-term mobility</td>
</tr>
<tr>
<td>2005</td>
<td>Hunters Point, San Francisco Bay, CA</td>
<td>PCBs and PAHs</td>
<td>Bioaccumulation reduction with AC mixed into sediment</td>
</tr>
<tr>
<td>2006</td>
<td>Grasse River, Massena, NY</td>
<td>PCBs</td>
<td>Bioaccumulation reduction with AC mixed into or placed on sediment</td>
</tr>
<tr>
<td>2006</td>
<td>Trondheim Harbor, Norway</td>
<td>Dioxins/furans</td>
<td>Placed AC and capped with 0.2 inches of sand for erosion protection</td>
</tr>
<tr>
<td>2006</td>
<td>Spokane River, WA</td>
<td>PCBs</td>
<td>Placed full-scale coal-amended cap to control long-term mobility</td>
</tr>
<tr>
<td>2009</td>
<td>De Veenkampen, Netherlands</td>
<td>Clean sediment</td>
<td>Only minor benthic community effects noted at AC doses of ≤4%</td>
</tr>
<tr>
<td>2009</td>
<td>Grenlandsfjords, Norway</td>
<td>Dioxins/furans</td>
<td>Hydraulic application of AC/clay mixture from 100- to 300-foot depths</td>
</tr>
<tr>
<td>2009</td>
<td>Bailey Creek, VA</td>
<td>PCBs</td>
<td>Bioaccumulation reduction with AC placed in freshwater wetland</td>
</tr>
<tr>
<td>2010</td>
<td>Canal Creek, MD</td>
<td>PCBs and mercury</td>
<td>Bioaccumulation reduction with AC placed in freshwater wetland</td>
</tr>
</tbody>
</table>
## AC and Biochar Field Studies Underway

<table>
<thead>
<tr>
<th>Year Initiated</th>
<th>Site</th>
<th>Contaminant</th>
<th>Project Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Onondaga Lake, NY</td>
<td>Chlorinated benzene/PAH</td>
<td>Evaluate mechanical placement of AC/cap mixtures</td>
</tr>
<tr>
<td>2011</td>
<td>South River, VA</td>
<td>Mercury</td>
<td>Evaluate placement of biochar and bioavailability control in pond</td>
</tr>
<tr>
<td>2011</td>
<td>Sandefjord Harbor, Norway</td>
<td>PCBs, TBT and PAHs</td>
<td>Evaluate placement of AC pellets and bioavailability control in estuary</td>
</tr>
<tr>
<td>2011</td>
<td>Bergen Harbor, Norway</td>
<td>PCBs and TBT</td>
<td>Evaluate effectiveness of AC-amended versus traditional caps</td>
</tr>
<tr>
<td>2012</td>
<td>Leirvik Sveis Shipyard, Norway</td>
<td>PCBs, TBT and metals</td>
<td>Full-Scale controlled placement of 2-inch AC-amended cap</td>
</tr>
<tr>
<td>2012</td>
<td>Naudodden, Farsund, Norway</td>
<td>PCBs, PAHs, TBT and metals</td>
<td>Full-Scale placement of layered isolation cap with AC amendment</td>
</tr>
<tr>
<td>2012</td>
<td>Berry’s Creek, NJ</td>
<td>Mercury and PCBs</td>
<td>Evaluate bioavailability control in vegetated wetland</td>
</tr>
<tr>
<td>2012</td>
<td>Puget Sound Naval Shipyard, WA</td>
<td>PCBs and mercury</td>
<td>Evaluate placement of AC pellets in under-pier areas</td>
</tr>
<tr>
<td>2012</td>
<td>Custom Plywood, Fidalgo Bay, WA</td>
<td>Dioxins/furans</td>
<td>Evaluate AC/cap effects in sensitive eelgrass environments</td>
</tr>
<tr>
<td>2012</td>
<td>Duwamish Slip 4, WA</td>
<td>PCBs</td>
<td>Full-scale AC-amended cap to control long-term mobility</td>
</tr>
</tbody>
</table>
Anacostia River, Washington, DC
2004 Coke Breeze Pilot Application

- Four treatments
  1. Sand cap (control)
  2. AquaBlok™ (seepage rate)
  3. Apatite (metal mobility)
  4. Coke breeze in geotextile (PAH mobility)

- 2½-year monitoring
  - Cap stability confirmed
  - Net accretion on cap surface
  - Porewater migration control

Source: Horne Engineering Services and LSU Hazardous Substance Research Center 2007
Hunters Point, California
2005 AC Pilot Application

- Intertidal marine environment
- Multiple AC treatments
  - Various application and mixing methods
- Black carbon, porewater, bioavailability, and benthic community monitoring
- AC placement confirmed as an effective method for reducing bioavailable PCBs and PAHs, provided ongoing sources are controlled

Source: Luthy et al. 2004
Grasse River, New York
2006 AC Pilot Application

- River environment
- Multiple AC treatments
  - Various hydraulic application and mechanical mixing methods
- Black carbon, sediment/AC stability, porewater, in situ/ex situ bioavailability and benthic community monitoring

Source: Alcoa 2010
Grasse River 2006 AC Pilot Application

Reductions in Porewater PCB Concentration vs. Dose

>99% reductions in PCB porewater concentrations by Year 3 (2009) for AC doses ≥4%

Source: Alcoa 2010
Grasse River 2006 AC Pilot Application

Reductions in Worm PCB Concentration vs. Dose

>90% reductions in PCB tissue concentrations by Year 3 (2009) for AC doses ≥4%

Source: Alcoa 2010
Spokane River, Washington 2006 Full-Scale Cap with Coal

- River environment (3.6-acre, full-scale cap)
- Local coal byproduct used for PCB mobility control
- Accurate mechanical placement (±1.5-inch precision)
- Sediment stability and PCB monitoring continue to confirm remedy protectiveness

Source: Anchor QEA 2010
Grenlandsfjords, Norway 2009 AC Pilot Application

- Marine fjord environment (2 to 10 acre study areas)
- AC mixed with locally dredged clay/applied hydraulically
- Diffusion chamber flux monitoring of dioxins/furans
- AC effectiveness similar to clay and limestone caps

Source: Cornelissen et al. 2012
Binder and Weighting Agent Amendments

- Can improve settling of AC through the water column
- Over time, the amendments break down, allowing AC to mix into the biologically active zone via bioturbation

Bioturbation of Sedimite™ After 30 Days

Source: Menzie and Ghosh 2011
Bailey Creek, Virginia 2009 AC Pilot Application

- Creek and wetland environments
- Pneumatic application of Sedimite™
- Black carbon, PCB bioavailability, and benthic community monitoring

Source: Menzie and Ghosh 2011
Canal Creek, Maryland
2010 AC Pilot Applications

- Freshwater wetland
  - John Bleiler Battelle 2013 presentation
- Pneumatic and mechanical applications of carbon slurry, Sedimite™ and AquaGate+PAC™
- Black carbon, PCB and mercury porewater and bioavailability, nutrient uptake, and benthic community monitoring

Sources: AECOM 2012, Exponent 2012, and AquaBlok 2012
Onondaga Lake, New York 2011 Pilot Cap with AC

- Lake environment (1 acre placement area; 5 to 30 feet depths)
- Cap isolation layer requires AC addition for mobility control
- Accurate mechanical placement; catch pan verification
  - Horizontally uniform AC distribution over a range of operating parameters

Source: Parsons and Honeywell 2012
South River, Virginia 2011 Charcoal Pilot Application

- Off-channel pond environment
- Pneumatic application of commercially available Cowboy Charcoal®
- Ongoing monitoring of black carbon, mercury porewater, surface water and biologic community
- Results pending

Source: DuPont 2012
Kirkebukten, Bergen Harbor, Norway
2011 Pilot Cap with AC

- Small marine harbor
  - Tore Lundh Battelle 2013 presentation

- Two caps with AC
  1. 6-inches BioBlok®
  2. 2-inches crushed stone + 4-inches BioBlok®

- Mechanical placement

- Ongoing monitoring
  - PCB and TBT mobility control
  - Cap stability

Source: BIOLOGGE, COWI 2012

a BioBlok® in Scandinavia = AquaBlok® in US
Leirvik Sveis Shipyard, Norway
2012 Full-Scale Cap with AC

- Marine environment
  - Steep slopes
  - Tore Lundh Battelle 2013 presentation
- Two caps with AC
  1. 2-inches BioBlock® cap
  2. 4-inches crushed stone + 4-inches gravel + 1-inches BioBlock®
- Placement with modified sand spreader
- Ongoing monitoring of black carbon, stability and benthic community

Source: BIOLOGGE 2012

a BioBlock® in Scandinavia = AquaBlock® in US
Naudodden, Farsund, Norway 2012 Full-Scale Cap with AC

- Small marine harbor
  - Tore Lundh Battelle 2013 presentation
- Layered isolation cap with AC
  1-inch sand (habitat) +
  3-inches gravel +
  3-inches sand +
  1-inch BioBloc®

Source: BIOLOGGE, COWI 2012

*BioBloc® in Scandinavia = AquaBloc® in US*
Berry’s Creek, New Jersey
2012 AC Pilot Application

• Urban vegetated wetland (*Phragmites*)
  - Potential impacts of dredging or capping on biological functions

• Successful AC application
  - Sedimite™
  - Activated carbon
  - Activated carbon + sand

• Ongoing monitoring of black carbon, sediment and porewater mercury/PCBs, and biologic community

• Results pending

Source: Parsons, Exponent, SERC, Anchor QEA, UMBC 2012
Puget Sound Naval Shipyard, Washington 2012 AC Pilot Application

- Marine underpier area
  - Difficult area to physically dredge or cap
- Mechanical telebelt AC application
- Ongoing monitoring of black carbon, sediment stability, PCB and mercury porewater, bioavailability, benthic toxicity and benthic community
- Results pending - Kirtay et al. Battelle 2013 presentation and poster

Source: Kirtay 2012
Custom Plywood, Fidalgo Bay, Washington
2012 AC Pilot Application

• Marine eelgrass environment
  - Sensitive area; potential impacts of dredging or capping on biological functions

• Mechanical applications
  - AC only
  - AC + 4-inches sand cover
  - AC + 8-inches sand cover

• Ongoing monitoring of dioxin/furan porewater, bioavailability and eelgrass

• Results pending

Source: Hart Crowser and Washington Dept. of Ecology 2012
Duwamish Slip 4, Washington 2012 Full-Scale Cap with AC

- Nearshore estuary (groundwater seepage zone)
- 1% AC mixed into cap filter layer for PCB mobility control
- Sand, gravel, and AC material blended onshore
- Accurate mechanical placement with clamshell
- 3.6 acre application area

Source: Schuchardt and Carscadden 2012
Summary of Ecological Effects of AC

- Limited toxicity or growth effects observed in laboratory tests at AC doses above 4%
  - But inconsistent and limited laboratory findings
  - Reduced plant growth largely due to nutrient dilution
- No community effects observed in any AC field pilot
  - Full recovery of diversity and abundance within 1 year
  - Adding AC reduces toxicity in contaminated sediments
- Potential ecological effects can be minimized by maintaining AC doses ≤4%
AC Placement Sediment Cleanup Remedy

- AC can be a permanent cleanup remedy
  - AC placed on the sediment surface and distributed by bioturbation can reduce diffusive flux to the overlying water by ≥99%
- Kinetics of AC adsorption improve over time
- Natural sedimentation (even at low rates) further enhances permanence
- Stability of AC over time demonstrated in the water treatment industry

Source: Cho et al. 2012
AC Placement Sediment Cleanup Remedy

- AC placement can have similar effectiveness as capping and better effectiveness than dredging
AC Sediment Cleanup Remedy Costs

- AC placement is less costly than capping or dredging
  - Estimated costs of AC placement at a 10-acre site to achieve a 4% AC dose after bioturbation into top 4 inches

<table>
<thead>
<tr>
<th>Component</th>
<th>Low-Range Unit Cost</th>
<th>High-Range Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated Carbon</td>
<td>€15,000/acre</td>
<td>€30,000/acre</td>
</tr>
<tr>
<td>Binder/Weighting Agents&lt;sup&gt;a&lt;/sup&gt;</td>
<td>€0/acre</td>
<td>€23,000/acre</td>
</tr>
<tr>
<td>Mixing in Sediment or Sand&lt;sup&gt;a&lt;/sup&gt;</td>
<td>€0/acre</td>
<td>€40,000/acre</td>
</tr>
<tr>
<td>Field Placement</td>
<td>€23,000/acre</td>
<td>€53,000/acre</td>
</tr>
<tr>
<td>Long-term Monitoring</td>
<td>€7,500/acre</td>
<td>€38,000/acre&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>€46,000/acre</strong></td>
<td><strong>€150,000/acre</strong></td>
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</tbody>
</table>

Notes:

<sup>a</sup> Adding a binder/weighting agent amendment or sediment/sand (but typically not both) may be required in some applications depending on site-specific conditions and project designs

<sup>b</sup> High-end monitoring cost of €38,000/acre reflects prior pilot projects and likely overestimates costs for full-scale remedy implementation
Summary and Recommendations

- In situ treatment with AC is a proven innovative sediment cleanup technology
  - Site-specific design requirements
- Can rapidly and sustainably address key exposures (e.g., bioaccumulation in fish)
- Placement demonstrated using conventional equipment
  - Demonstrated uniform AC placement in deep and moving water
- Less disruptive than dredging or capping
- Less costly than dredging or capping
- Full-scale implementation now underway
- Technical summary publication pending