Introduction to and appropriateness of in-stream innovative approaches to sediment remediation

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Integrating Science and Developing Approaches to Inform Management for Contaminants of Concern in Agricultural and Urban Settings
A Scientific and Technical Advisory Committee (STAC) Workshop
Dates: May 22-23, 2019

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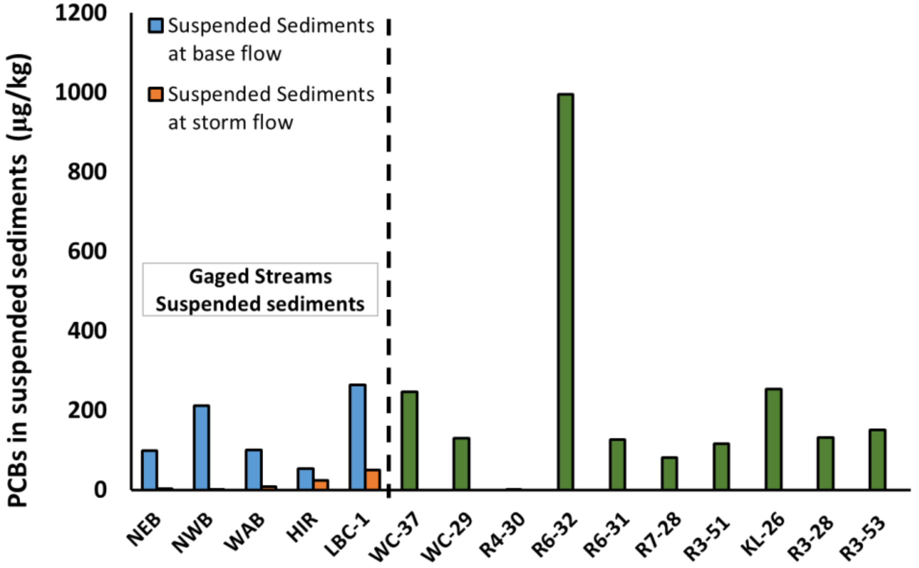
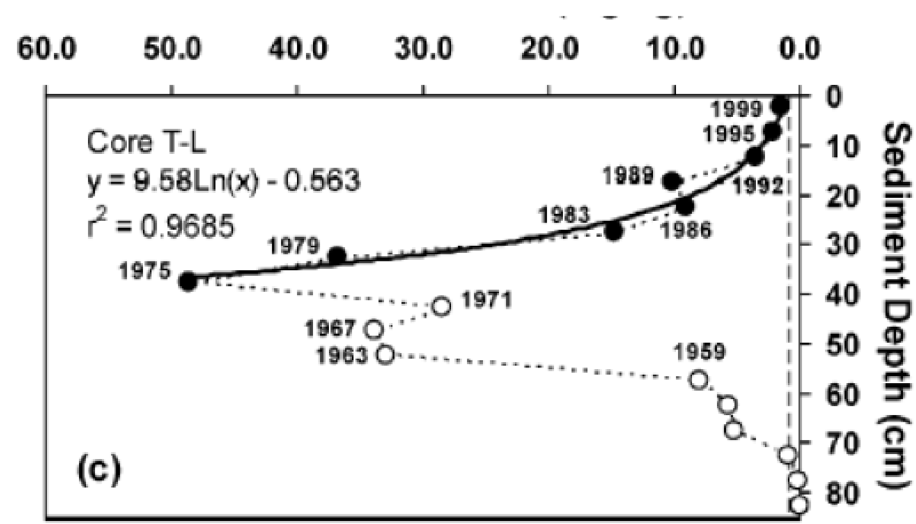
Chemical Biochemical and Environmental Engineering

POTENTIAL INTERACTIONS WITH NUTRIENT AND SEDIMENT REDUCTIONS:

Some traditional practices for **sediment reduction** can have a negative consequence for toxic pollutant recovery:

- A major process for natural recovery is deposition of cleaner sediments over time
- NE and NW branches of the Anacostia River bring 30 million MT of cleaner sediment each year
- Turning off this clean sediment delivery will slow down natural recovery for legacy pollutants in sediments





Source: Long-Term Recovery of PCB-Contaminated Surface Sediments at the Sangme-Weston/Twelvemile Creek/Lake Hartwell Superfund Site. Brenner et al., Environmental Science and Technology, 2004.

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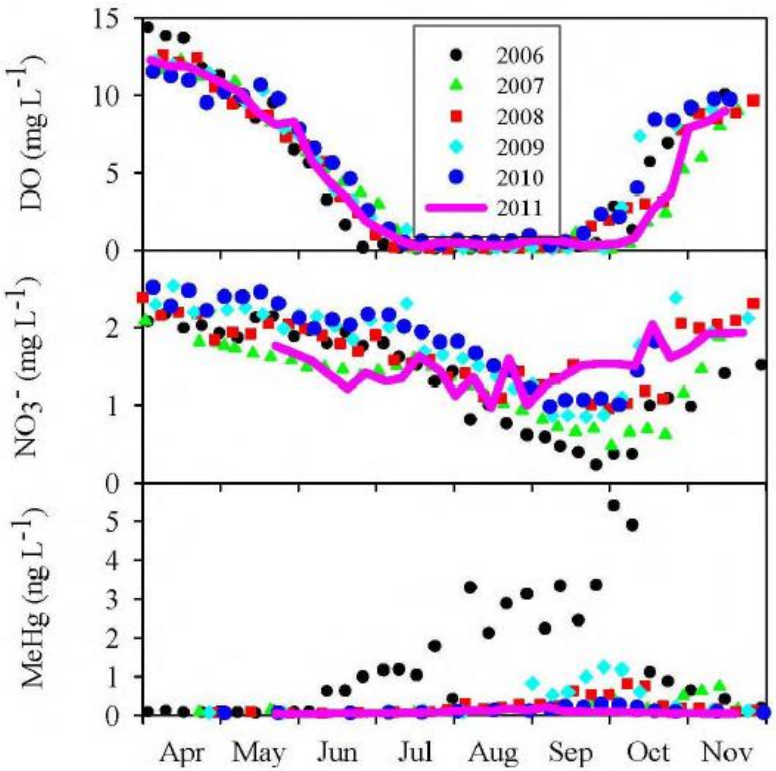
POTENTIAL INTERACTIONS WITH NUTRIENT AND SEDIMENT REDUCTIONS:

Some traditional practices for **nutrient reduction** can have a negative consequence for toxic pollutant recovery: Onondaga Lake Hg story

- Nitrification of wastewater increased nitrate loading to lake, eliminated sulfate reducing conditions
- NO_3 in bottom water inhibits sulfate reducing bacteria and keeps MeHg bound to sediments
- Further upgrades in nutrient reductions reduced nitrate and increased MeHg in water & fish
- Had to inject nitrate back in the lake to control MeHg in fish!



Report for the first year of the nitrate addition pilot test in the hypolimnion of onondaga lake (2011)

Whole lake nitrate addition for control of MeHg in Onondaga Lake. D. Mathews. Clean Waters, Winter 2017

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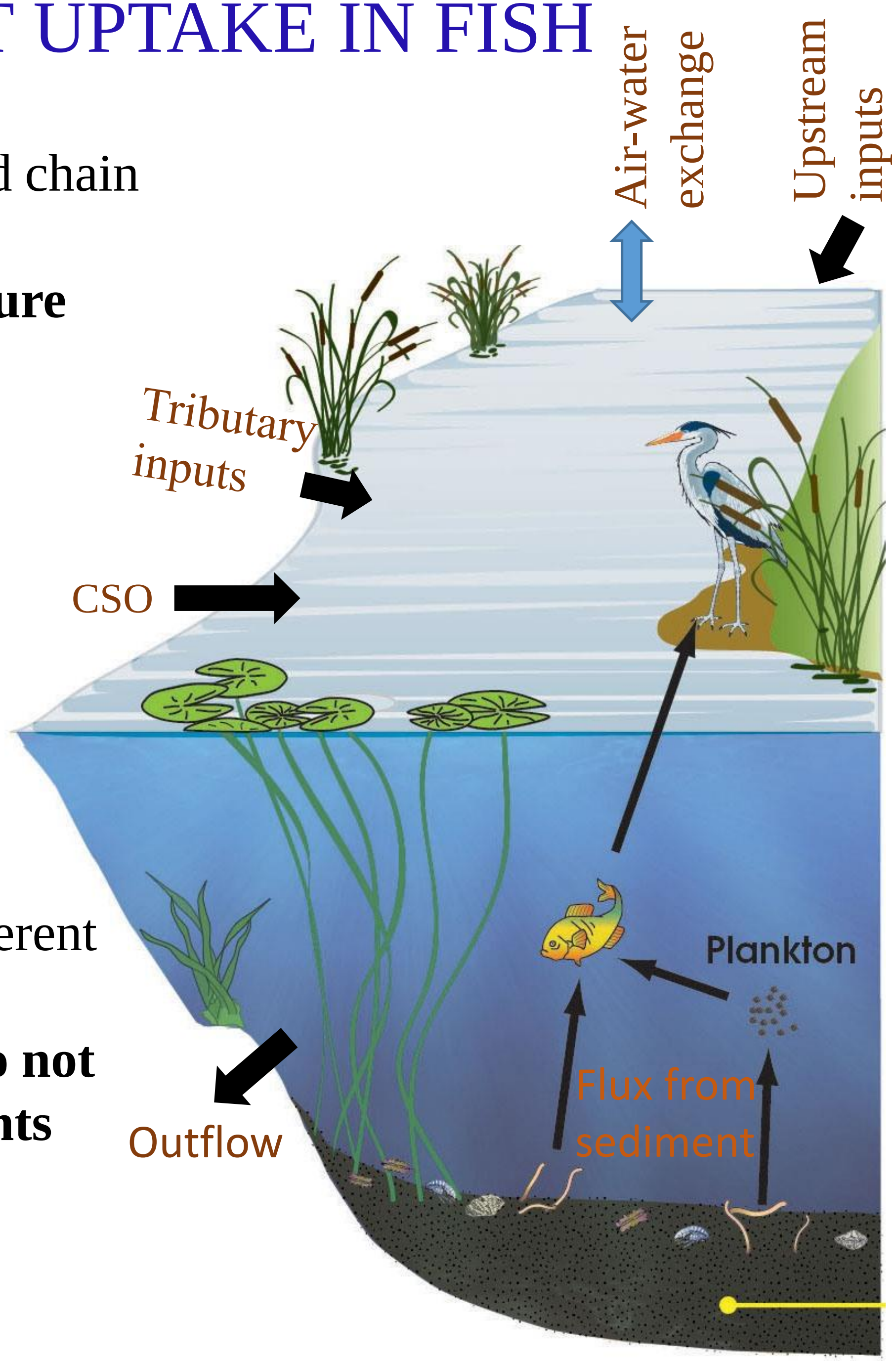
CONTROLLING POLLUTANT UPTAKE IN FISH

- Human exposure from water through food chain
- **Dissolved concentrations control exposure**
- Contributions to water from:
  1) Bed sediments
  2) Inputs from tributaries and outfalls
  3) Air-water exchange
- Ongoing inputs difficult to characterize
- Have to account for freely dissolved vs. particle-associated. Impacts are very different
- **Traditional TMDL approaches often do not capture the complexity of toxic pollutants**



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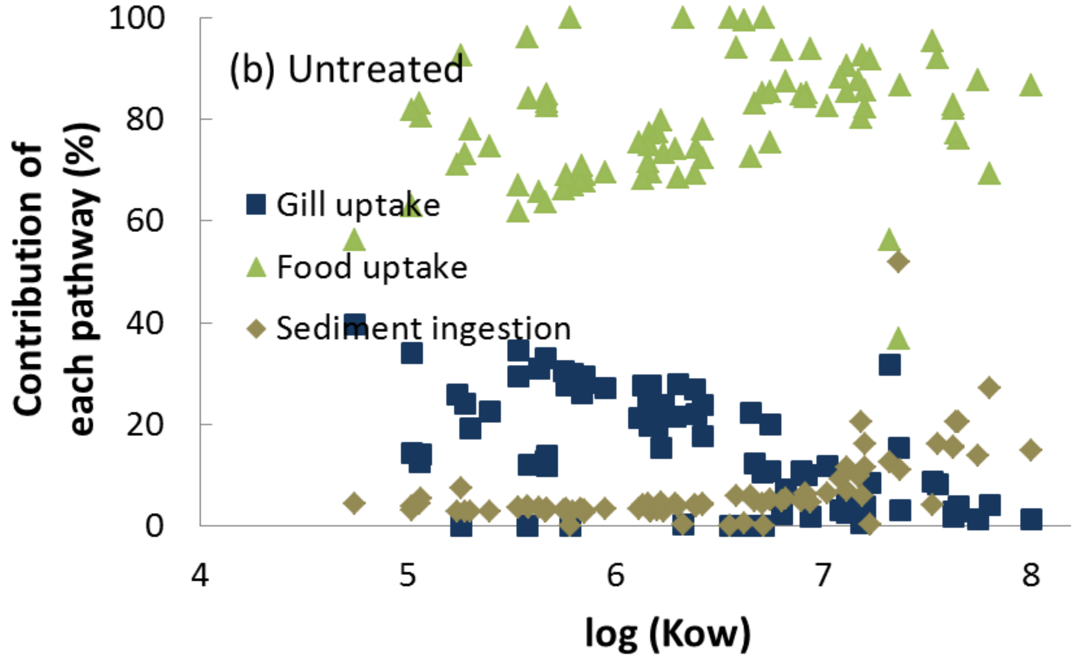
UPTAKE ROUTES IN FISH



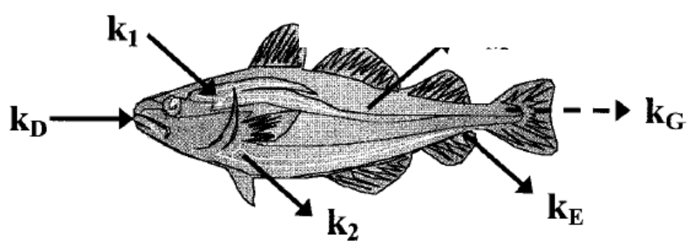


Fig. 1. A conceptual diagram representing the major routes of chemical uptake and elimination in an aquatic organism. k_D = dietary uptake rate constant; k_1 = gill uptake rate constant; k_2 = gill elimination rate constant; k_M = metabolic transformation rate constant; k_E = fecal egestion rate constant; k_G = growth dilution rate constant.

- Up to 40% uptake directly through gills
- 60-90 % from food – indirectly controlled by water
- benthic invertebrates ✓ algae and zooplankton ?

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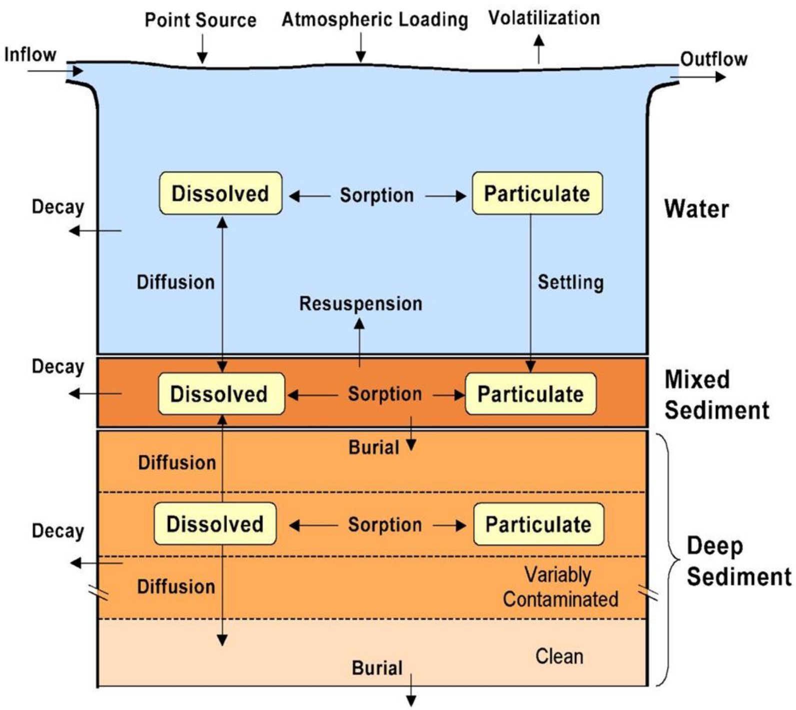
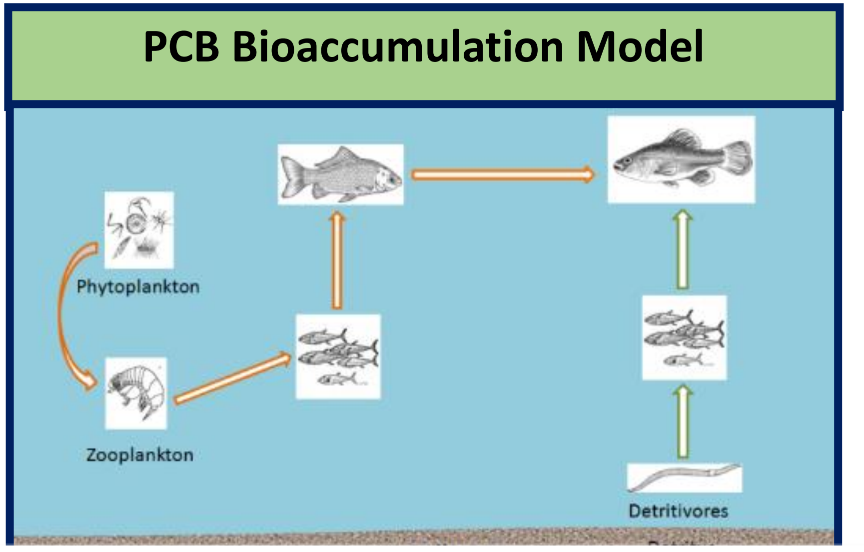
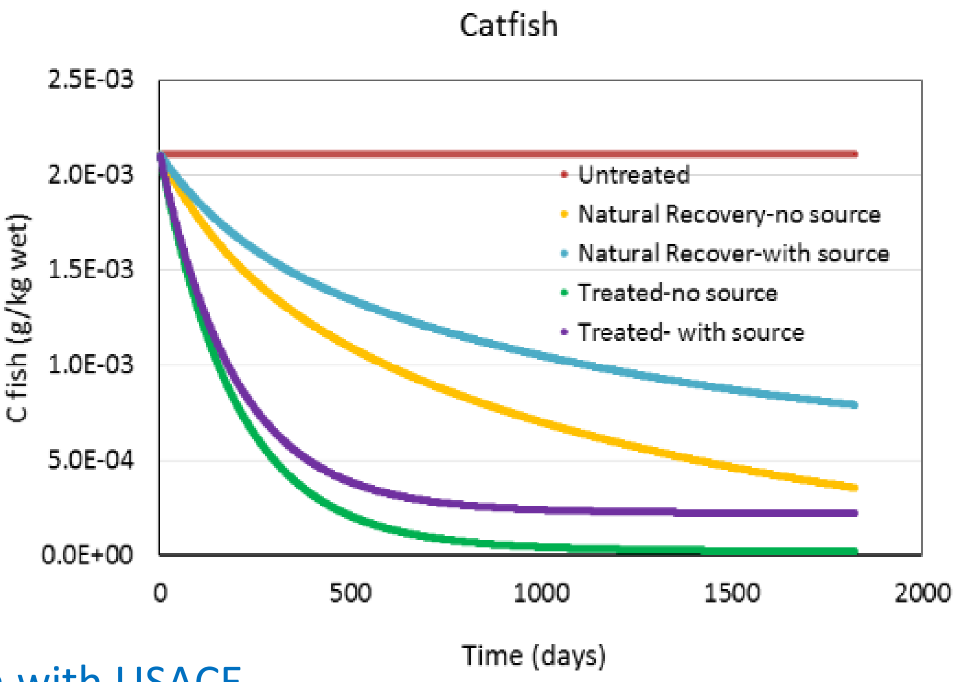
NEED TO QUANTIFY EXPOSURE TO DESIGN EFFECTIVE REMEDY



Schematic of ERDC RECOVERY model





1. Link fate and transport to bioaccumulation model
2. Incorporate freely dissolved concentrations in model
3. Parameterize correctly
4. Predict long-term scenarios to evaluate management options

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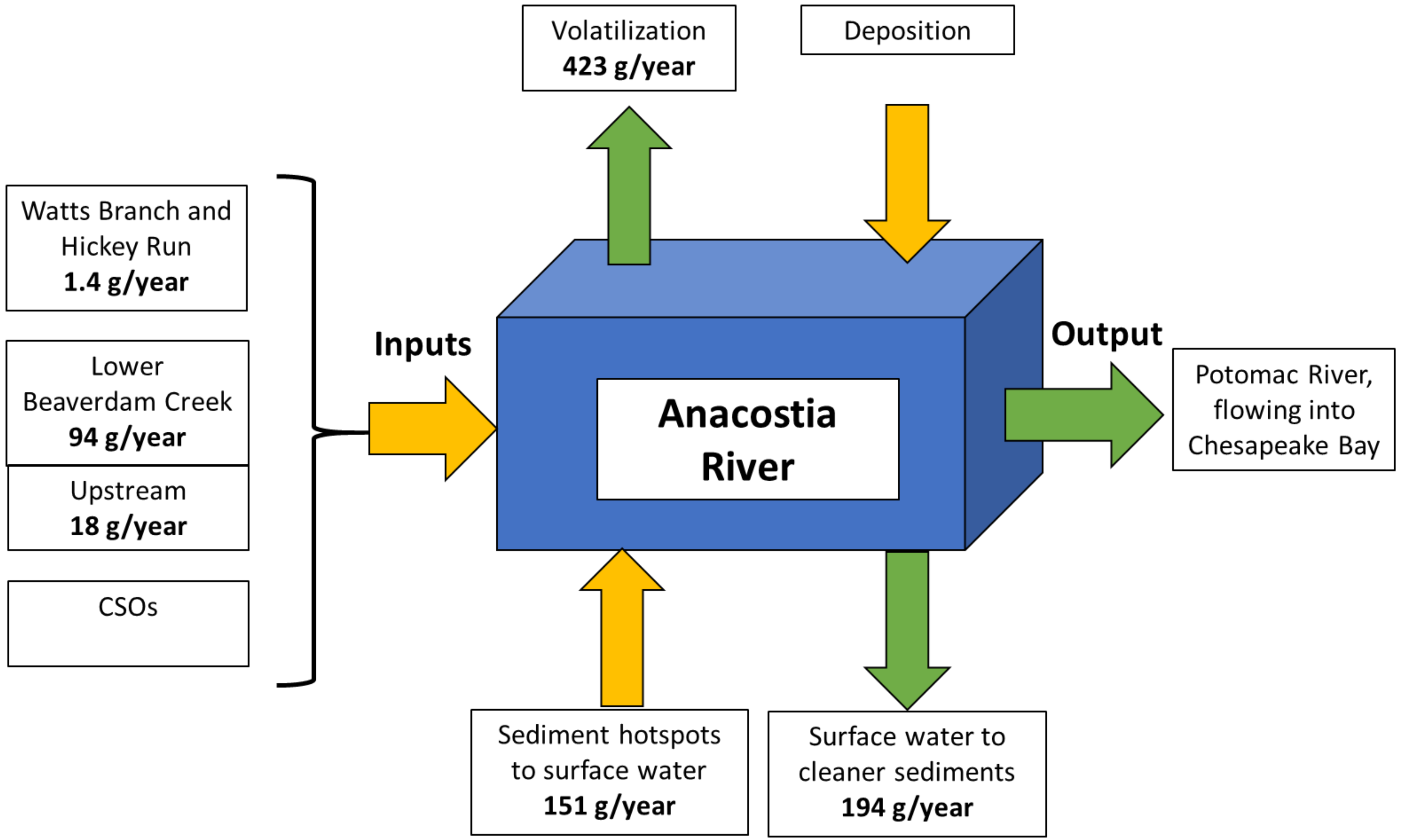
Collaboration with USACE

Measured dissolved PCB loads for the Anacostia River



- Sediment hotspots and Lower Beaverdam Creek contribute most of the dissolved PCBs

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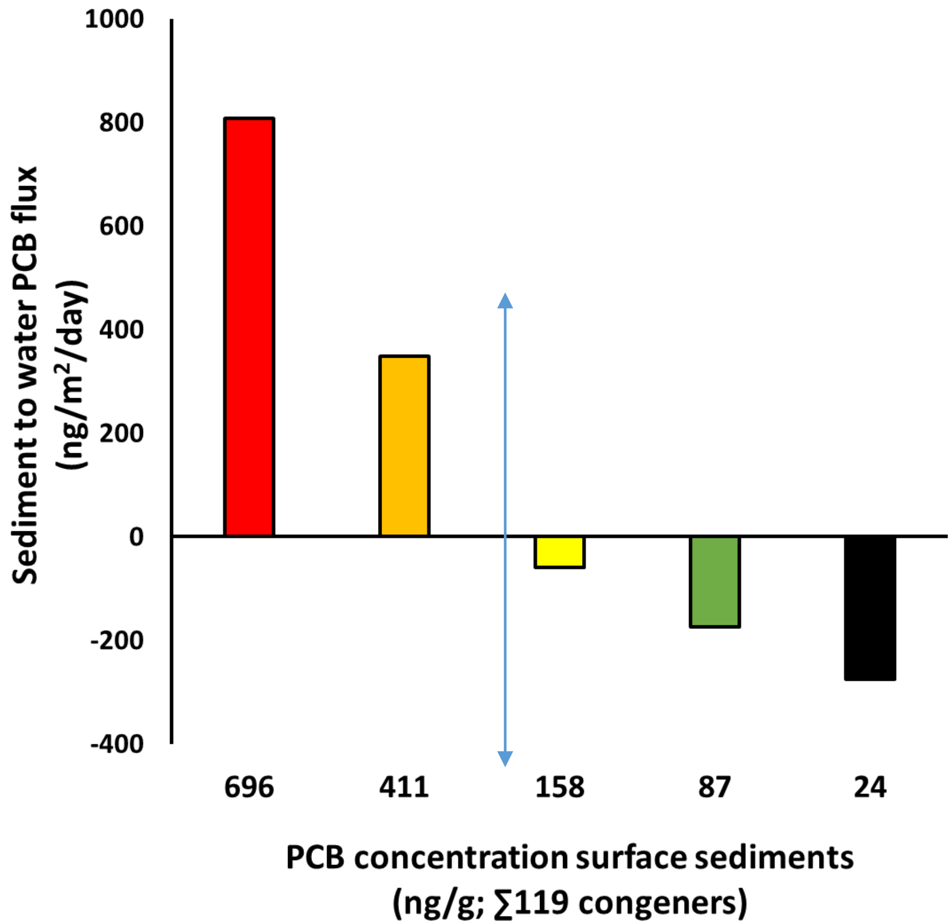
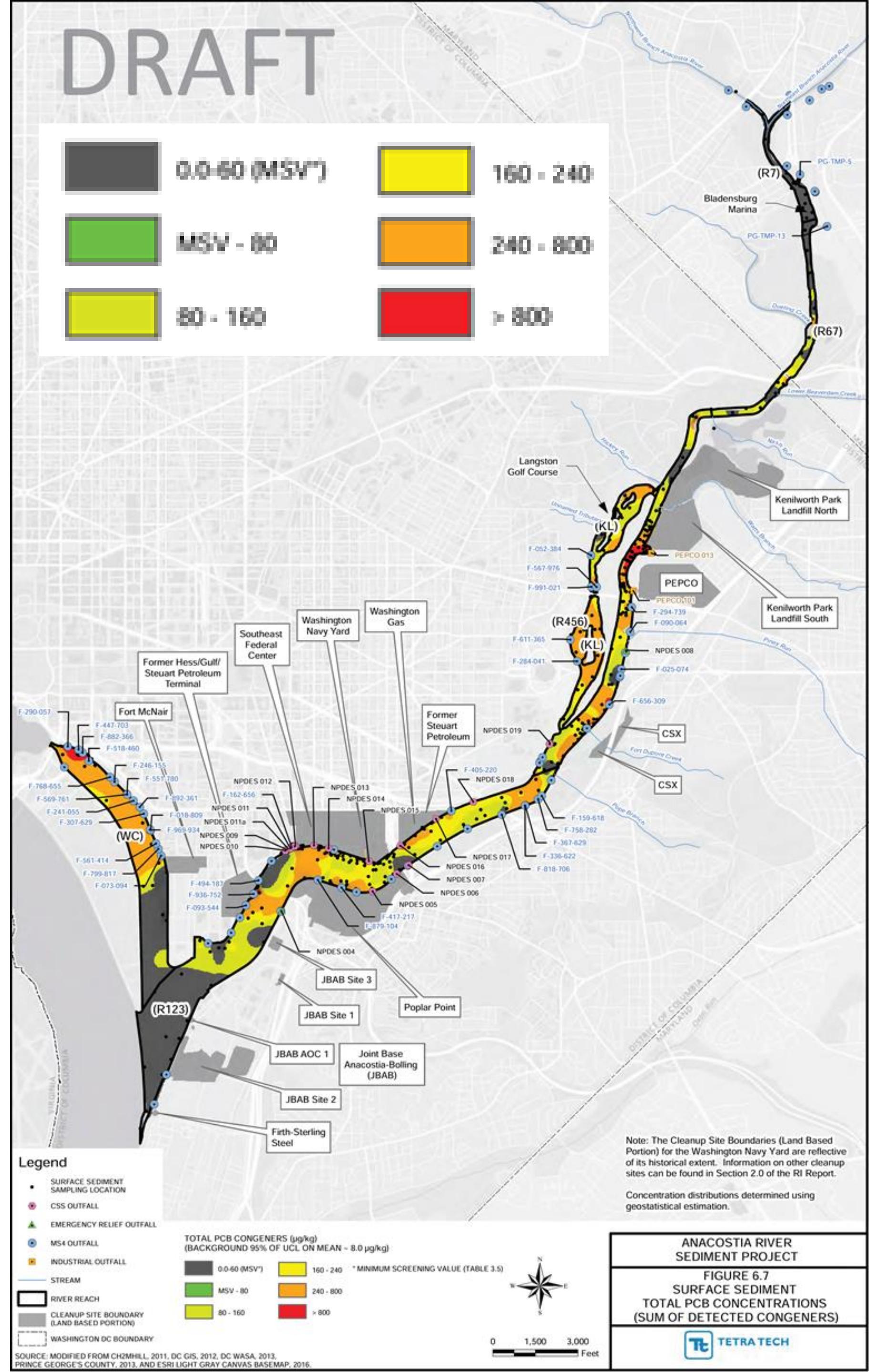
Provisional data subject to change

Sediment-water flux of PCBs



- Above **200 ng/g**, sediments act as a source of PCBs to the water column
- Below **200 ng/g**, sediments act as sinks of PCBs



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Provisional data subject to change

PROBLEM: MANAGING EXPOSURE FROM HISTORIC DEPOSITS OF CONTAMINATED SEDIMENTS

- Contaminated sediment sites are large
- How do you clean up an ecologically sensitive site without destroying it?
- Current technologies dredging and capping are expensive and disruptive.
- Need for innovative techniques that reduce risks

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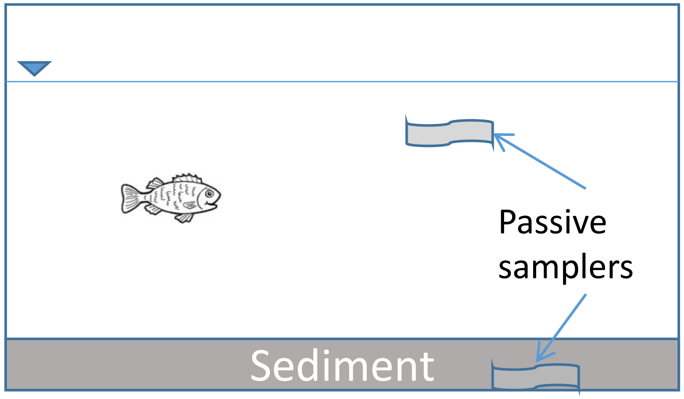
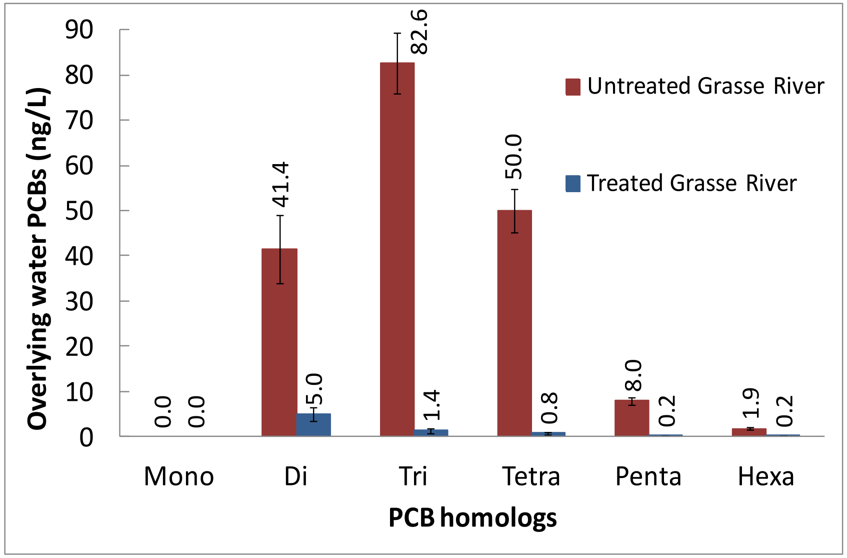
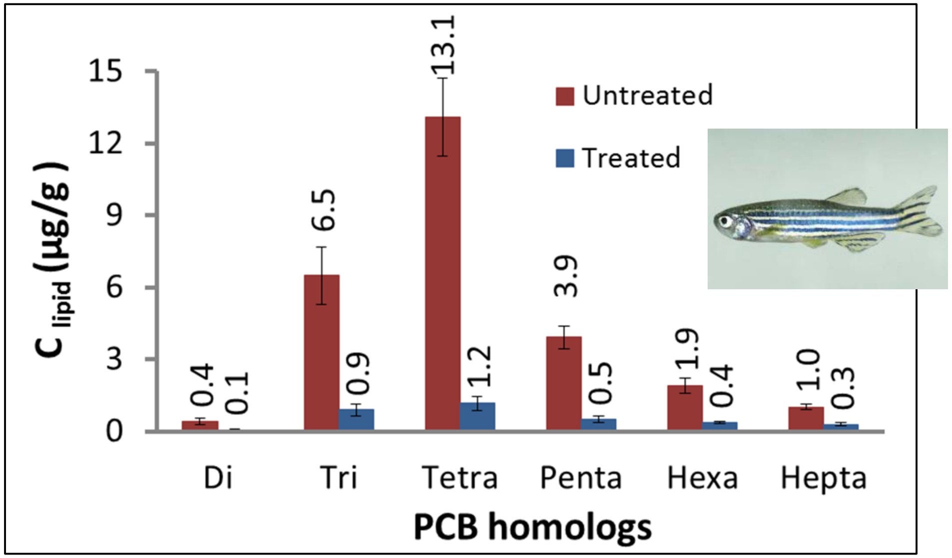
STRONG SORPTION REDUCES PCB UPTAKE IN FISH



Components in each aquaria

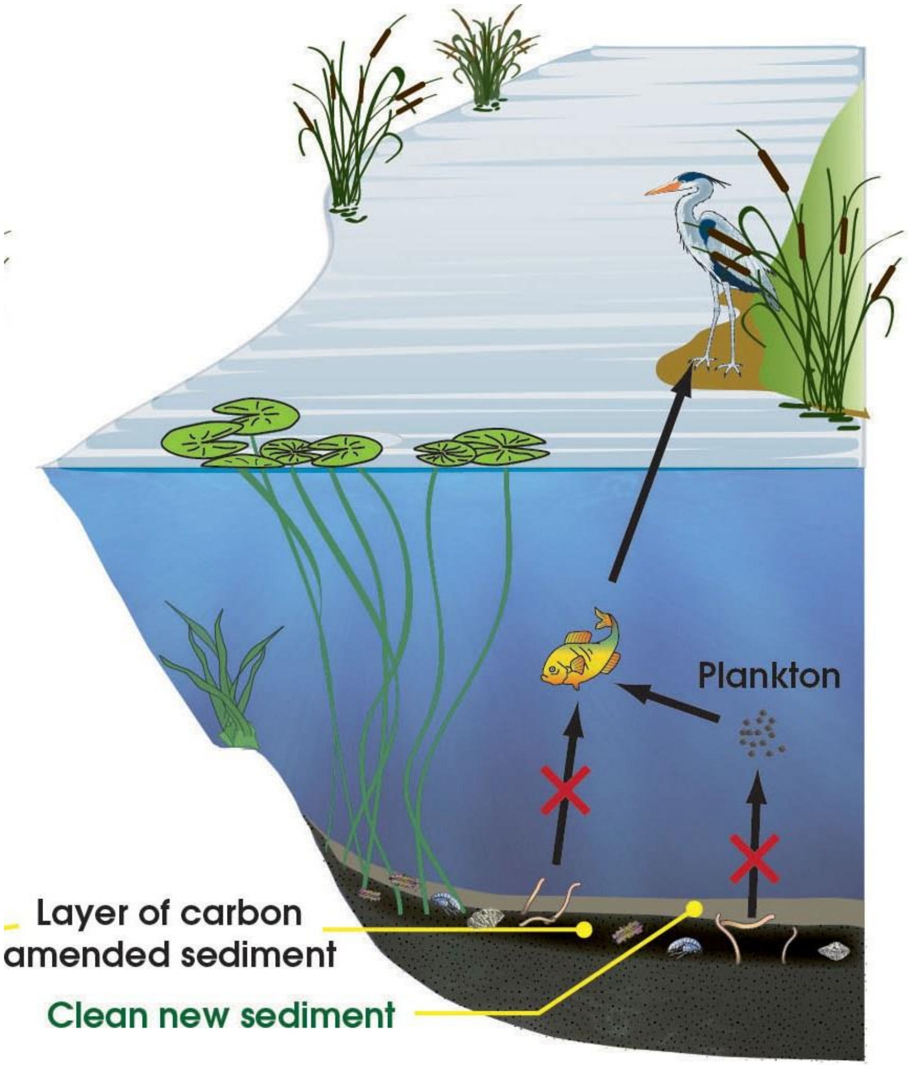
NIEHS R01 project





- PCBs in water reduced by **> 95%** upon amendment with AC.
- The AC amendment reduced the PCB uptake in fish by **87%**
- **Need solid mechanistic understanding of processes to scale up and translate to field**

CONCEPTUAL MODEL OF IN-SITU TREATMENT WITH AC



AC amended reduces exposure to food chain through:

1) Reduced bioaccumulation in benthic organisms

2) Reduced flux into water column and uptake in the pelagic food web.

3) In the long-term, the carbon amended layer is covered with clean sediment.

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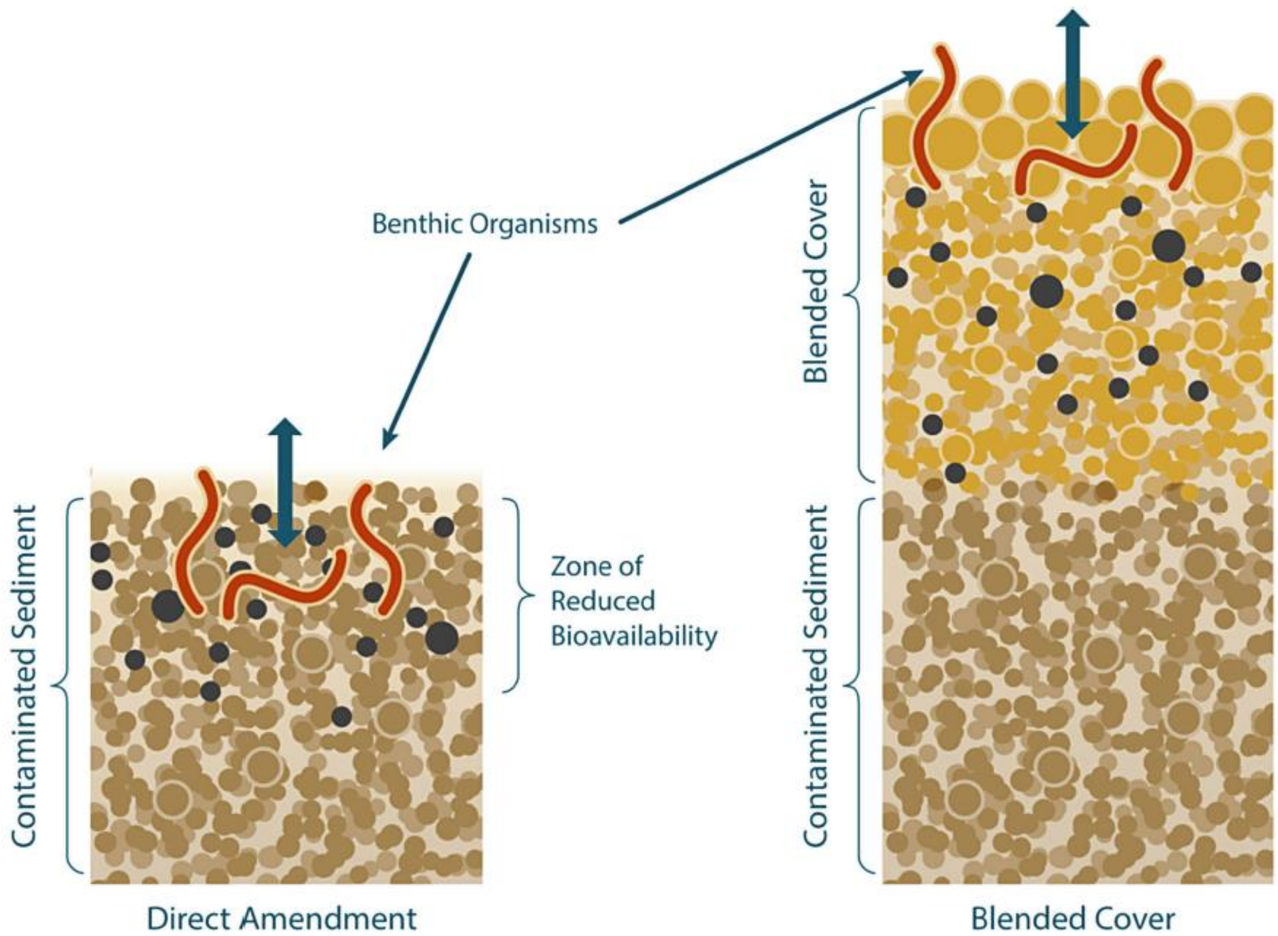
TWO BASIC ENGINEERING APPROACHES



Sediment amendment involves integration of a sorbent like AC into the surficial bioactive zone of sediments (shown on the left) while blended cover involves placement of a new layer of cover materials (typically a relatively thin layer of clean sand or sediment) that includes a sorbent like AC either dispersed within (shown in right) or placed as a discrete layer as part of a multi-layer cover. Although these approaches have several differences, the ultimate goal of both approaches is to reduce exposure of benthic organisms to HOCs in sediments and also to reduce HOC flux from sediment into water.

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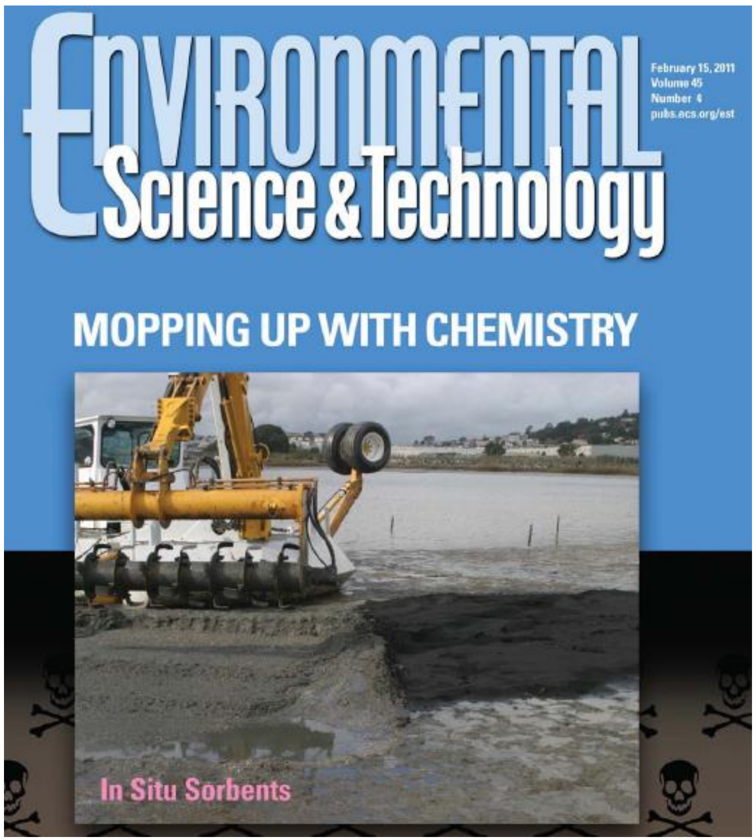
From Patmont et al. IEAM 2015

RECENT FEATURE ARTICLE IN ES&T:

In-situ Sorbent Amendments:
A New Direction in Contaminated Sediment Management

Environ. Sci. Technol. 2011, 45, 1163–1168



ENVIRONMENTAL Science & Technology
FEATURE
pubs.acs.org/est

In-situ Sorbent Amendments: A New Direction in Contaminated Sediment Management†

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University of Maryland Baltimore County, Baltimore, Maryland 21250, United States
Richard G. Luthy
Stanford University, Stanford, California, United States
Gerard Cornelissen
Norwegian Geotechnical Institute, Oslo, Norway, University of Life Sciences, Ås, Norway; Stockholm University, Stockholm, Sweden
David Werner
Newcastle University, Newcastle upon Tyne, United Kingdom
Charles A. Menzie
Exponent, Alexandria, Virginia, United States

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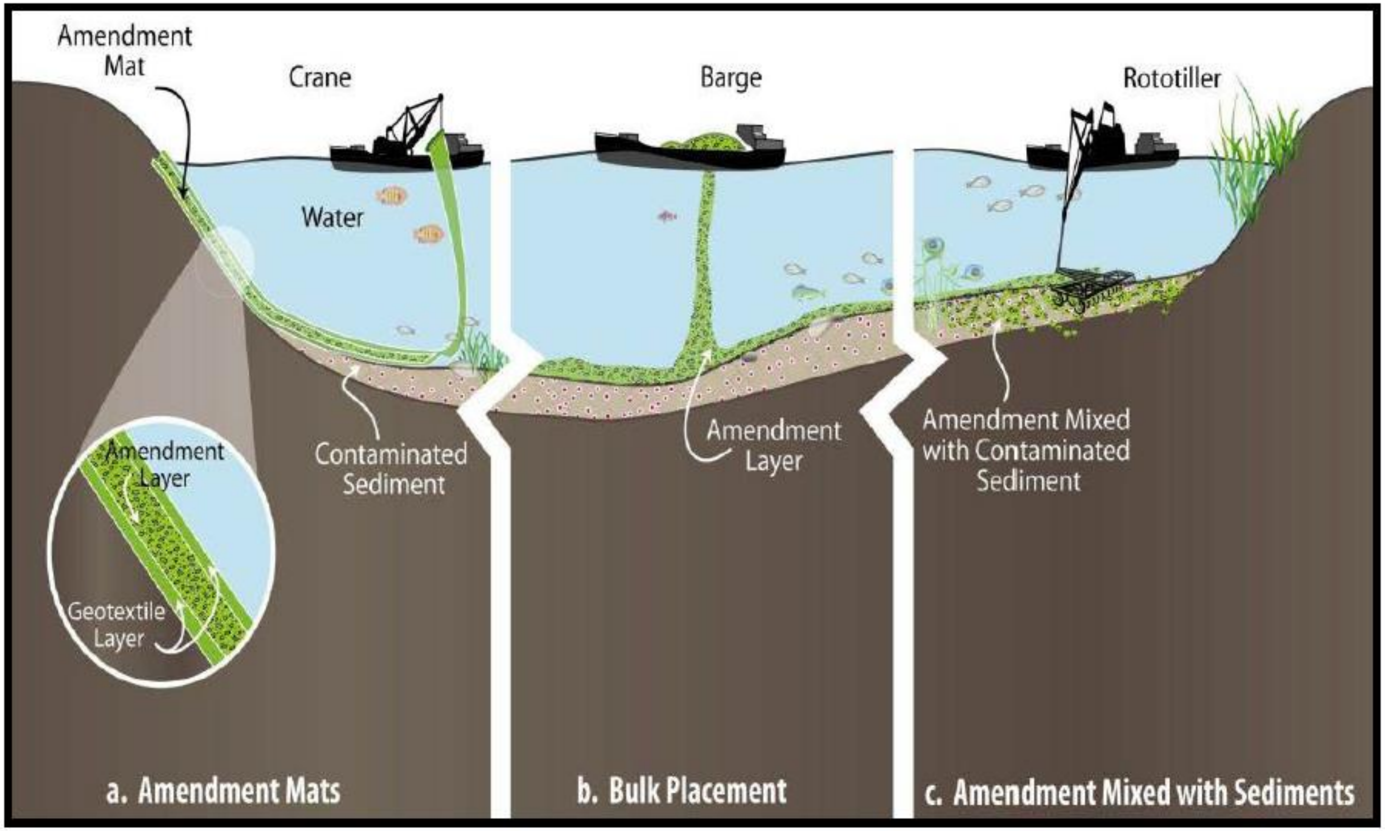
USE OF AMENDMENTS FOR IN-SITU REMEDIATION OF SUPERFUND SEDIMENT SITES

USEPA OSWER Directive 9200.2-128FS; April 2013



Several recent RODs have included AC amendment as a component of the proposed remedy

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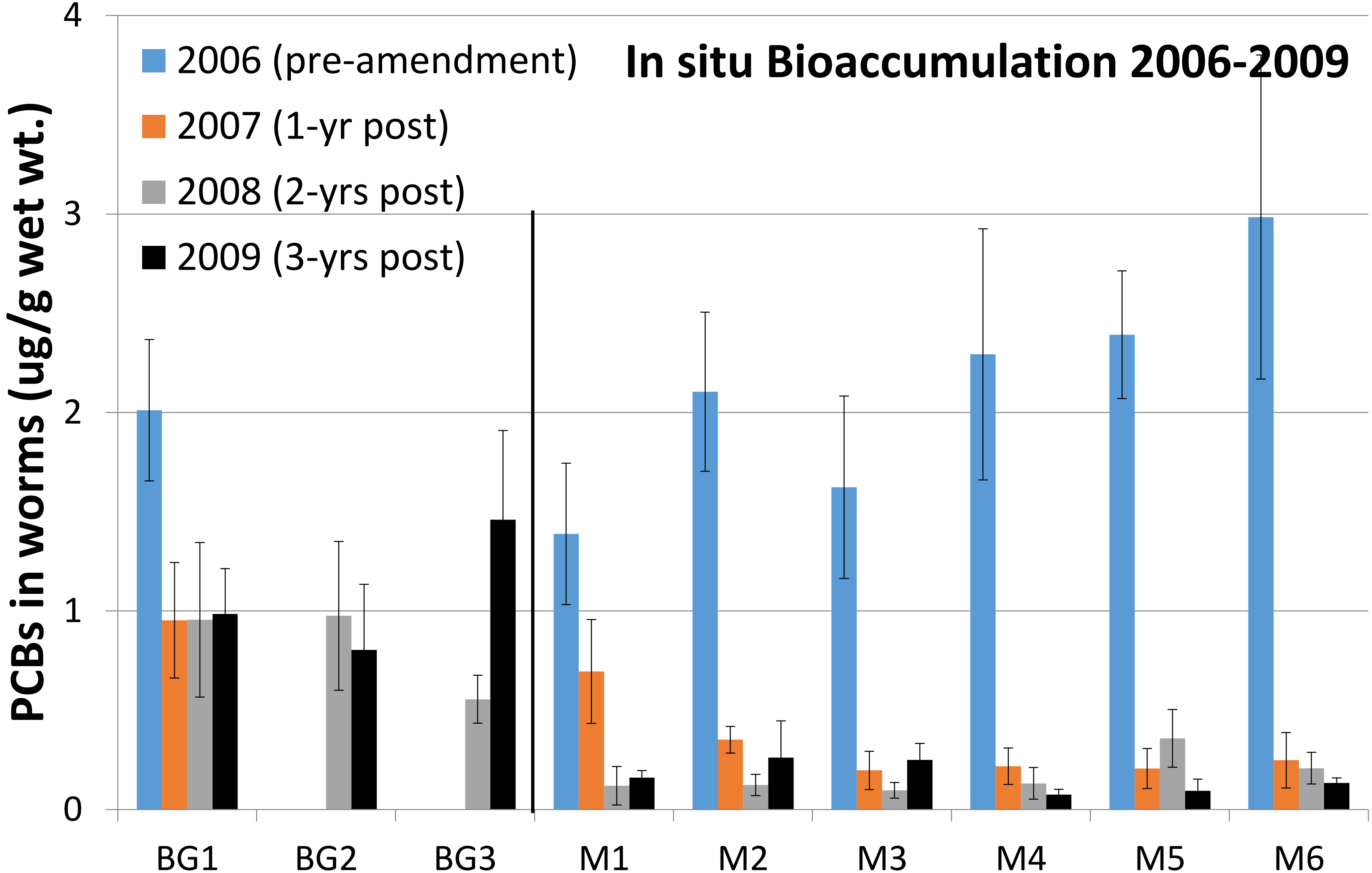
PILOT DEMONSTRATION IN GRASSE RIVER

(Participants: Alcoa, EPA, UMBC, Stanford University, Anchor Env., Brennan, Tetra Tech, Arcadis-BB&L, QEA)

Mixed Tiller (75’ x 100’)	Unmixed (50’ x 50’)	Tine Sled (50’ x 60’)	Initial testing area (50’ x 100’)

- L-shaped silt screen to minimize suspended particle transport
- Equipment mobilized on barges
- Target dose of activated carbon = 0.5x TOC in surficial sediments (+50% safety factor)
- No measurable change in water-column PCBs downstream
- Post-treatment monitoring for 2-3 years

PCB IN L. VARIEGATUS IN-SITU EXPOSURE



- % reduction over 3 years: 46% in BG sites and 92% for AC-amended sites

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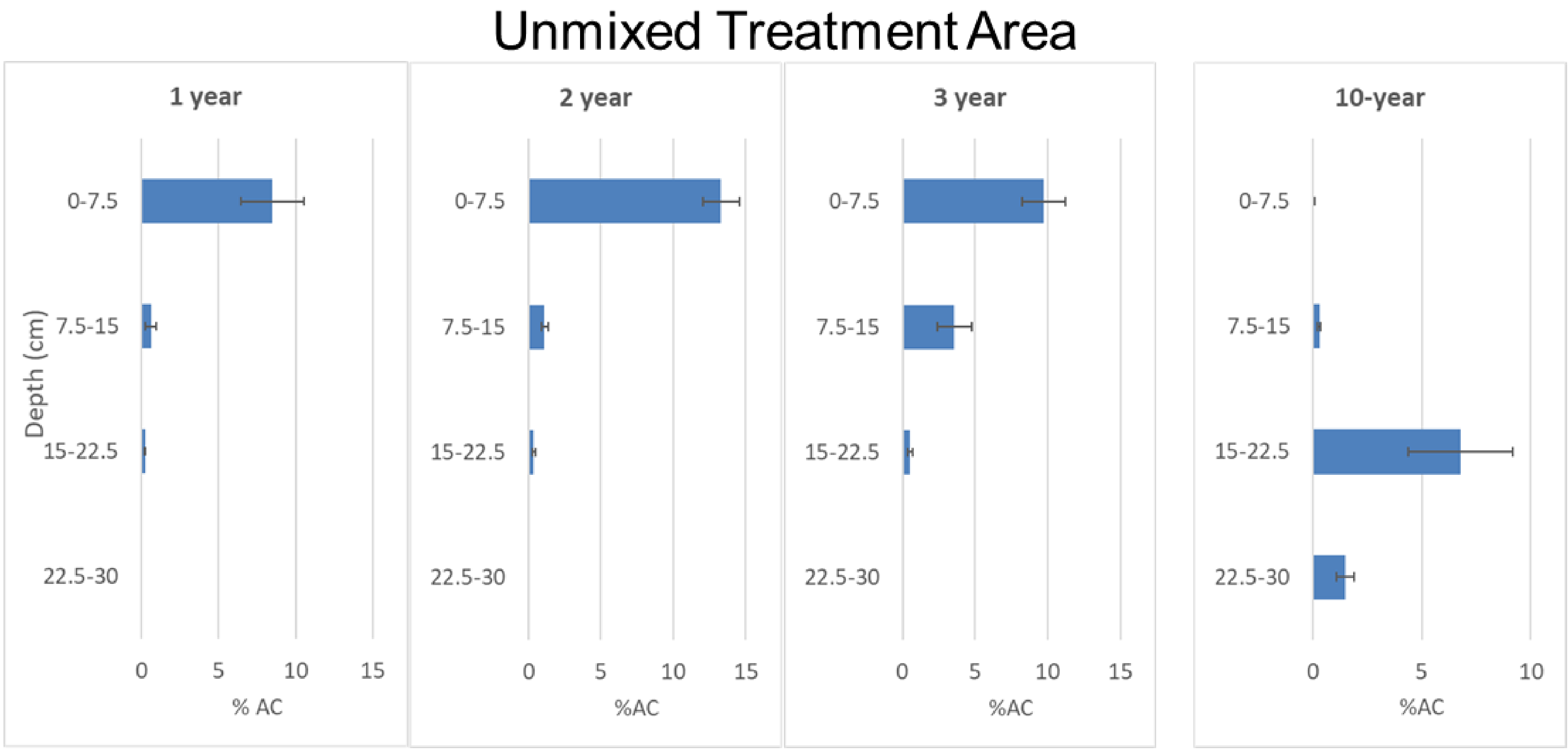
LONG-TERM PERSISTENCE OF AC IN SEDIMENTS



- Significant deposition of new sediment over the last 10 years (about 15 cm) with the AC layer now down in the 15-30 cm zone
- No loss of AC over 10 years in the field
- Remained effective in reducing transport and bioavailability of PCBs from deeper sediments

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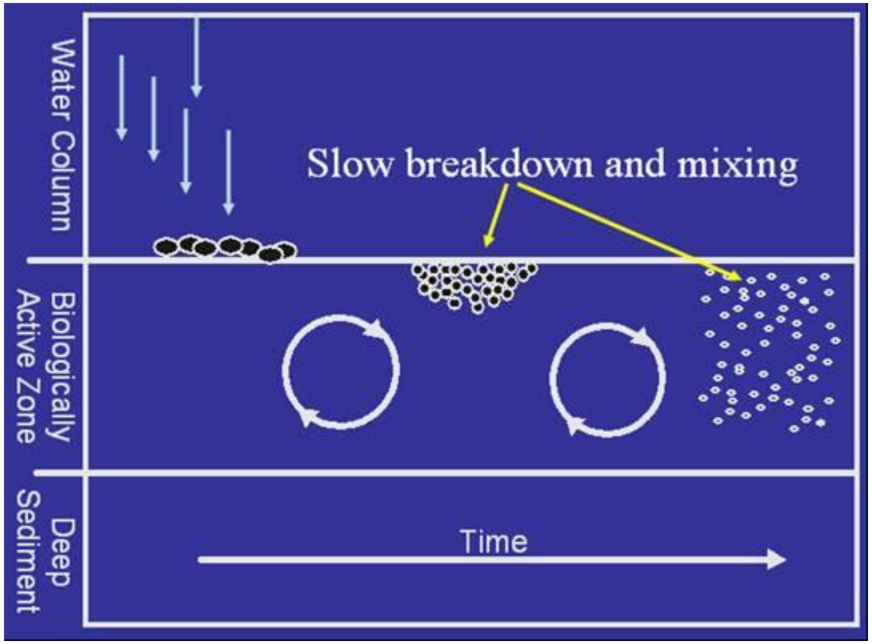
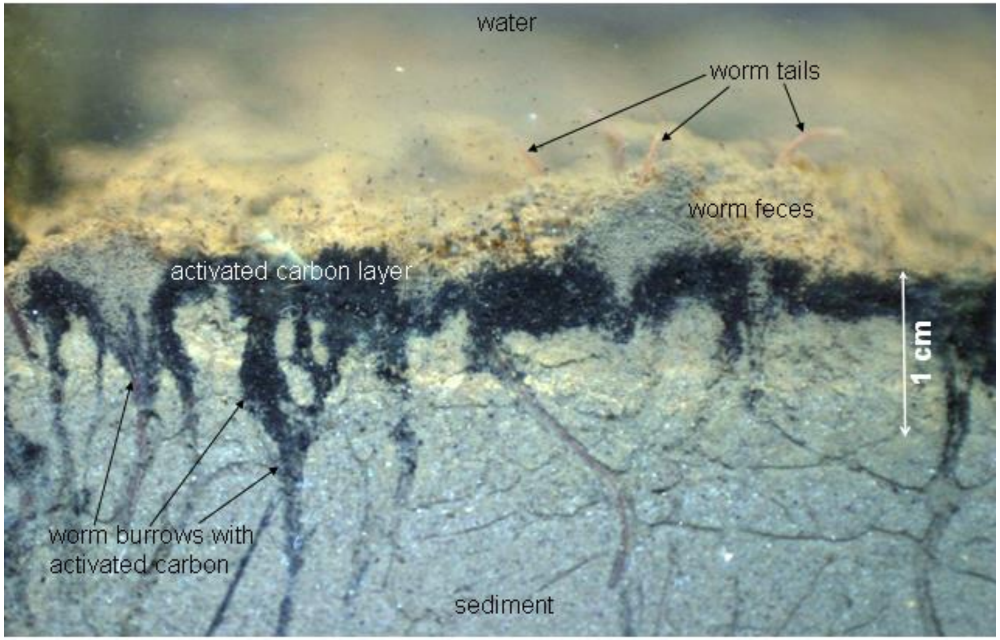
TRANSITION TECHNOLOGY: NEW PRODUCTS





1. Agglomerates delivered from water surface
2. Sinks to sediment surface and resists resuspension
3. Breaks down slowly
4. Mixed into sediment by bioturbation
5. Developed at UMBC in collaboration with Dr. Charlie Menzie (Menzie Cura & Assoc.) **EPA SBIR**

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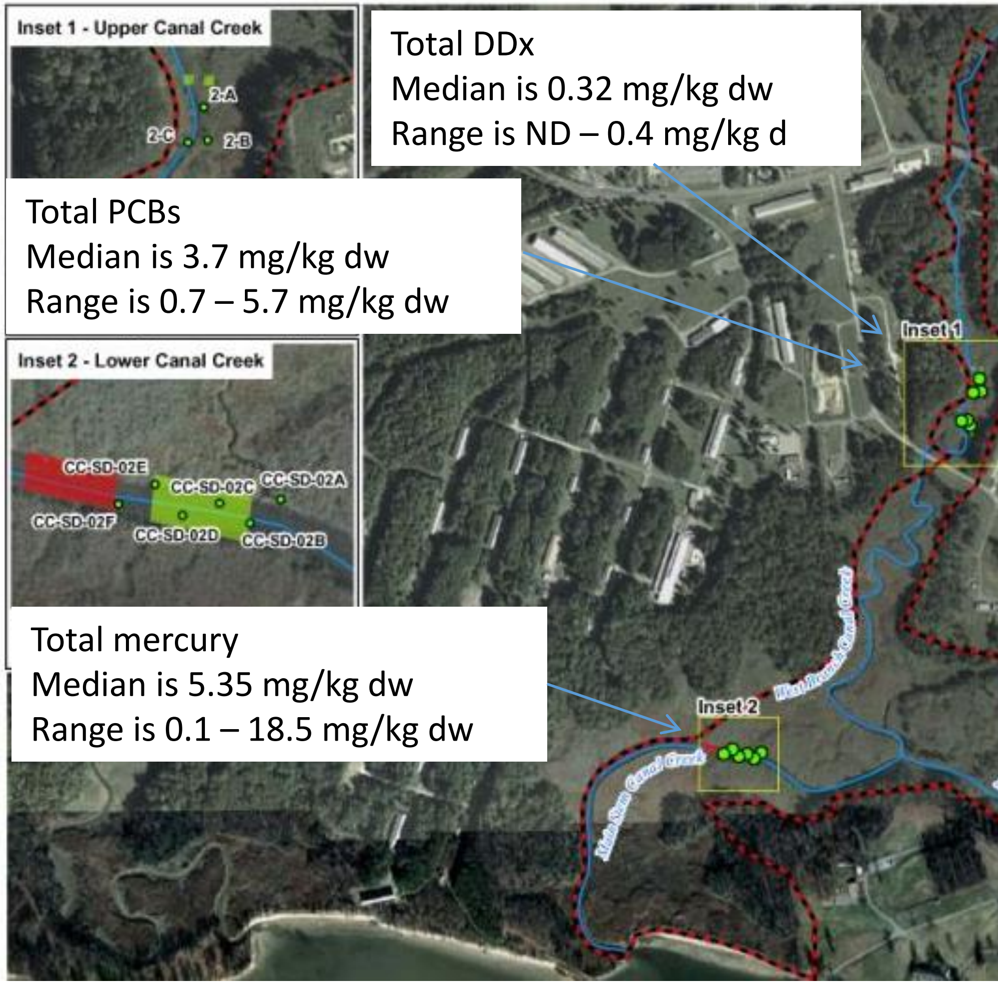
Pilot Demonstration: Canal Creek

Edgewood Area of Aberdeen Proving Ground (APG)



Total DDx
Median is 0.32 mg/kg dw
Range is ND – 0.4 mg/kg d

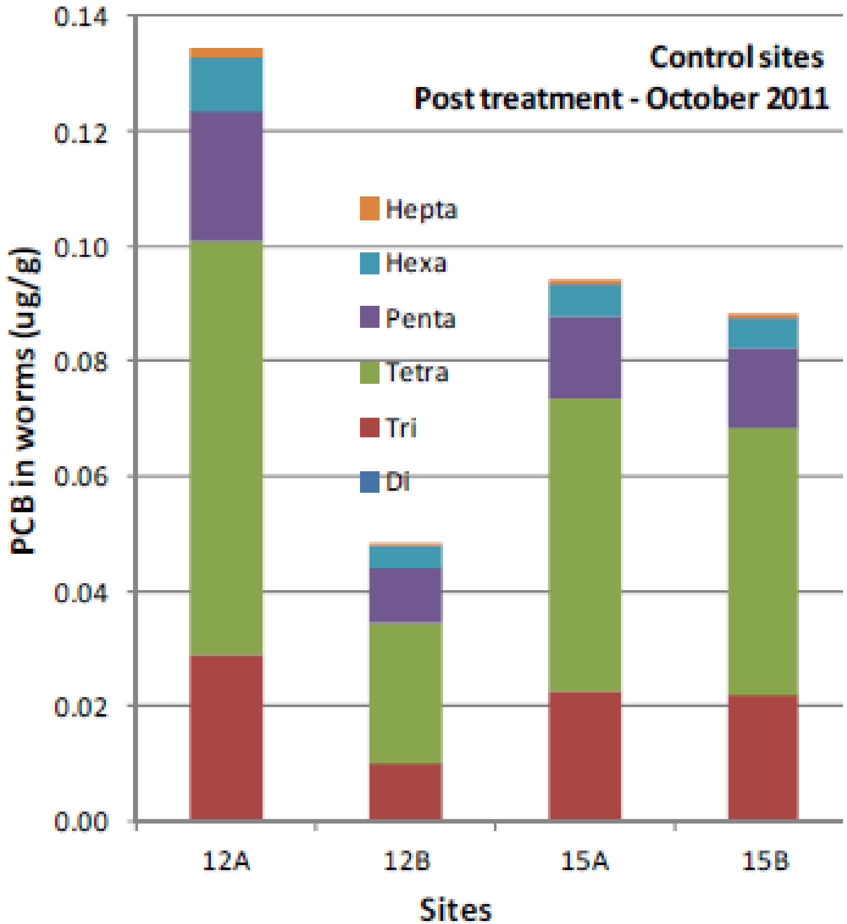
Total PCBs
Median is 3.7 mg/kg dw
Range is 0.7 – 5.7 mg/kg dw

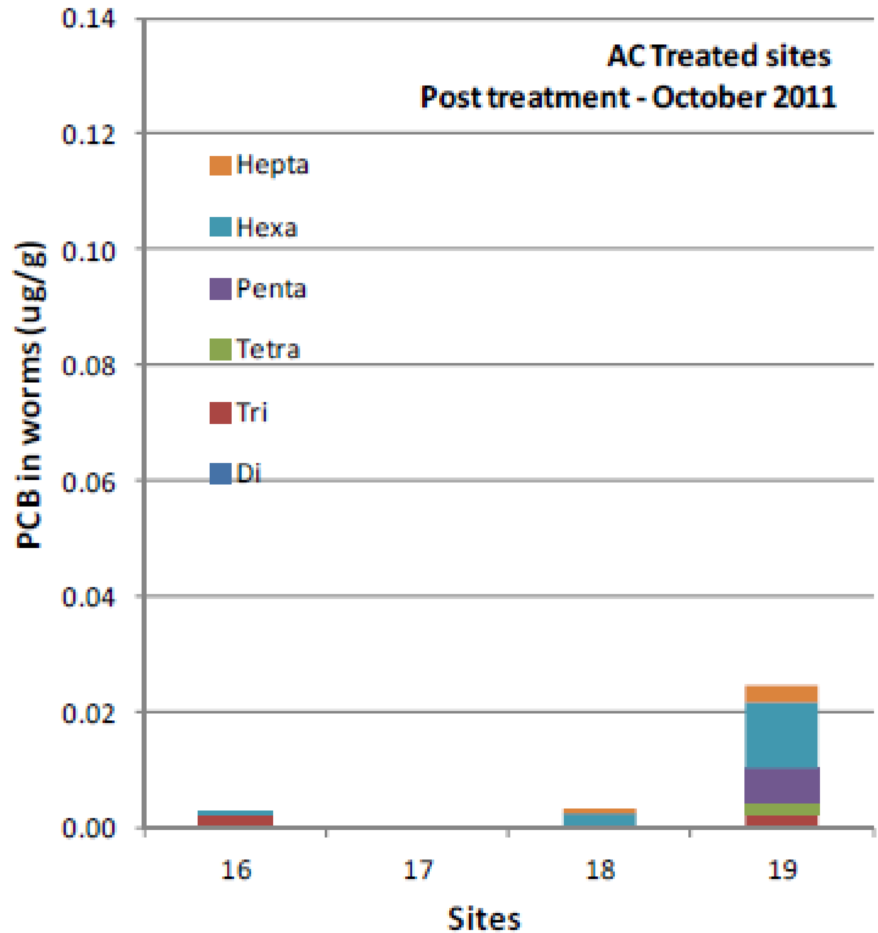
Total mercury
Median is 5.35 mg/kg dw
Range is 0.1 – 18.5 mg/kg dw

Permits obtained
Needed to avoid eagles and UXOs!
SediMite placed in February 2011

PCB bioaccumulation in worms in post-treatment sediment samples

Edgewood Area of Aberdeen Proving Ground (APG)





The reduction in tissue levels for treated plots was 92% relative to the control plots

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RESTORATION & REMEDIATION OF A LAKE

- Urban lake sediments impacted with PCBs and PAHs
- Ecological restoration will include removal of sand bar and creation of wetlands
- In-situ treatment of surface sediments with AC to reduce exposure.
- Monitoring includes PCBs in porewater, surface water, benthic invertebrates, and fish.
- In addition, ongoing inputs are being tracked.

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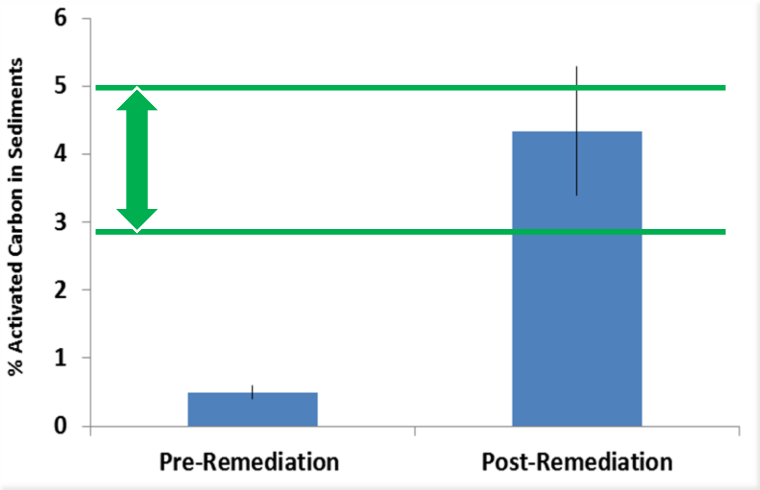
ACTIVATED CARBON IN SEDIMENTS

AC application using a tele-belt

- Optimum dose of 3 – 5% met
- 70 – 90% reduction in contaminant bioavailability expected.

http://www.youtube.com/watch?v=l88oE6aTHK8&feature=youtu.be



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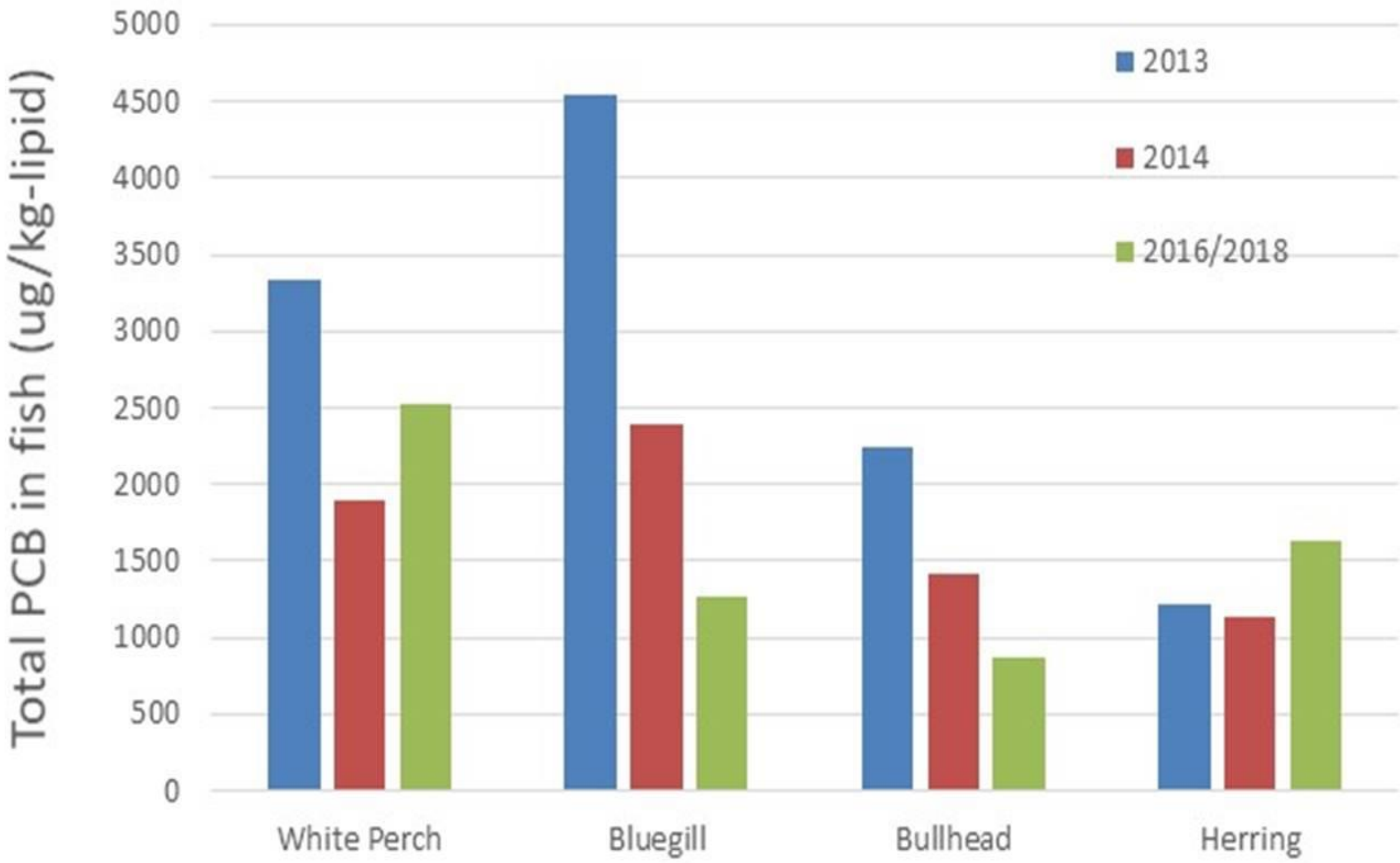
PCB IN FISH TISSUE



- 48% - 87% reduction in resident fish (brown bullhead and bluegill, respectively)
- 27% reduction in migratory white perch
- 43% increase in migratory blueback herring

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Microbial Biodegradation

- PCB aerobic degradation and anaerobic dechlorination observed 3 decades ago
- Aerobic transformation pathways reasonably well understood
- Dechlorination pathways identified; dechlorinators isolated and grown in the absence of sediments
- Biology reasonably well understood
- Anticipation of natural attenuation and engineering for remediation challenged by:
  - poor mechanistic understanding of biotransformation kinetics
  - issue of residuals after partial degradation

Polychlorinated Biphenyl Dechlorination in Aquatic Sediments

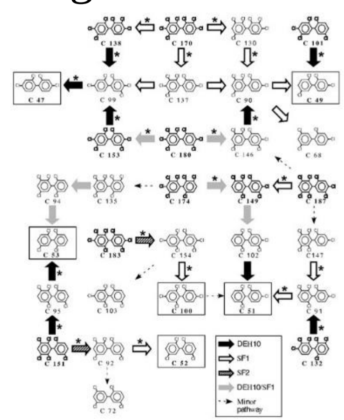
JOHN F. BROWN, JR., DONNA L. BEDARD, MICHAEL J. BRENNAN, JAMES C. CARNAHAN, HELEN FENG, ROBERT E. WAGNER

Science, 1987

In Situ Stimulation of Aerobic PCB Biodegradation in Hudson River Sediments

M. R. Harkness, J. B. McDermott, D. A. Abramowicz,* J. J. Salvo, W. P. Flanagan, M. L. Stephens, F. J. Mondello, R. J. May, J. H. Lobos, K. M. Carroll, M. J. Brennan, A. A. Bracco, K. M. Fish, G. L. Warner, P. R. Wilson, D. K. Dietrich, D. T. Lin, C. B. Morgan, W. L. Gately

Science, 1993



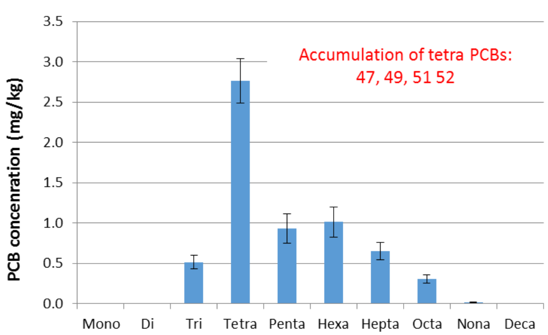
anaerobic pathways

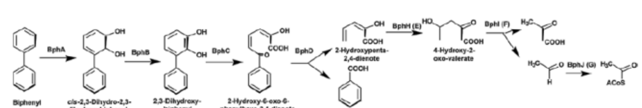
Long-Term Recovery of PCB-Contaminated Sediments at the Lake Hartwell Superfund Site: PCB Dechlorination. 1. End-Member Characterization

VICTOR S. MAGAR,*,† GLENN W. JOHNSON,‡ RICHARD C. BRENNER,§ JOHN F. QUENSEN, III,‖ ERIC A. FOOTE,† GREG DURELL,⊥ JENNIFER A. ICKES,†,# AND CAROLE PEVEN-MCCARTHY⊥

U.S. Environmental Protection Agency, National Risk Management Research Laboratory, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268, and Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio 43201

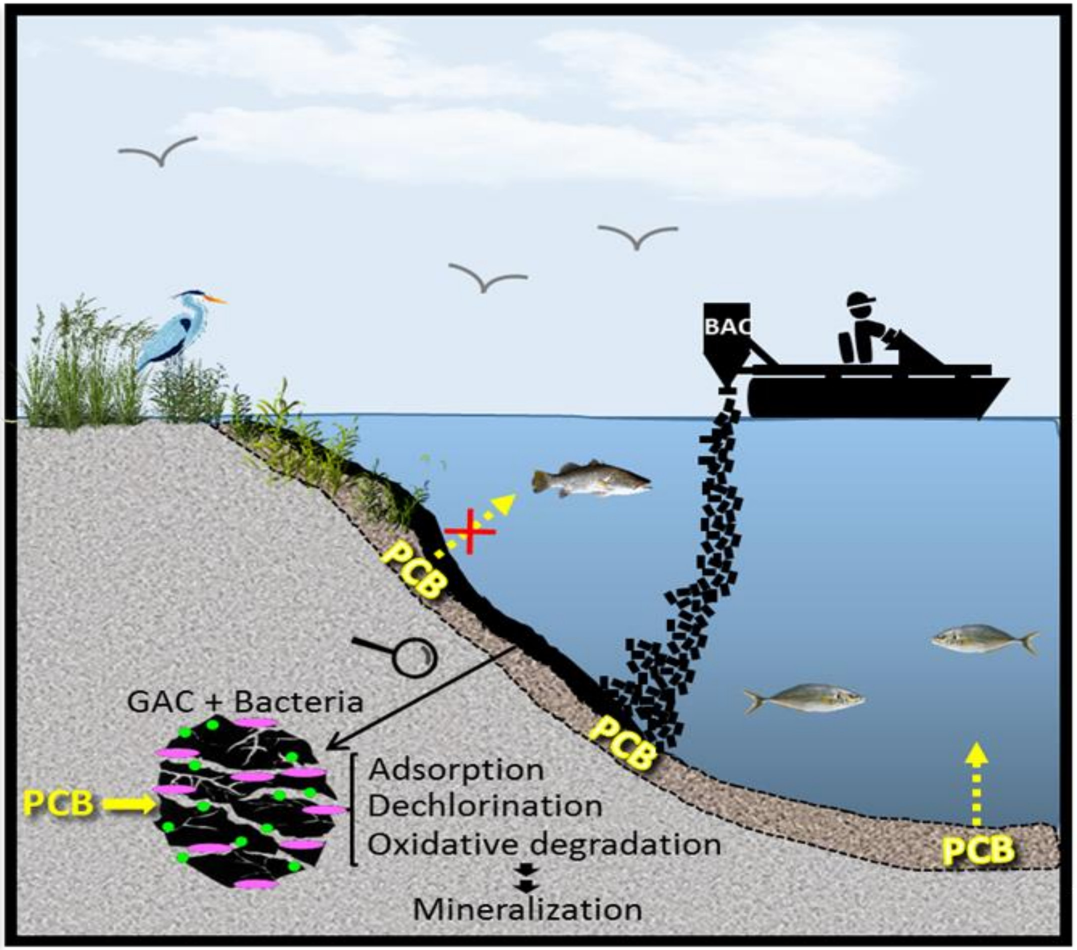
ES&T 2005





Aerobic pathway

Application of Bioamended AC



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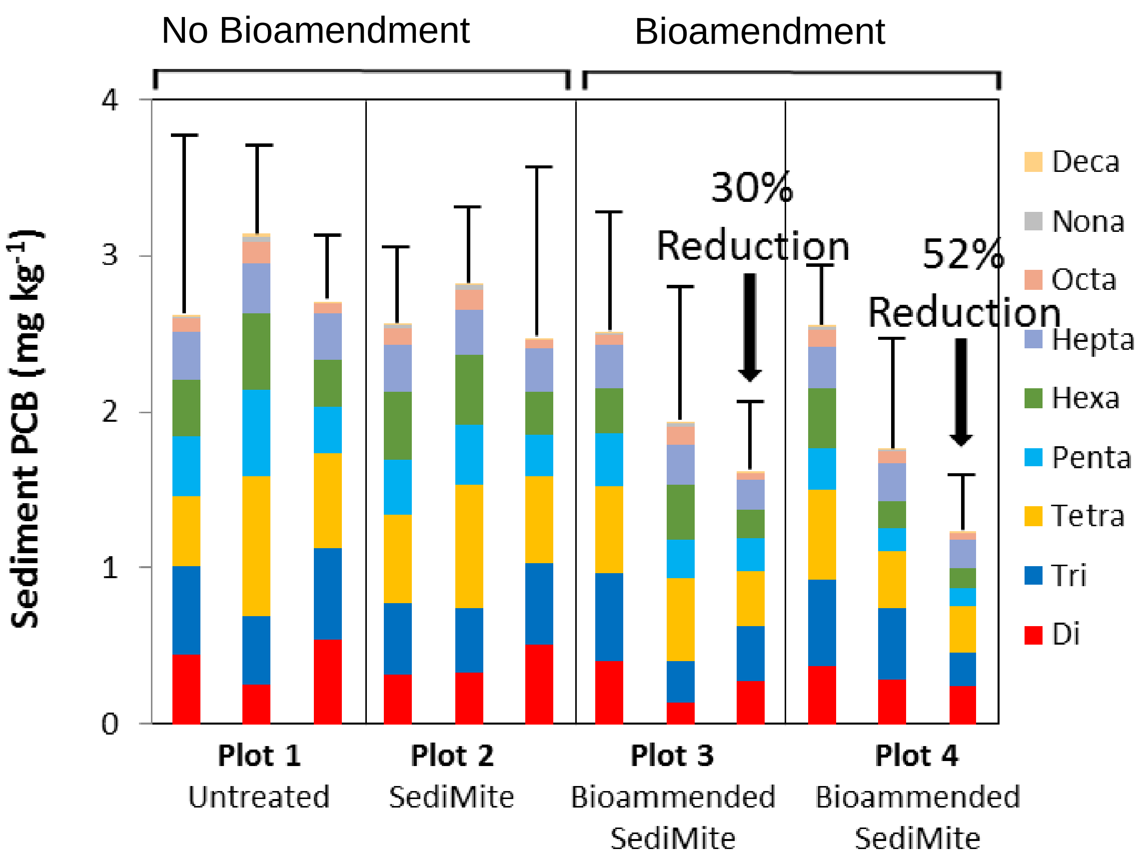
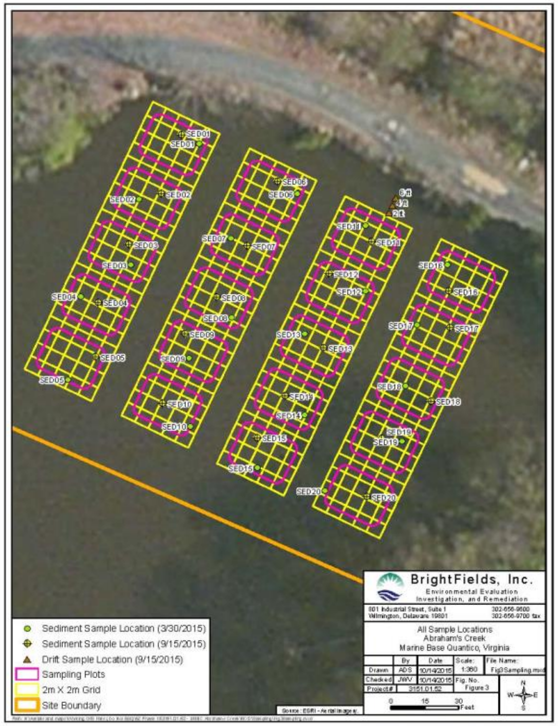
Performance Assessment-Total PCBs





- Decrease in bioamended plots after *409* days
- 80% reduction in total mass of coplanar PCBs
- No significant change in untreated plots and below benthic zone
- Difference observed between Plots 3 & 4

Environmental Science & Technology
Article
Cite This: Environ. Sci. Technol. XXXX, XXX, XXX−XXX
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A Pilot-Scale Field Study: In Situ Treatment of PCB-Impacted Sediments with Bioamended Activated Carbon

Rayford B. Payne,[†] Upal Ghosh,[‡] Harold D. May,[§] Christopher W. Marshall,[∥,⊥] and Kevin R. Sowers*,[†]

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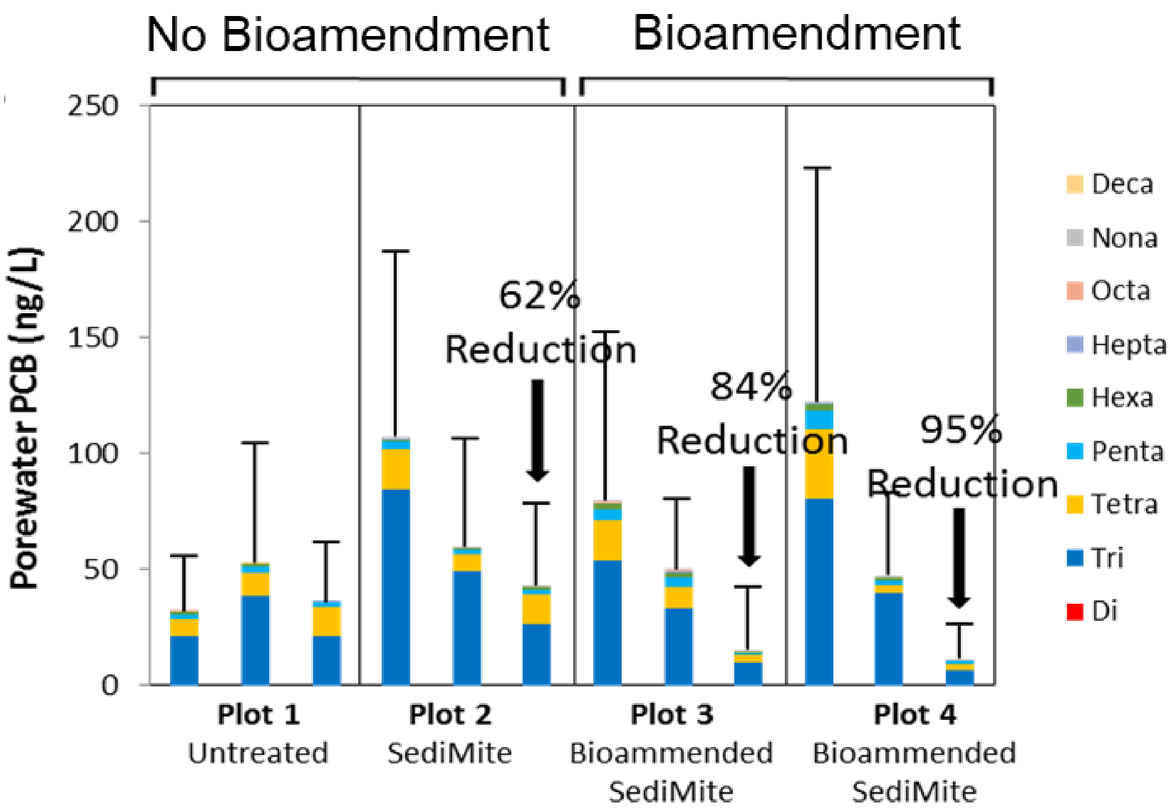
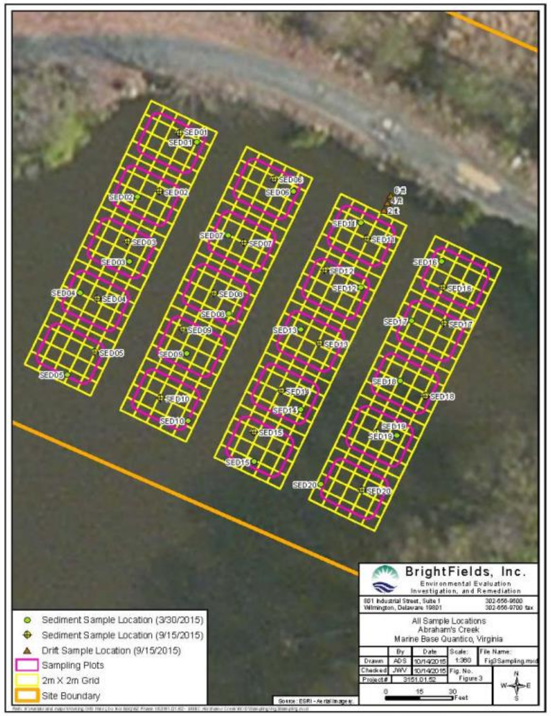
Performance Assessment-Dissolved PCBs





- Decrease in bioamended plots after *409* days
- Some decrease with AC due to adsorption, but significantly less decrease than bioamended plots
- No significant change in untreated plot and below benthic zone

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KEY CONCLUSIONS

- Site-specific complexities of fate/transport and bioaccumulation of toxic pollutants need to be addressed in a remedy
- Need to move away from the concept of total load reductions
- Pollutant bioavailability can be altered in-situ by altering sediment geochemistry
- Works in full-scale
- Persistence and performance demonstrated long-term – 10 years
- Bioaugmentation for PCB degradation in sediment demonstrated at pilot-scale

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Collaborators:

Allen Place, IMET; Richard Greene and John Cargill, Delaware Dept of Natural Resources and Environmental Control; Brightfields Inc. Kevin Sowers

Disclosure statement:

Upal Ghosh is a co-inventor of two patents related to the technology described in this paper for which he is entitled to receive royalties. One invention was issued to Stanford University (US Patent # 7,101,115 B2), and the other to the University of Maryland Baltimore County (UMBC) (U.S. Patent No. 7,824,129). In addition, UG is a partner in a startup company (Sediment Solutions) that has licensed the technology from Stanford and UMBC and is transitioning the technology in the field.

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