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

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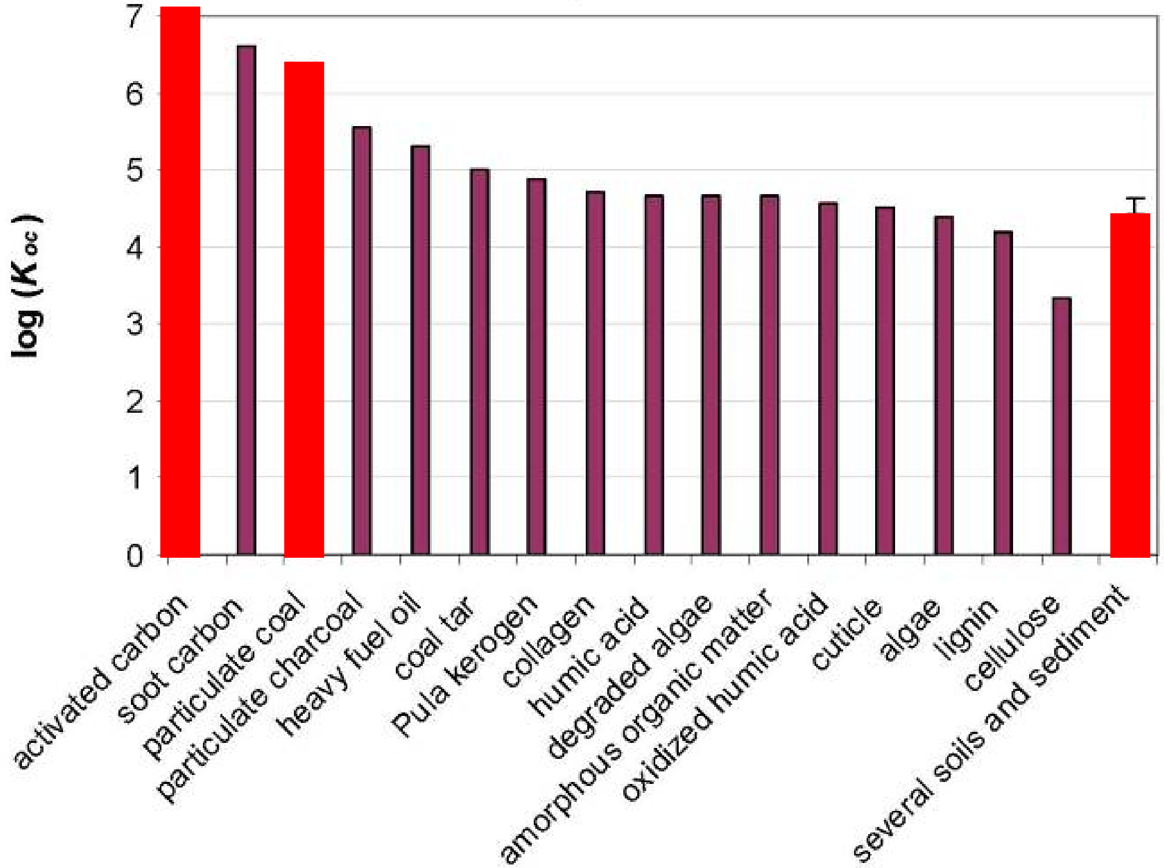
Presentation Overview

- 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

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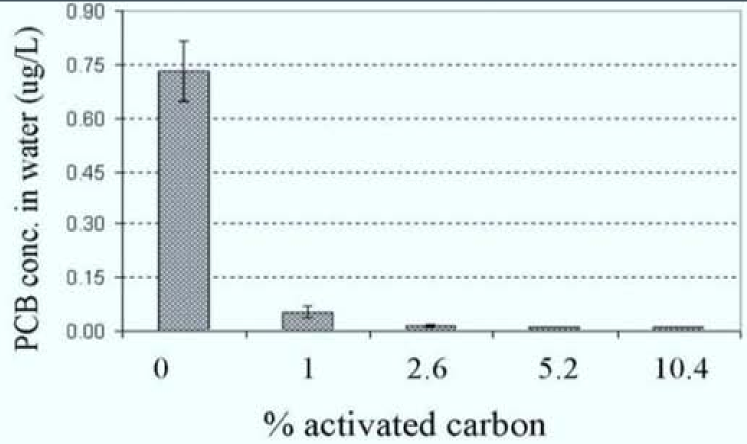
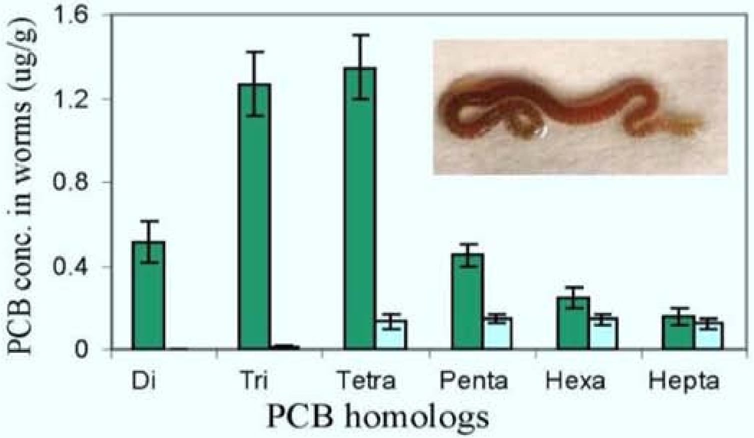
In Situ Treatment by Direct Amendment

- 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



Pore water PCB concentration decreases with increasing dose of activated carbon



PCB uptake in freshwater worms reduced after amending sediment with activated carbon

Source: Ghosh 2012

Completed AC and Biochar Field Pilots

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

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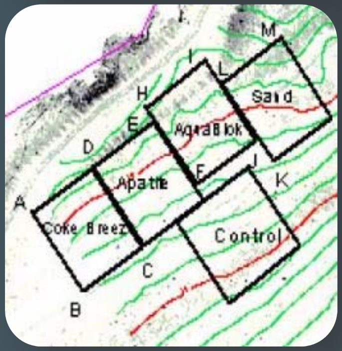
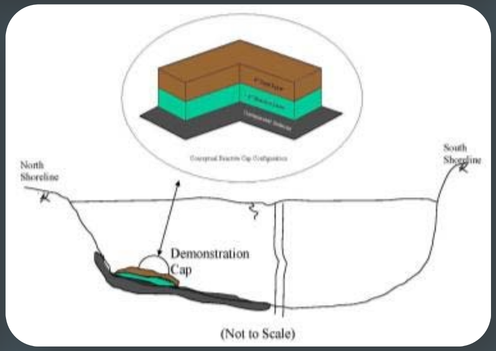
AC and Biochar Field Studies Underway

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

Anacostia River, Washington, DC
2004 Coke Breeze Pilot Application

- Four treatments
    1. Sand cap (control)
    2. AquaBlok[TM] (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

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Grasse River, New York
2006 AC Pilot Application

Application Area

Rototiller

Tine sled

Source: Alcoa 2010

- 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

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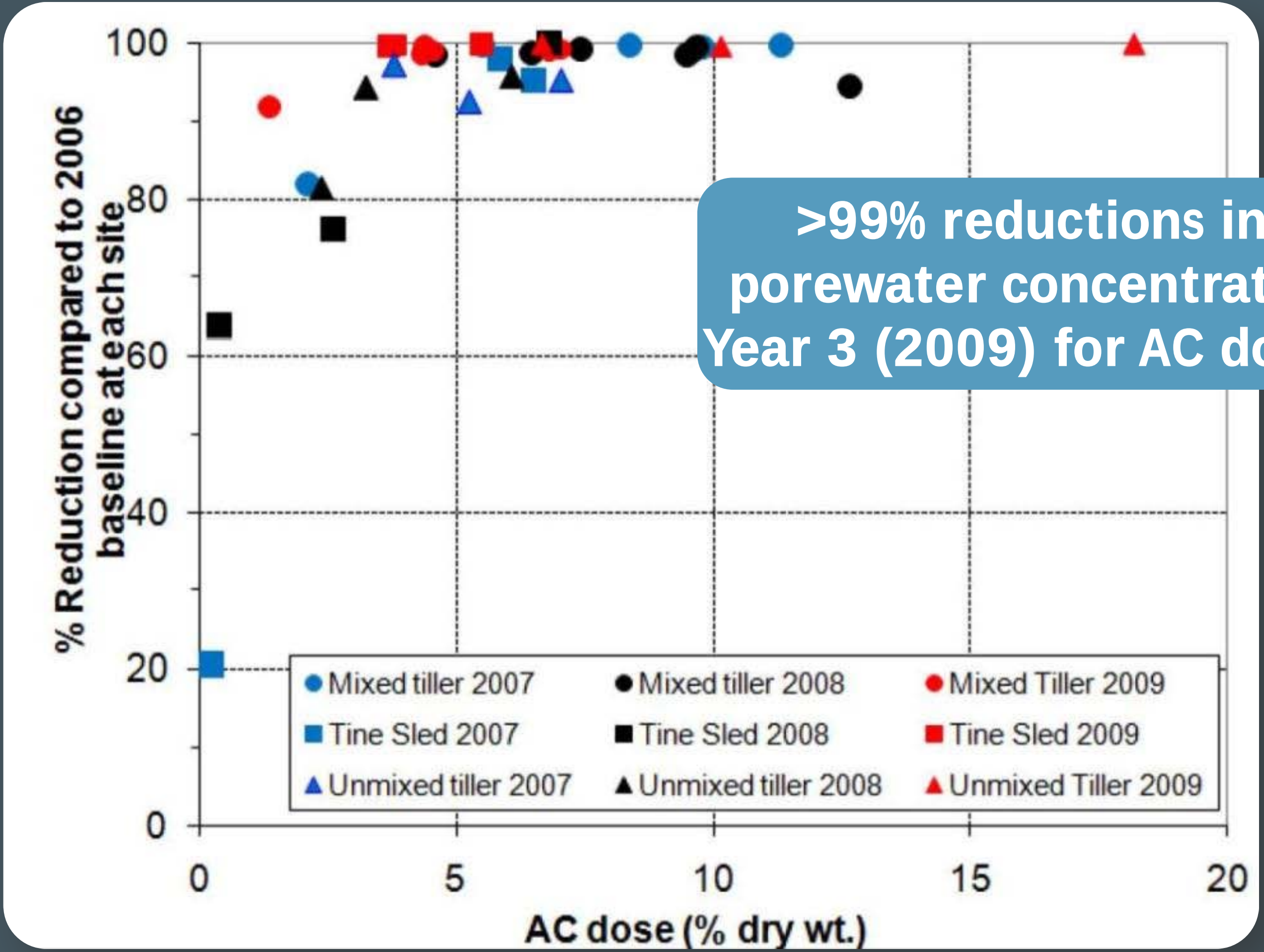
Grasse River 2006 AC Pilot Application

Reductions in Porewater PCB Concentration vs. Dose



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

Source: Alcoa 2010

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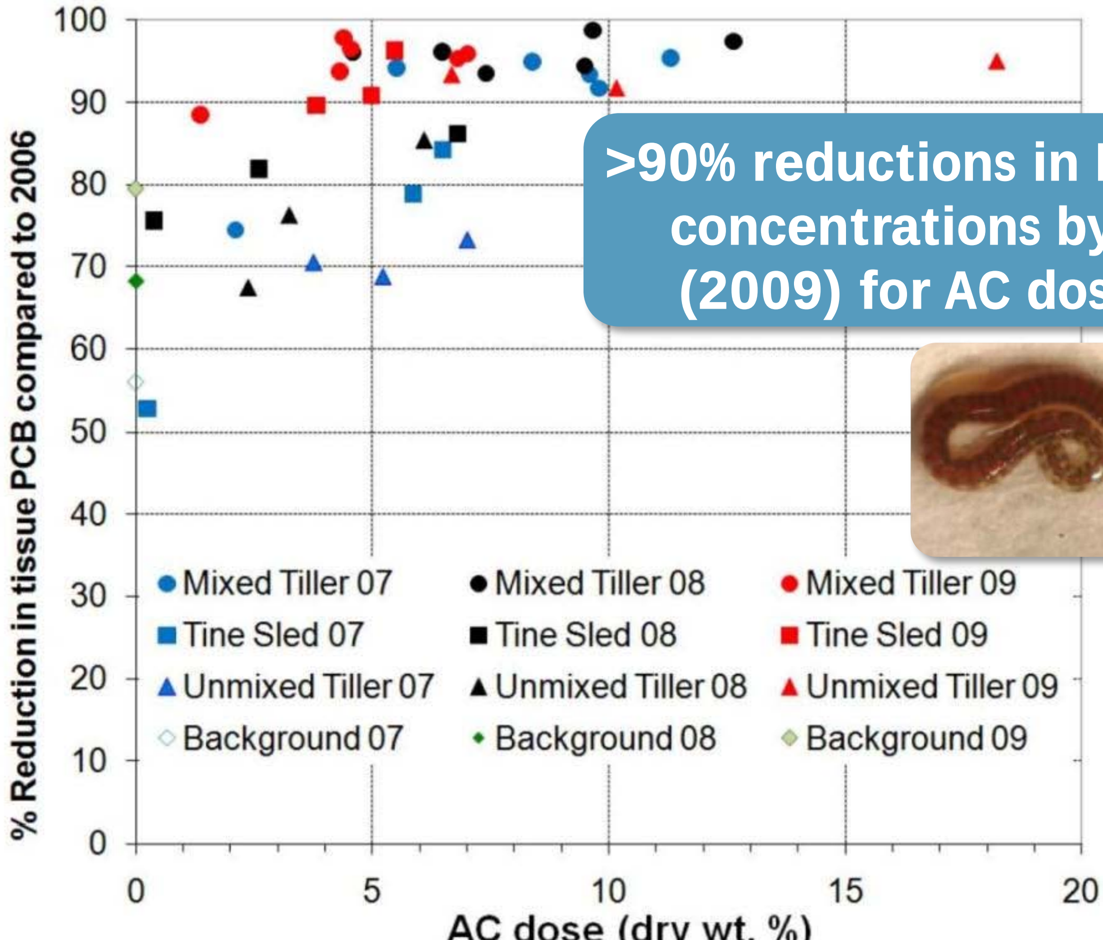
Grasse River 2006 AC Pilot Application

Reductions in Worm PCB Concentration vs. Dose



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

Source: Alcoa 2010

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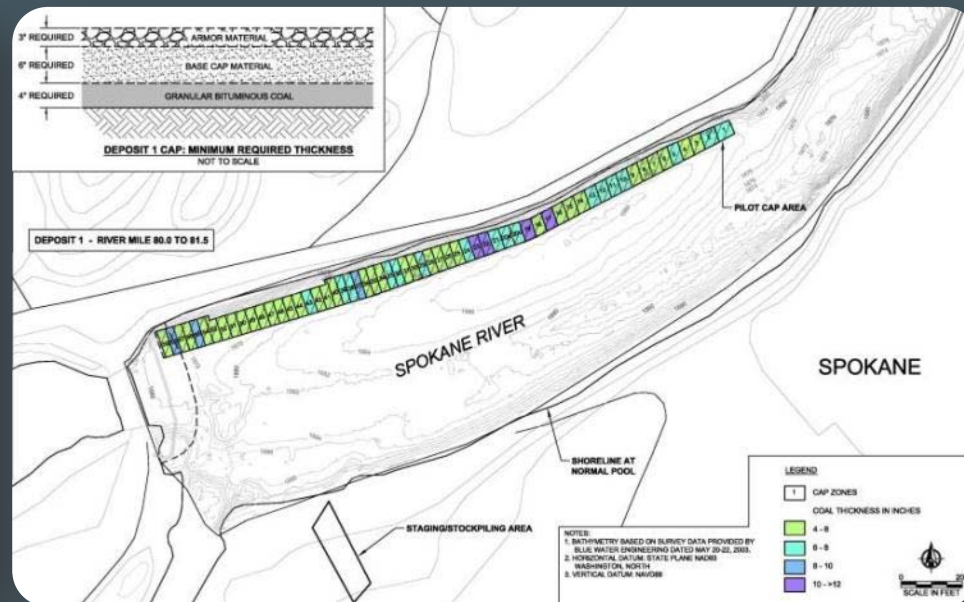
Spokane River, Washington
2006 Full-Scale Cap with Coal



Source: Anchor QEA 2010

- 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

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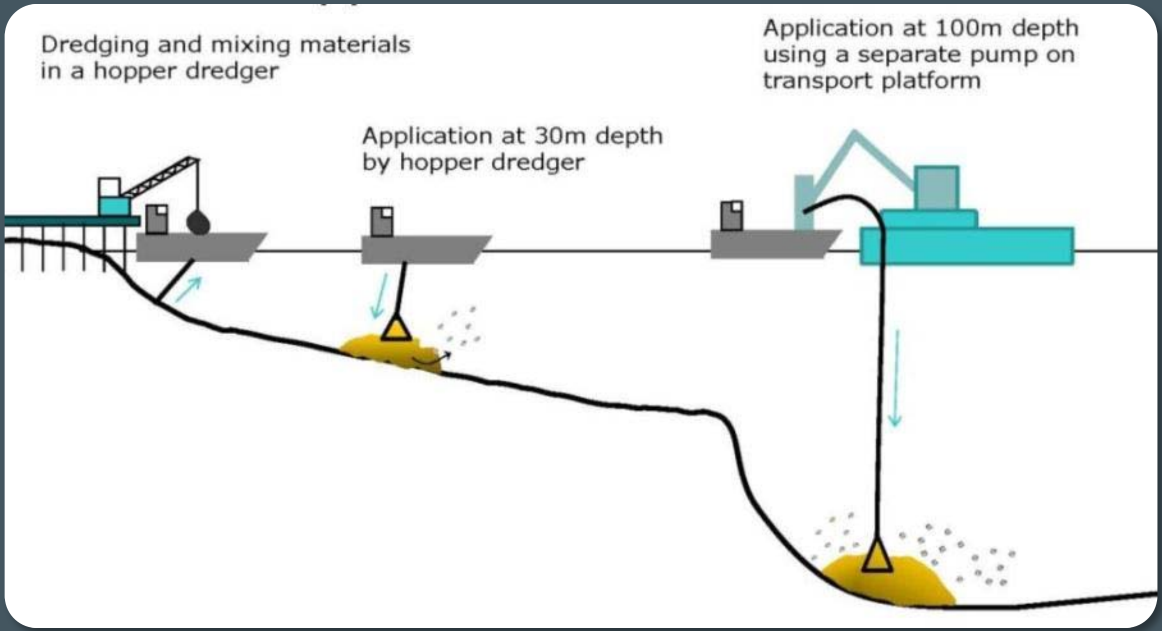
Grenlandsfjords, Norway
2009 AC Pilot Application



Source: Cornelissen et al. 2012

- 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

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

Sedimite™

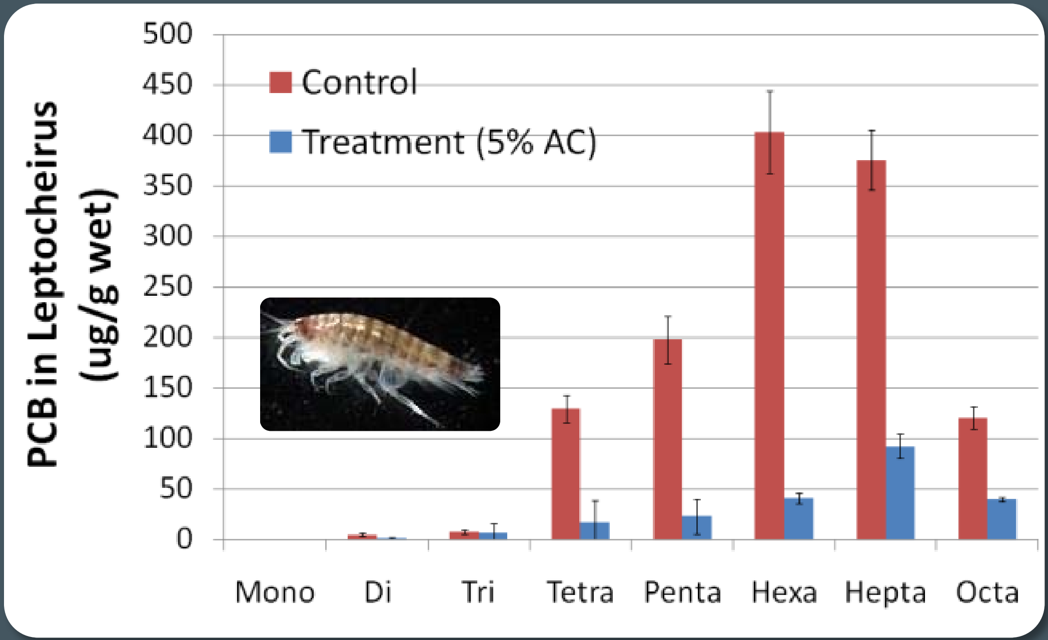
Bioturbation of Sedimite ™ After 30 Days

Source: Menzie and Ghosh 2011

AquaGate+PAC™ /BioBlok®

Bailey Creek, Virginia
2009 AC Pilot Application

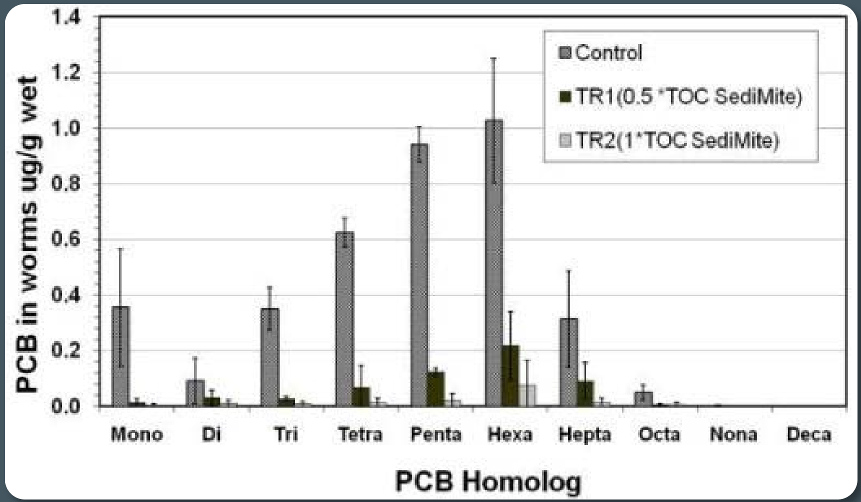
- Creek and wetland environments
- Pneumatic application of Sedimite™
- Black carbon, PCB bioavailability, and benthic community monitoring



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

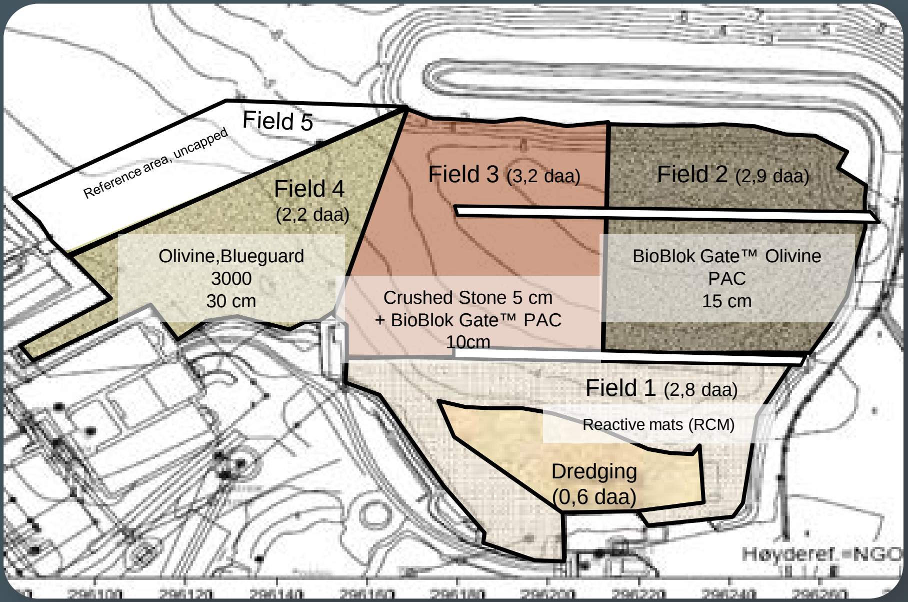
South River, Virginia
2011 Charcoal Pilot Application

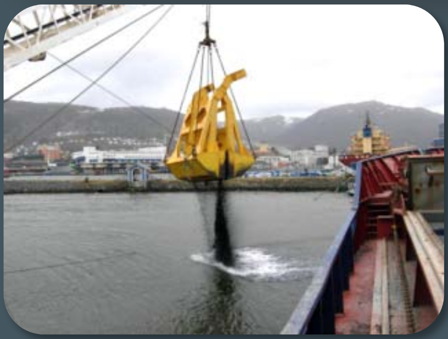
- Off-channel pond environment
- Pneumatic application of commercially available Cowboy Charcoal®
- Ongoing monitoring of black carbon, mercury porewater, surface water and biologic community
- Results pending

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®[a]
  2. 2-inches crushed stone + 4-inches BioBlok®[a]
- Mechanical placement
- Ongoing monitoring
  - PCB and TBT mobility control
  - Cap stability





Source: BIOLOGGE, COWI 2012

[a] BioBlok® in Scandinavia = AquaBlok® in US

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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 BioBlok®[a] cap
  2. 4-inches crushed stone + 4-inches gravel + 1-inches BioBlok®[a]
- Placement with modified sand spreader
- Ongoing monitoring of black carbon, stability and benthic community

Source: BIOLOGGE 2012

[a] BioBlok® in Scandinavia = AquaBlok® in US

Naudodden, Farsund, Norway
2012 Full-Scale Cap with AC

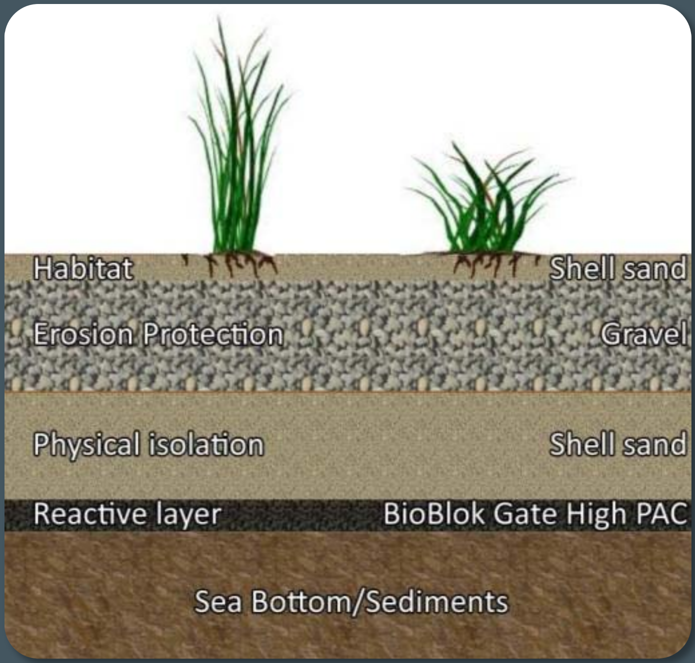
- Small marine harbor
  - Tore Lundh Battelle 2013 presentation
- Layered isolation cap with AC

  1-inch sand (habitat) +

  3-inches gravel +

  3-inches sand +

  1-inch BioBlok®[a]



Source: BIOLOGGE, COWI 2012

[a] BioBlok® in Scandinavia = AquaBlok® in US

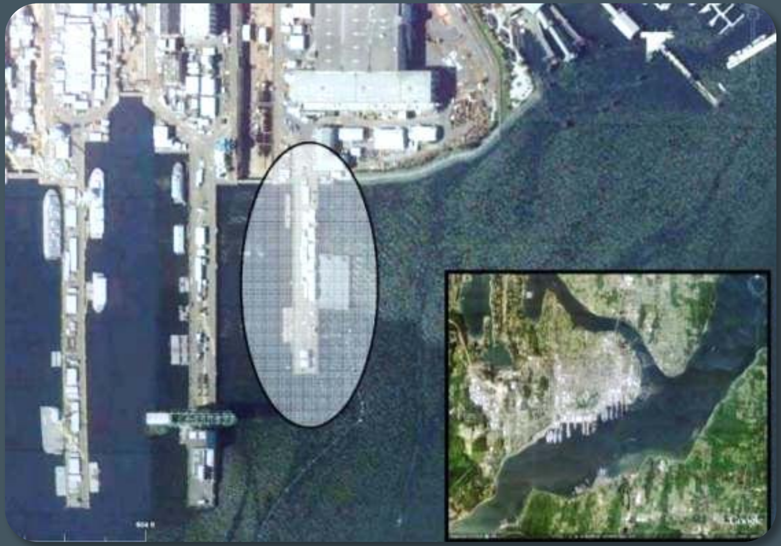
Berry's Creek, New Jersey
2012 AC Pilot Application

- 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



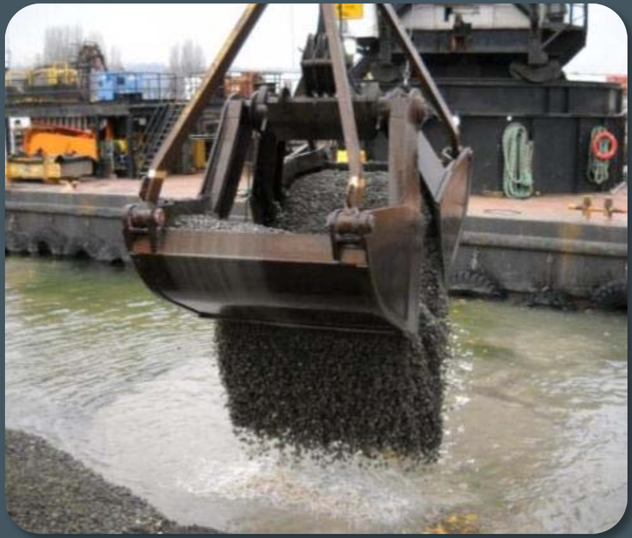
Source: Kirtay 2012

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



Source: Schuchardt and Carscadden 2012

- 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

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%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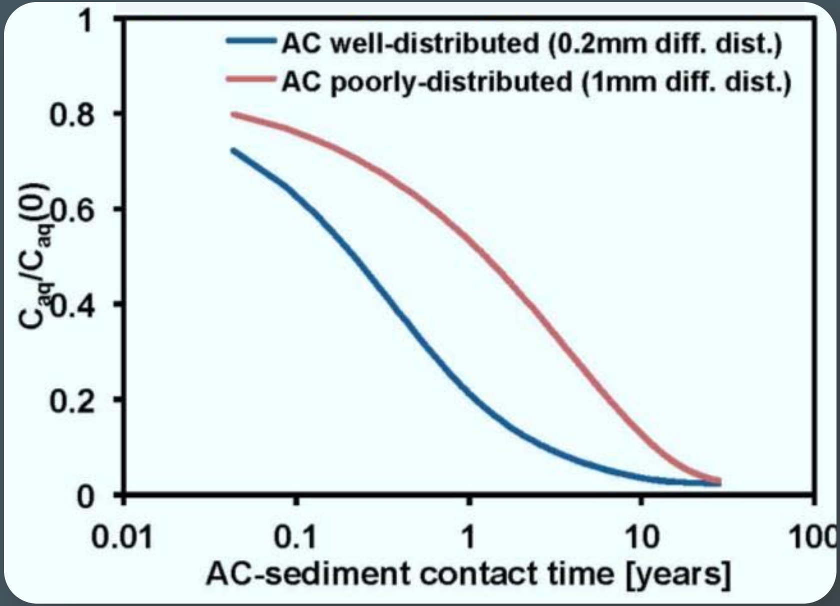
Long-Term Recovery of Benthic Communities in Sediments Amended with Activated Carbon

D. Kupryianchyk,*,† E. T. H. M. Peeters,† M. I. Rakowska,‡ E. P. Reichman,†,‡ J. T. C. Grotenhuis,‡ and A. A. Koelmans†,§

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

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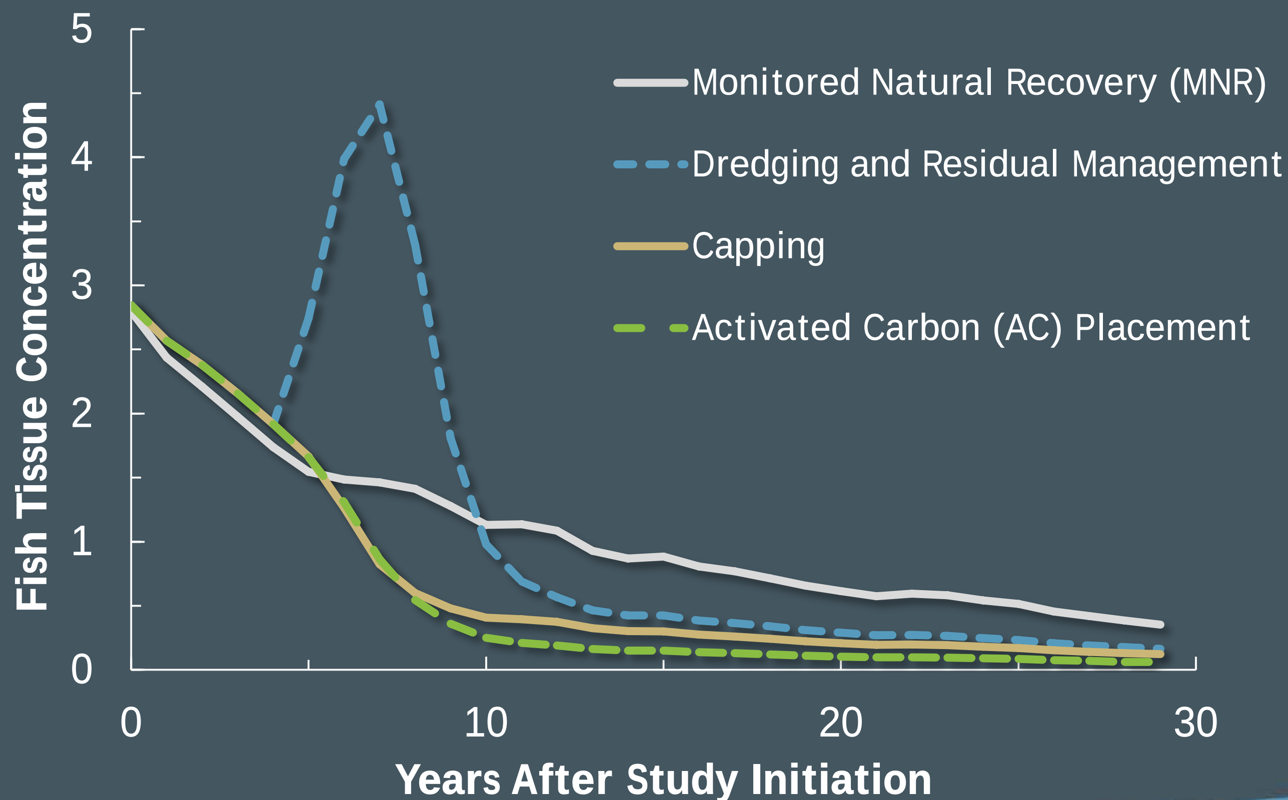
AC Placement Sediment Cleanup Remedy

- 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

Component	Low-Range Unit Cost	High-Range Unit Cost
Activated Carbon	€15,000/acre	€30,000/acre
Binder/Weighting Agents[a]	€0/acre	€23,000/acre
Mixing in Sediment or Sand[a]	€0/acre	€40,000/acre
Field Placement	€23,000/acre	€53,000/acre
Long-term Monitoring	€7,500/acre	€38,000/acre[b]
Total	**€46,000/acre**	**€150,000/acre**

Notes:

[a] *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*

[b] *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

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