June 15-16, 2011

Workshop on Characterization and Remediation for Contaminated Sediment Sites

Taipei, Taiwan

R301, 3F,
National Taiwan University Hospital
International Convention Center
ROC (Taiwan)

Proceedings

- Environmental Protection Administration, ROC
- United States Environmental Protection Agency
- Taiwan Association of Soil and Groundwater Environmental Protection
- Working Group of East and Southeastern Asian Countries on Soil and Groundwater Pollution and Remediation

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Agenda

6/15（Wednesday）

Time	Topic	Speaker
8:30 – 9:00	Registration	
9:00 – 9:20	Opening Remark	Taiwan EPA; USEPA
Session 1. Introduction to Remedy Selection at Contaminated Sediment Sites under US EPA's Superfund Program		
9:20 – 10:15	Remedial Options for Sediment Sites – Overview of Advantages, Disadvantages and Applicability	Mr. Stephen J. Ells
10:15 – 10:30	Break	
Session 2. Case Studies and Site Characterization		
10:30 – 11:30	Environmental Dredging in the Hudson River	Dr. Marc S. Greenberg
11:30 – 12:00	Discussion	
12:00 – 13:00	Lunch	
13:00 – 13:45	Capping and In-Situ Amendments	Dr. Marc A. Mills
13:45 – 14:30	Performing a Sediment Erosion and Deposition Assessment (SEDA) at Sediment Sites	Mr. Stephen J. Ells
14:30 – 15:15	Using Passive Samplers to Evaluate Contaminant Release, Pore Water, and Bioavailability	Dr. Marc A. Mills
15:15 – 15:30	Break	
15:30 – 16:30	Sediment eco-toxicity testing: what works, where and why?	Dr. Marc S. Greenberg
16:30 – 17:00	Discussion	

Agenda

6/16（Thursday）		
Time	**Topic**	**Speaker**
8:30 – 9:00	Registration	
	Session 3. Remedial Technologies and Effectiveness Monitoring	
9:00 – 9:30	Monitoring Objectives and Baseline Data Acquisition	Mr. Stephen J. Ells
9:30 – 10:30	Surface Weighed Average Concentration (SWAC)	Dr. Marc S. Greenberg
10:30 – 10:45	Break	
10:45 – 11:30	Evaluating Dredge Residuals	Dr. Marc A. Mills
11:30 – 12:00	Discussion	
12:00 – 13:00	Lunch	
13:00 – 14:05	Treatment of Contaminated Sediments	Mr. Stephen J. Ells
14:05 – 15:00	Disposal Options for Dredged Sediment	Dr. Marc A. Mills
15:00 – 15:15	Break	
15:15 – 16:00	Risk-Based Decision-Making	Dr. Marc S. Greenberg
16:00 – 17:00	Discussion	

Proceedings

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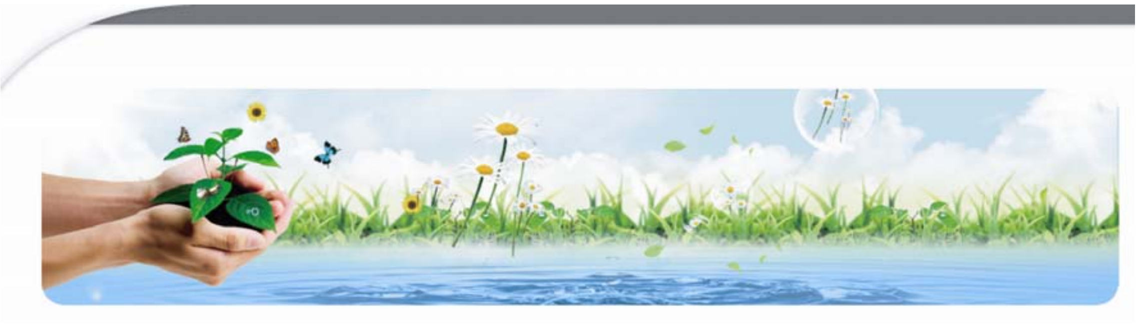
Invited Speakers

Mr. Stephen J. Ells

Dr. Marc S. Greenberg

Dr. Marc A. Mills



Stephen J. Ells

US Environmental Protection Agency

1200 Pennsylvania Ave. NW, 5204P

Washington DC 20460

E-mail: ells.steve@epa.gov

EDUCATION:

M.S. – Fisheries Biology (Jan. 1974). University of Connecticut, Storrs, CT.

B.S. – Biology (May 1972). Villanova University, Villanova, PA.

CURRENT POSITION:

Senior Environmental Scientist, Science Policy Branch, Assessment and Remediation Division, Office of Superfund Remediation and Technology Innovation

- Team Leader for the Superfund Sediment Team, responsible for coordinating and leading all activities in the Office relating to sediment issues including: preparing national guidance on site characterization and remedy selection, preparing responses to requests from Congress and other outside groups, and preparing reports that summarize the effectiveness of all remedies selected at Superfund sites. Provide expert advice on questions and issues concerning Superfund site characterization, contaminated sediment sites, ecological risk assessment, risk-based decision making, and Record of Decision quality.
- Chairs the 16-person group of Headquarters and Regional scientists and engineers (Contaminated Sediments Technical Advisory Group, CSTAG) that oversees the site characterization and remedy selection process at the biggest Superfund sediment sites.
- Reviews the Proposed Plan and Record of Decision for every sediment site prior to remedy selection.
- Co-chairs an interagency group that seeks collaboration on sediment research projects. Represents the Superfund Program on various Agency workgroups.

PROFEESIONAL EXPERIENCE:

- Section Chief, Toxics Integration Branch, Hazardous Site Evaluation Division, Office of Emergency and Remedial Response, EPA. June 1994 to October 1995.

- Section Chief of Technical Oversight Section, Guidance and Evaluation Branch, Office of Waste Programs Enforcement. Dec. 1990 to May, 1994.
- Senior Environmental Scientist, Guidance and Evaluation Branch, July 1989 to Dec. 1990.
- Biologist, Test Rules Development Branch, Office of Toxic Substances, Jan. 1986 to 1989.
- Biologist, Environmental Effects Branch, Office of Toxic Substances, Jan. 1980 to Nov. 1986.
- Manager of Aquatic Toxicology, Equitable Environmental Health, Woodbury, N.Y. Feb. 1979 to Jan. 1980.
- Chief, Standard Toxicity Testing, Springborn Life Sciences, Wareham, MA. Feb. 1974 to Feb. 1979.

EPA GUIDANCES AUTHORED OR CO-AUTHORED

Ecological Risk Assessment and Risk Management Principles for Superfund Sites. OSWER Directive 9285.7-28P. Oct. 1999.

Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites. OSWER Directive 9285.6-08. Feb. 2002.

Guidance for Developing Ecological Soil Screening Level. OSWER Directive 9285.7-55. Nov. 2003.

Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. OSWER Directive 9355.0-85. Dec. 2005

Using Fish Tissue Data to Monitor Remedy Effectiveness. OSWER Directive 9200.1-77D. July 2008.

RECENT PUBLICATIONS

Bridges TS, Gustavson KE, Schroeder PR, Ells SJ, Hayes D, Nadeau SC, Palermo MR, Patmont C. 2010. Dredging Processes and Remedy Effectiveness: Relation to the 4 Rs of Environmental Dredging. Integr. Environ. Assess. Manag. 6: 619-630.

Stahl RG, Bachman RA, Barton AL, Clark JR, defer PL, Ells SJ, Pittinger CA, Slimak MW, and Wetzel RS. Risk Management: Ecological Risk-Based Decision-Making. 2001. Pensacola, FL. Society of Environmental Toxicology and Chemistry (SETAC). 222p.

Marc S. Greenberg, Ph.D.

Environmental Toxicologist

U.S. EPA-OSWER/OSRTI/TIFSD/ERT

Office of Solid Waste and Emergency Response
Office of Superfund Remediation and Technology Innovation
Technology Innovation and Field Services Division
Environmental Response Team
2890 Woodbridge Ave., Bldg. 18
Edison, NJ 08837
+732 452 6413 (T) +732 321 6724 (F)
greenberg.marc@epa.gov

Dr. Marc S. Greenberg is an Environmental Scientist and Toxicologist on the U.S. EPA's Environmental Response Team where he supports various clean-up, emergency, and other response actions within the Superfund program His primary area of focus is the assessment, remediation, and management of contaminated sediment sites, including the development of innovative remediation technologies. His technical experience includes research in both human health and aquatic ecological toxicology with a focus on pharmacokinetics, contaminated sediments, bioavailability, and the role of dynamic environmental conditions on *in situ* effects. Dr. Greenberg has provided technical advice for the formulation of policy in the fields of contaminated sediments, oil spill response, toxicology, ecological risk assessment, and ground water-to-surface water interactions and their relevance to exposure and risk. He has supported the development of baseline and post-remedial monitoring programs, sediment sampling programs, emergency response plans, performance standards, habitat assessments, and remedial investigations. He continues to conduct field investigations on contaminated sediments at several Superfund sites. Dr. Greenberg serves as an advisor to the Hudson River PCBs, Grasse River PCBs, Anniston PCB, Molycorp Mine, Upper Columbia River, and Newtown Creek Management Teams. At the National level, Dr. Greenberg is a member of the EPA Contaminated Sediments Technical Advisory Group (CSTAG) and the OSRTI Sediments Team; he is the EPA Headquarters Chair of the Agency's Ecological Risk Assessment Forum (ERAF); and he presented a review of U.S. EPA's post-remedial monitoring strategies to the National Research Council Review Panel on Dredging at Superfund Megasites. During the Deepwater Horizon oil spill, he served as an Environmental Unit Leader in

EPA's Emergency Operations Center in Dallas, TX, and in the Unified Area Command in New Orleans, LA. Internationally, he has advised the Government of Thailand regarding potential environmental quality issues associated with offshore oil operations; he has consulted with the French Ministry of the Environment on issues regarding PCBs in the Rhône River; and he has consulted with researchers and government officials in Finland regarding contaminated sediment management. He serves as an Adjunct Assistant Professor at Clemson University, SC, and has served as a Visiting Scientist at the National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory, and an Inhalation Research Toxicologist at the Air Force Toxicology Laboratory, Wright-Patterson Air Force Base, OH. Dr. Greenberg continues to conduct basic research, and is currently a co-investigator on three collaborative research grants aimed at improving sediment assessment techniques, evaluating the recovery of sediment environments following remediation, and further developing spatially-explicit exposure models in ecological risk assessments. He participated in the standardizing of sediment toxicity testing methods for the U.S. EPA, has co-authored many EPA technical and guidance documents, and has published numerous peer-reviewed research articles. As an internationally recognized expert in sediments, Dr. Greenberg has been invited to give many presentations and lectures; serve on scientific steering and advisory committees, workshops, and panels; and review articles for scientific journals. Dr. Greenberg is an active member of the international Society for Environmental Toxicology and Chemistry (SETAC) and he served on its North America Board of Directors (2007-2010) and is presently on the Editorial Board for the SETAC journals. He obtained a B.A. in Zoology and a M.S. in Aquatic Toxicology from Miami University, Oxford, OH in 1990 and 1993, respectively, and a Ph.D. in Biomedical Sciences from Wright State University, Dayton, OH in 2002.

Marc A. Mills, Ph.D.

Environmental Engineer
U.S. EPA

Office of Research and Development
National Risk Management Research Laboratory
26 W. Martin Luther King Drive
Cincinnati, OH 45268

513.569.7322 (T)
513.569.7620 (F)
mills.marc@epa.gov

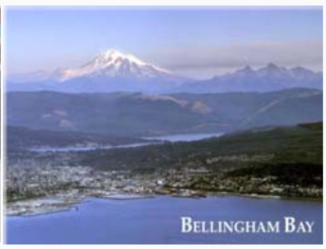
Dr. Marc A. Mills is an Environmental Engineer at the National Risk Management Research Laboratory within the Office of Research and Development at U.S. EPA. He is responsible for a research program focused on evaluating the effectiveness of remediation of contaminated sediments in support of U.S. EPA's Superfund program and the Great Lake National Program Office. Dr. Mills has served on numerous federal and non-federal technical committees focused on coordinating research regarding approaches and methods for characterizing the contaminated sediments sites prior to remedy selection, evaluating the impacts of the remediation efforts, and the long term monitoring following the implementation of remediation strategies. He has co-authored many technical documents on the subject and has numerous peer-reviewed publications in the areas of contaminated sediments, petroleum degradation, and the fate of emerging contaminants in wastewater and receiving waters.

Remedial Options for Sediment Sites – Overview of Advantages, Disadvantages and Applicability

Stephen J. Ells
U.S. EPA
Science Policy Branch
Office Of Superfund Remediation And Technology Innovation
ells.steve@epa.gov

Taiwan EPA Contaminated Sediments Workshop
June 15 – 16, 2011

Remedial Options for Sediment Sites – Overview of Advantages, Disadvantages and Applicability



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Overview

- Primary Remedies: Dredging, Capping, Monitored Natural Recovery
  - Remedy Description
  - Case Studies
  - Advantages
  - Limitations
  - Conditions Conducive to Choosing Each Remedy
  - FAQs
- Take Home Messages

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Contaminated Sediment Remediation

- When is a contaminated sediment remedy needed in US?
  - Unacceptable risks to human health or the environment; e.g., cancer risk > 1 x 10-4, HI > 1
- What is the goal?
  - Implement a cost effective remedy that:
    - Controls sources
    - Achieves long-term protection
    - Minimizes short-term impacts

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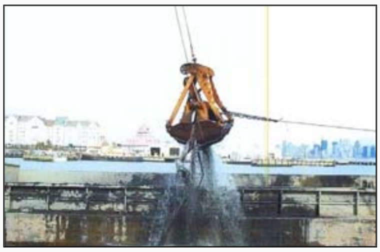
Three Primary Remedies to Address Contaminated Sediment

- Dredging
- In-situ capping
- Monitored natural recovery



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Dredging

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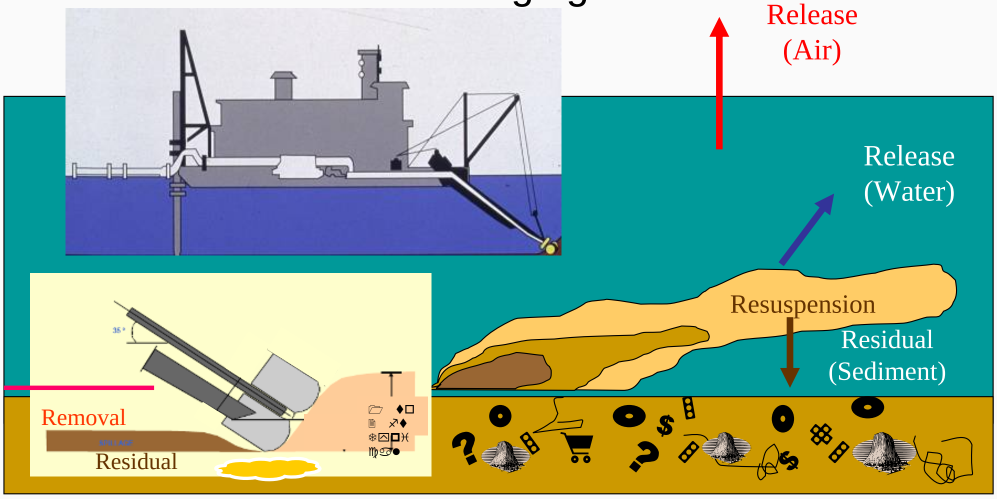
Conceptual Illustration Of Environmental Dredging And Processes



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From D. Reible, 2007

Head of Hylebos, WA

- Project
  - Dredged 404,000 cy from 2004 – 2006
- Contaminants
  - PCBs, PAHs, Arsenic
- Project Goals
  - PCBs: 0.3 ppm
  - PAHs: 17 ppm
- Results
  - Average surficial PCB concentrations decreased from 0.69 ppm to 0.07 ppm
  - One area had to be capped

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Head of Hylebos, WA

- Lessons Learned
  - Source control prior to dredging was critical
  - Soft black muck over clean sand provided clear visual differentiation between impacted and clean sediment
  - Overdredging feasible
  - Relatively little debris
  - Site conditions conducive to dredging

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Case Study: Grasse River Pilot, NY – 2005

- Project
  - Remedial Options Pilot Study
  - 20,600 cy dredged over 4 months
- Contaminants
  - PCBs
- Project Goals
  - Goal: Dredge 64,000 cy in 3 areas to test dredging's potential effectiveness under site-specific conditions
- Results
  - Dredged only 1/3 of desired volume
  - Average surficial concentrations increased from 4.1 ppm to 150 ppm
  - 3% of PCBs were released into the water column in dissolved fraction
  - Concentrations of PCBs in fish increased temporarily

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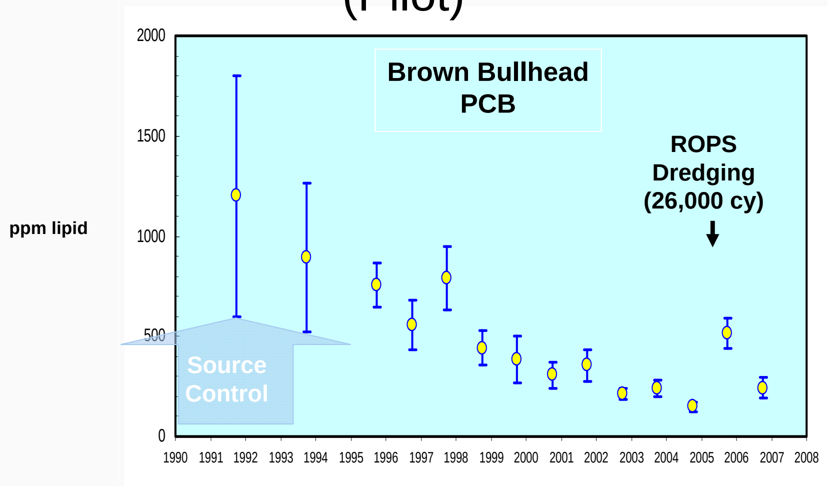
Case Study: Grasse River, NY – 2005 ROPS (Pilot)



Data Source: Alcoa (2007)

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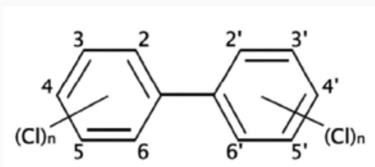
Grasse River, NY - 2005 ROPS (Pilot)

- Lessons Learned
  - Low sediment levels not achieved despite significant dredging efforts
    - ~100 dredge cuts in each 25 ft x 25 ft unit
  - Complex and hard bottom conditions/rock and cobble hampered ability to remove all targeted sediments
  - Unable to characterize site sub-bottom conditions despite state-of-the-art technology
  - Significant release of PCBs downstream
  - PCB concentrations in fish increased



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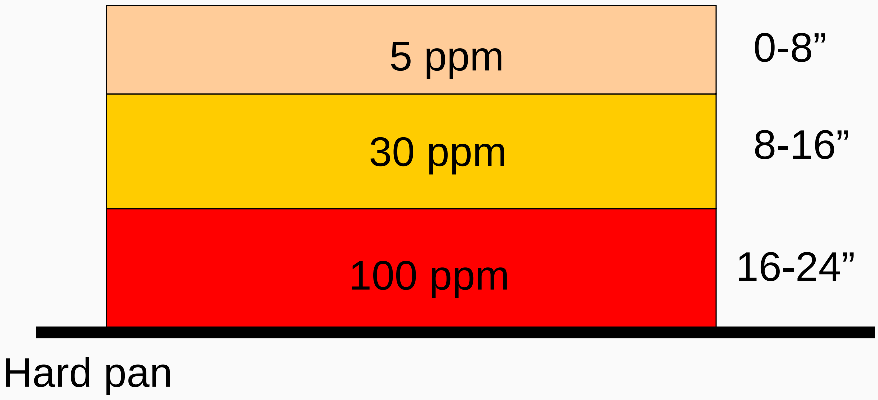
Example: Pre-Dredge Contaminant Concentration In Sediment Column



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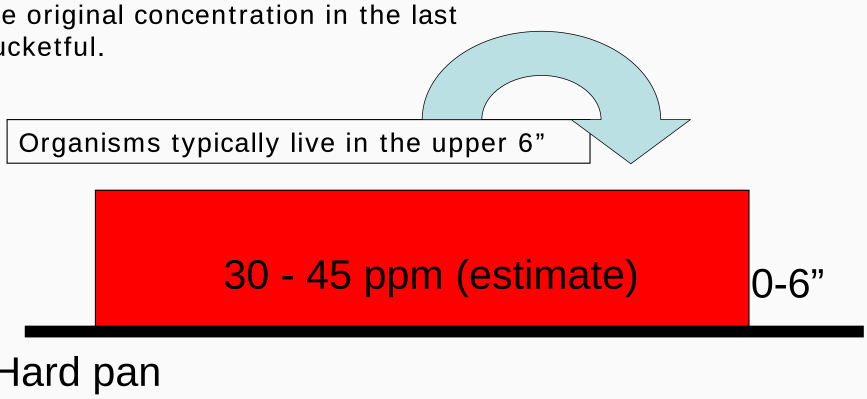
Example: Post-Dredge Residual Sediment Contaminant Concentrations

Result is approximately the average of the original concentration in the last bucketful.



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Fox River, WI – OU 1 2004 - 2009 Remedial Action

- Project
  - Dredged 750,000 cy (173 acres)
  - Capped 114 acres
  - Covered 142 acres
- Contaminants
  - PCBs
- Project Goals
  - Remedial Action Level: 1.0 ppm in sediment
  - Remedial Goal: post-dredging SWAC – 0.25 ppm
- Results
  - Mean conc. in dredged areas = 0.41 ppm, some areas > 5 ppm
  - SWAC over entire area = 0.26 ppm
  - Preliminary data shows fish tissue conc. reduced 32 – 76% in four species after one year
    - 1.9 to 1.1 ppm in carp
    - 0.14 to 0.033 ppm in walleye

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Fox River, WI – OU 1 2007 Remedial Action

- Lessons Learned
  - Despite use of different dredge heads, dredging alone could not achieve 0.25 ppm SWAC
  - Combination of remedies (about 50% capping) was used; final SWAC for entire area of 0.26 ppm was achieved
  - Have seen significant reductions in fish tissue

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Dredging Advantages

- Moves contaminants from the aquatic environment where they might be mobile to a landfill or to a confined disposal facility (CDF) or confined aquatic disposal facility (CAD)
- Does not limit future water body uses
- Does not reduce flood control capacity

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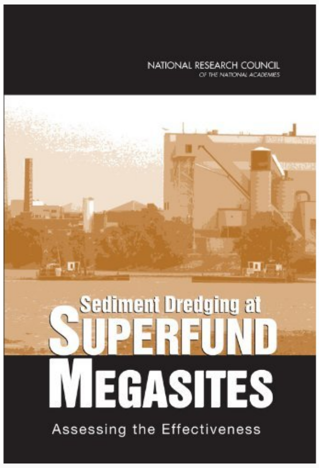
Limitations Of Dredging

- Complex and time-consuming to design and implement
- Lack of capacity in disposal facilities, transport to distant facility can be very costly
- Resuspension and release of contaminants to water, leading to an increase in bioavailability and biota uptake
- Residual sediment contamination affects ability to achieve risk reduction goals

"[R]esuspension, release, and residuals occur to some extent with all dredging projects."
Sediment Dredging At Superfund Megasites: Assessing The Effectiveness. 2007 National Research Council, p. 63.



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Dredging – Elements Potentially Continuing Or Increasing Risk

- Contaminant releases during sediment removal, transport, and disposal
- Community impacts (e.g., accidents, noise, odor, residential and/or commercial disruption)
- Worker risk during sediment removal, handling, and transportation

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Dredging – Elements Potentially Continuing Or Increasing Risk

- Residual contamination following sediment removal
- Continued exposure to contaminants currently in food chain
- Releases from contaminants remaining outside of dredged/excavated area
- Disruption of bottom dwelling organisms

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Conditions Especially Conducive To Dredging

- ☐ Contaminated sediment is underlain by clean sediment
- ☐ Low incidence of hardpan, bedrock, and/or rocks
- ☐ Low incidence of debris
- ☐ Low incidence of low dry density sediment ("fluff")
- ☐ Discrete areas of higher contaminant concentrations (hot spots)
- ☐ Water diversion is practical or current velocity is low or can be minimized to reduce resuspension and downstream transport during dredging

Debris is not conducive to dredging.

Note: Not all of the listed conditions need to be present to select dredging.

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Conditions Especially Conducive To Dredging

- ☐ Existing shoreline areas and infrastructure can accommodate dredging
- ☐ Navigational dredging is scheduled or planned
- ☐ Suitable work area is available
- ☐ Suitable disposal sites are nearby
- ☐ Contaminants can be properly treated for transport and disposal
- ☐ Overall, long-term risk reduction outweighs contaminant releases and habitat disruption

Constructing staging area for sediment.

Note: Not all of the listed conditions need to be present to select dredging.

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Dredging Frequently Asked Questions

Won't removing contaminated sediments immediately and permanently reduce risk?

- According to a review by the National Research Council "Simple mass removal … may not reduce risk."
- After dredging, surface sediment contaminant concentrations may still be higher than target clean up levels.

Sediment Dredging At Superfund Megasites: Assessing The Effectiveness. 2007 National Research Council.

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Dredging Frequently Asked Questions

Will I be able to eat the fish after dredging is completed?

- Reducing impacts to the food chain can take a long time – from a few years if all sources are controlled, to many decades if not.
- Fish consumption advisories typically continue for a number of years following dredging.
- For example, Fox River OU4 walleye fish consumption advisory anticipated to continue for over 20 years following completion of remedy.

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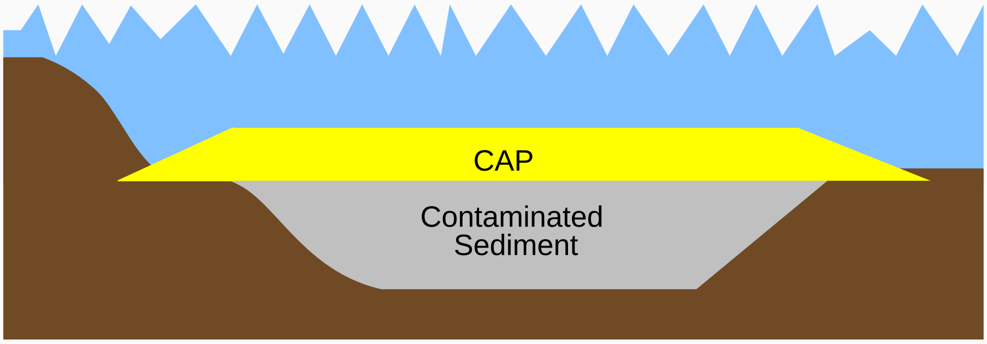
Capping



From D. Reible, 2007

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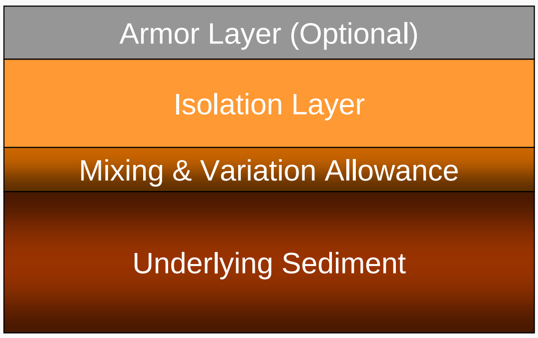
Conceptual Illustration of Common Cap Design



Note: Many caps do not require an armor layer.

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Case Study: St. Paul Waterway, WA

- Project
  - Early capping project - 1988
  - 17 acres capped in place plus habitat enhancement
- Contaminants
  - phenols, PAHs, copper, dioxins, furans
- Project Goals
  - Maintain integrity of the cap
  - Chemically stable
  - Biological recovery within 2 yrs of completion of cap

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Case Study: St. Paul Waterway, WA

- Results
  - 10 yrs of intensive monitoring showed:
    - No chemical migration through cap
    - No contaminants in the surficial layer of cap
    - Rapid recolonization of cap by biota
    - Biotic communities indistinguishable from reference area communities
- Lessons Learned
  - As an added benefit to the cap's demonstrated long-term reduction of risk, it provided intertidal habitat in industrial bay

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Case Study: Ward Cove, Ketchikan, AK

- Project
  - 80 acre Area of Concern
  - ~27 acres capped (6-12 inch sand cap) in 2000/2001
  - 3 acres navigationally dredged
  - MNR for remainder of site
- Contaminants
  - Ammonia, 4-methylphenol, sulfide
- Project Goals
  - Reduce toxicity of surface sediments
  - Enhance recolonization of surface sediments to support a healthy marine benthic invertebrate community

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Case Study: Ward Cove, Ketchikan, AK

- Results
  - Post-construction monitoring in 2004 and 2007:
    - Reduction in sediment toxicity
    - Colonization by healthy, diverse benthic macroinvertebrate communities
  - 2009: RAOs achieved
- Lessons Learned
  - Thin layer capping and MNR effectively reduced risks to benthic communities

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Capping Advantages

- Achieves greater risk reduction more quickly (almost immediately)
- Less short-term risk
- Fewer quality of life issues
- Implemented relatively quickly
- Requires much less work area than dredging
- Can facilitate habitat restoration

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Limitations Of Capping

- Contamination remains in the aquatic environment, but isolated by an engineered barrier
- Water depths reduced (if not dredged first)
- Must evaluate if subject to periodic disturbances such as storms, floods, etc.
- Long term monitoring/maintenance required
- Institutional controls may be required

Note: Institutional controls are non-engineering measures designed to affect human activities to limit exposure to hazardous substances (e.g., no-wake zones, fish consumption advisories).

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Elements Potentially Continuing Or Increasing Risk - Capping

- Potential contaminant releases during capping, but typically much less than with dredging
- Continued exposure to contaminants currently in the food chain
- Community quality of life impacts (e.g., accidents, noise, residential and/or commercial disruption), but typically less than with dredging due to shorter duration of the remedy implementation
- Worker risk during transport of cap materials and cap placement
- Potential contaminant movement through cap
- Disruption of bottom dwelling organisms

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Conditions Especially Conducive To Capping

- Sediment has sufficient strength to support cap
- Rate of contaminant movement through cap, if any, is not likely to create unacceptable risk or can be accommodated in cap design
- Anticipated or existing infrastructure (e.g., piers, pilings, buried cables) is compatible with cap

Note: Not all of the listed conditions need to be present to select capping.

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Conditions Especially Conducive To Capping

- Water depth is adequate to accommodate cap with anticipated uses (e.g., navigation, flood control) or depth can be changed to maintain adequate water depth
- Suitable types and quantities of cap material are available
- Long-term risk reduction outweighs habitat disruption and/or habitat improvements are provided by the cap

Note: Not all of the listed conditions need to be present to select capping.

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Conditions Especially Conducive To Capping

- Hydrodynamic conditions (e.g., floods, ice) are not likely to compromise cap or can be accommodated in design
- Rate of ground water flow in cap area, if any, is not likely to create unacceptable conditions
- Incidence of cap-disrupting human behavior, such as large boat anchoring, is low or controllable

Note: Not all of the listed conditions need to be present to select capping.

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Capping Frequently Asked Questions

Isn't capping a new technology, i.e., experimental and unproven?

- Some type of cap or cover (including CAD cells) have been placed at over 100 locations worldwide.

www.hsrcssw.org/capsummary.pdf

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Capping Frequently Asked Questions

What about groundwater flow through caps? Will that force contaminants to the surface of the cap?

- Contaminant movement, if any, is highly dependent on rates of groundwater flow and contaminant solubility. There are engineering solutions that can account for high groundwater flow areas.

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Capping Frequently Asked Questions

I heard all caps will eventually fail. Is that true?

- When caps erode, it usually is in localized areas. Erosion can be effectively addressed by modeling and engineering solutions during cap design.
- Caps require monitoring to determine if maintenance is needed.
- Many caps have been successfully in place for decades.

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Capping Frequently Asked Questions

I can see how a cap in a lake would work, but can you place caps in rivers?

- It depends on where you are in the river. Some river areas, like slower flowing reaches, may be better suited to capping. However, many faster flowing rivers have been successfully addressed with design/engineering solutions, such as armoring with stone.

Capping at the Fox River, WI

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Monitored Natural Recovery (MNR)

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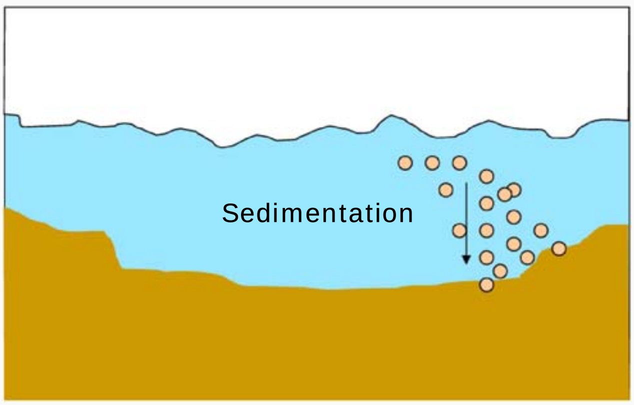
Conceptual Illustration of MNR



Note: Sedimentation is one of several processes that may contribute to MNR.

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MNR Defined

- MNR allows natural processes to reduce the bioavailability or toxicity of contaminants in sediment
- Some natural processes that reduce the bioavailability or toxicity of contaminants in sediment include:
  - Transformation of contaminants reduces toxicity
  - Burial by deposition of clean sediment reduces exposure
  - Binding of contaminant to sediment organic carbon reduces contaminant mobility and bioavailability

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MNR Defined

- MNR includes:
  - Setting remedial action objectives
  - Monitoring to assess whether risk is being reduced as expected and the remedial action objectives are being or will be met

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Bellingham Bay, WA

- Project
  - Chronic toxicity to bottom dwelling organisms in the sediment from mercury (source: chlor-alkali plant)
  - MNR following source control (partial source control – 1971; complete source control – 1979)
- Contaminants
  - Mercury (Hg)
- Project Goals
  - Cleanup level: 1.2 mg/kg
- Results
  - After source control, Hg reduced to near or below target cleanup level
  - Toxicity to bottom dwelling organisms significantly reduced
- Lessons Learned
  - Source control is a crucial first step to achieving project goals
  - Natural recovery is functioning well

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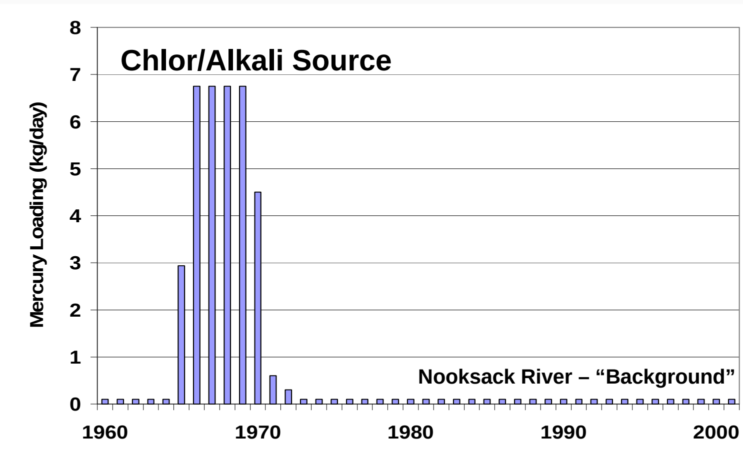
Bellingham Bay: Mercury Release and Source Control



Data Source: Georgia-Pacific (2004)

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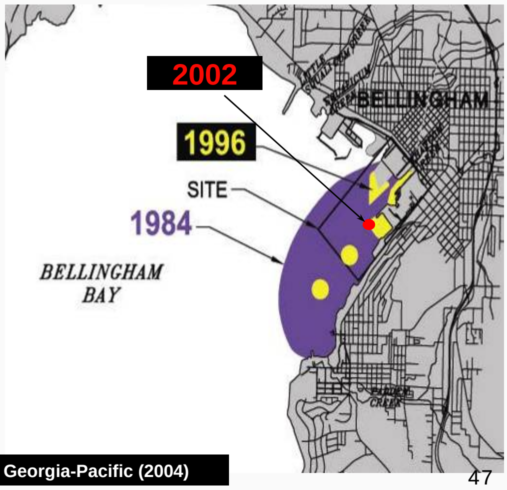
Bellingham Bay Natural Recovery Biological Endpoint: Sediment Toxicity

Toxicity tests showed that following source control areas exhibiting toxicity were greatly reduced



Data Source: Georgia-Pacific (2004)

47

MNR Advantages

- MNR allows the existing eco-system to remain in place
- MNR avoids disruption to the use of the waterbody

Excavation of river bed.

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MNR Advantages

- MNR avoids disruption to the surrounding neighborhood
- MNR does not require transport of contaminated sediment or capping materials through the neighboring community and beyond
- MNR is less costly than dredging and capping

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Limitations Of Monitored Natural Recovery

- Leaves contaminants in place
- Time to reduce risks may be longer compared to other remedies, although when realistic timeframes for dredging design and implementation are considered, this time difference may not be significant
- Potential disruption of natural recovery by external events
- Future natural recovery processes and rates may not be similar to historical natural recovery processes and rates

50

Elements Potentially Continuing Or Increasing Risk - MNR

- Continued exposure to contaminants present at sediment surface and in food chain
- Potential for undesirable changes in the site's natural processes
- Potential for contaminant exposure due to erosion or human disturbance

51

Conditions Especially Conducive To MNR

- Anticipated land uses compatible with MNR
- Anticipated waterbody uses compatible with MNR
- Contaminant concentrations in biota and in the biologically active zone of sediment are moving towards risk-based goals
- Natural recovery reasonably anticipated to reduce risk within an acceptable time frame

Note: Not all of the listed conditions need to be present to select MNR.

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Conditions Especially Conducive To MNR

- Current human exposure is low or manageable
- Site includes sensitive or unique habitats
- Sediment deposition is occurring in areas of contamination
- Hydrodynamic conditions are not likely to compromise natural recovery

Note: Not all of the listed conditions need to be present to select MNR.

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MNR Frequently Asked Questions

Isn't MNR really a do nothing, or a "wink and a walk" remedy?

- MNR is a remedy that recognizes natural processes will achieve remedial goals within an acceptable length of time. The system is monitored to assess whether the system is recovering as predicted.

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MNR Frequently Asked Questions

If the risk posed by sediment is unacceptable, shouldn't we do something about it now?

- Depending on site conditions, including its size and complexity, a dredging or capping project may take several years or even decades to plan, design, permit, and implement.
- Site-specific conditions may make dredging ineffective at reducing risk or unlikely to materially speed up risk reduction (due to risk from resuspension, releases and residuals).
- Both near-term and long-term risks of all cleanup alternatives must be evaluated and compared to select the most effective and efficient remedy or combination of remedies while considering the needs of the community.
- U.S. EPA's policy is to consider MNR on an equal footing with dredging and capping.

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Enhanced Natural Recovery

- When natural recovery could be an appropriate remedy, but the rate of recovery is too slow, engineering means can be used to accelerate recovery
- Engineering means include:
  - Thin-layer placement of clean sediment or sand over contaminated sediment
  - Flow control structures to enhance natural deposition

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Database on US EPA Superfund Sediment Sites

- Historically, EPA did not have a central repository of information on sediment sites.
- Now have a well-referenced compendium on sites to summarize national experience.
- Reference tool to query site characteristics.
- Track progress and performance at sites.
- Compare effectiveness of technologies

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Compilation of Sites

- List developed from polling EPA Regions on sites with significant sediment contamination
- Supplemented with other sources
- Tier 1 Site Criteria
  - Signed Decision Document
  - 10,000 cy or more removal
  - 5 acres capping or MNR
  - Not waste pits, lagoons, or settling basins
- 69 Sites, 124 Areas within those Sites

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Site Characteristics

- Site / Operable Units / Area Name
- Websites (Superfund, Region)
- Fieldwork Dates / Remedy Status
- Remedy (Dredge, Backfill, Excavation, Cap, MNR, EMNR, In-situ Amendments)
- Volume Removed or Area Capped or MNR
- Contaminants of Concern
- Action Level and Cleanup Levels (CULs)
- Fish Tissue Goal
- Remedial Action Objectives (RAOs)
- Estimated and Actual Cost

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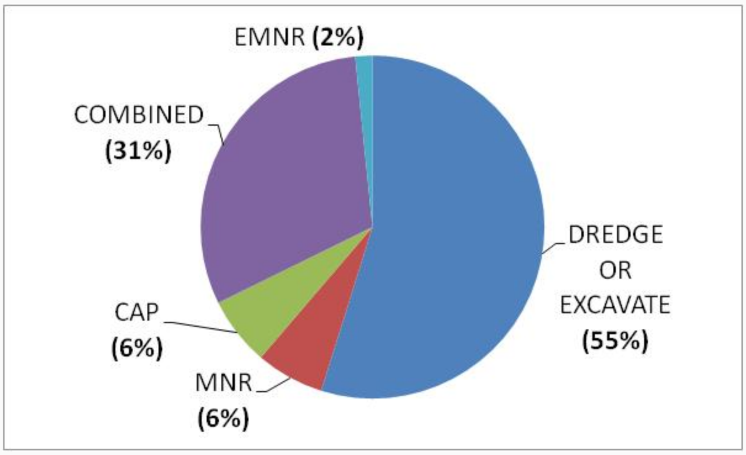
Remedy Selection at Superfund Sediment Sites



60

Take Home Messages

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Take Home Message - Dredging

- Dredging can be an effective remedy if conditions are conducive (e.g., low debris or underlain by clean sediment)
- Important to identify and characterize site conditions that reduce dredging effectiveness
- Debris, rocks and hard pan significantly affect residuals and decrease the risk reduction potential of this remedy

62

Take Home Message - Dredging

- ☐ All dredges require skilled operators, but:
  - – All dredges re-suspend sediment and release contaminants
  - – All dredges leave residuals
- ☐ At sites with conditions not favorable for dredging, dredging alone is unlikely to be effective in achieving both short-term and long-term cleanup levels
- ☐ Dredging is a highly complex and costly integrated train of processes (e.g., removal, transport, rehandling, treatment, disposal)

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Take Home Message - Capping

- ☐ Caps or covers have been placed at over 100 locations worldwide
- ☐ Capping provides immediate exposure control
- ☐ Capping can be an effective remedy
- ☐ Conventional sand caps are easy to place
- ☐ Methods are available to address key cap design issues
  - ☐ Long-term physical stability
  - ☐ Contaminant movement

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Take Home Message - MNR

- Can be an effective remedy either as a stand alone remedy or as part of a combination remedy
- Can provide long-term exposure control
- Can be integrated with other remedies: MNR is a component of virtually every remedy
- Monitoring is an integral component of MNR to measure long-term protectiveness
- Enhanced MNR, such as adding sand, also may be used to accelerate achievement of risk reduction goals
- Like all remedies, must have adequate source control to achieve risk reduction

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Take Home Message – Combination Remedies

- At large or complex sites, there is no one-size fits all remedy
- A combination of remedies, each targeted to specific areas based on area conditions, may be appropriate
- Combination remedies are becoming the norm, rather than the exception

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Technical Resources

Contaminated Sediment Remediation Guidance for Hazardous Waste Sites

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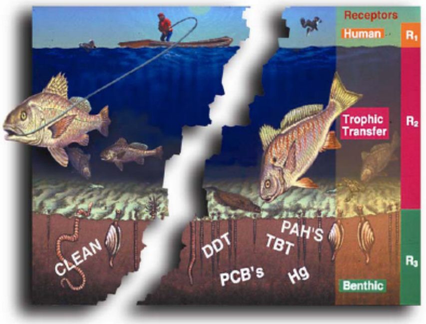
Office of Superfund Remediation and Technology Innovation
and
Office of Research and Development

Sediment Assessment and Monitoring Sheet (SAMS) #1

Using Fish Tissue Data to Monitor Remedy Effectiveness



OSWER Directive 9200.1-77D

July 2008

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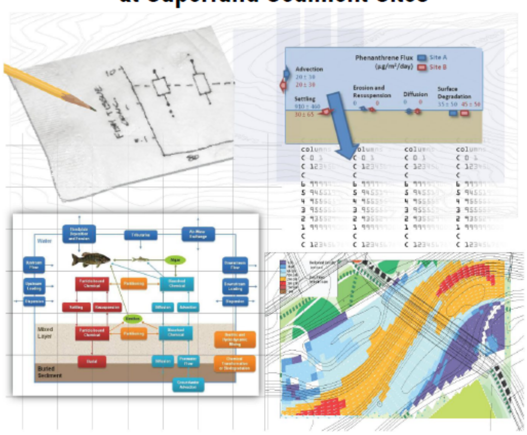
Office of Superfund Remediation and Technology Innovation

Sediment Assessment and Monitoring Sheet (SAMS) #2

Understanding the Use of Models in Predicting the Effectiveness of Proposed Remedial Actions at Superfund Sediment Sites



OSWER Directive 9200.1-96FS

November 2009

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ERDC/EL TR-08-4

Environmental Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Dredging Operations and Environmental Research Program

The Four Rs of Environmental Dredging: Resuspension, Release, Residual, and Risk

Todd S. Bridges, Stephen Ells, Donald Hayes, David Mount, Steven C. Nadeau, Michael R. Palermo, Clay Patmont, and Paul Schroeder

January 2008

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Evaluating *the* Effectiveness *of* Contaminated-Sediment DREDGING


J. F. BRENNAN CO., INC.

As the science of environmental dredging and sediment management changes, adaptive management strategies can help long-term remediation projects keep pace.

KARL E. GUSTAVSON
U.S. ARMY ENGINEER RESEARCH AND DEVELOPMENT CENTER
G. ALLEN BURTON
WRIGHT STATE UNIVERSITY
NORMAN R. FRANCINGUES, JR.
OA SYSTEMS CORP.
DANNY D. REIBLE
UNIVERSITY OF TEXAS AUSTIN
DONNA J. VORHEES
BOSTON UNIVERSITY AND THE SCIENCE COLLABORATIVE
JOHN R. WOLFE
LIMNOTECH

Water bodies fed by current or former industrial, agricultural, or mining areas frequently contain contaminated sediments, and throughout the U.S., miles of riverbeds and vast areas of harbors, lakes, and estuaries are affected (*1, 2*). Contaminants in sediments can have direct toxic effects on organisms and can accumulate in organisms consumed by humans. The presence of sediment contamination also limits the productive use of a water body and its associated economic benefits (e.g., Ref. 3). The Hudson River in New York State is probably the best-known example of a large river system with widespread sediment contamination. The proposed cleanup addresses the upper 40 miles of river where 2.65 million cubic yards are slated to be removed (*4*). Cleanup has yet to begin, although dredging of 265,000 cubic yards

72

ERDC/EL TR-08-29

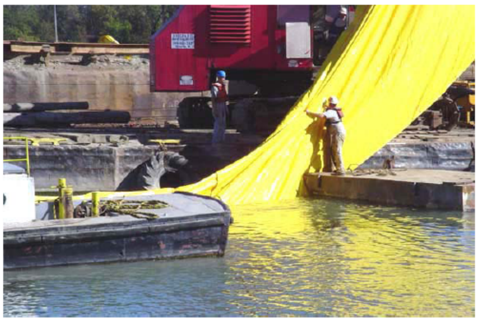
Environmental Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Technical Guidelines for Environmental Dredging of Contaminated Sediments

Michael R. Palermo, Paul R. Schroeder, Trudy J. Estes, and Norman R. Francingues

September 2008



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TECHNICAL REPORT 1960
September 2007

User's Guide for Assessing Sediment Transport at Navy Facilities

A. C. Blake
D. B. Chadwick
SSC San Diego

P. J. White
CH2M HILL

C. A. Jones
Sea Engineering, Inc.

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SPAWAR Systems Center San Diego

SSC San Diego
San Diego, CA 92152-5001

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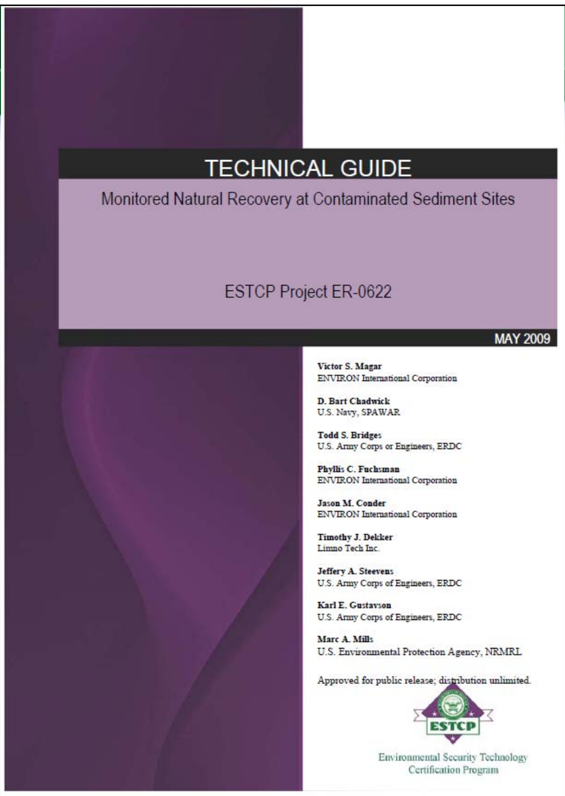
TECHNICAL GUIDE

Monitored Natural Recovery at Contaminated Sediment Sites

ESTCP Project ER-0622

MAY 2009

Victor S. Magar
ENVIRON International Corporation

D. Bart Chadwick
U.S. Navy, SPAWAR

Todd S. Bridges
U.S. Army Corps or Engineers, ERDC

Phyllis C. Fuchsman
ENVIRON International Corporation

Jason M. Conder
ENVIRON International Corporation

Timothy J. Dekker
Limno Tech Inc.

Jeffery A. Steevens
U.S. Army Corps of Engineers, ERDC

Karl E. Gustavson
U.S. Army Corps of Engineers, ERDC

Marc A. Mills
U.S. Environmental Protection Agency, NRMRL

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ESTCP
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- OSRTI Contaminated Sediments Homepage: http://www.epa.gov/superfund/health/conmedia/sediment/index.htm
- Contaminated Sites Clean-Up Information (Clu-In): http://www.clu-in.org/contaminantfocus/default.focus/sec/Sediments/cat/Overview/
- EPA Contaminated Sediments in Water: http://water.epa.gov/polwaste/sediments/cs_index.cfm
- USACE Dredging Operations & Environmental Research: http://el.erdc.usace.army.mil/dots/doer/doer.html
- Interactive Sediment Remedy Assessment Portal: (Navy SPAWAR, 2010, http://www.ert2.org/israp/)

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Taiwan-EPA Contaminated Sediment Workshop June 14-15, 2011: U.S. EPA's Approach to Understanding Sediment Site Conditions, Characterizing Contamination, and Reducing Uncertainties in Making Decisions to Manage Risks from Contaminated Sediments

ENVIRONMENTAL DREDGING IN THE HUDSON RIVER

Marc S. Greenberg, Ph.D.

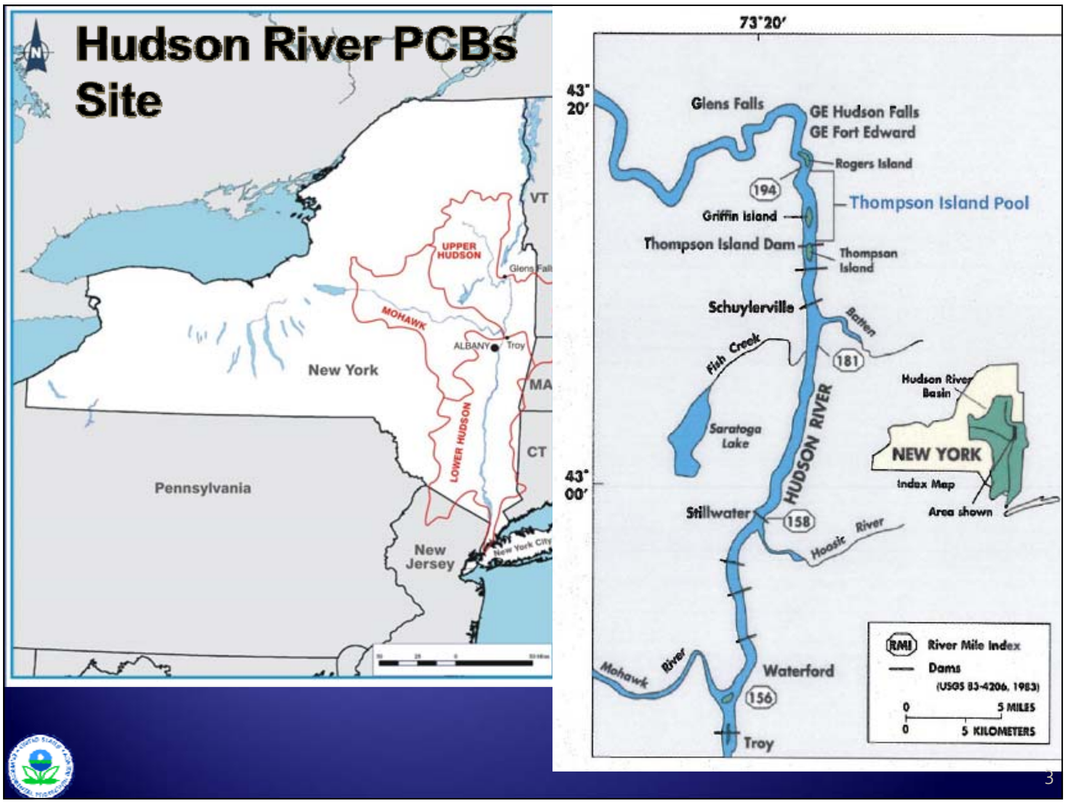
U.S. EPA OSWER OSRTI Environmental Response Team
2890 Woodbridge Ave.
Edison, NJ 08837
732-452-6413
greenberg.marc@epa.gov

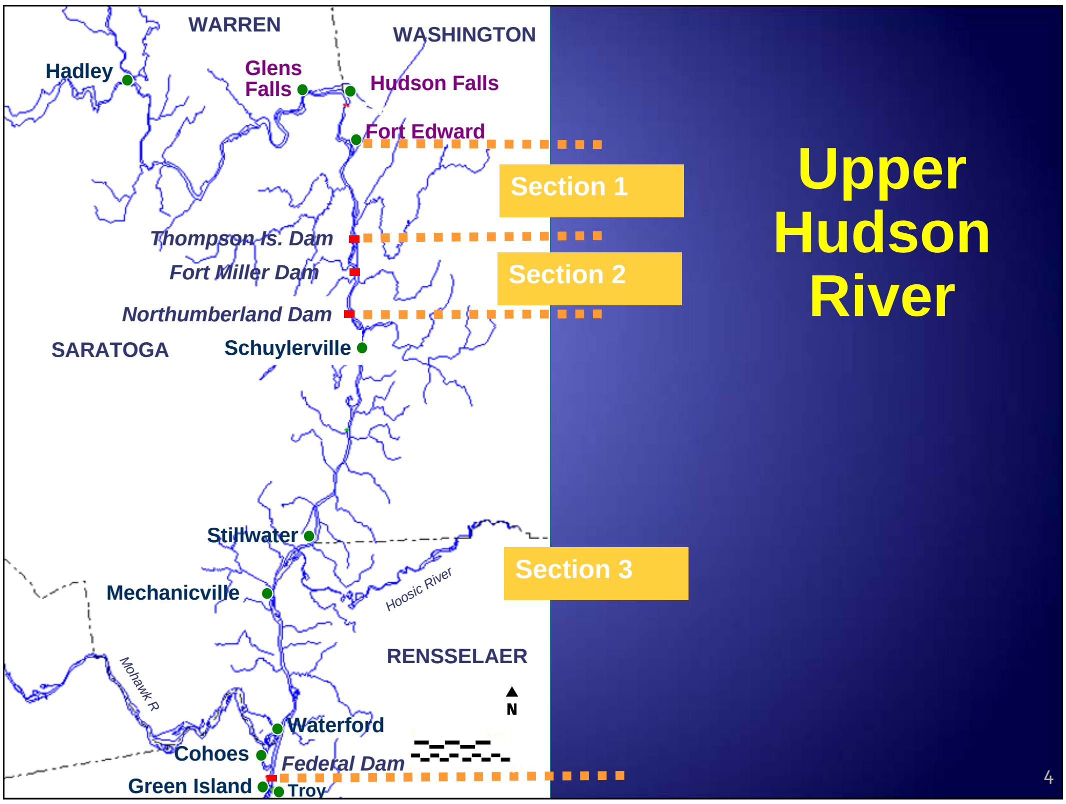
Acknowledgements

Ben Conetta[1], Gary Klawinski[1], David King[1], Edward A. Garvey[2], Juliana Atmadja[2], Solomon Gbondo-Tugbawa[2], Bruce Fidler[2], Shane McDonald[2], Chitra Prabhu[2], Xiulan Wang[2], John Kern[3]

1. US Environmental Protection Agency
2. The Louis Berger Group, Inc. Morristown, NJ
3. Kern Statistical Services, Sauk Rapids, MN, USA

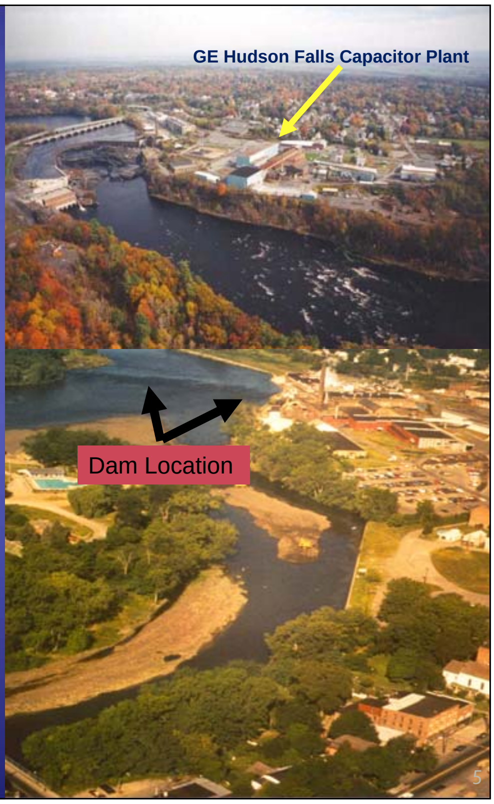
2


Hudson River PCBs Site
New York
Pennsylvania
New Jersey
UPPER HUDSON
MOHAWK
LOWER HUDSON
ALBANY
Troy
VT
MA
CT
73°20'
43° 20'
43° 00'
Glens Falls
GE Hudson Falls
GE Fort Edward
Rogers Island
Thompson Island Pool
Griffin Island
Thompson Island Dam
Thompson Island
Schuylerville
Batten
Fish Creek
Saratoga Lake
HUDSON RIVER
Hudson River Basin
NEW YORK
Index Map
Area shown
Stillwater
Hoosic River
Mohawk River
Waterford
Troy
RMI River Mile Index
Dams
(USGS 83-4206, 1983)
5 MILES
5 KILOMETERS
3


WARREN
WASHINGTON
Hadley
Glens Falls
Hudson Falls
Fort Edward
Section 1
Thompson Is. Dam
Fort Miller Dam
Section 2
Northumberland Dam
SARATOGA
Schuylerville
Stillwater
Mechanicville
Section 3
Hoosic River
RENSSELAER
Mohawk R
N
Waterford
Cohoes
Federal Dam
Green Island
Troy
Upper Hudson River
4

The Hudson: History

- 1948-1977: PCBs used by GE capacitor manufacturing plants
- 1973: Removal of Ft Edward Dam - PCBs spread downstream
- 1976: New York and GE settle enforcement action for PCB discharges
- 1984: 1st Record of Decision (ROD) – shoreline capping (60 acres)
- 1989-1990: GE implements 1984 Remedy
- 1990 – EPA reassessment
- 2/1/2002 : EPA dredging ROD



5

Project Overview

- 2002: Record of Decision selects dredging remedy
- 2004: EPA completes Quality of Life and Engineering Performance Standards, Siting of Processing Facility and Community Relations
- 2002-2005: Three EPA/GE agreements to perform work
  - 2007-2009— Sediment sampling (complete)
  - — Engineering design of 2-phase project (Phase 1 complete)
  - — Performance of Phase 1 of project followed by peer review of Engineering Performance Standards
- : GE Constructs of Sediment Processing Facility
- 2009: Phase 1 dredging commences May 15, continues to November

6

Engineering Performance Standards

- Strict Engineering Performance Standards were developed to:
  - minimize resuspension of PCBs during dredging (*Resuspension*)
  - set limits on PCBs left in sediment (*Residual*)
  - set production rates (*Productivity*)
- Resuspension standard designed to:
  - Protect drinking water intakes downriver of the dredging operations, and
  - Limit the downriver transport of PCBs

7

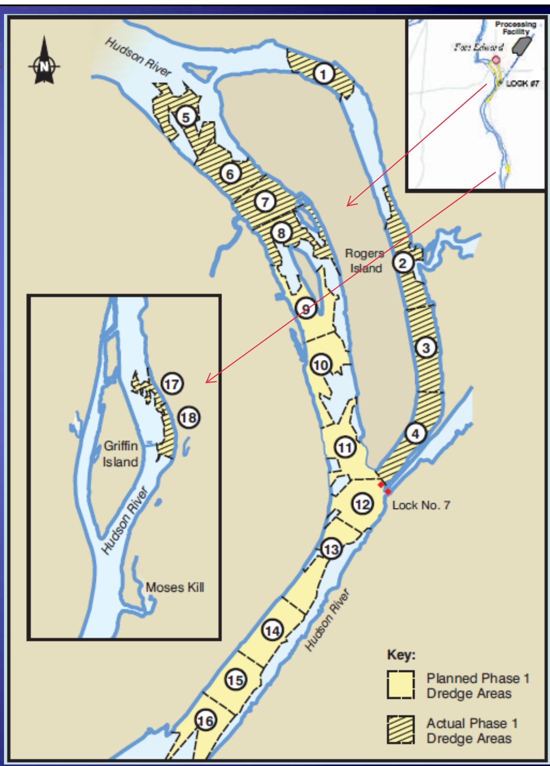
Phase 1 and 2 Design – Dredge Area Delineation

- **50,000+ sediment samples** (11,000+ locations)– mostly 80 foot on center cores
  - Determine the distribution of PCBs
  - Refine estimates of the amount and location
  - Establish sediment characteristics (silt, sand, gravel)
- 490 acres planned to be dredged—
  - 90 acres Phase 1; 400 acres Phase 2
- Typical Depth 3 feet (some areas 5 feet or more)
- Many incomplete cores

8

2009 Activities

- 10 of 18 planned areas were dredged (May 15-Oct 27, 2009)
- Original Target: 265,000 cy and 88 acres
- Roughly 20,000 kg of PCBs and 280,000 cy of sediment were removed in 48 acres
- Contamination was deeper than originally mapped
- **80% increase in volume and mass for CU's dredged**
- Water quality monitoring conducted before, during and after dredging



9

Dredging Operations

- Constant monitoring
  - Engineering Performance Standards
- Resuspension controls
  - Rock dike
  - Silt curtain
  - Steel sheet piling
- Backfill if meet Residuals Standard
  - 165,000cy; 12" of cover (much of area)
  - 38,000cy nearshore backfill to match original bathymetry
  - Additional backfill in certain specified planting areas
- Capping
  - Depended on residual concentrations
  - Review capping as an option if residuals not removed after 2 passes (but up to 4 passes)
  - Required EPA approval

Overview of 2009 Phase 1 Operations

- Debris Removal: Mid May - June
- Dredging: Mid May – October
- Backfill/Capping: Oct - Nov
- Demobilization: December
- Placed >150,000 CY of Backfill/cap
- Processed >370,000 Tons of sediment
- Treated >85 Million Gallons water
- Loaded up to 38 railcars/shift(103 Ton/railcar)
- Shipped 15+ unit trains (81 railcars)
- Daily EPA & NYSDEC oversight

11

12


06/30/2009
13


14


15


16

Overview of Phase 1 Operations (Cont.)

- 500+ workers during 24/6 dredging operations
- ***100+ vessels*** in river
- 12 dredges w/ enclosed clamshell dredges
- 20 hopper barges; 10 deck barges
- 18 tugs (400 & 600 hp), 3 carpenter barges
- Continuous monitoring & survey - 20 real-time monitoring buoys & 7 monitoring vessels
- 5 CY barge unloader
- 8 CY railcar loaders w/ bucket scale
- 450 railcars for unit trains

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Challenges

- **Incomplete closure of clam shell**
- **Wood and debris**

Phase 1 issues have informed Phase 2

- Higher than normal flows –impacts Load
- Extent of wood debris – less in Phase 2
- Depth of Contamination (DoC)
- NAPL releases
- Limitations on scow unloading
- Extent of bedrock/clay bottom
- Certification Units (CUs) open entire dredging season
- Bucket Decanting

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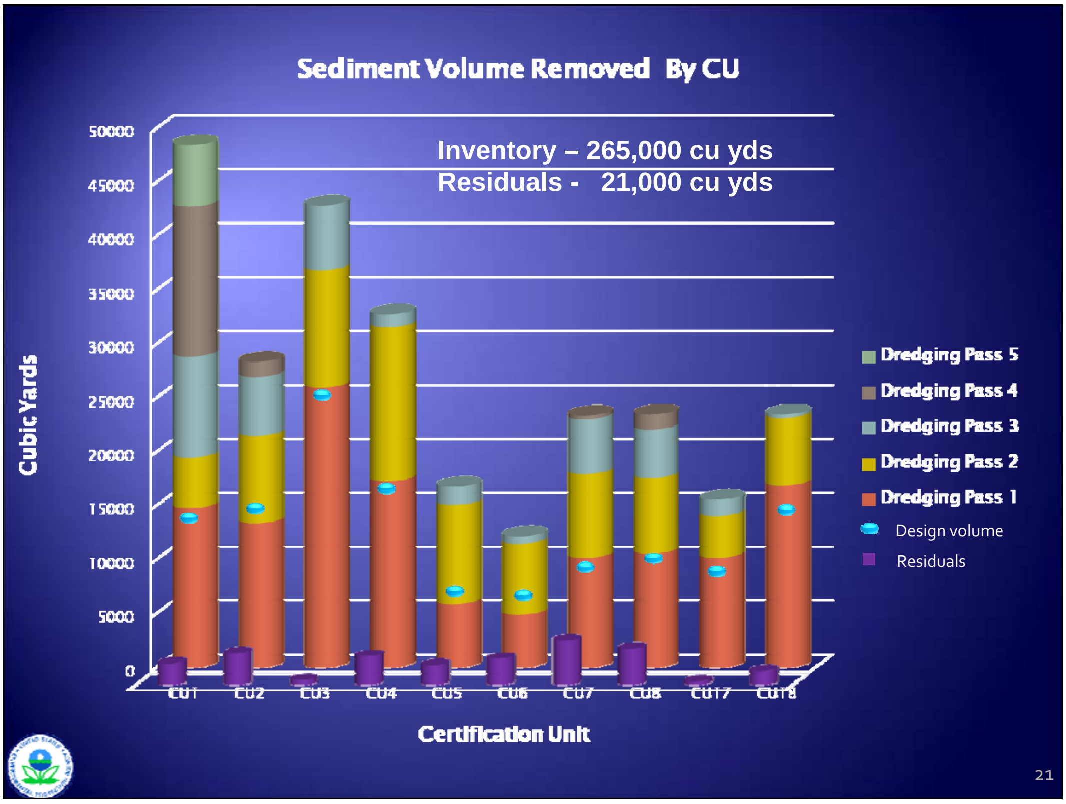
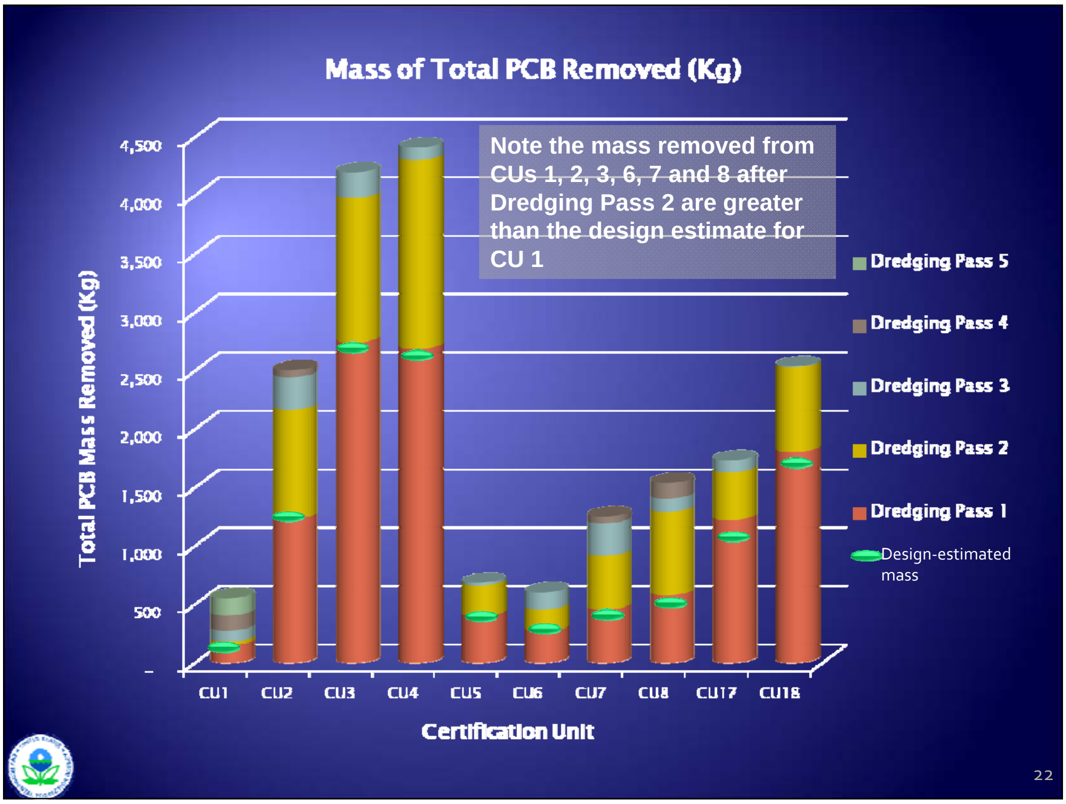
More Mass of PCBS Identified

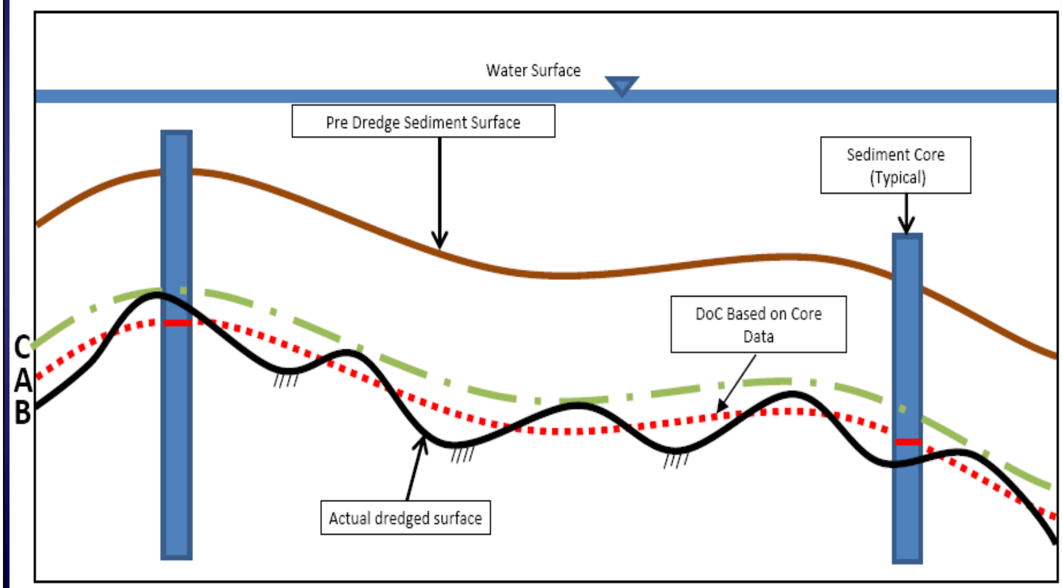
- Design Mass to be removed was 11,000 kg – Actual Mass removed was at least 20,000 kg
- ROD to Design to Phase 1 – Estimates of mass increased from 70,000 kgs to 113,000 kgs to 150,000 kgs
- Original Project estimates to remove 2.6Mcy of contaminated sediment—revised to 1.8 Mcy to 2.4 Mcy

20


Sediment Volume Removed By CU
Inventory – 265,000 cu yds
Residuals - 21,000 cu yds
Cubic Yards
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
CU1
CU2
CU3
CU4
CU5
CU6
CU7
CU8
CU17
CU18
Certification Unit
Dredging Pass 5
Dredging Pass 4
Dredging Pass 3
Dredging Pass 2
Dredging Pass 1
Design volume
Residuals
21


Mass of Total PCB Removed (Kg)
Note the mass removed from CUs 1, 2, 3, 6, 7 and 8 after Dredging Pass 2 are greater than the design estimate for CU 1
Total PCB Mass Removed (Kg)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
-
CU1
CU2
CU3
CU4
CU5
CU6
CU7
CU8
CU17
CU18
Certification Unit
Dredging Pass 5
Dredging Pass 4
Dredging Pass 3
Dredging Pass 2
Dredging Pass 1
Design-estimated mass
22

Phase 1 Dredge Elevations



Impacts of Underestimated DoC and Fine Grading

Underestimated DoC

- Additional Dredge Passes
- Time Lost in Mapping, Sampling, And Designing New Cut Lines
- CUs Open Longer

Fine Grading

- Reduced Production Rate
- Reduced Residuals ? Only seen in 1/3 of cores

(Both factors increased resuspension losses)

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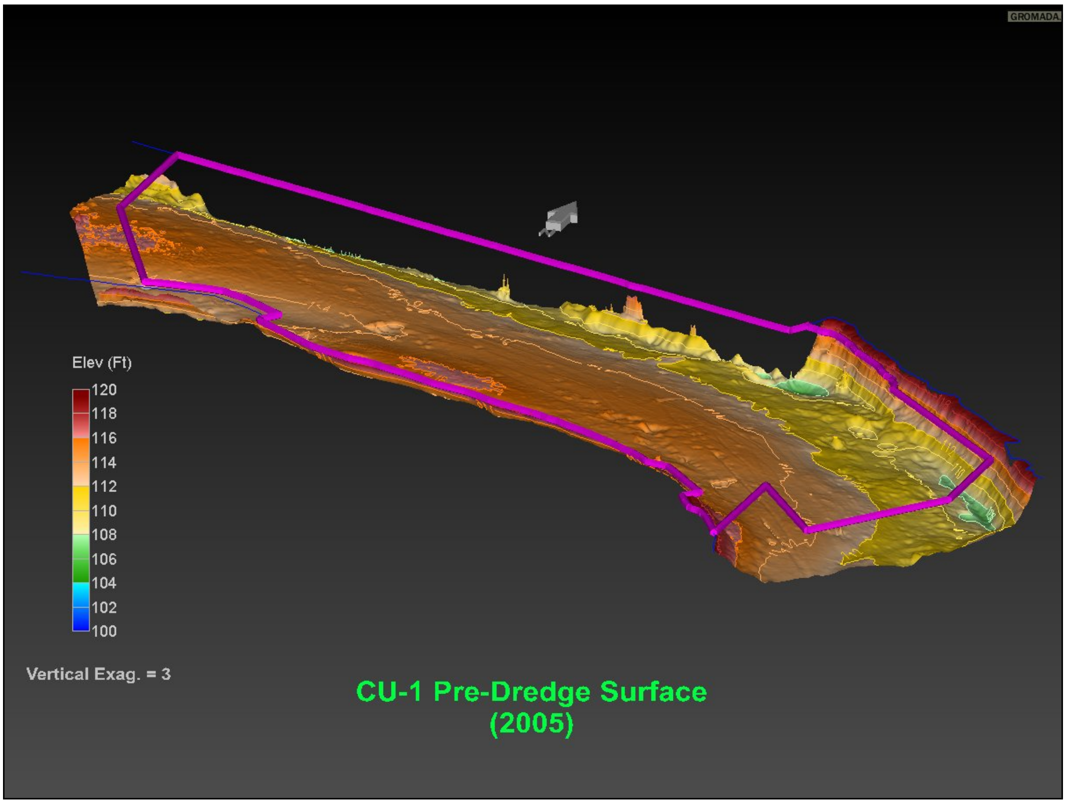
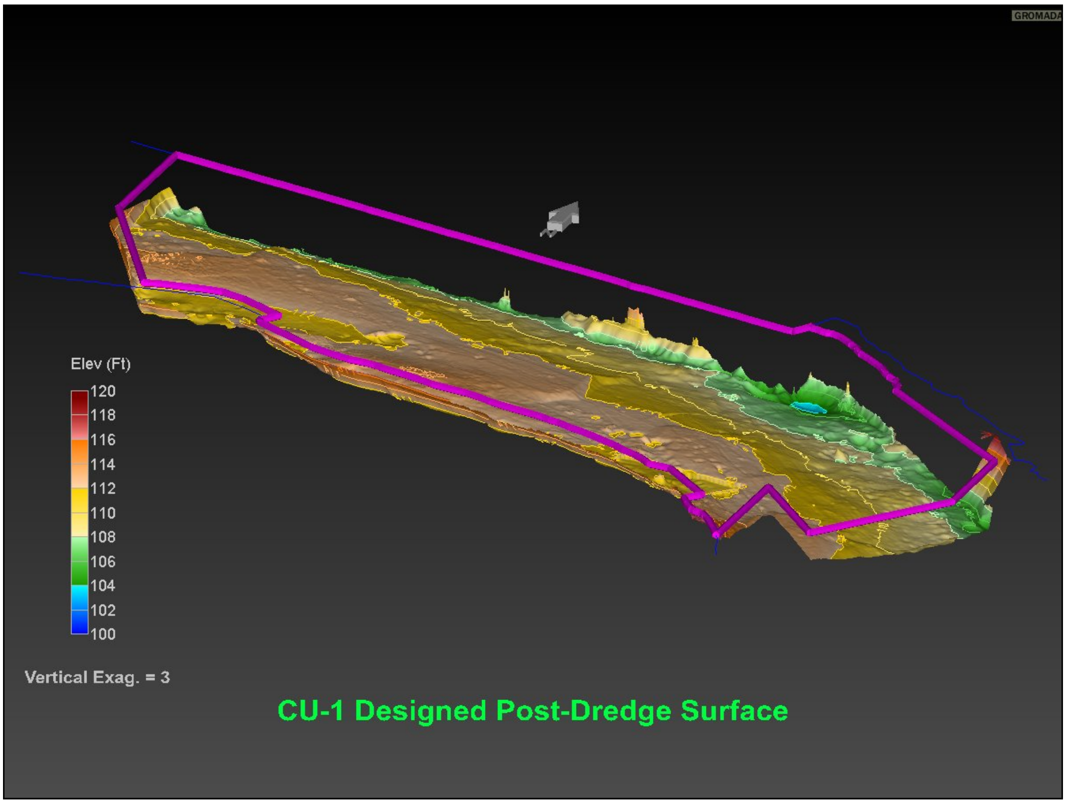
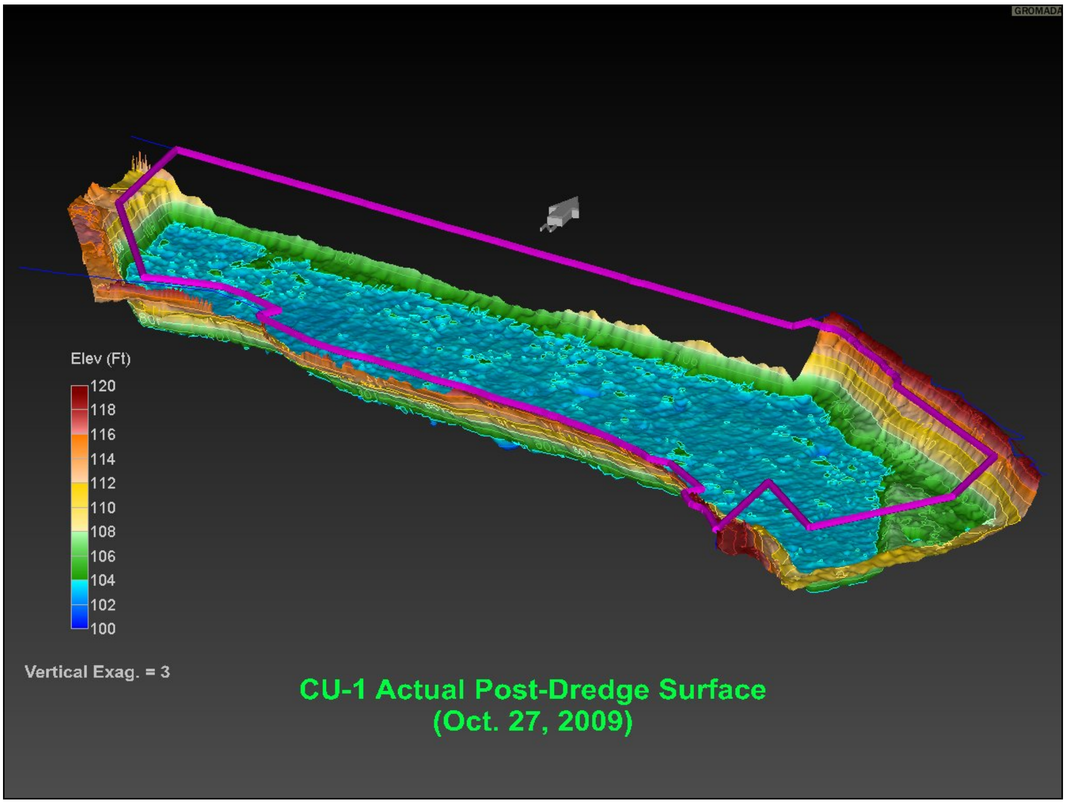
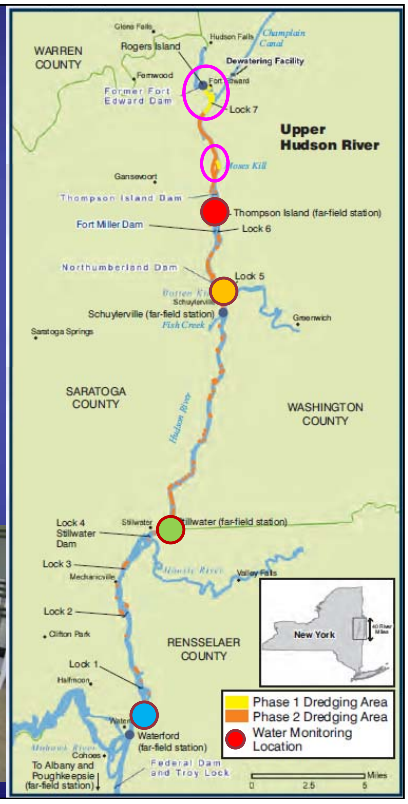

GROMADA
Elev (Ft)
120
118
116
114
112
110
108
106
104
102
100
Vertical Exag. = 3
CU-1 Pre-Dredge Surface
(2005)

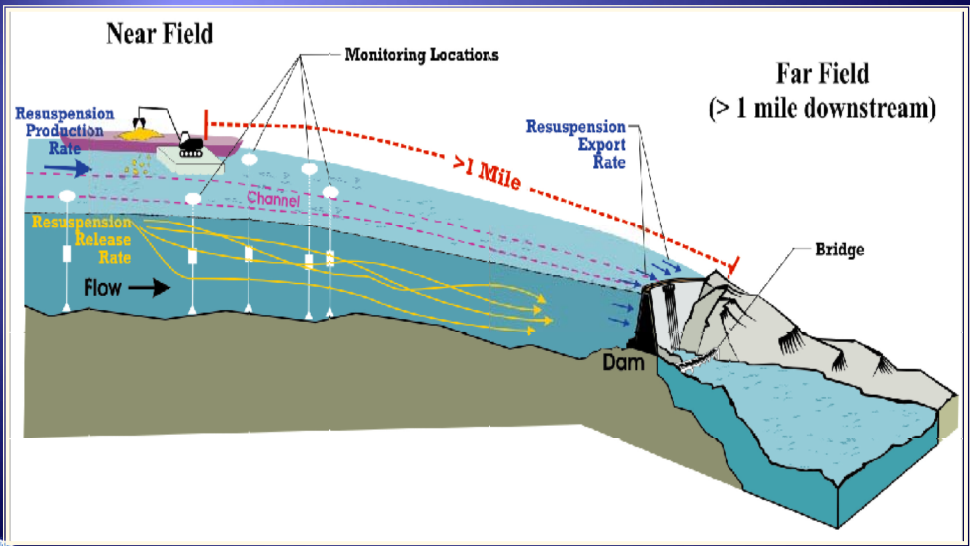

GROMADA
Elev (Ft)
120
118
116
114
112
110
108
106
104
102
100
Vertical Exag. = 3
CU-1 Designed Post-Dredge Surface



Water Quality Monitoring and PCB Load



Resuspension Performance Standard



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Challenges Encountered

- 500 ng/L was exceeded four times- 3 work stoppages
- Targets for cumulative load exceeded at all stations
- Loads not updated based on revised mass estimates
- Releases not particulate driven
- Neither TSS nor Turbidity were an indicator of PCBs
- **Redeposition Concerns** – Is there a real impact?
- Concerns with monitoring station– duplicates; NAPL?
- Higher than normal flows
- Post Dredging Effects??
- Difficult to measure resuspension in the near field

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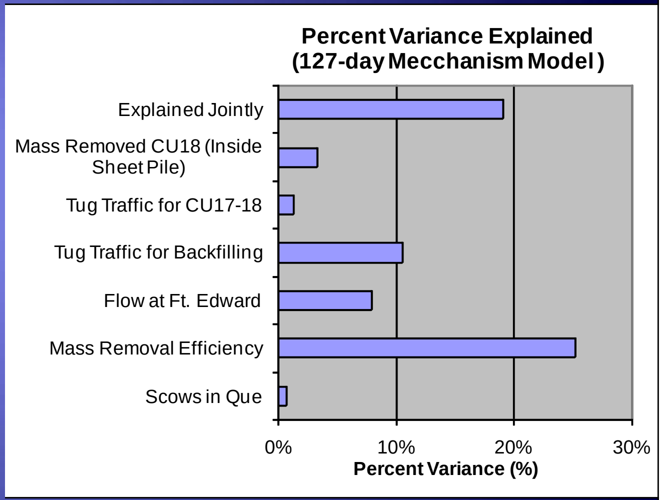
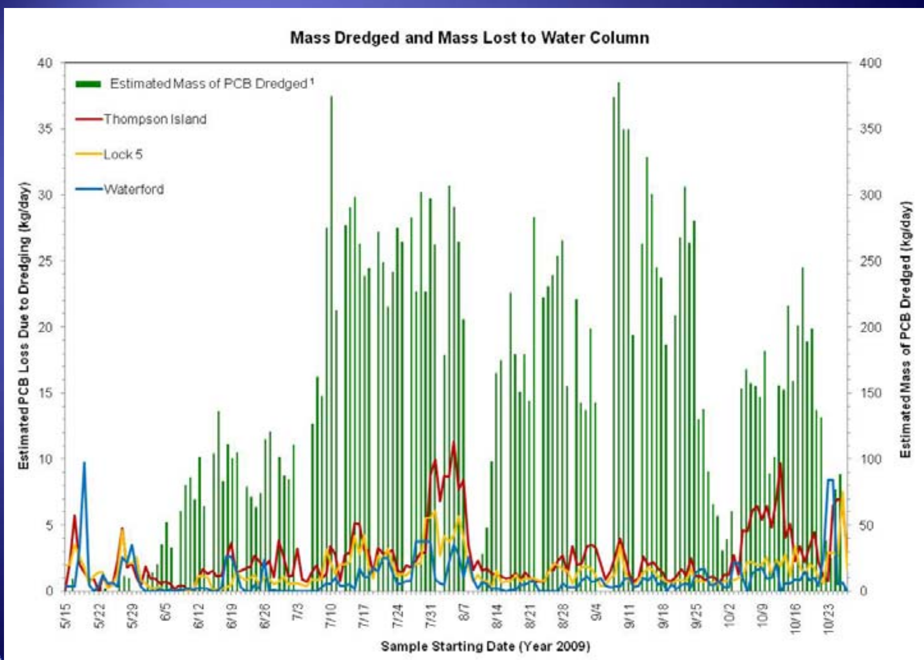
CAUSES OF RESUSPENSION DURING PHASE 1 DREDGING

- Multiple regression model
- Six dredging related variables were identified that in combination with flow explained 68% of variation in water column PCB concentrations at TID
- Tug traffic was important, especially in shallow water even during backfilling
- Less than half of the explanatory power was explained by mass removal alone
- It was more than just water velocity and mass



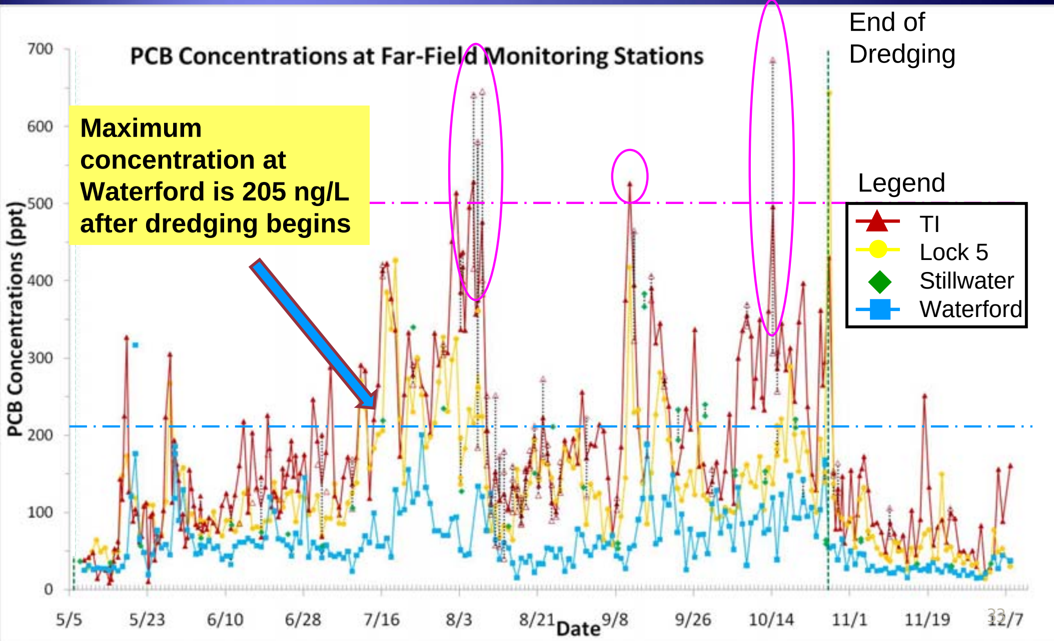
Mass loss did not correlate with mass removed

Loads

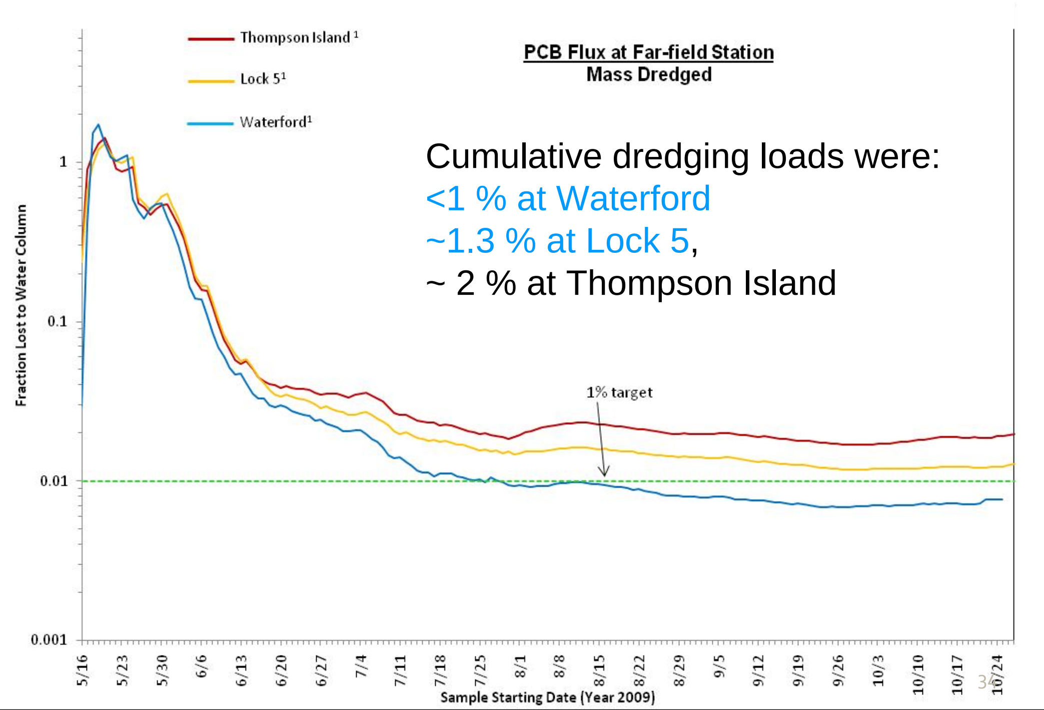


32

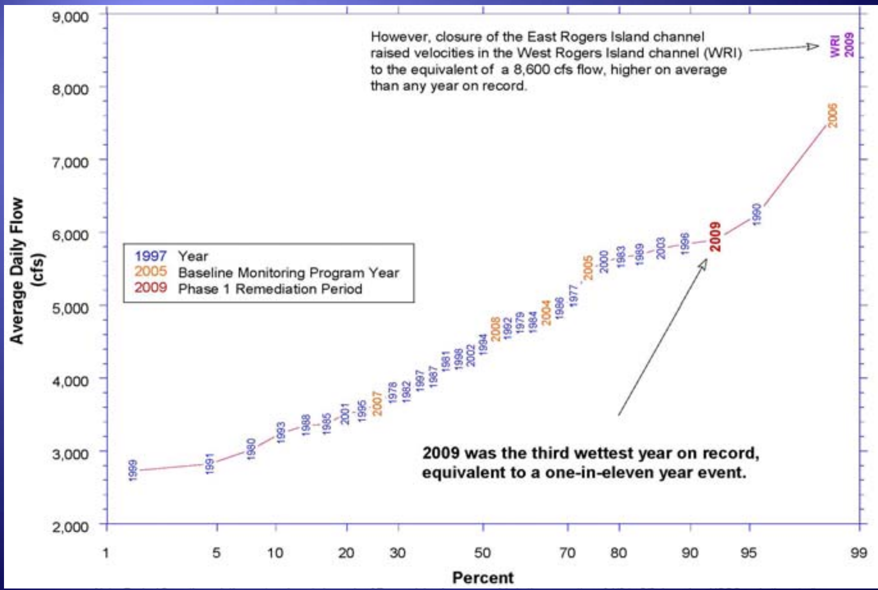
500 ng/L was exceeded 3 times in 5 months Aug 6 – 8, Sept 10, and Oct 13



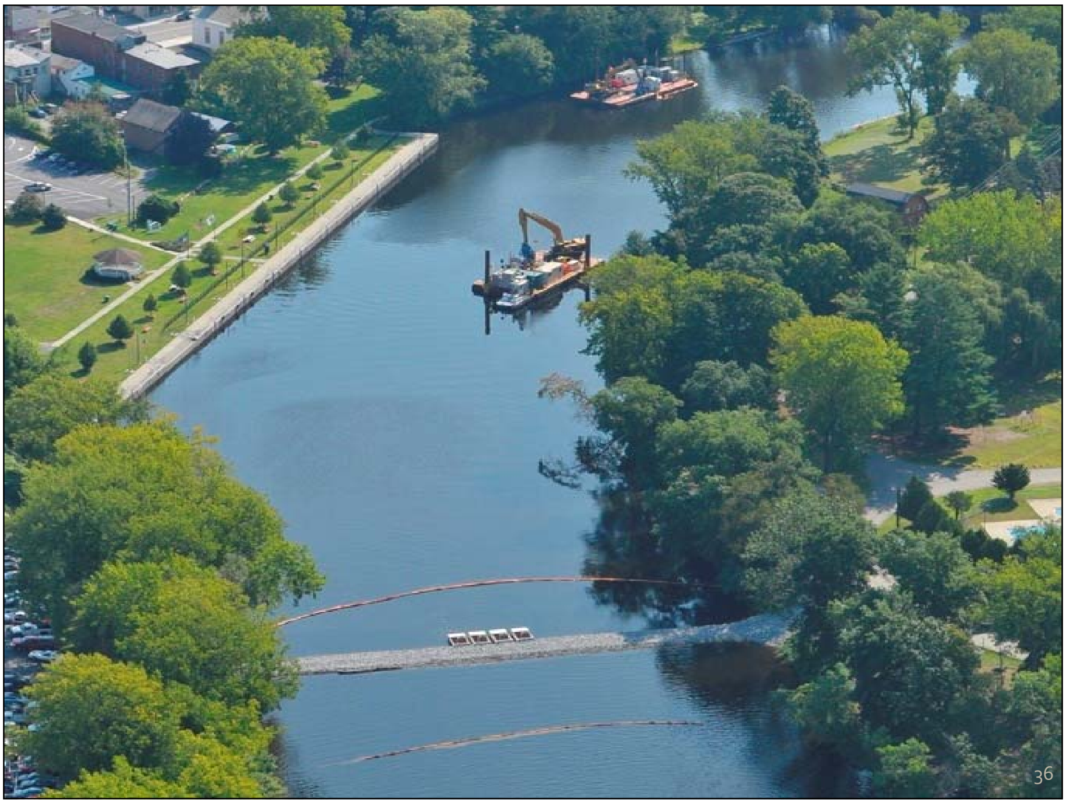
Cumulative Mass Loss As a Fraction of Mass Removed



High Flow in 2009 – Exacerbated by Rock Dike
Load is velocity and concentration dependent



35



36

2011 – 100 Year Flood

PCB-bearing oil sheens were extensive and are a potentially important vector for PCB release

Water conc. Ranged from 2,210 - 393,000 ng/L. Duplicates varied by order of magnitude. Oil not separated from water.

38

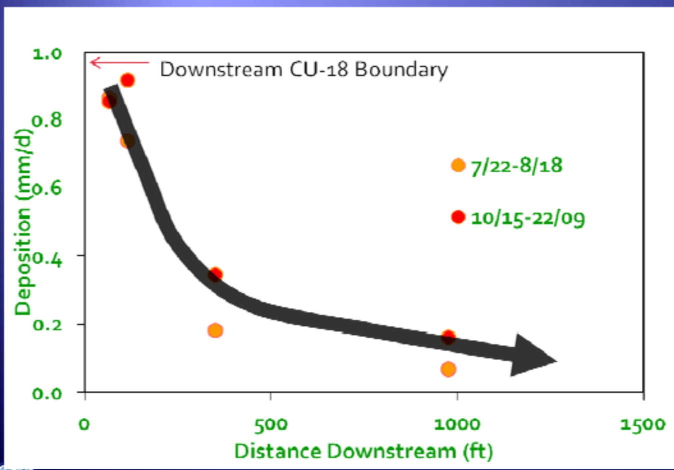
Majority of dredging-induced Total Suspended Solids (TSS) redeposits a short distance downstream

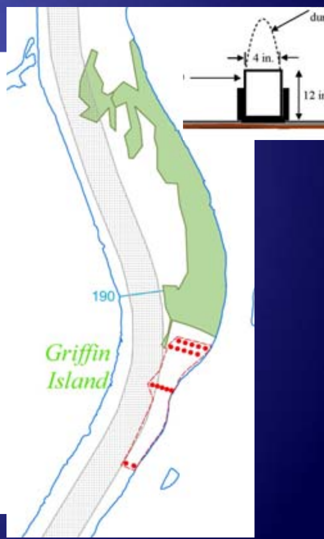
- All available data support conclusion
  - Sediment trap data below CU-18
  - ***Near-field TSS data***
  - Bucket decant study
- Consistent with field team observations
- Result: Limited TSS redistribution beyond dredging footprint

40

Sediment Trap downstream of CU 18

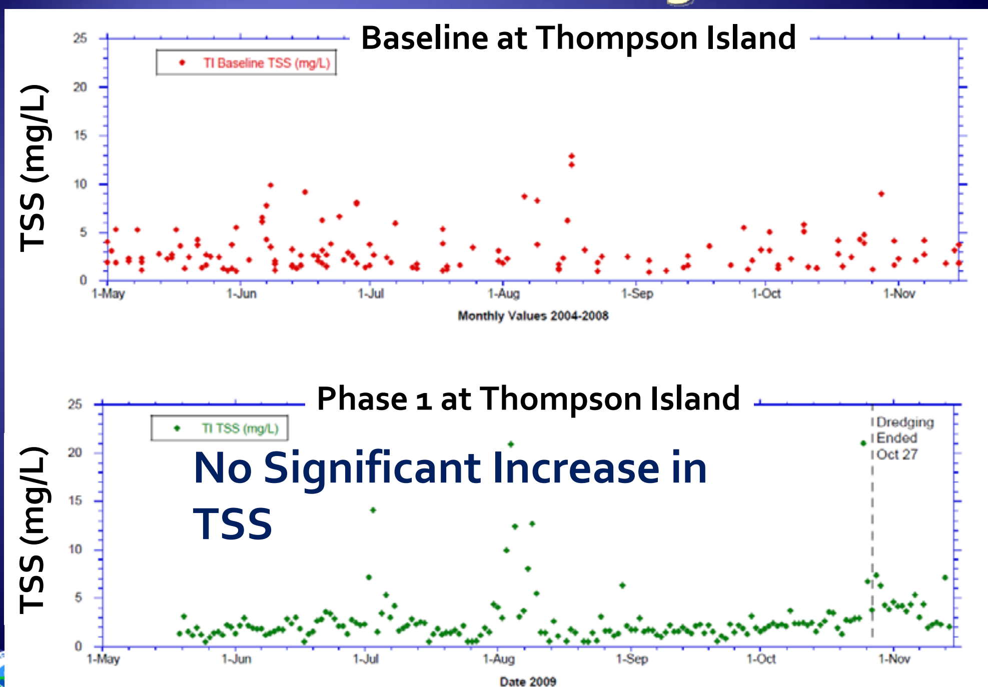
Contributions of resuspended sediments are limited to the proximity of the dredging footprint.





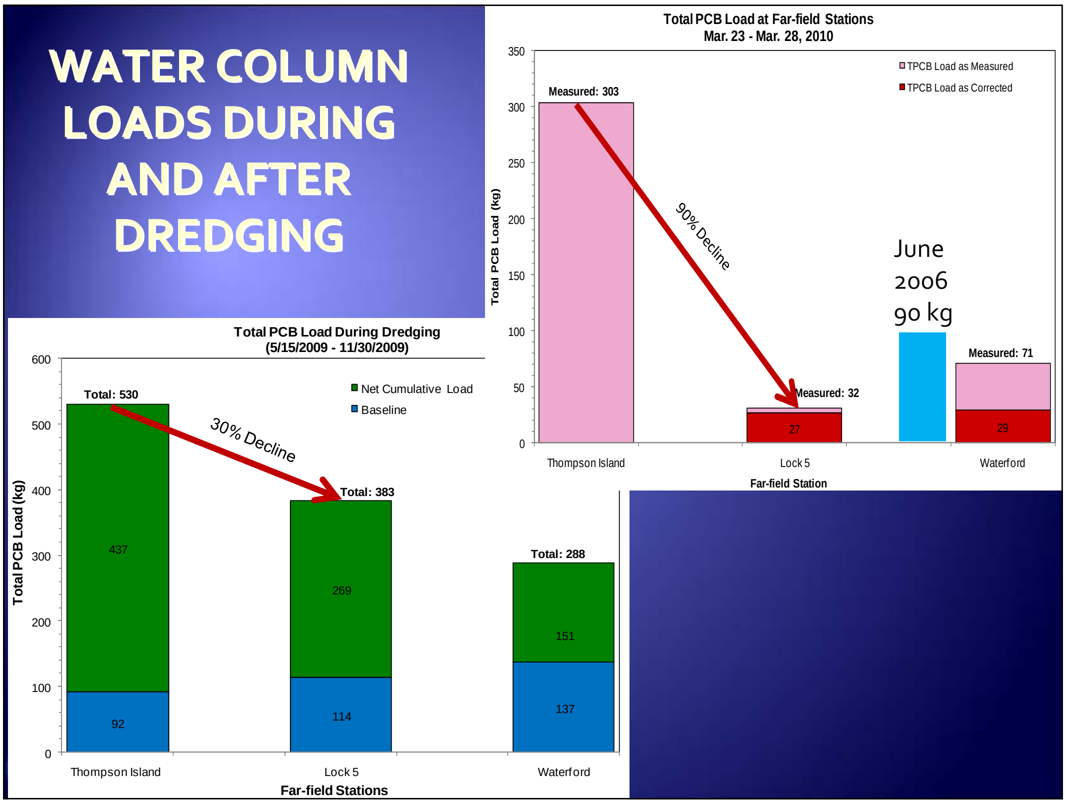
41

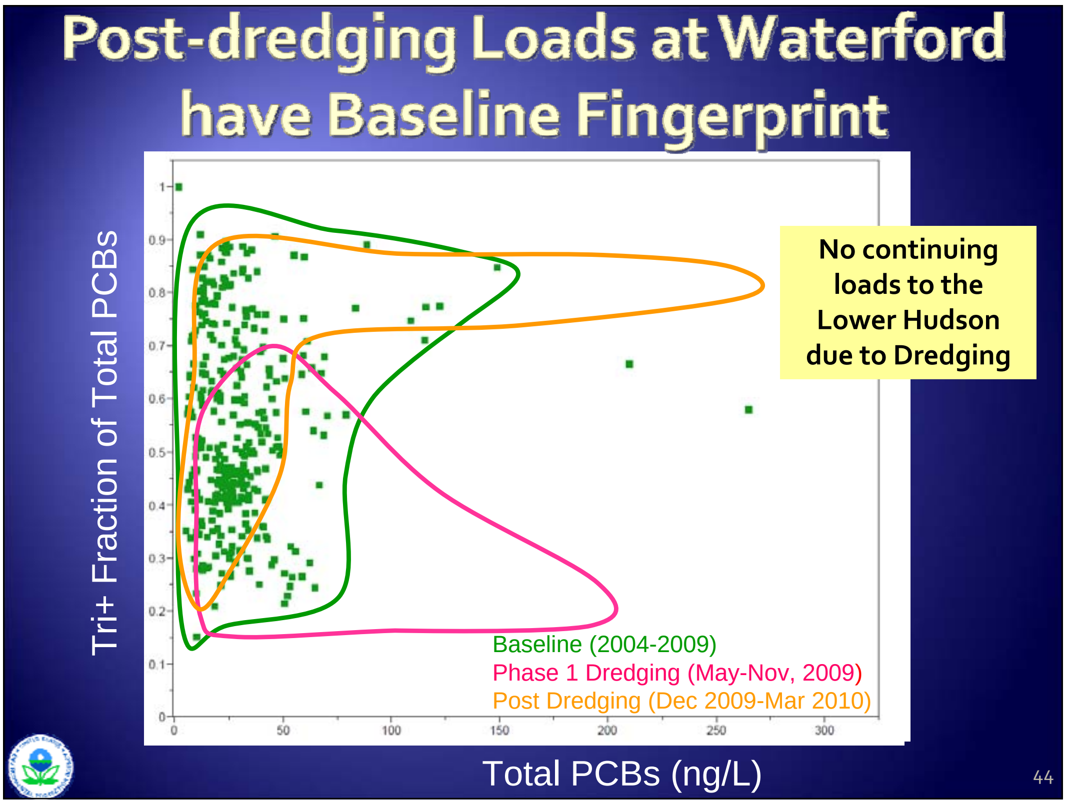
Water Column Monitoring Results



No Significant Increase in TSS

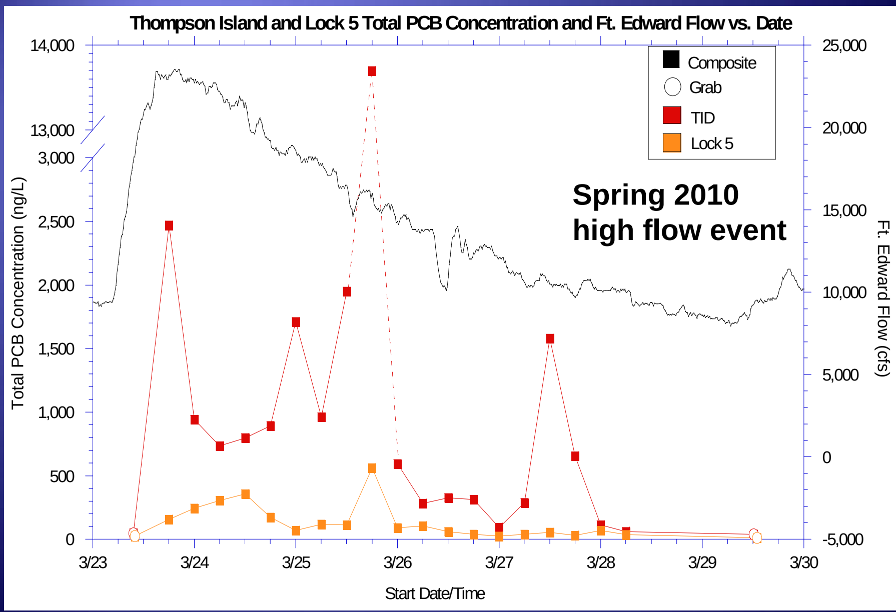
42


WATER COLUMN LOADS DURING AND AFTER DREDGING
Total PCB Load at Far-field Stations
Mar. 23 - Mar. 28, 2010
TPCB Load as Measured
TPCB Load as Corrected
Measured: 303
90% Decline
Measured: 32
27
June 2006 90 kg
Measured: 71
29
Total PCB Load (kg)
Thompson Island
Lock 5
Waterford
Far-field Station
Total PCB Load During Dredging
(5/15/2009 - 11/30/2009)
Net Cumulative Load
Baseline
Total: 530
30% Decline
Total: 383
Total: 288
437
269
151
92
114
137
Total PCB Load (kg)
Far-field Stations


Post-dredging Loads at Waterford have Baseline Fingerprint
No continuing loads to the Lower Hudson due to Dredging
Baseline (2004-2009)
Phase 1 Dredging (May-Nov, 2009)
Post Dredging (Dec 2009-Mar 2010)
Tri+ Fraction of Total PCBs
Total PCBs (ng/L)
44

WATER COLUMN LOADS AFTER DREDGING

Thompson Island and Lock 5 Total PCB Concentration and Fort Edward Flow vs. Date



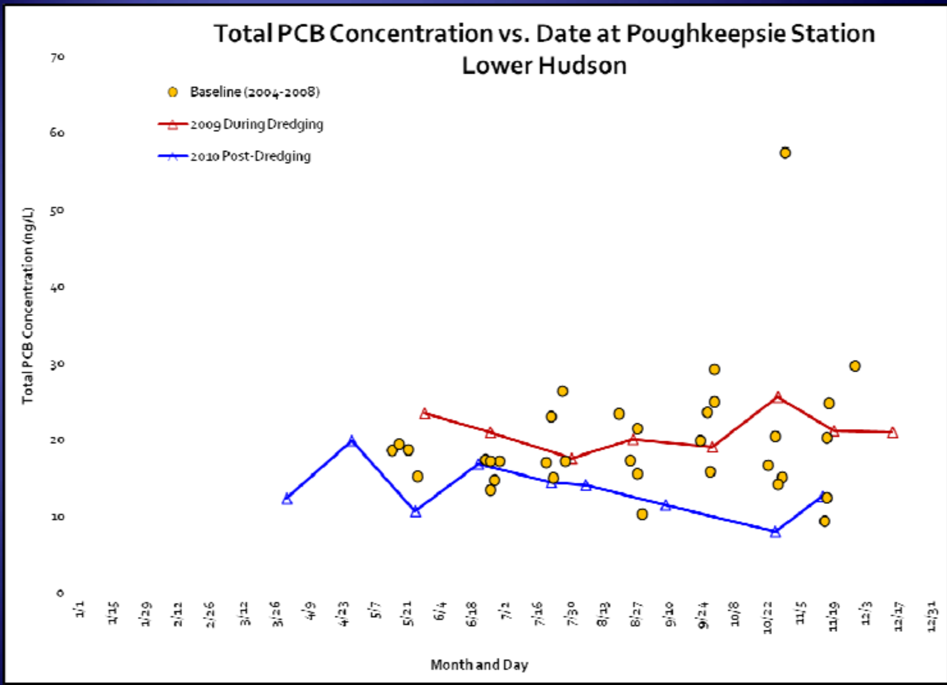
Post Dredging PCB Data During High Flow Events – Real?

- High Flow monitoring events indicated elevated PCB results – 13,000 ppt at TI station
- Post dredging effect and redeposition ?
- Levels well beyond those seen during dredging
- High Flow Monitoring Data Suspect at TI
- High Flow Monitoring Program only at Waterford
- BMP data was collected manually – another variable
- Post dredging data is from Automated Stations

46


Lock 5 Intake No.4
Lost intake screen and clogged with mud and vegetation
04.21.2010 12:01
47


Lock 5 Intake No. 2
Muddy water flow from intake during backflush
04.21.2010 10:59
48



49

Resuspension Summary

- Dredging operations halted when the 500 ng/L criterion was exceeded on three occasions
- No observable impacts to downstream of Waterford
- At Thompson Island, Lock 5, and Waterford, net loading for Total PCBs and Tri+ PCBs were exceeded
- 1 % loss rate to the Lower Hudson River was achieved
- PCBs in the vicinity of the dredging operations appeared dominated by dissolved and NAPL phases
- TSSconcentrations/Turbidity were not good predictors for Total PCB transport downstream

50

Resuspension Summary (Cont'd)

- Low flow concentrations have returned to baseline
- High flow concentrations have returned to baseline at Waterford – no comparable record at TI & L5
- Post Dredging high flow data at TI and Lock 5 have issues with automated sampler
- Geochemical fingerprint identifies recent PCB concentrations as reflective of baseline
- No apparent post dredging impacts to WQ
- No appreciable difference in 2010 fish tissue concentrations from baseline levels

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Residuals Performance Standard

- Dredge design cut lines were too shallow
- Design cores did not penetrate the full DoC - debris and recoveries were poor
- Many post-dredging cores did not fully penetrate the DoC until the final cut
- Most dredging passes addressed inventory
- Approximately 75% of the dredged area was closed in accordance with the Residuals Standard

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Inventory or Residual Dredging?

- Objective is to remove inventory on 1st pass
  - Reduce resuspension
  - Increase productivity
- Volume of Sediment
  - 40-50 % 1st pass
  - 30-40 % 2nd pass
  - 20% of total in final pass(es)
- PCB Mass
  - 40-50 % 1st pass
  - 30-40 % 2nd pass
  - 20% of total final pass(es)
- 4 of 10 CUs required 4 or more passes

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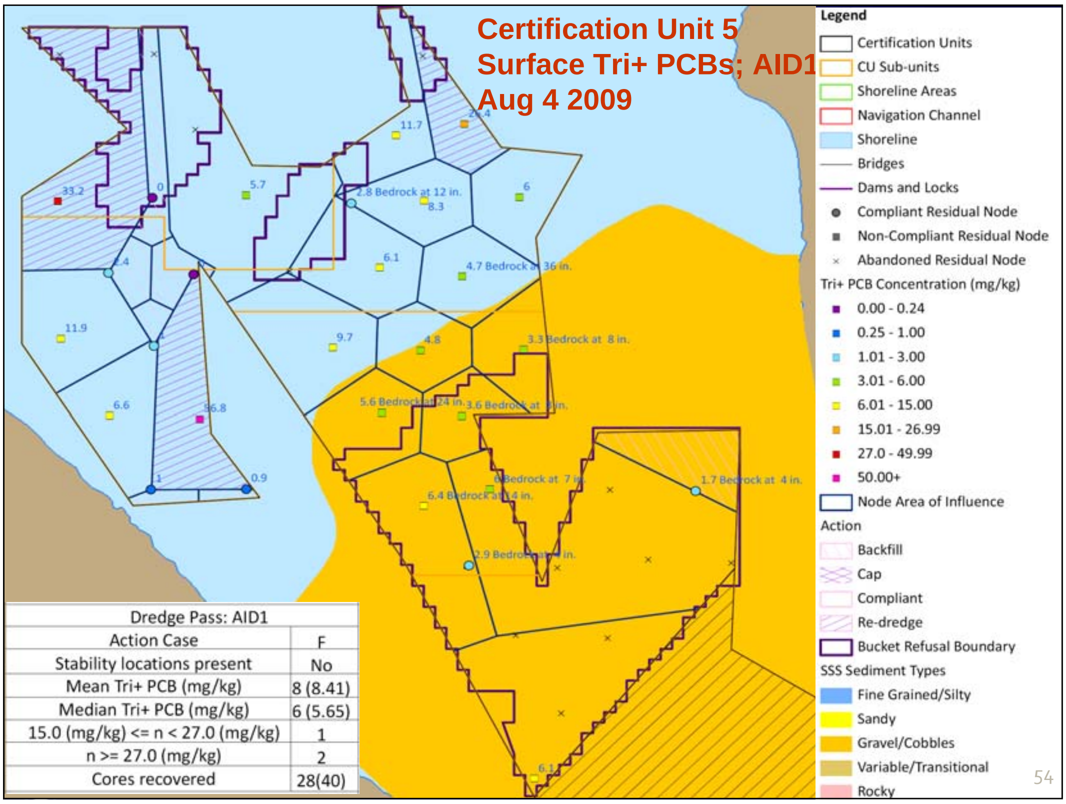
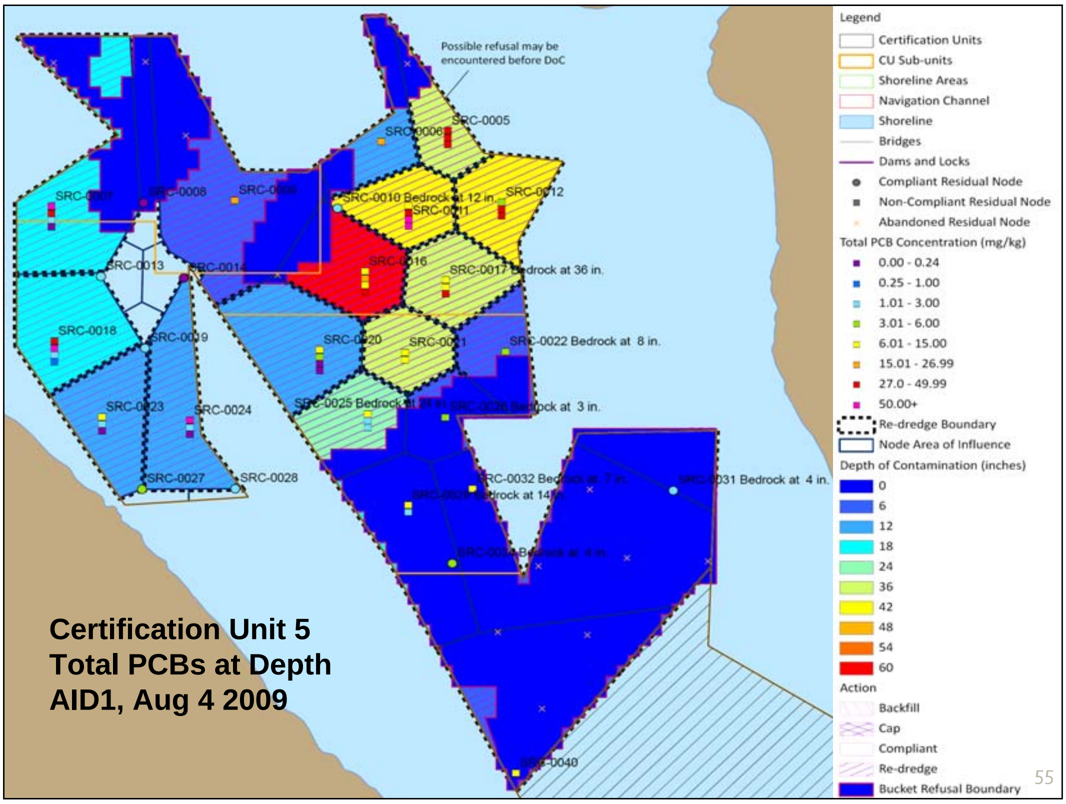
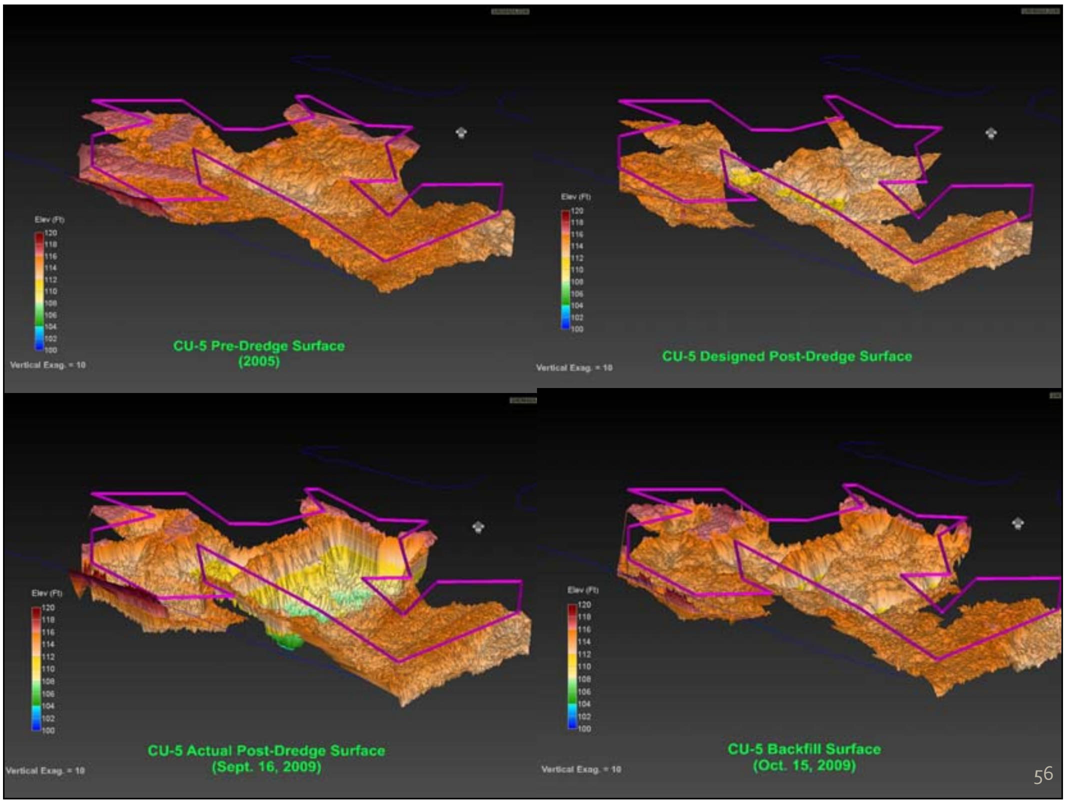


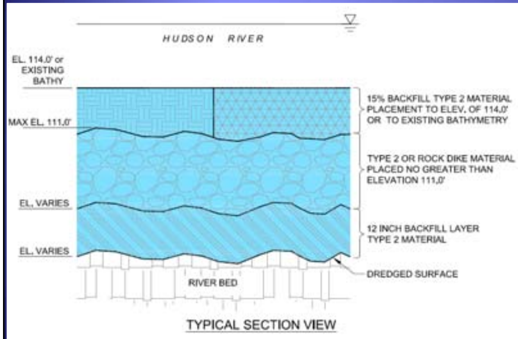
Dredge Pass: AID1	
Action Case	F
Stability locations present	No
Mean Tri+ PCB (mg/kg)	8 (8.41)
Median Tri+ PCB (mg/kg)	6 (5.65)
15.0 (mg/kg) <= n < 27.0 (mg/kg)	1
n >= 27.0 (mg/kg)	2
Cores recovered	28(40)

54

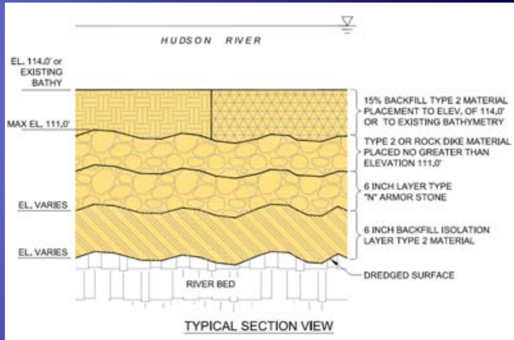

Certification Unit 5
Total PCBs at Depth
AID1, Aug 4 2009
Possible refusal may be encountered before DoC
Legend
Certification Units
CU Sub-units
Shoreline Areas
Navigation Channel
Shoreline
Bridges
Dams and Locks
Compliant Residual Node
Non-Compliant Residual Node
Abandoned Residual Node
Total PCB Concentration (mg/kg)
0.00 - 0.24
0.25 - 1.00
1.01 - 3.00
3.01 - 6.00
6.01 - 15.00
15.01 - 26.99
27.0 - 49.99
50.00+
Re-dredge Boundary
Node Area of Influence
Depth of Contamination (inches)
0
6
12
18
24
36
42
48
54
60
Action
Backfill
Cap
Compliant
Re-dredge
Bucket Refusal Boundary
55


CU-5 Pre-Dredge Surface
(2005)
CU-5 Designed Post-Dredge Surface
CU-5 Actual Post-Dredge Surface
(Sept. 16, 2009)
CU-5 Backfill Surface
(Oct. 15, 2009)
56

Cap Details for CU-5



DETAIL 2
15% BACKFILL
CU5-1, CU5-3 & CU5-4
NOT TO SCALE



DETAIL 1
15% BACKFILL & CAP
CU5-3 & CU5-4
NOT TO SCALE

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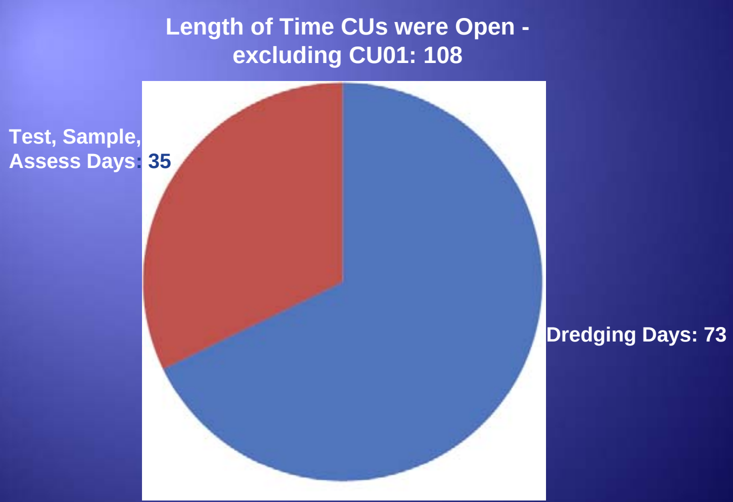
Results: CUs Were Open for More than 3 Months - GE slide



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Major Factors Affecting Productivity

- Scow Unavailability Due to Scow Unloading Capacity at Dewatering Site
- Presence of Slab Wood Debris in Sediment
- Limited Capacity of Mini-Scows
- Underestimated DoC
- Fine Grading to Meet Cut Line Tolerances
- Bucket Decanting

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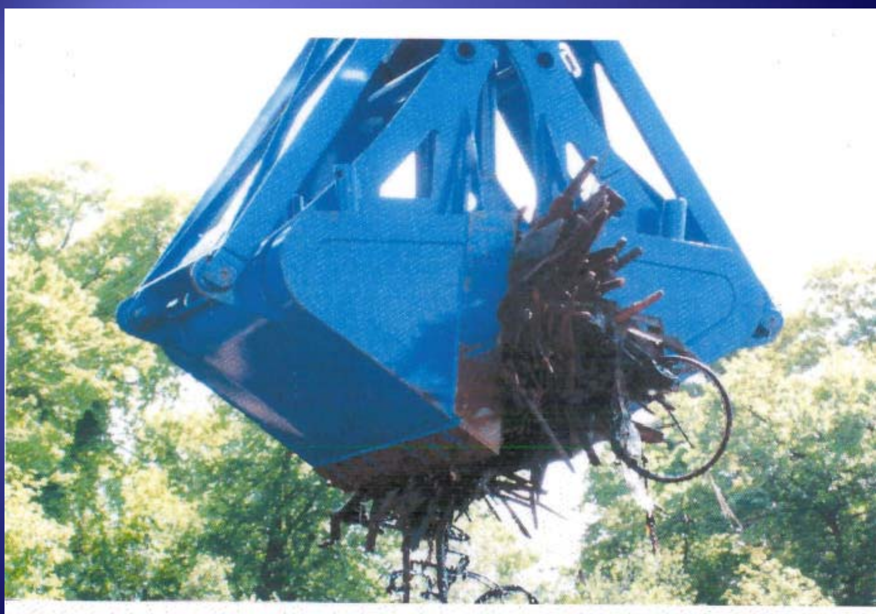
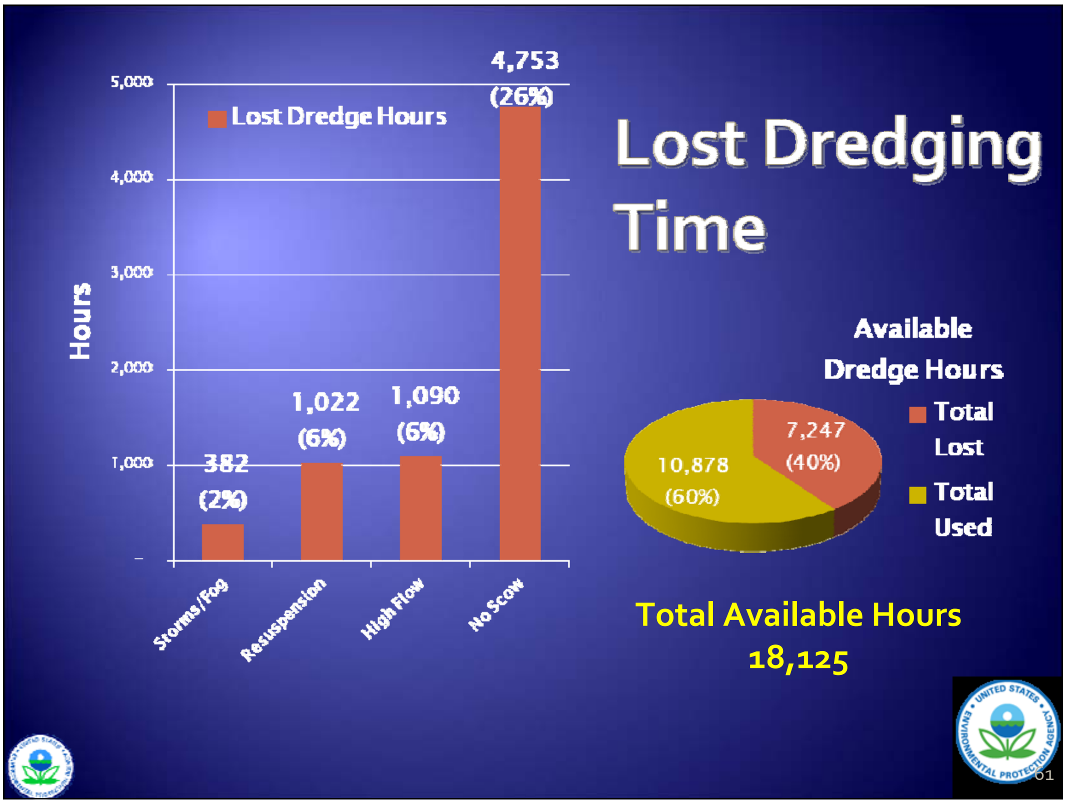
Debris



60

60



Room for Improvement

- Problems are manageable
- Schedule is important but does not impact project benefit
- Correlations with boat traffic, exposed area, bucket efficiency all indicate capacity for improvements
- Residuals Standard was streamlined and simplified
- Scow unloading
- Minimize time dredged areas left open – CU's were left open for months – some the entire dredging season

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Room for Improvement (Cont'd)

- Near-field monitoring – PCBs & TSS
- Monitoring diagnostics – concerns about automated station at Thompson Island
- Address DoC uncertainty – coring this year
- Re-examine dredging tolerances
- Practicable improvements found in Field Oversight Report; more in Peer Review Report
- Key to efficiency and reducing resuspension is to remove most inventory on 1st pass and reduce multiple cuts

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Measuring Success

- Redeposition – Lines of Evidence
  - Mud Flood Data – Floodplain soil samples collected post high flows
  - High flow events
  - 2010 EPA Surface Sediment Data
    - Good news - maybe
  - TSS Results during dredging

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Measuring Success (Cont'd)

- Fish Tissue Concentrations
  - Impacts if any are likely to be short lived
- Sediment recovery rates

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Phase 2 Dredging Project Update

- Performance Based – Not prescriptive
- Number of dredging passes (limit to two)
  - 2nd pass required to remove inventory, concentrations greater than 27 Tri +
  - Re-delineate DoC after 1st Pass
- Capping Metric – A performance metric (11% total capping; 3% inventory capping)
  - Dredging Tolerances and Uncertainty – up to GE to set
  - "True Up Points" – EPA prescribe if metric is not met
- 95% of post dredge surface at or below DoC elevation

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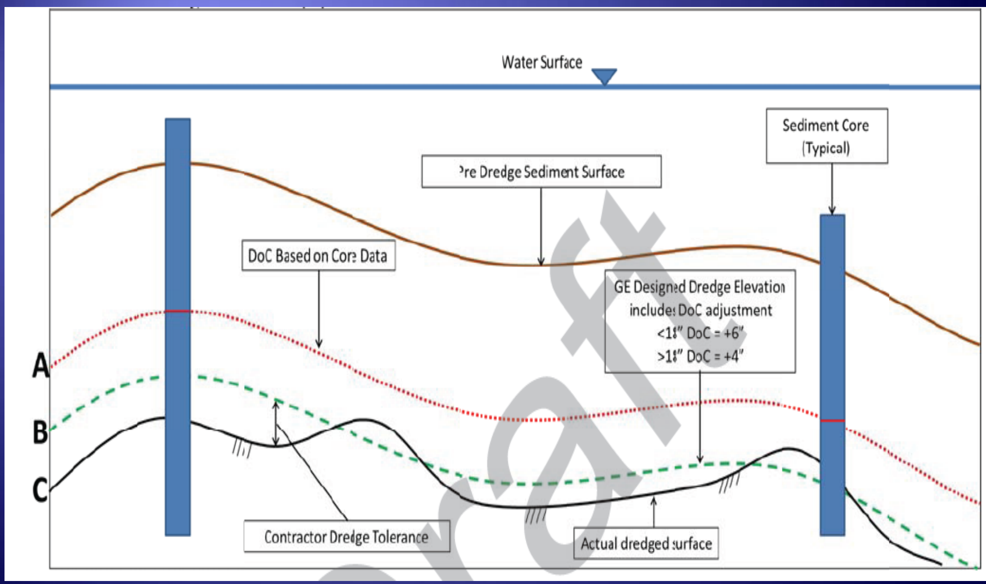
Phase 2 Dredge Elevations



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Phase 2 Dredging Project Update

- Resuspension Standard
  - 2% at Thompson Island; 1% at Waterford - Tri + PCBs
  - 500 ppt MCL Total PCBs – alternate water supplied
  - Place a 3- to 6-inch backfill cover to limit resuspension
  - Close CUs more quickly
- Incorporate Adaptive Management

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Phase 2 Dredging Project Update

- Productivity (350,000 cy) for year 1
- Project 7 to 9 yrs; original projection - 6 yrs
- Determine DoC and address uncertainty
- Coring program in 2010 and beyond
- Limited use of Sonic Vibracores
- Adjust dredge cuts
- Achieve residual of 1 ppm Tri+ PCB (prior to backfilling)
- Navigation Channel – 14 ft draft if capped

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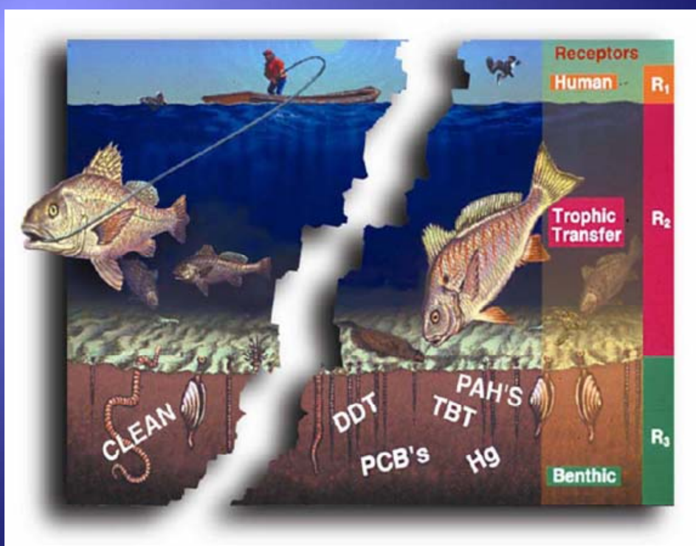
Hudson River Fish Monitoring



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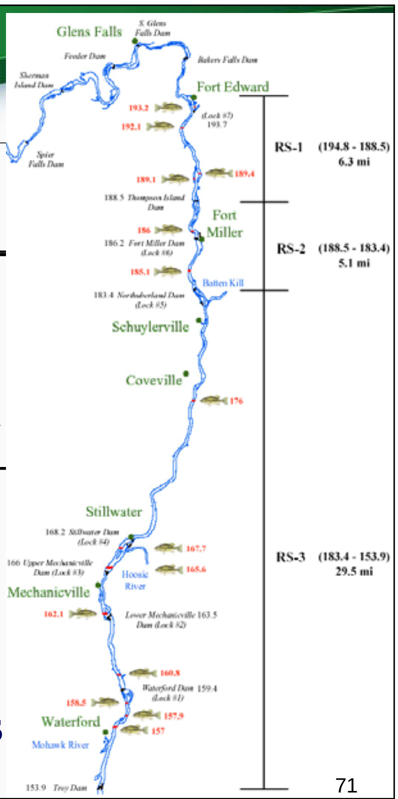
Baseline, Remedial Action & Long Term Fish Monitoring Plans for UHR

River Area	No. Spp. Groups	No. Indiv/Spp Groups	Total Samples
Feeder Dam	4	20	80
RS-1	4	30	120
RS-2	4	25	100
RS-3	4	30	120
Albany/Troy	4	20	80
			500

Four species/groups sampled ANNUALLY:

- Top-level pred: Blk Bass (LMB, SMB) SF
- Water col feeder: Perch (YP) SF
- Bottom-feeder: Bullhead (YB, BB) SF
- Yearling: Pumpkinseed WH

Annual composites of Forage Fish; n=10 per RS



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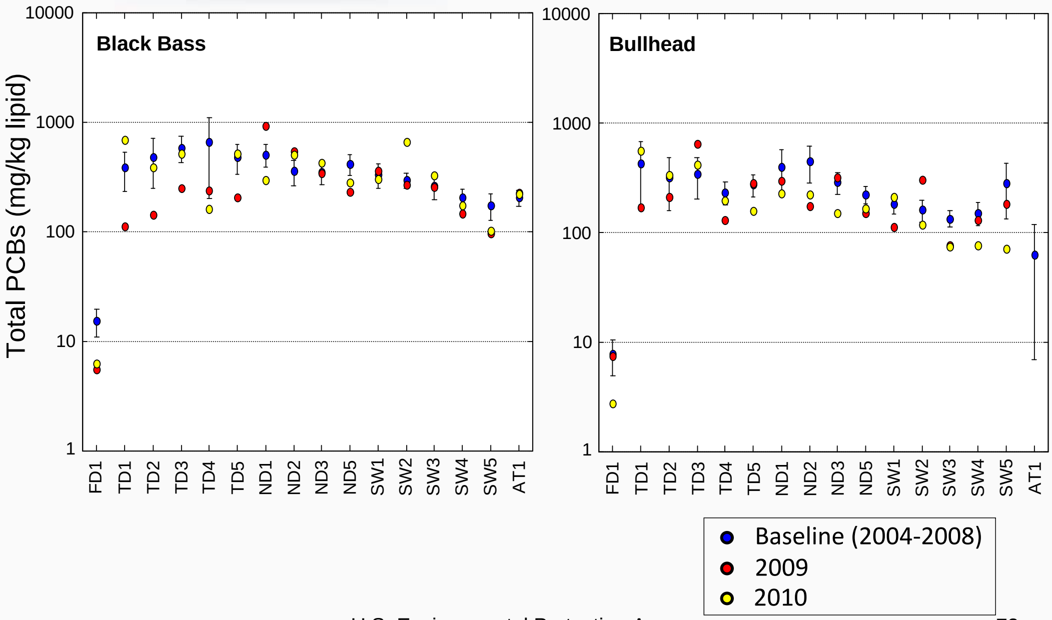
Hudson River Fish: Baseline vs. 2009 and 2010



U.S. Environmental Protection Agency

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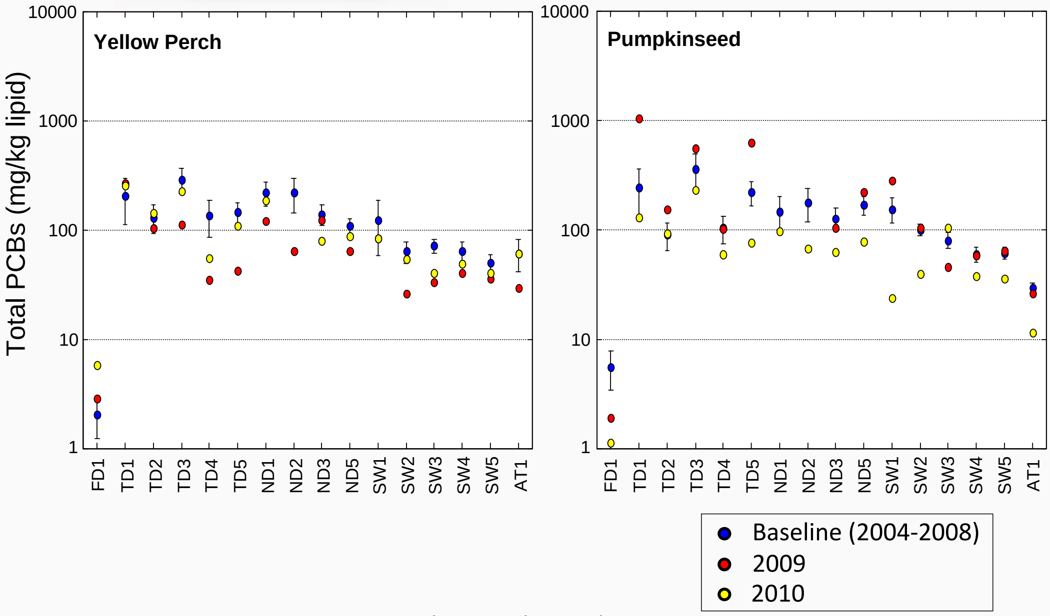
Hudson River Fish: Baseline vs. 2009 and 2010



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Total PCBs in Fish Tissues: Baseline vs. 2009

SECTION	STATION	Approx. River Mile	Black Bass	Bullhead	Yellow Perch	Pumpkin-seed
1	ALL	188.5-195	-		-	+
2	ALL	183.4-188.5	(-)		-	+
3	ALL	168.2-183.2		-	-	
SECTION	STATION					
--	FD1	201.1			+	
1	TD1	194			+	+
1	TD2	193	-			+
1	TD3	192	-		(-)	
1	TD4	190-191			-	
1	TD5	189.3	-		-	+
2	ND1	187		(-)		(+)
2	ND2	186.4			-	
2	ND3	185.5				
2	ND5	183.5	-		-	
3	SW1	181.2				
3	SW2	178.2				
3	SW3	177.3		-	-	
3	SW4	172.1				
3	SW5	167.8				
--	AT1	153.2 & 142		NA	-	

Phase 1 Dredging
May through Oct 2009

- Neutral p > 0.10
- (-) Decrease between 2004-8 and 2009; p<0.05
- (+) Increase between 2004-8 and 2009; p<0.05
- ( ) p<0.10

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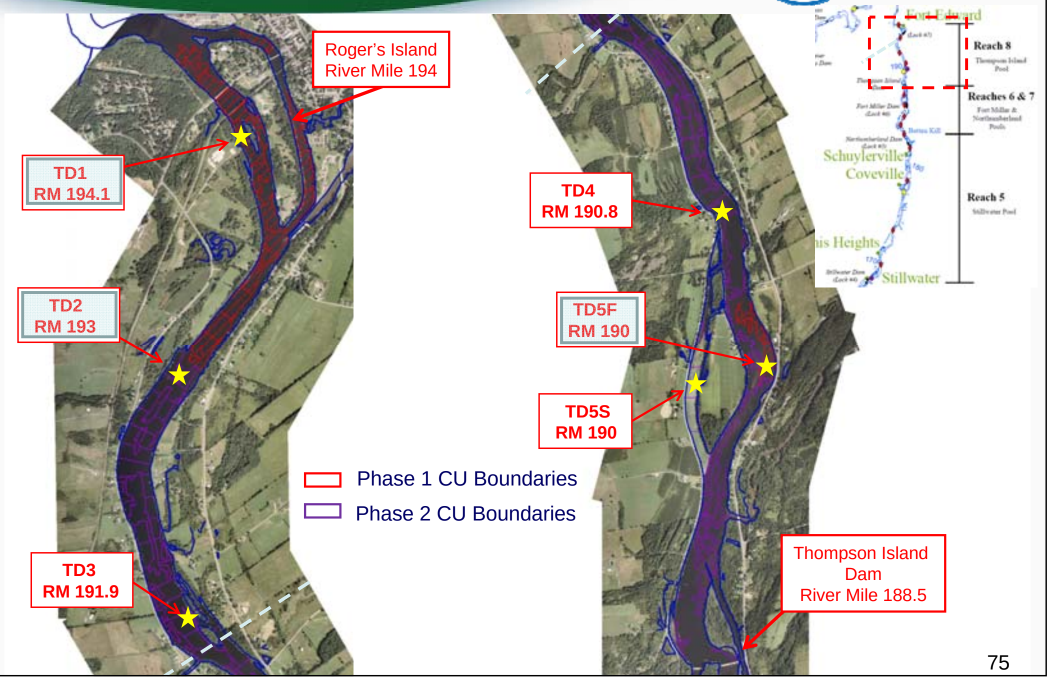
BMP Fish Sampling Transect Locations: Thompson Island Pool



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Review of EPA Phase 1 Evaluation Report based on 2009 Data

- **We observed some increases in fall 2009 whole body pumpkinseed tissue PCB levels in the upper Hudson compared to baseline (2004-2008).**
- **We expected that any dredging-related increases in PCB concentrations in adult sport fish would be observed in fish collected in spring 2010**
- **We concluded that:**
  - Resuspension of PCBs from sediments during dredging affected fish locally—greatest impact in the immediate vicinity of the dredging activity;
  - The data did not support the idea that dredging had an effect on PCB levels in fish more than 2-3 miles downstream of the Thompson Island Pool.

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Total PCBs in Fish Tissues: 2009 vs. 2010

Section	Station	Approx River Mile	Black Bass	Bullhead	Yellow Perch	Pumpkin-seed
1	All	188.5-195	+		+	-
2	All	183.4-188.5	(+)		(+)	-
3	All	168.2-183.2	(+)	(-)		-
Section	Station					
---	FD1	201.1	+		+	
1	TD1	194	+	(+)		(-)
1	TD2	193	+			-
1	TD3	192			+	
1	TD4	190-191				-
1	TD5	189.3	(+)	-	+	-
2	ND1	187		(-)		-
2	ND2	186.4			NA	-
2	ND3	185.5		-	-	
2	ND5	183.5	+			-
3	SW1	181.2				-
3	SW2	178.2			+	-
3	SW3	177.3	(+)			(+)
3	SW4	172.1				-
3	SW5	167.8				-
---	AT1	153.2 & 142		NA	NA	-

	Neutral p>0.10
-	Decrease btwn 2009 and 2010; p < 0.05
+	Increase btwn 2009 and 2010; p < 0.05
()	0.05< p < 0.10

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Total PCBs in Fish Tissues: Baseline vs. 2010

Section	Station	Approx River Mile	Black Bass	Bullhead	Yellow Perch	Pumpkin-seed
1	All	188.5-195				-
2	All	183.4-188.5		-		-
3	All	168.2-183.2		-		-
Section	Station					
---	FD1	201.1			+	(-)
1	TD1	194		+		
1	TD2	193				
1	TD3	192				
1	TD4	190-191				
1	TD5	189.3		-		-
2	ND1	187				
2	ND2	186.4			NA	-
2	ND3	185.5		-	(-)	(-)
2	ND5	183.5				-
3	SW1	181.2				-
3	SW2	178.2	(+)	-		-
3	SW3	177.3		-		
3	SW4	172.1		-		-
3	SW5	167.8		-		-
---	AT1	153.2 & 142		NA		-

	Neutral p > 0.10
-	Decrease btwn 2004-8 and 2010; p<0.05
+	Increase btwn 2004-8 and 2010; p<0.05
( )	p<0.10

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Conclusions

- **Spring 2010 Adult Sport Fish**
  - **No appreciable increases in tissue concentrations of PCBs relative to the five-year baseline period (2004-2008)**

- **Fall 2010 Pumpkinseed**
  - **Tissue concentrations appear to have nearly recovered from the localized dredging impacts reported in 2009**

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Good data allows for developing technical perspective

- **We expected that short-term, localized increases in fish PCB levels would occur during Phase 1**
  - **These apparent dredging impacts were clearly observed within or immediately below the Phase 1 dredging areas**

- **We anticipate that short-term, dredging related, localized body burden increases of PCBs in fish will rapidly return to baseline levels, and continue to decline thereafter following remediation**
  - **Exposures related to dredging are expected to be brief**
    - **Dredging only occurs in a given area for single dredging season, or a portion thereof (weeks to months)**
    - **Tissue concentrations of PCBs in fish have been shown to decrease rapidly following spikes related to exposure events and environmental dredging.**

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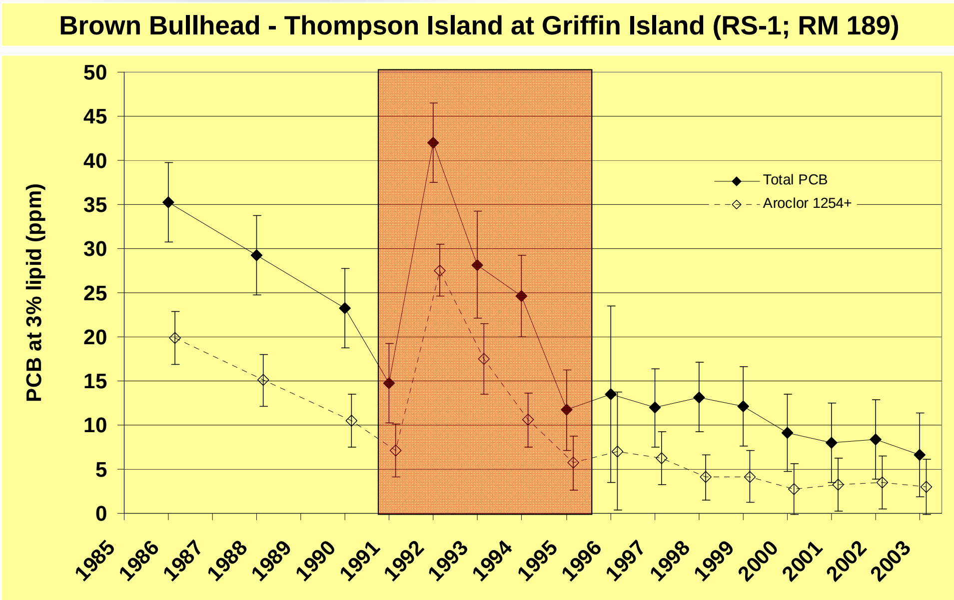
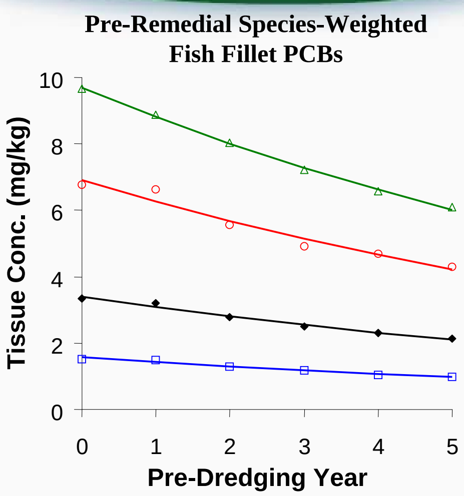
Spikes in tissue conc. linked to exposure events have been observed to recover



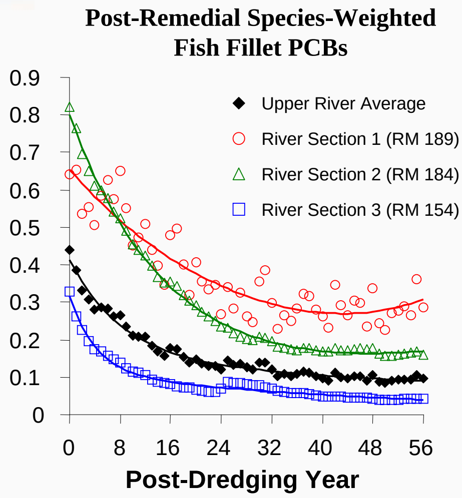
U.S. Environmental Protection Agency *Figure courtesy of NYSDEC (2005)* 81

Expected Rates of Decline from FISHRAND Predictions



$$C_{a_t} = C_{a_0} \cdot e^{-kt}$$

k = -9.5 to -9.9% per year



$$C_{a_t} = A \cdot e^{-k_1 t} + B \cdot e^{-k_2 t}$$

k_1 = -3.1 to -24% per year

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Record of Decision (FISHRAND) Predictions of Attainment of Risk-Based Remedial Action Objectives

- 0.05 mg/kg PCBs in fish fillet; 1/2 lb. meal/wk (protective of cancer & non-cancer risks)
- 0.2 mg/kg PCBs in fish fillet; protective for 1/2 lb. meal/mo
- 0.4 mg/kg PCBs in fish fillet; protective of the CT or average angler, at 1/2 lb. meal/2 mo

Years at which Human Health RGs will be achieved in Species-Weighted Fish Fillet (Value is mg/kg)

Years After Dredging	Upper River Average	River Section 1	River Section 2	River Section 3
0*	--	--	--	0.389
2	0.386	--	--	--
4	--	--	--	0.195
14	0.184	--	0.398	--
15	--	0.397	--	--
30	--	--	0.198	--
41	--	--	--	0.047

Model-Predicted Attainment of Ecological RGs

- River otter: reduced by 2035 (0.29 mg/kg; LMB average)
- Mink: reduced by 2007 (<0.7 mg/kg in spottail shiner)

* Based on assumed 6 year project period; originally 2004-2010.

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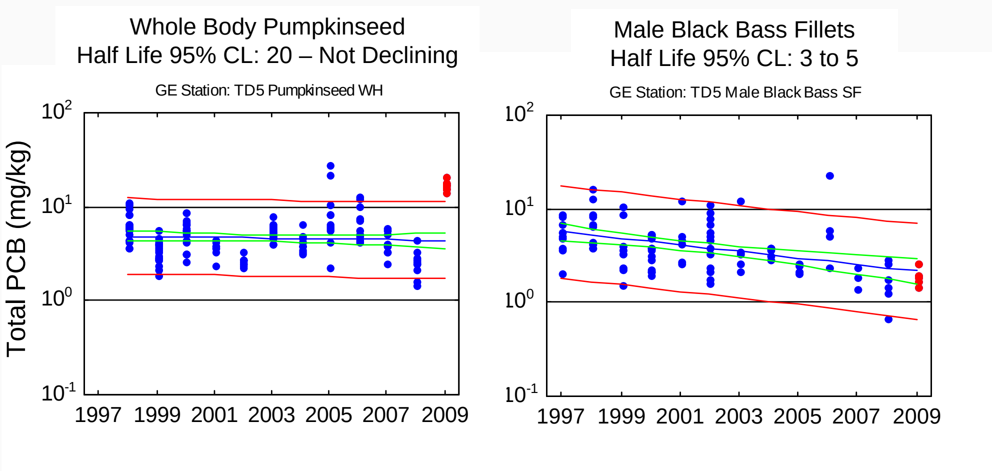
Annual & spatial patterns in trends can be important



U.S, Environmental Protection Agency

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For more information

Phase 1 Evaluation Report, Phase 1 Field Oversight Report and Revised Performance Standards are available at:

- www.hudsondredgingdata.com
- www.epa.gov/hudson

GE Data and reports available at:

- http://www.hudsondredging.com/

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COMMENTS/QUESTIONS

Capping and In-Situ Amendments

Marc Mills, PhD

Edwin F. Barth, PhD, PE, CIH

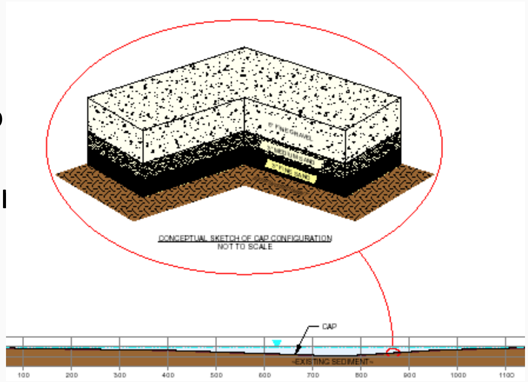
U.S. Environmental Protection Agency

Danny Reible, PhD
University of Texas

1

Sediment Capping

- Reduce risk by:
  - Stabilizing sediments
  - Physically isolating sediment contaminants
  - Reducing contaminant flux to benthos and water column
- Sand surprisingly effective for strongly solid associated contaminants
- “Active caps” for other situations (w/amendments)
- Some amendments also appropriate for direct placement into sediments

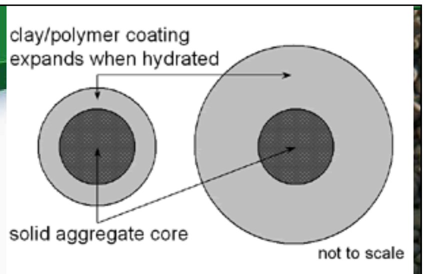


2

Isolation/Active Cap Design Approaches

- Layered or element concept
- Control of source and amt. sediment removed
- Sorption capacity (mass COCs / mass organoclay)
- Mass transport modeling (breakthrough time)
- Consolidation/compression of soft sediment base
- Geotextiles
- Armoring
- Gas release contingencies

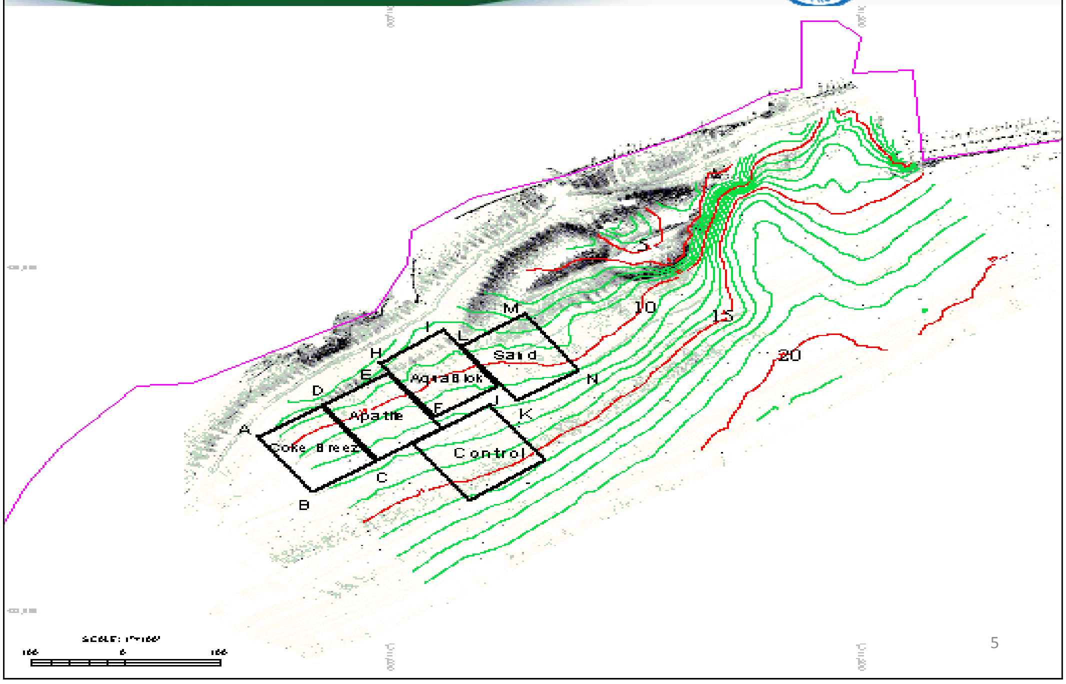
Permeability Control



- Aquablok - Clay polymer around a granular core to allow easy placement Amendments for sequestration & degradation available
- Bentonite –requires placement in mat to control loss
- Impermeable materials such HDPE have also been used
- Organoclay can exhibit much
- reduced permeability after contact with NAPL

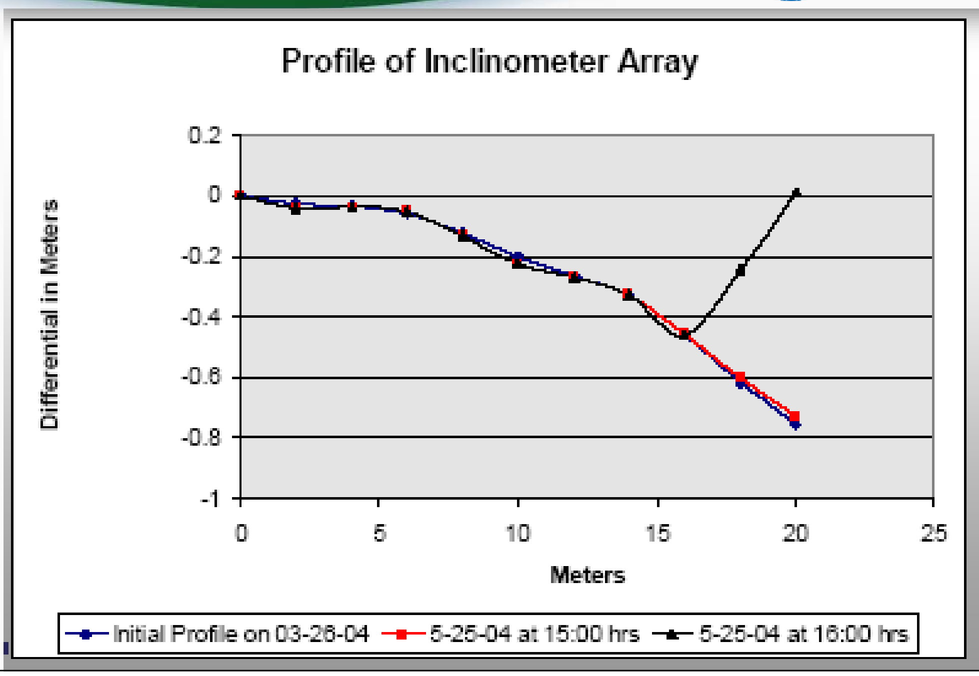
4

Anacostia Active Capping Demonstration



5

Gas related uplift of impermeable cap (AquaBlok)



Active Cap Sorbent Material

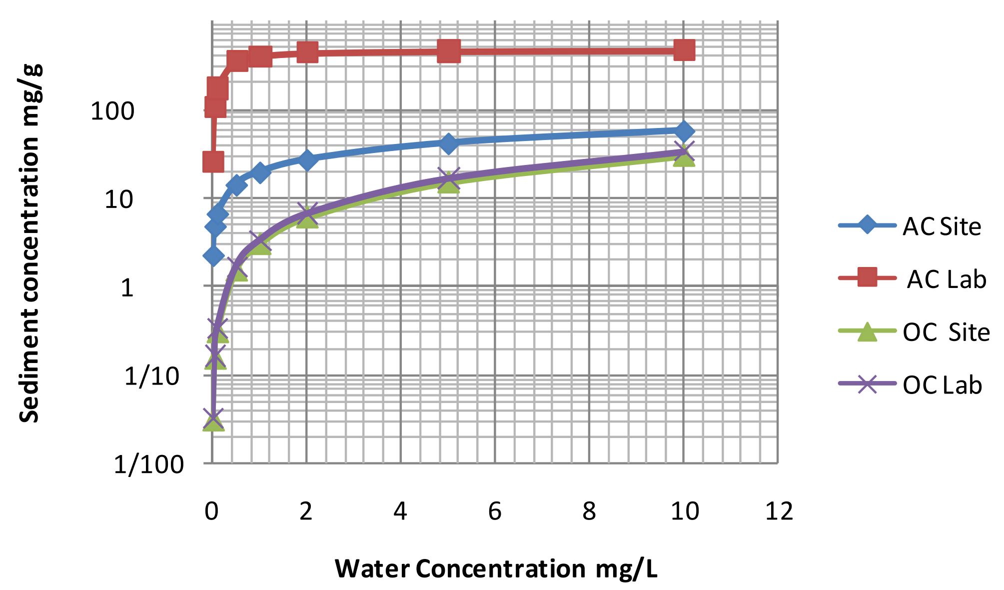
Activated carbon

- High K_{oc} for dissolved
- Non-linear @ high conc.
- Surface then inner diffusion
- Interference with NOM, oil
- pH sensitive

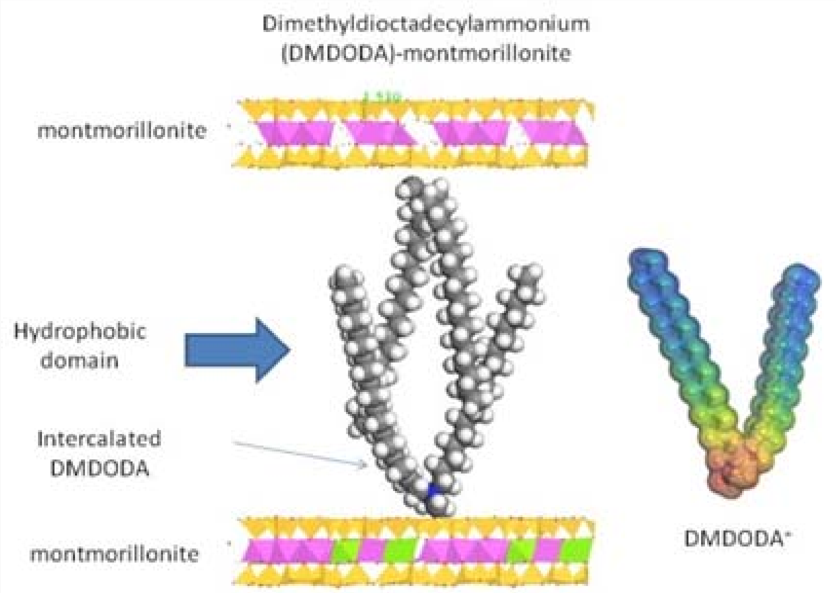
Organoclay

- Medium K_{oc} for dissolved K_{oc}
- Linear isotherms
- Surface (internal)
- Limited interference
- Possible breakdown

Interference of NOM on Carbon Sorption



Organoclay Structure

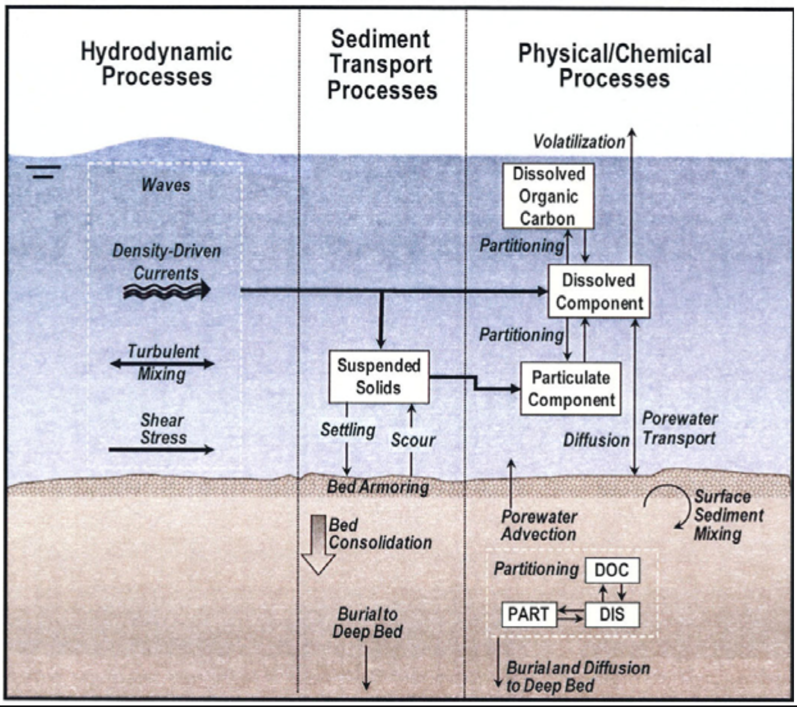


Lampert and Reible Cap Model

- Mass transport through isolation and bioturbation layer
- Advection, diffusion, partitioning, reaction, upwelling, erosion
- Predicts contaminant breakthrough time
- Inputs (K_{oc}, C_o, V, proposed thickness, porosity, diffusion/dispersion coefficient)

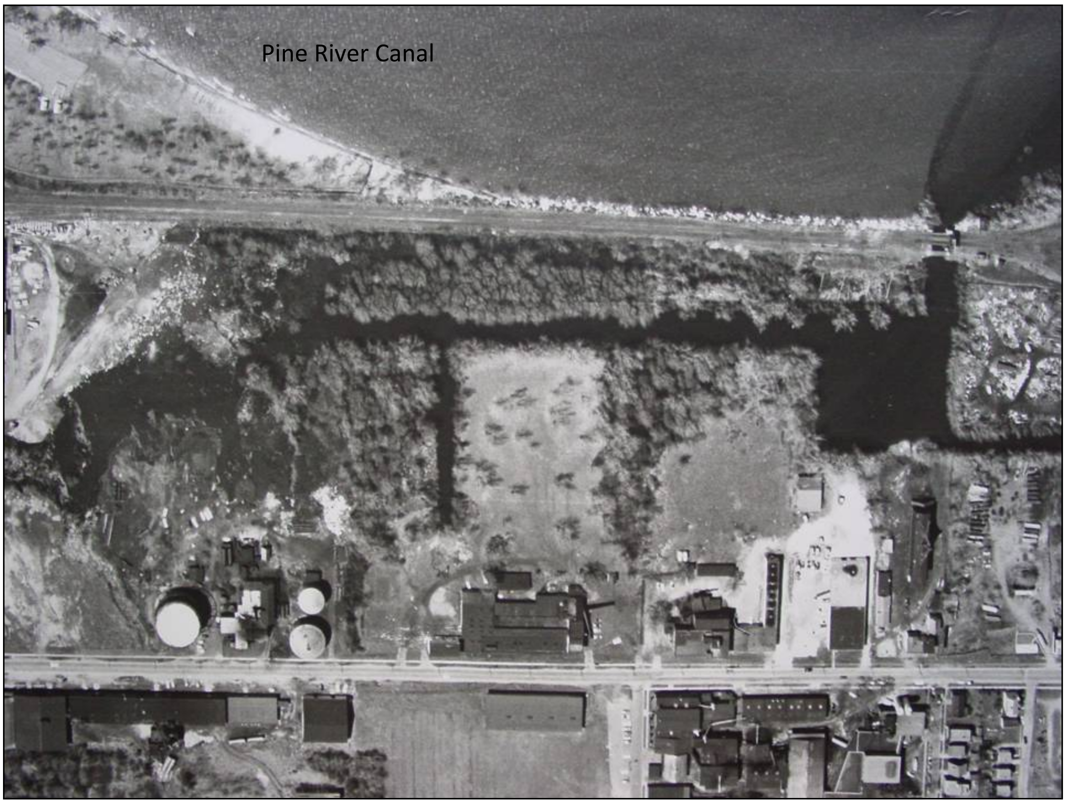
(Soil and Sed. Cont. 18: 470-488, 2009)

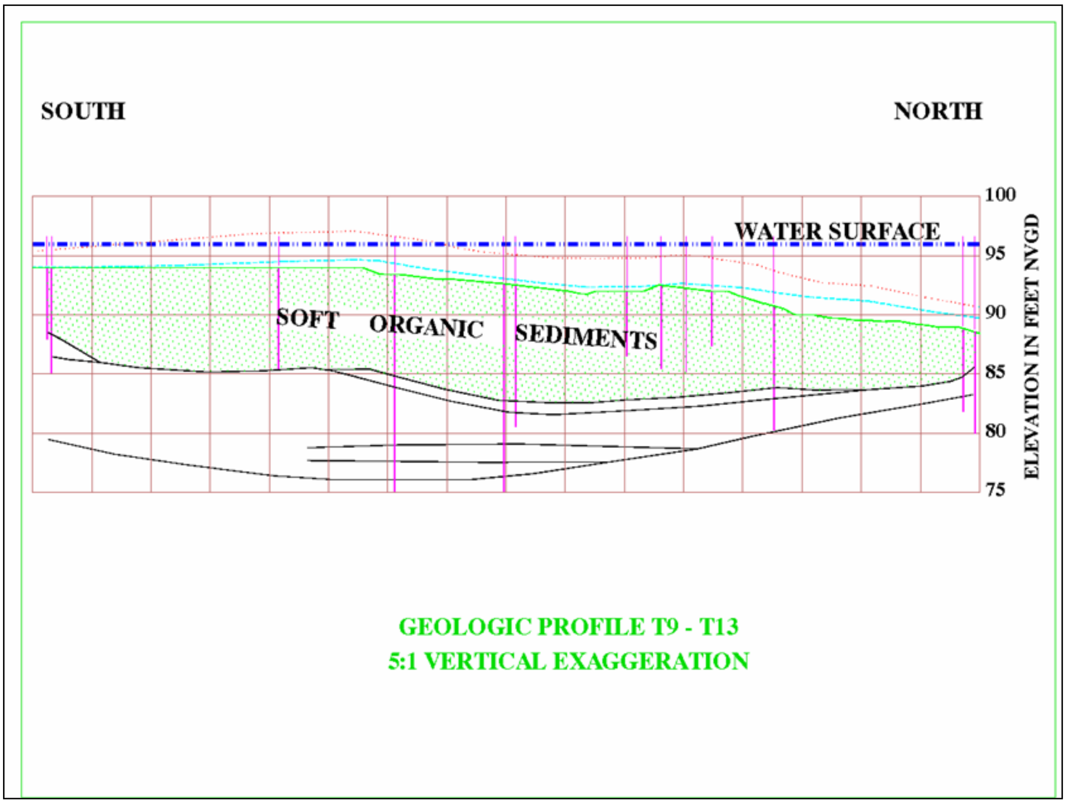
Model Processes



Cap Placement Techniques

- Mechanical (barge, shore, helicopter, injection) – for bulk or core material coating
- Mats (RCM) – evaluate shear, particle movement, gas permeability
- Specify in-place thickness, density (reactivity)


Pine River Canal


SOUTH
NORTH
WATER SURFACE
SOFT ORGANIC SEDIMENTS
100
95
90
85
80
75
ELEVATION IN FEET NVGD
GEOLOGIC PROFILE T9 - T13
5:1 VERTICAL EXAGGERATION

Geotechnical Laboratory Data for Organic Sediments (geometric mean values of six or more tests)

Bulk Density	66.3 pcf
Moisture Content	286.5%
Dry Density	16.2 pcf
Void Ratio	5.52
Compression Index (Cc)	1.02

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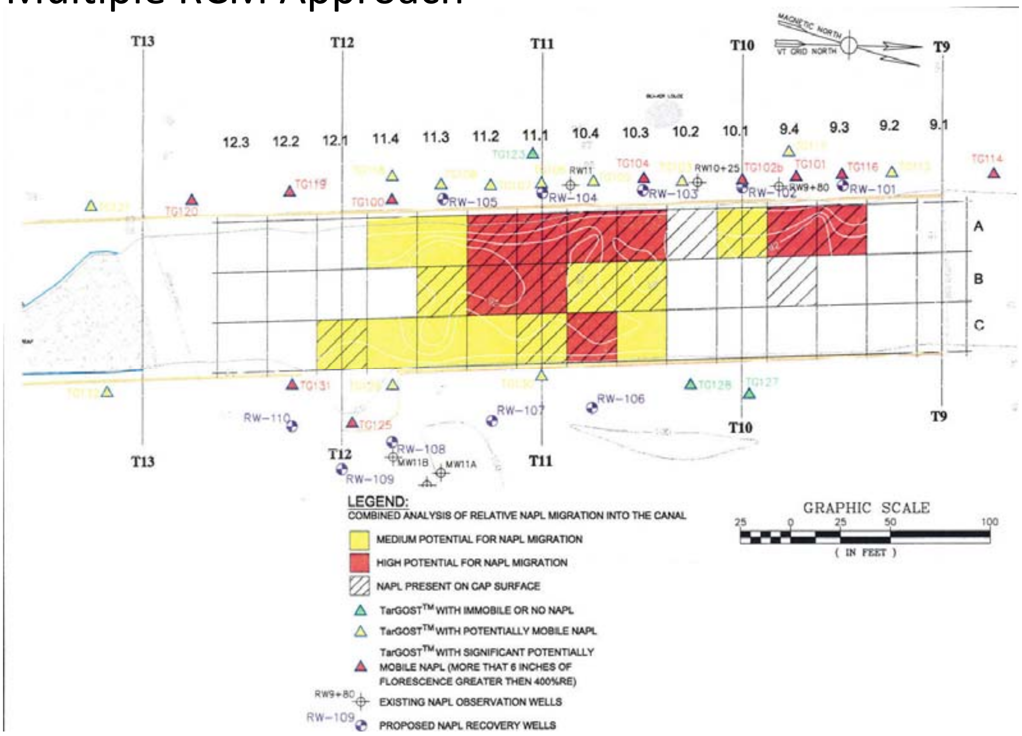
Exposed Post and Beam Cribbing COC Pathway

Liner and Sand Cap

Remedy Adaptations

- Adaptations After Liner Shear Failure and NAPL Release:
  - Amendment for NAPL sorption
    - Organophylic clay in reactive core mats
    - Multiple mats employed to provide sufficient organophylic clay rather than bulk clay
  - Improved capping of cribbing
    - Cut cribbing at level of cap
    - Tie-in of reactive core mats beyond cribbing

Multiple RCM Approach



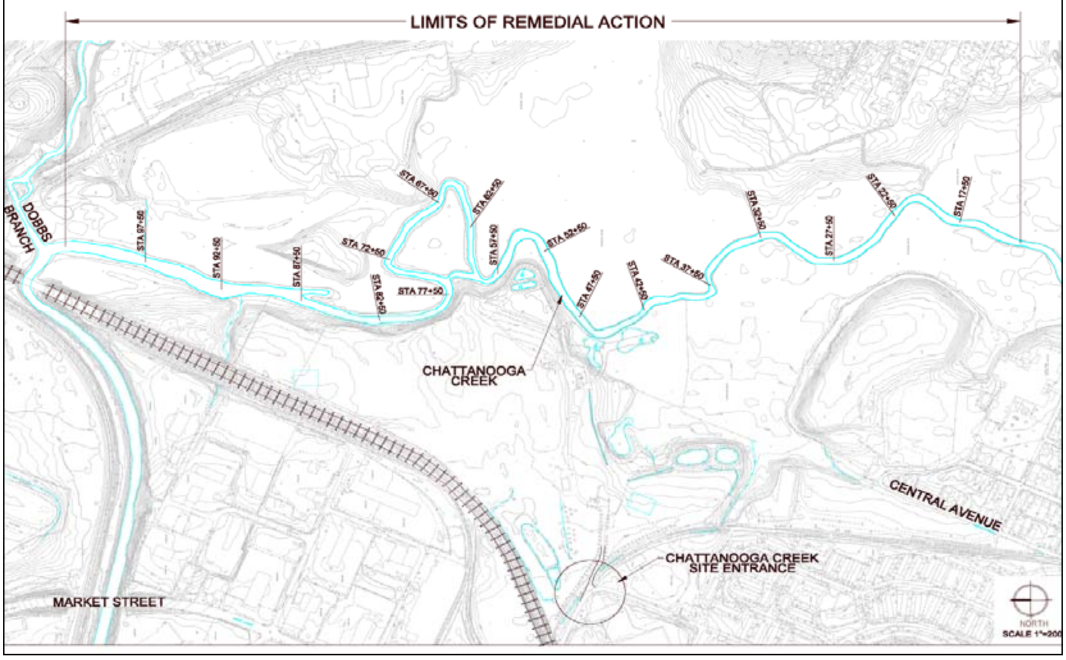

<<<Corrected End
of the RCM

Grand Calumet River RCM Installation

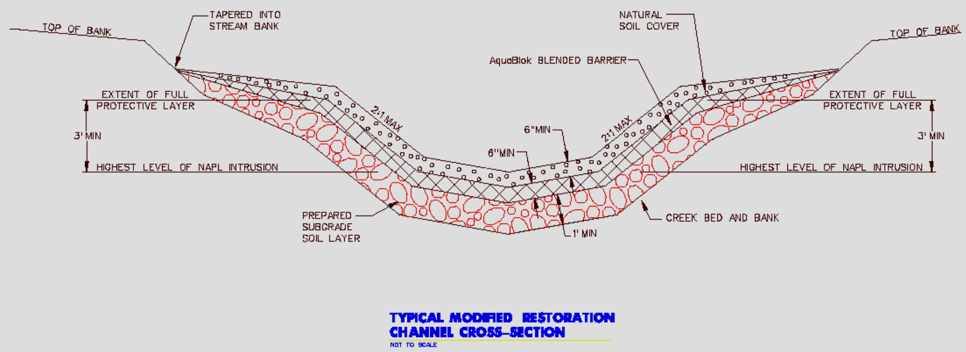

Sevenson
03/16/2011 11:38

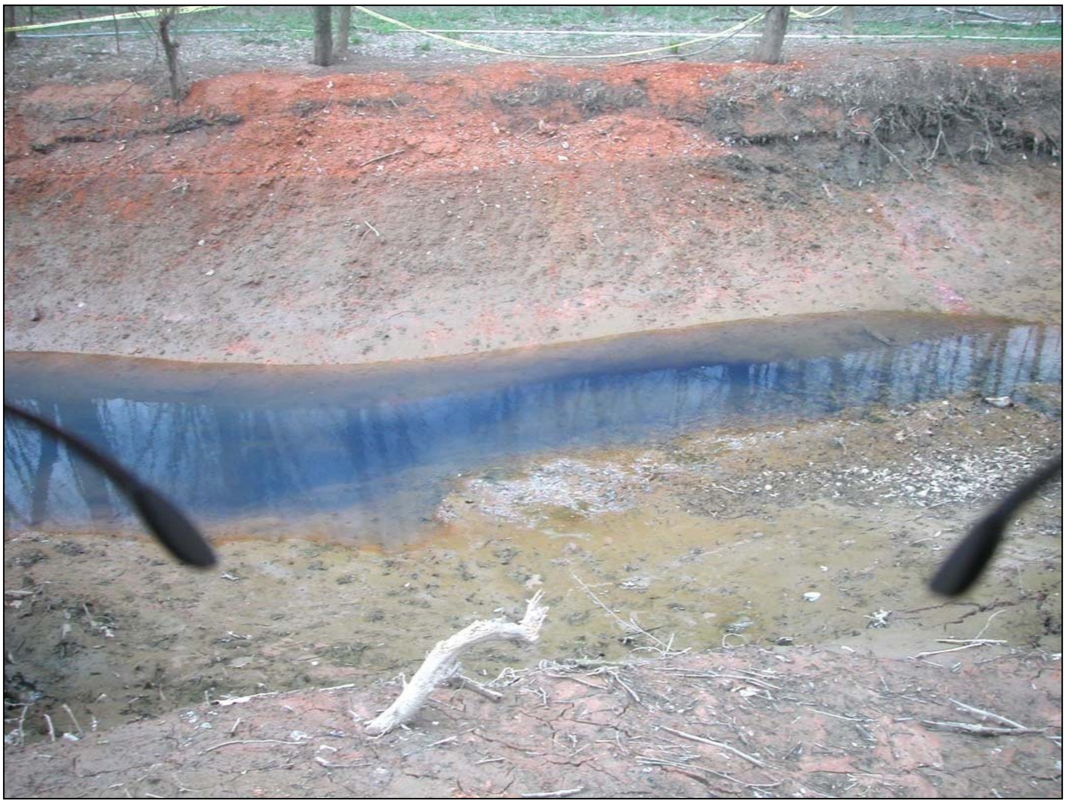

02/22/2011 14:11

CHATANOOGA CREEK



Cap Installation Above Highest Level of NAPL Intrusion






OCT 4 2006

M&B Historic Operation

- Wood treatment facility operating 47 years - 1944 to 1991
- Process wastes and waste water discharges: creosote, PCP, and metals on land and in the Willamette River
- Site footprint:
  40 acres upland soil
  22 acres sediment

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Sediment OU Status: O&F

- **Sediment Cleanup Criteria:** prevent human and aquatic organisms for direct contact > risk-based concentrations, minimize releases to Willamette River > AWQCs
- **Remedy:** 22 acre, 2-foot sand cap, granular organoclay, RCM, and armoring isolate contaminated sediments and groundwater from Willamette River **complete in September 2005, ongoing** performance monitoring

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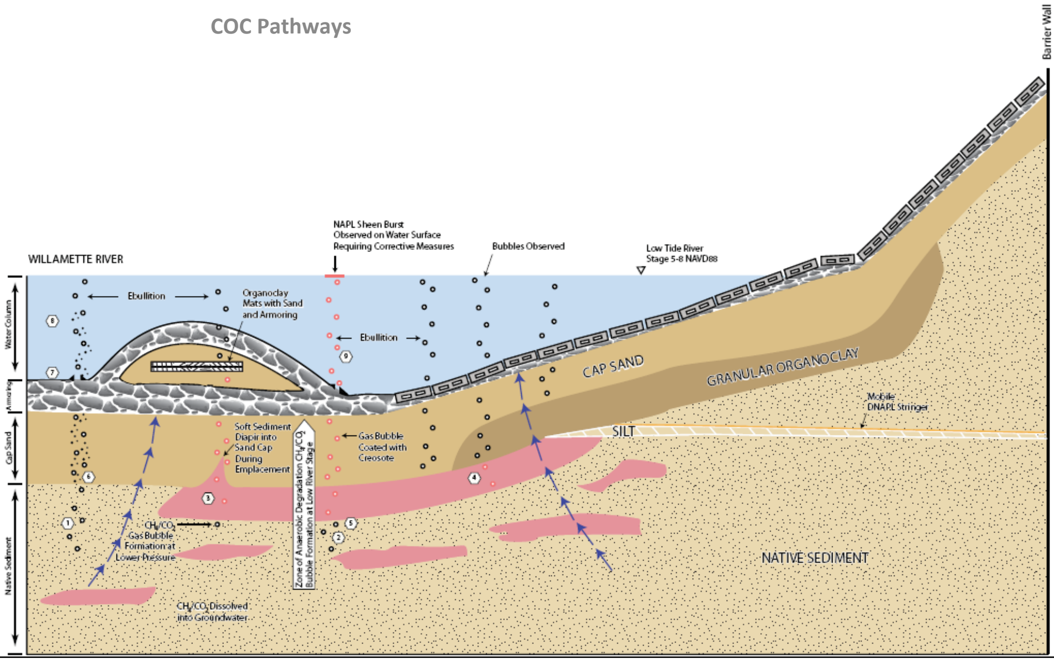
Conceptual Model Ebullition Pathways

COC Pathways



Three Outstanding Concerns

- Sheens along bank during times of groundwater discharge in TFA and Willamette Cove
- Ebullition as a contaminant pathway
- Observe prolific ebullition in bulk OC area in TFA – what is the potential for the OC to degrade

M&B Observations

- Organoclay retains sufficient sorption capacity – both OC mats and granular
- Permeability remains near fresh organoclay (similar to sand)
- HEM fraction higher in ET-1 – likely reason for enhanced microbial activity in bulk granular organoclay
- Some loss in carbon content from granular AquaTech organoclay through degradation
- Porewater and sediment concentrations below comparison criteria
- Ebullition is an insignificant pathway for contamination –
- Sheen origin related to concentration of iron

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Grasse River AC Pilot

1. **Initial Testing Area** – application techniques tested to refine equipment and operation
2. **Tine Sled Mixed Treatment Area -** AC injected through tines, pulled along river bottom
3. **Mixed Tiller Treatment Area** – AC applied to sediment surface and mixed using roto-tiller device
4. **Unmixed Tiller Treatment Area** – AC applied to surface without mixing to assess long-term bioturbation

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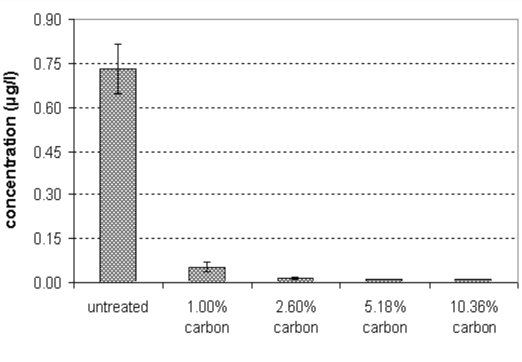
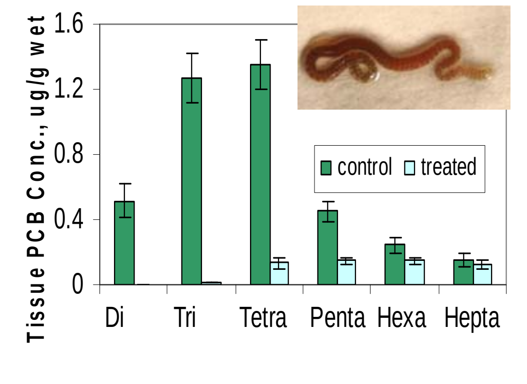
Reduction in Worm and Aqueous PCBs





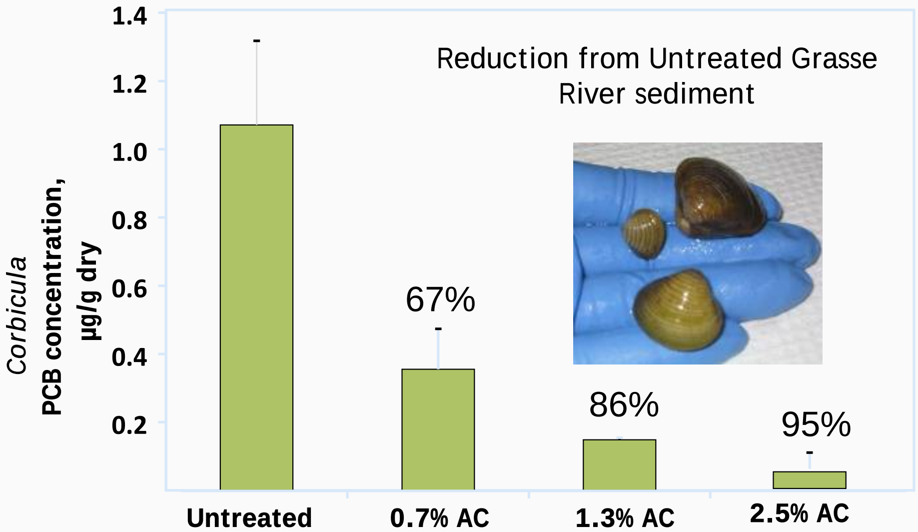
Progressive reductions in Grasse River sediment porewater PCB concentrations with increasing doses of AC

Amendment of Grasse River sediment with 2.5% AC reduced PCB biouptake in a freshwater oligochaete

45

EPA GLNPO study at UMBC

Stanford Lab Bioaccumulation Study



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- Cliff Johnston, Purdue University
- Jack Fowler, Geotec
- Tom Stolzenburg, RMT, Madision, WI
- SulTRAC

Performing a Sediment Erosion and Deposition Assessment (SEDA) at Sediment Sites

Stephen Ells
US EPA
ells.steve@epa.gov
and
Earl Hayter
US Army Engineer Research and Development Center
Earl.Hayter@usace.army.mil

What is a SEDA?

- A SEDA is an evaluation of processes that affect that transport or burial of contaminated sediments.
- Physical and biological processes at a site can either *erode*, *resuspend*, and *transport* contaminated sediments and/or serve to isolate and bury those sediments through the process of *deposition* and *consolidation*.
- To be most useful, the evaluation should support future predictions of those processes with enough certainty to make cleanup decisions.

2

Definitions

- *Deposition* is the process of suspended sediment settling and coming to rest on the bed/bottom of the water body.
- *Erosion* is the removal or wearing away of sediment particles from the bottom or sides of a water body through the action of moving water, i.e., currents and/or waves.
- *Erodibility* is a measure of a sediment bed's propensity to lose sediment particles due to the action of currents and/or waves.

3

Definitions

- *Resuspension* is normally defined as the process by which erosive forces or other actions such as dredging activities dislodge bedded sediment particles and disperse them into the water column.
- *Stability* of a sediment bed refers to its ability to resist erosional forces acting on the bed surface due to the action of currents and/or waves.
- *Transport* refers to the physical movement of sediment particles due to the action of moving water.

4

Definitions

- *Consolidation* is the process by which the weight of overlying deposited sediment forces porewater upward in a cohesive sediment bed and crushes the underlying sediment.

5

SEDA Purposes

- Developed to inform the Conceptual Site Model (CSM) that includes sediment transport and contaminant fate processes.
- Used to evaluate the permanence of caps and the evaluation of risks from no-action and MNR remedies.
- It should answer two key questions:
  - Will buried contamination stay buried?
  - Will deposition of cleaner sediment be adequate to reduce risks in the long-term?

6

Fundamentals of Sediment Transport

- Types of sediment: inorganic, cohesive, organic, mud
- Sediment beds will often be composed of a mixture of cohesive and noncohesive sediments.
- Lick *et al.* (2004) found that 2% of fine-grained sediment can have a large effect on erosion rates because of the binding effect of cohesive sediments.
- Determining site-specific variation in grain size distributions, bed densities, sediment erosion rates, and floc settling speeds is key.

7

Fundamentals of Sediment Transport

- Sediment transport and erodibility are governed by the sum of natural and human impacts that impart mixing or erosive forces on the sediment bed, either through direct disturbance or by moving water.
- Because many contaminated sediment sites are contaminated with organic compounds that have a strong affinity for organic carbon, they are also located in areas of the waterbody that are primarily depositional, or in areas where only a limited surface layer of cohesive sediment is routinely mobilized.

8

Possible Natural and Human Disturbances to the Sediment Bed

Natural Disturbances	Human Disturbances
Hydraulic impacts •Currents, tides, wind waves, sieches •Storm events – high flows, waves, or surges •Breach of natural dams (e.g., beaver dam, ice jam) •Flow under ice cover Direct impacts •Activity of fish, waterfowl, and mammals •Bioturbation and benthic activity (activity of organisms that dwell in or on the sediment bed) •Impact by debris or ice •Groundwater advection and gas ebullition	Hydraulic impacts •Hydraulic structure operations (locks and dams, sewer outfalls, etc.) •Watershed development (altered runoff and sediment loading) •Breach of dams Direct impacts •Commercial fishing •Vessel activity (including propeller, bow wake, anchoring, etc.) •Construction •Placement of fill or structural stone •Dredging / excavation

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Fundamentals of Sediment Transport

- Need to differentiate between routine processes which affect the surface layer and extreme events that may disrupt deeper sediments.
- Both routine processes and extreme events are important in understanding potential future exposures and risks.
- Routine processes should still be quantified; they affect the rate of potential natural recovery of contaminant concentrations in fish, water and sediment.

10

Fundamentals of Sediment Transport

- Sediment erodibility under extreme event conditions is one of the primary considerations in evaluating the permanence of in-place management options such as engineered capping and thin-layer capping of dredge residuals.

11

Fundamentals of Sediment Transport

- Sediment erodibility under extreme event conditions is one of the primary considerations in evaluating the permanence of in-place management options such as engineered capping and thin-layer capping of dredge residuals.

12

SEDA Methodology

- Project Scoping
- Current and Historical Site Review
- Bathymetric Analysis
- Hydrodynamic Assessment
- Geomorphology Assessment
- Anthropogenic Impacts
- Sediment Stratigraphy and Geochronology Analysis

13

SEDA Methodology

- Data Needed for Most Sites
  - Quantification of Sediment Erodibility
  - Measurement of Settling Velocity of Cohesive Sediment
  - Sediment Transport during a Major Hydrologic Event

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Project Scoping

- Formulate study questions.
- Key site-specific questions, e.g., what is the spatial extent of contamination at various depths?
- Focus on identifying the most relevant information needs concerning the SEDA for remedial decision-making at the site.
- Careful framing of these questions will greatly facilitate data collection and analysis and latter decision making.

15

Current and Historical Site Review

- Availability of historical data including geomorphologic classification.
- Understanding of site characteristics including geomorphologic classification, sediment and chemical properties, and sediment dynamics provided from existing information.
- Potential natural events that may impact sediment erodibility (increased flow, large waves, storm surge, tropical storms, etc.).
- Potential human activities that may impact sediment erodibility (navigation, road construction, land use changes, etc.).

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Current and Historical Site Review

- Sources of clean sediment and contaminants to the potential remediation area.
- Transport of contaminated sediments to receiving waters.
- Historic and future use of hydraulic control structures such as dams, etc.

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Bathymetric Analysis

- Bathymetric data reflect water body evolution over time due to sediment accumulation, erosion, dredging, filling, or other actions.
- Bathymetric data exist for most U.S. waterways. Has been collected by various federal and state agencies.
- The US Corps of Engineers has a lot of data on navigable waterways. Taiwan?

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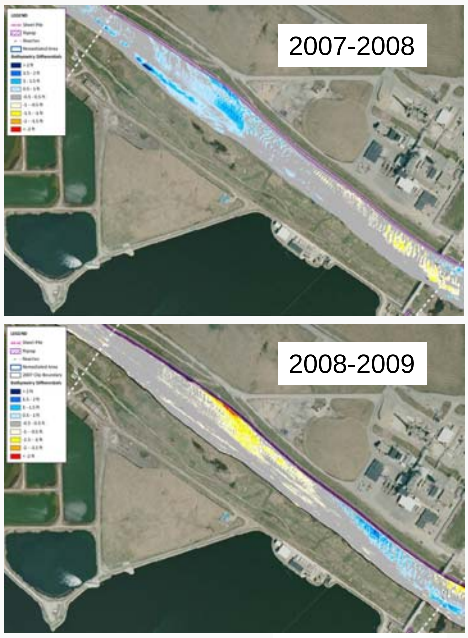
Multi-beam Bathymetry

- Useful to elucidate deposition and stability.
- Wide coverage to produce spatially comprehensive representation.
- Can be quantitative between measurements -- no indication of changes during interval between time points.

Blue = 1 – 11/2 ft deposition, yellow = 1 – 11/2 ft. scour



Dow Chemical et al. 2010

Hydrodynamic Assessment

- In rivers and estuaries, water flows will be the primary driver of sediment transport; must understand flow rates and their variation during daily, seasonal, and extreme events.
- Where possible, flow rates and water elevation data in rivers, estuaries, and lakes should be collected prior to developing your Conceptual Site Model (CSM).
- These data are needed to understand the expected range of flow conditions and evaluate the potential for event-induced erosion.

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Hydrodynamic Assessment

- For estuarine or coastal sites, tidal forces, including water level fluctuations with storm events should be considered.
- Relevant hydrodynamic events may also include ship passage and maneuvering.
- An issue at some sites is recreational craft induced suspension of sediments.

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Hydrodynamic Assessment

- Hydrodynamic models are well-developed and robust; many sites would benefit from hydrodynamic modeling.
- Hydrodynamic modeling can be used to determine:
  - residence times of dissolved contaminants
  - areas of the water body expected to be erosional and depositional during simulated flow events.
- The latter can be determined using a contour map of flow-induced bed shear stresses that can be generated from hydrodynamic models.

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Geomorphology Assessment

- Considers local and watershed-scale processes governing the ongoing geomorphological changes of the water body.
- Examples of local scale factors include bar formation; scour zones; accretion or degradation of nearshore areas, channel infilling/dredging; and bank erosion.
- Sediment transport will cause geomorphological changes in most water bodies due to sedimentation and erosion. Landslides and bank erosion can also cause significant changes.

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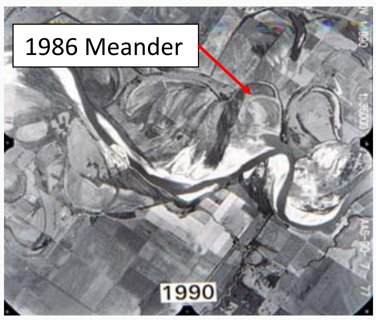
Geomorphology Assessment

- Geomorphology generally considered separate from sediment transport (scale difference).



24

Evaluate Anthropogenic Impacts

- At many sediment sites, the sediment bed is not in a completely natural state.
- Rivers and estuaries where contaminants are present as a result of industrial activity are typically altered due to dredged navigational channels, bridge abutments, bulkheads, hardened structures on banks, etc.
- These structures may have localized impacts (e.g., depositional areas immediately downstream of large bridge piers), or large-scale impacts (e.g., dam control of water levels, or dredged navigational channels).

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Sediment Stratigraphy and Geochronology Analysis

- Sediment stratigraphy refers to the characteristics and ordering of layers in the sediment bed.
- The stratigraphic record can provide useful information about deposition patterns.
- Useful when it can be compared to radio-dated sediment cores from which geochronology of the sediments can be inferred.
- High flow events that have had a significant impact on sediment transport may be revealed as distinct bands of sediment in the core.

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The Area is Depositional

M.A Beckwith, USGS

27

Sediment Stratigraphy and Geochronology Analysis

- A geochronology analysis uses depth profiles of radioisotope measurements to estimate sedimentation rates by radio-dating layers in the core.
- Geochronology analyses are generally conducted using three types of radioisotope data: Cesium-137 (^{137}Cs), lead-210 (^{210}Pb) and Beryllium-7 (^{7}Be).
- Each radioisotope provides a specific type of geochronologic information.

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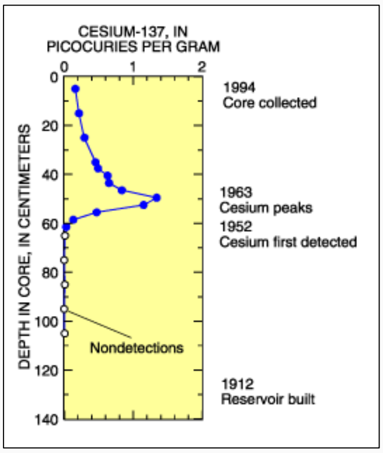
Geochronology Analysis

- While lead and Cesium can provide estimates of deposition rate over the past 20-50 years, Beryllium-7 (^{7}Be) is only useful for indicating recent deposition and possible mixing in the top bed layer over a period of months due to its half-life of 53 days.
- The relative "sharpness" of the profile around the ^{137}Cs peak is indicative of the strength of mixing processes in the surface layer, e.g., a sharp well-defined peak suggests a relatively low rate of surficial mixing, whereas a broad poorly-defined peak suggests a relatively high rate of mixing.

29

The Area is Depositional



USGS, Circ 1171, 1996

30

Data Need for Most Sites

- Data needed to perform a SEDA and to develop a CSM depend on:
  - the type of water body
  - the type of sediment present in the water body
  - the forces which govern the motion of the water.
- It may be beneficial to apply a hydrodynamic model before sediment data collection
  - Even an uncalibrated model can be beneficial
  - Can guide sediment and hydrodynamic data collection to areas of interest (e.g., high velocity regions)

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Data Need for Most Sites

- Water column suspended sediment data should be collected simultaneously with hydrodynamic data.
- Sediment bed data collection should address bed heterogeneity.
- Modeling team should be involved in data collection plan (a lot of good data have been collected that are not needed for modeling study or assessment).
- Sediment Bed Data Collection
  - Surface grab samples
  - Sediment cores

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Quantification of Sediment Erodibility

- Quantification of sediment erodibility at several locations where fine-grained and/or mixed cohesive and noncohesive sediments occur is usually needed at sites to estimate the depths to which the sediment may erode.
- All of the devices (next slide) measure critical shear stress of erosion and erosion rate; the primary differences between them are related to whether they can be used in situ and whether they can measure sediment erodibility below the surficial sediment layer.

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Device	Flow Conditions (over sediment surface)	In-Situ	Ex-Situ	Transport Measured	τ c	Erosion Rate	Sediment Type	Depth Measured	Shear Stress Range
Straight Flume	Linear/ Oscillatory	Yes	Yes	Total load	Yes	Yes	Clay/silt/ sand	Surficial layer	0-4 Pa
Annular Flume / Sea Carousel	Linear	Yes	Yes	Suspended load only	Yes	No	Clay/silt/ Sand	Surficial layer	0-1 Pa
Shaker	Unknown	No	Yes	Suspended load only	Yes	No	Clay/silt/ Sand	Surficial layer	0-1 Pa
SEDFLUME	Linear	No	Yes	Total load	Yes	Yes	Clay/silt/ Sand	0-1 m	0-10+ Pa
ASSET flume	Linear	No	Yes	Suspended and bedload	Yes	Yes	Clay/silt/ Sand	0-1 m	0-10+ Pa
SEAWOLF flume	Linear/ Oscillatory	No	Yes	Total load	Yes	Yes	Clay/silt/ sand	0-1 m	0-10+ Pa

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Measurement of Settling Velocity of Cohesive Sediment

- These settling velocities are a function of the salinity of the water, the mineralogy of the clays present, the fraction of organic matter suspended in the water column, and the concentration of suspended matter.
- As such, settling velocities of cohesive sediments cannot be predicted using a universally applicable equation such as the equation used to predict the settling velocities of noncohesive sediments.

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Measurement of Settling Velocity of Cohesive Sediment

- *In-situ* measurement of the settling speeds of cohesive sediments should be performed at sites where the CSM reveals that the transport of these fine-grain sediments is a significant factor in understanding the transport and fate of contaminants.
- The Particle Imaging Camera System (PICS) developed by the US Army Corp can measure the *in-situ* floc sizes and settling velocities (Smith and Friedrichs 2010).

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Sediment Transport during a Major Hydrologic Event

- Major meteorological and hydrologic events such as rain induced floods and tropical storms can have a very significant impact on the transport of sediments
- The vast majority of sediment transport in a given year occurs during these events.
- Is important to try to quantify the hydrodynamics in during these extreme events (but safely).

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Sediment Transport Analysis

- How to Determine What Level of Analysis is Needed at a Site?
- How to Use Collected Data?
  - Data analysis
  - Methods and limitations of interpolation of sparse data
  - Data use in mathematical models

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Sediment Transport Analysis

- Sediment Transport Modeling
  - Uses of models
  - Types of models
  - How to determine the appropriate level of model
  - Model verification, calibration, and validation
  - Sensitivity and uncertainty of models
  - Recommendations for performing sediment transport modeling studies

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Sediment Transport Modeling

- Uses of models
  - Identify data gaps during the initial stages of a site investigation
  - Illustrate how sediment properties and contaminant concentrations vary spatially at a site
  - Predict sediment transport and contaminant transport over years to decades, or during episodic, high-energy events (e.g., tropical storms or low-frequency flood events).

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Sediment Transport Modeling

- Uses of models
  - Predict future contaminant concentrations in sediment and water that can then be used to predict biota contaminant uptake.
  - Model output can be used to evaluate relative differences in predicted effectiveness among the proposed remedial alternatives, ranging from MNR to dredging and capping; and
  - Comparing modeled results to measurements to show (hopefully) convergence of information.

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Sediment Transport Modeling

- Uses of models
  - Both modeling results and data have a measure of uncertainty, and modeling can help to quantify the uncertainties and refine estimates of remediation effectiveness.
  - If the decision is made that some level of mathematical modeling is appropriate at their site, the following section should assist project managers in deciding what type of model should be used.
  - Develop modeling plan in consultation with experienced sediment transport modelers.

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Sediment Transport Modeling

- Types of models
- How to determine the appropriate level of model
  - Use the CSM
  - Determine processes that can and cannot be currently modeled
  - Select appropriate model
- Model verification, calibration, and validation

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Sediment Transport Modeling

- Model verification: Consists of evaluating the model theory, the consistency of the computer code with model theory, and the computer code itself for integrity in the calculations.
- Model calibration: Consists of using site-specific information from a historical period of time to adjust model parameters in the governing equations (e.g., bottom friction coefficient in hydrodynamic models) to obtain an optimal agreement between a measured data set and model calculations for the simulated state variables.

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Sediment Transport Modeling

- Model validation: Consists of demonstrating that the calibrated model accurately reproduces known conditions over a different period of time than that used for model calibration. The parameters adjusted during the calibration process should not be adjusted during validation.
- It is important that both calibration and validation be conducted at the space and time scales associated with the questions the model must answer.

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Sediment Transport Modeling

- Data sets for model calibration and validation
- Sensitivity and uncertainty of models
- Recommendations for modeling studies
  - Because of the cost and time involved, development of new models should be avoided if at all possible.
  - To insure a technically defensible modeling study, experienced modeling consultants should be contracted to perform the modeling project. This is usually a more critical step than the selection of the model to use.

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Sediment Transport Modeling

- A collaborative approach to model development and use between the regulator and regulated party is highly recommended; i.e., avoid dueling models.
- A phased approach to modeling is also highly recommended. With this approach, the decision to develop a sediment transport model is not made up front, i.e., before the SEDA is complete.
- Need measurements of erosion properties:
  - sediment bed erosion rates
  - critical shear stresses for resuspension
  - grain size distributions and bulk densities
  - settling velocities of flocs

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Sediment Transport Modeling

- Mass balance analysis for water and sediment needs to be evaluated using model results to insure water and sediment mass are adequately conserved during model simulations.
- All assumptions made in the model framework need to be justified based on the physics/chemistry of the system being modeled. Decrease in model runtimes is not a defensible reason to use decoupled hydrodynamic and sediment transport models.

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Sediment Transport Modeling

– A sensitivity analysis should be performed on the chosen grid resolution to determine the optimal resolution required to be able to successfully calibrate and validate both the hydrodynamic model and the sediment transport model.
– If the hydrodynamic model cannot adequately represent flow phenomena such as density-stratified flows due to salinity and/or temperature gradients in lakes using the chosen numerical grid, then the grid resolution should be altered to improve the agreement between the model and data.

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Using SEDA Results to Make Site Decisions

- Identifying multiple lines of evidence
  – One of the program manager's strongest tools is historic site data. These data may include bathymetric surveys, flow histograms, construction records, navigation channel surveys, aerial photography, etc. Each of these data sources is analyzed to determine if it is sufficiently robust to develop an independent 'line of evidence' (LOE) that provides conclusions pertaining to sediment stability.

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Using SEDA Results to Make Site Decisions

– At most remediation sites, data should be collected to quantify hydrodynamic conditions, sediment types, contaminant distribution, and sediment processes.
– Additional field and laboratory data collection usually need to be collected if numerical modeling will be used as a LOE for evaluating sediment stability.

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Using SEDA Results to Make Site Decisions

– These data are used to develop model initial conditions, boundary conditions, and to parameterize the model.
– One of the main parameterization data sets is site-specific critical shear stress and erosion rate experiments. These data, coupled with hydrodynamic model output, can be used to develop an independent LOE for sediment stability.
– Numerical modeling of hydrodynamics and sediment transport are used to develop LOE.

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Using SEDA Results to Make Site Decisions

- The advantage of modeling is that is can also be used to predict what will happen in the future.
- These lines of evidence can be used to quantify sediment stability under specific remediation conditions, such as capping, enhanced natural recovery, or removal.
- These LOE permit the project manager to compare benefits of various remediation options. Therefore, the predictive models are one of the most powerful tools that a program manager has when assessing sediment stability.

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Concluding Thoughts

- Assessment of sediment transport requires very specific expertise.
- Sediment processes at each site are unique and appropriate methodology should be tailored for each site.
- Except for the most cursory assessment, outside expertise will probably be required to optimize and perform the SEDA.
- Understanding of processes at a specific site, coupled with experience from other sites is critical to success.

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More Concluding Thoughts

- Given the uncertain nature of this area of study, it cannot be expected that one person or organization can develop an optimized plan to develop a SEDA.
- The most successful SEDA studies have been guided by a technical review panel working with the site manager.
- Successful performance of a SEDA requires adaptive management so it will reflect improved process understanding as the study progresses.

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Discussion

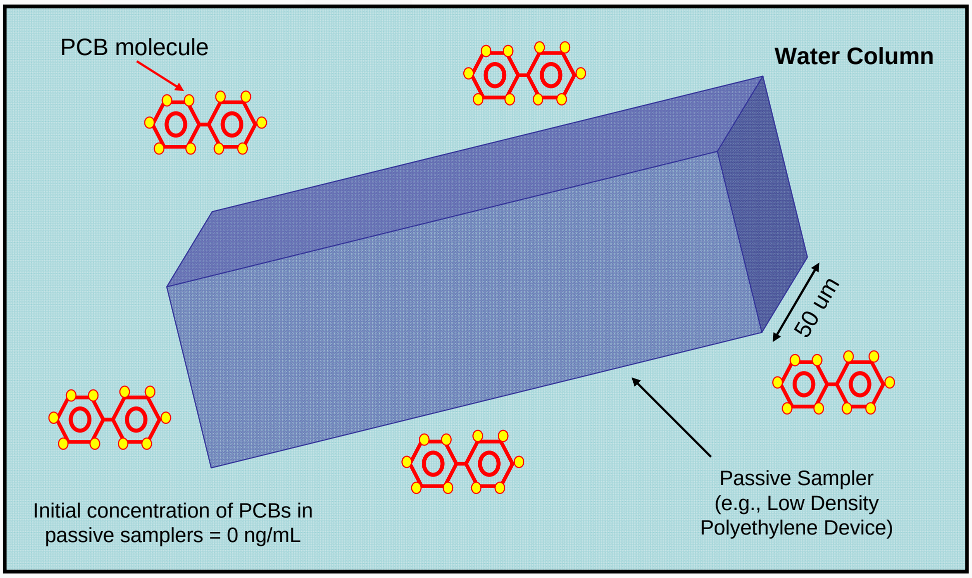
Using passive samplers to evaluate contaminant release, pore water, and bioavailability

Marc A. Mills, Ph.D.
USEPA
Office of Research and Development

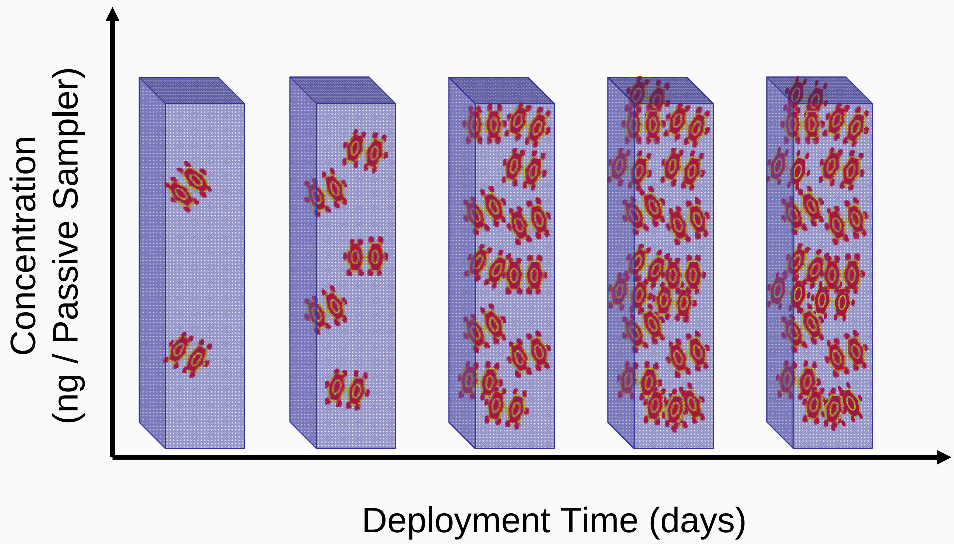
Outline

- Application of passive samplers
  - Passive sampler theory
  - Passive samplers
  - Technical issues using passive samplers
- Contaminant release
- Porewater
- Bioavailability
- Overall summary

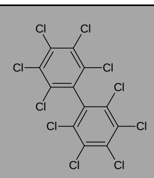
Passive Sampler Theory

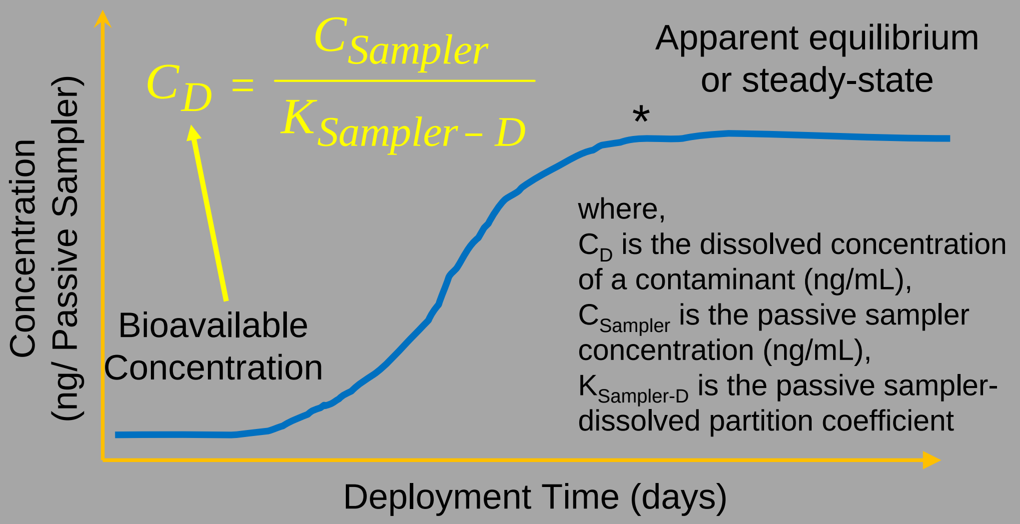


Passive Sampler Theory



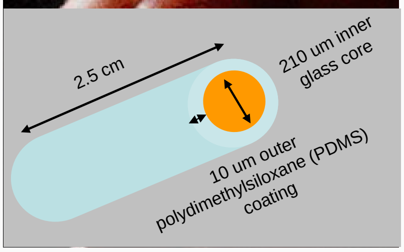
Passive Sampler Theory

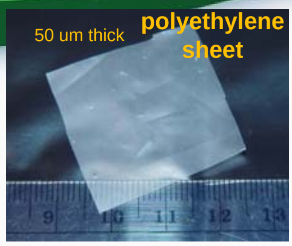




Types of Passive Samplers

SPME



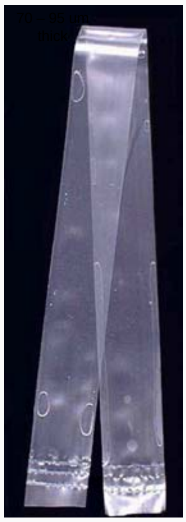


PED

(PED and SPMD allow access to molecules <600 molecular weight units)

POM

polyoxymethylene



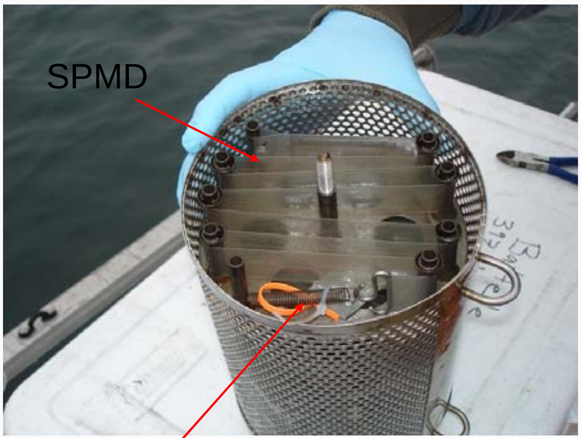
0.25 m

2.5 cm

SPMD (polyethylene tubing containing triolien)

Passive Samplers

PED



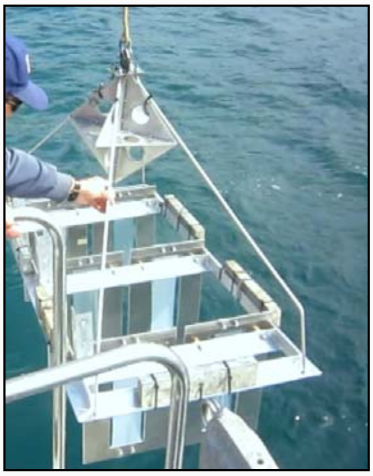
(NRMRL and Battelle)

SPME (stainless steel mesh cover)

Passive Sampler Application

Deployments

Water Column – PEDs
(flow meter deployment)

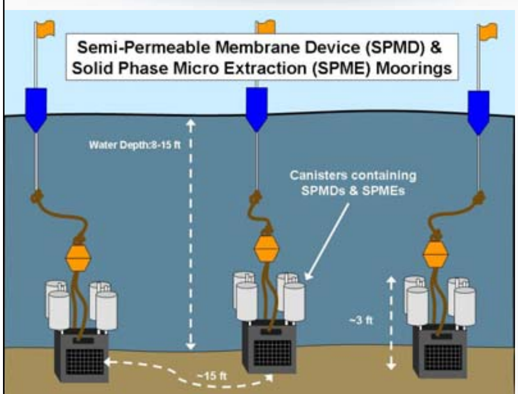


LACSD

Sediments – PEDs, POMs & SPME
(flux platform deployment)

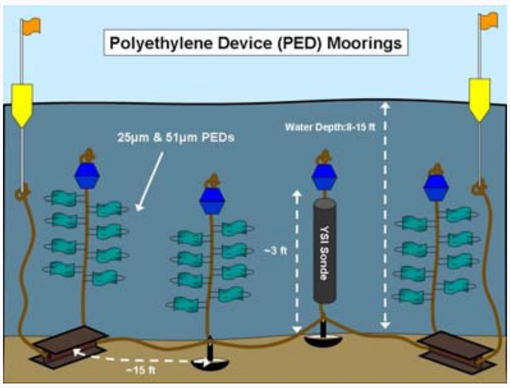
Passive Sampler Application

Passive Samplers



(Battelle)

Water Column Deployment



(Battelle)

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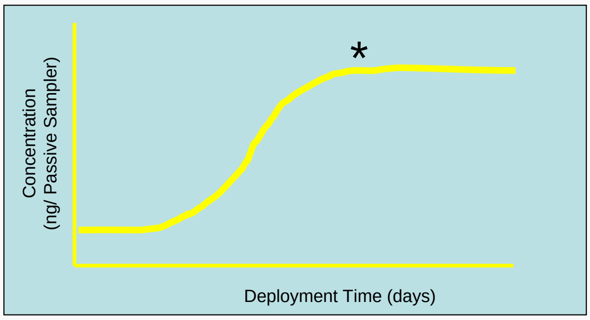
Technical Issues using Passive Samplers

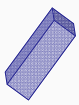
- Establishing when equilibrium occurs



  - Unless deployment time series data is available (i.e., $$$)
  - Challenge in all monitoring (including biomonitoring)
  - Solution: Use of performance reference compounds (PRCs) to establish equilibrium

Technical Issues using Passive Samplers

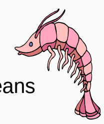
- Relating passive sampler accumulation to animal bioaccumulation



Passive Sampler (e.g., PED)

? =

Crustaceans



  - Critical for determining how to interpret passive sampler data
  - Large dataset needed to address this question
    - Ultimately generate a general linear model:

Animal concentration (ng/ml) = $\alpha + \beta *$ Sampler concentration (ng/ml)

Technical Issues using Passive Samplers

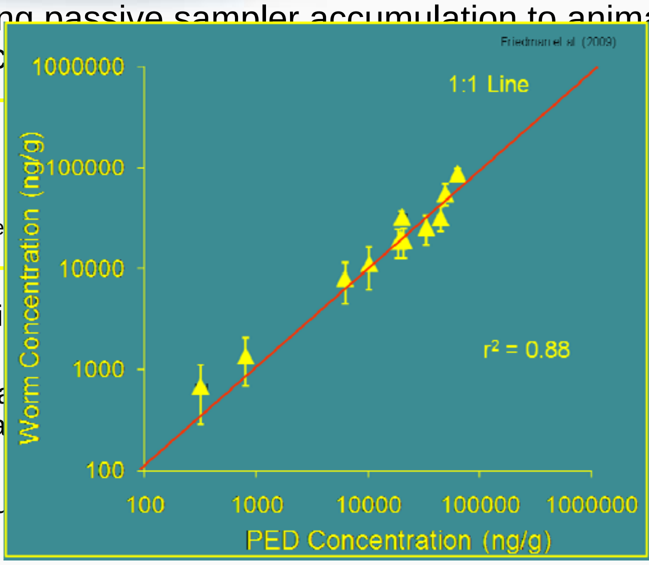
- Use of performance reference compounds (PRCs) to establish equilibrium
  - Concept
    - Pre-load passive sampler (e.g., SPMD, PED) with unique organic chemical similar to target contaminants
      - Similar K_{OW}s
      - For PCBs, rare congeners or polybrominated biphenyl ethers (PBDEs)
  - Approach
    - Measure initial (N_i) and final (N) PRC concentrations
    - Calculate PRC elimination rate constant (K_s (/time))
    - Adjust target contaminant concentration by PRC elimination rate constant

Technical Issues using Passive Samplers

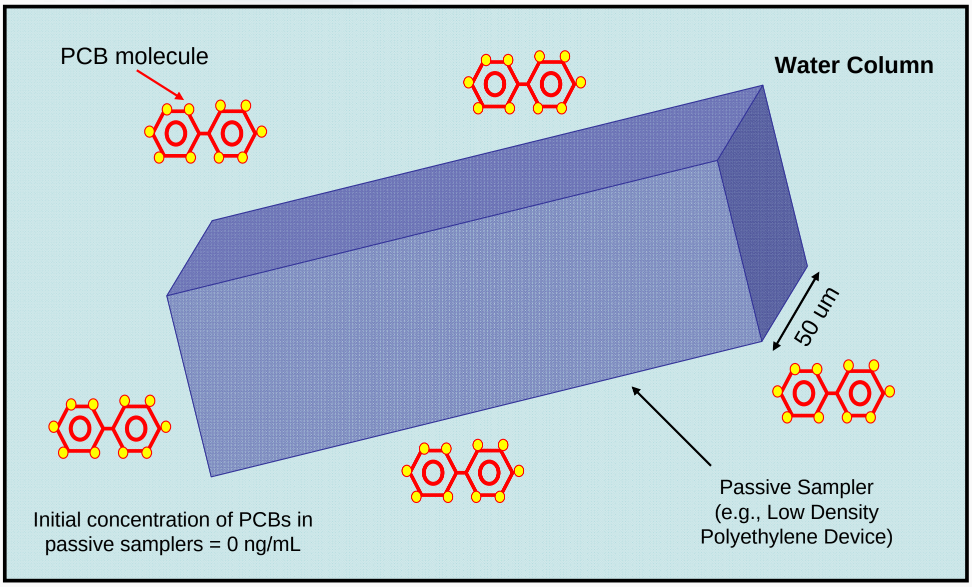
- Relating passive sampler accumulation to animal bioacc

Passive

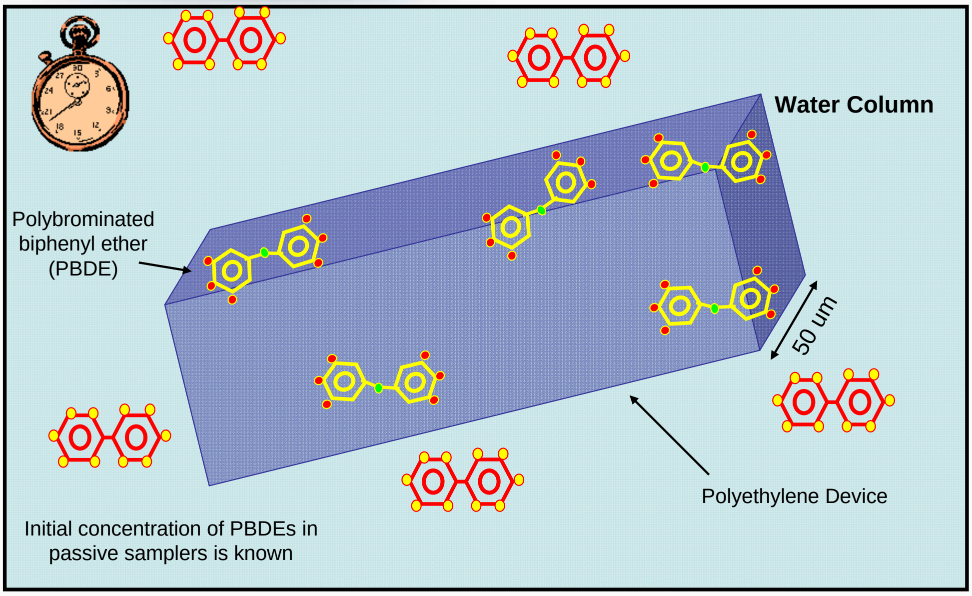
  - Criti ... er data
  - Data ... animal bioa
  - Solu



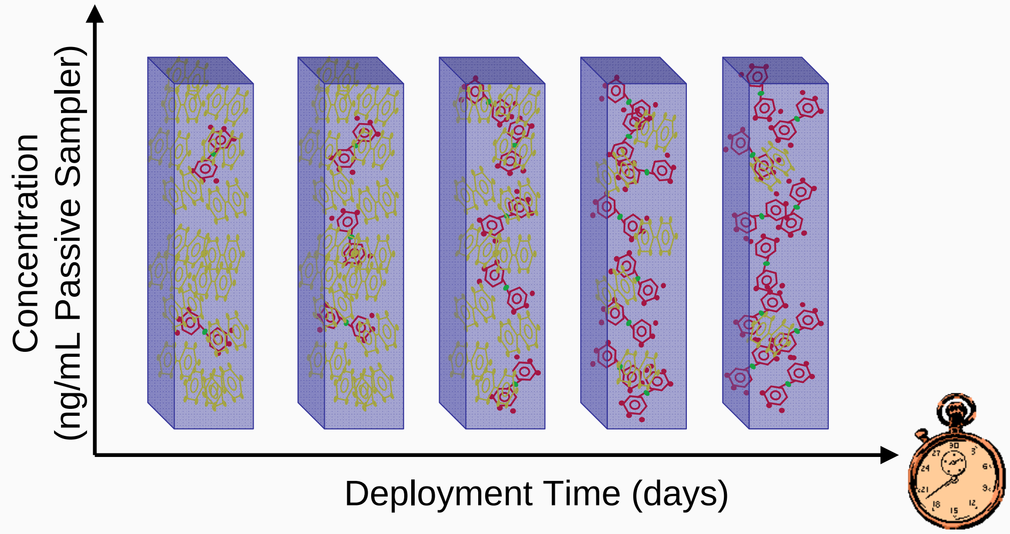
Passive Sampler Theory



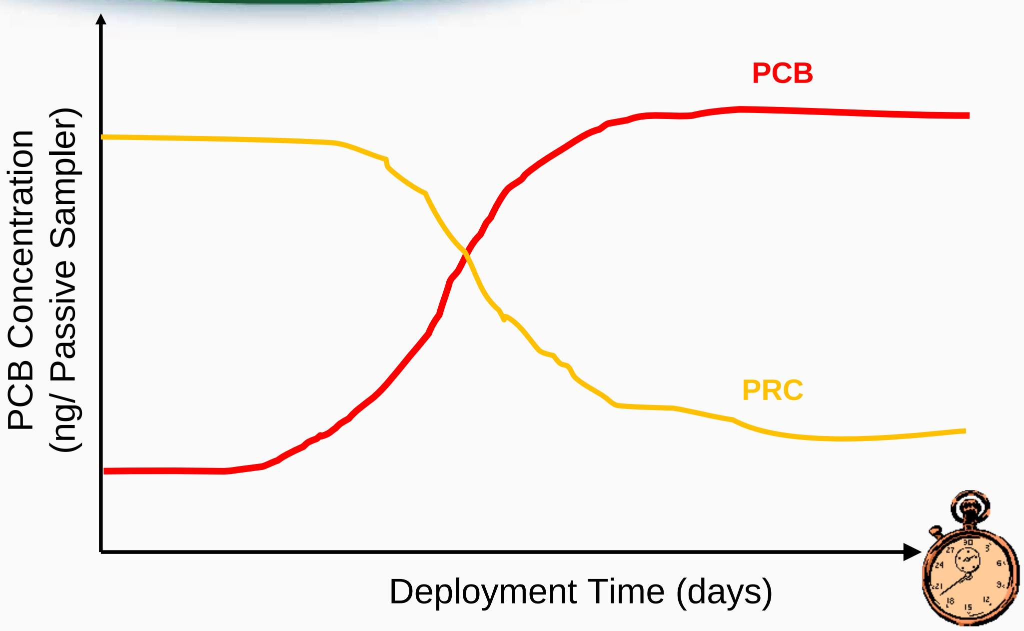
Technical Issues using Passive Samplers



Technical Issues using Passive Samplers



Technical Issues using Passive Samplers



Technical Issues using Passive Samplers

Using this experimental data, adjust sampler concentrations for equilibrium

- Calculate elimination rate constant (k_e) at time *t* (d):

$$k_e = -\frac{\ln(N / N_i)}{t}$$

- Calculate elimination ratio (R_e):

$$R_e = 1 - e^{-k_e t}$$

- Calculate equilibrium adjusted sampler concentration ($C_{SamplerEq}$) (ng/mL):

$$C_{samplerEq} = \frac{C_{sampler}}{R_e}$$

Advantages/Disadvantages Passive Samplers

Type	Advantages	Disadvantages
SPMD	Very well established	Analytical challenges
	Large scientific literature	Expensive
	Used globally	Establishing equilibration time
		Not viable in sediments (?)
SPME	Large scientific literature	Expensive to deploy
	Used widely	Fragile
	Analytically easy	
	Rapid equilibrium	
PED and POM	Growing scientific literature	Not established
	Used in North America and Europe	Establishing equilibration time
	Analytically easy	
	Inexpensive and rugged	

Costs Associated with Passive Samplers

Cost ($/sampler)

Type	Materials (samplers and deployment equipment)	Preparation (dialysis)	Chemical Analyses[a]	Total
SPMD[b]	390	115	400	905
SPME[c]	~35	-	450	~485
PED	<5	-	400	~405
POM	~50	-	400	~450

[a] - 2007-2008 Battelle costs (Duxbury, MA, USA)
[b] - Environmental Sampling Technologies (St. Joseph, MO, USA)
[c] - J. Schubauer-Berigan (U.S. EPA, NRMRL, Cincinnati, OH, USA)

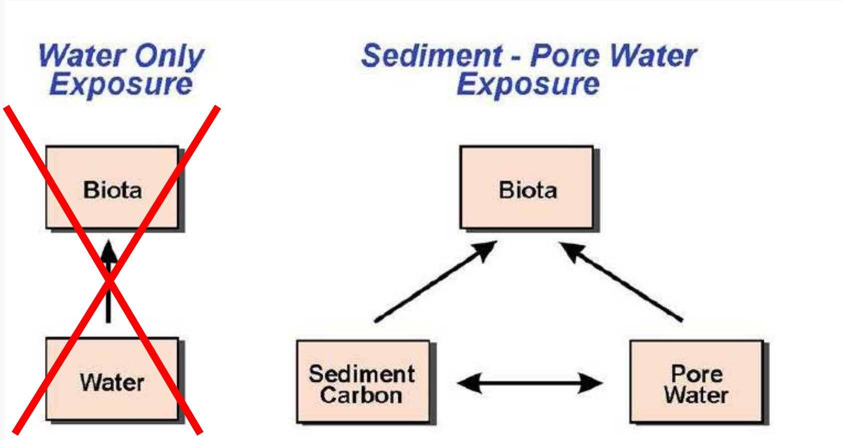
Pore Water Sampling

- Assessment of availability
  - Most direct relationship for partitioning HOCs

$$\frac{W_b}{f_l} \sim K_{ow} C_{pw}$$

  - Indicator for other contaminants
- In –situ treatment
  - Bulk solid concentration doesn't change
  - Porewater can provide indication of performance
- In-situ capping
  - Sands do not absorb contaminants
  - Absorption onto sorbents does not imply failure
  - Porewater concentration, profiles and change with time can indicate performance

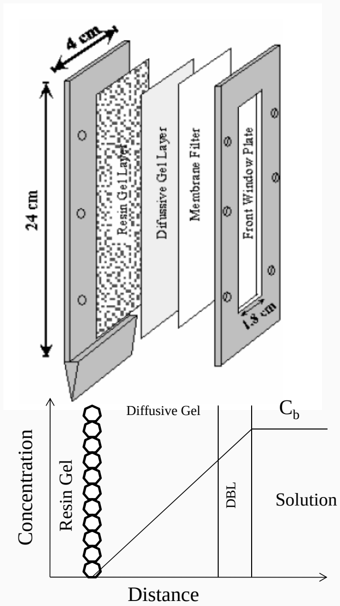
Does not imply porewater = route of uptake



Passive Sampling- Inorganics

Diffusion Gel Thin Film Device

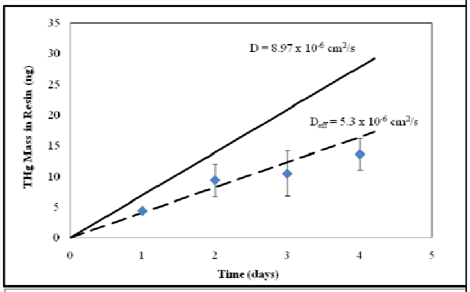
- Resin – Chelex 100
  - Hg, MeHg – thiol (3-mercaptylpropyl silica resin)
  - Acrylamide gel base
- Diffusion layer
  - Agarose gel

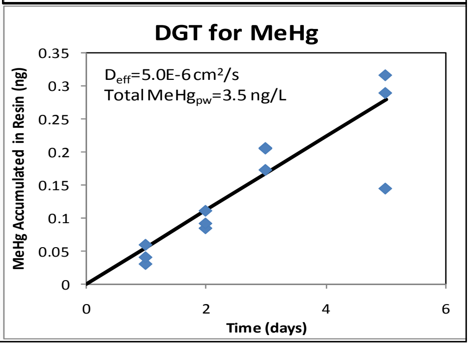


Hg/MeHg DGT

- Solid phase conc.
  - Hg – 9.7 ± 1 mg/kg
- Porewater conc.
  - Hg – 240 ng/L
  - MeHg – 3.5 ng/L

DGT for Hg





Passive Sampling- Organics

- Direct in-situ measurement
  - Polydimethylsiloxane (PDMS)
    - Thin coating on glass fibers- Moderate volume, good surface area to volume ratio, high internal diffusion rates, good insitu feasibility
  - Polyethylene (PE)
    - Thin rectangular sheets - High volume, good surface area to volume ratio, moderate internal diffusion rates, marginal insitu feasibility
  - Polyoxymethylene (POM)
    - Molded thermoplastic- High volume, fair surface area to volume ratio, slow internal diffusion rates, marginal insitu feasibility
- Similar sorption (POM>PE>PDMS), different geometries
- pg/L -ng/L detection with high resolution (~1 cm)
- Equilibrium uptake may require weeks to months
- Kinetics generally controlled by environmental setting

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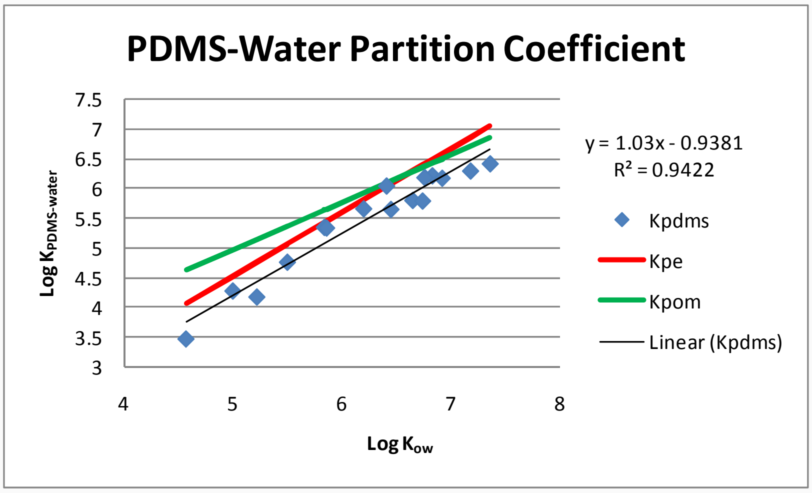
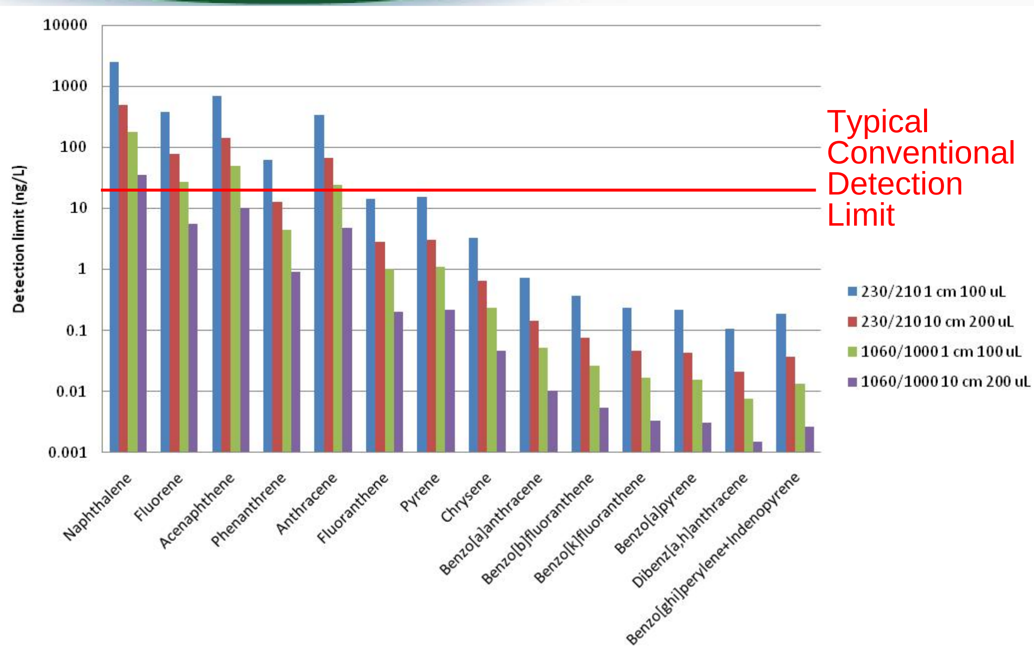
Partition Coefficient

- PAHs & PCBs on PDMS
- Comparison to PE/POM



Detection Limits of PAH_{16} (8310)



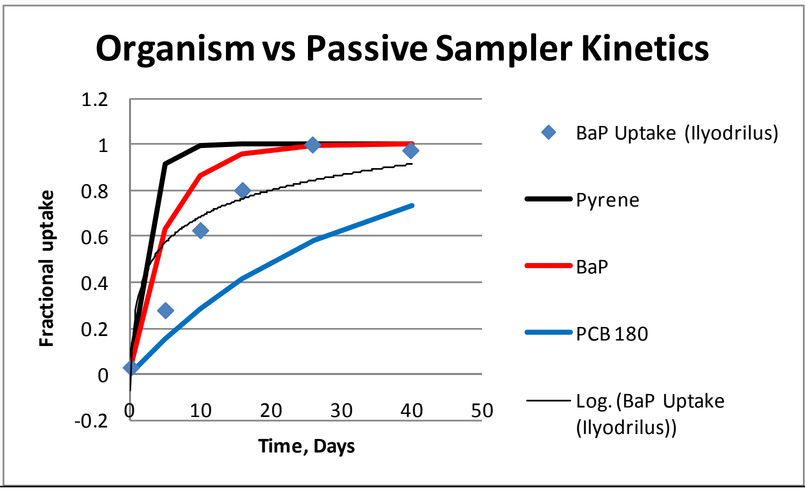
Polymer HOC Sampler Kinetics

- Largely defined by time required to replenish zone depleted of contaminant by sampler
- Large zone depleted and slow equilibrium
  - More hydrophobic compounds
  - Strongly sorbing passive sampler
  - Low sediment sorption capacity
  - Static (diffusion controlled) conditions
- Options
  - Performance reference compounds
  - Environmental exposure of sampler for different times
  - Different size (kinetics) samplers for same time
  - Model external transport (Lampert, 2010 PhD Dissertation)

- Organism uptake defined by sampler ***At Equilibrium***

$$\frac{W_b}{f_l} \sim K_{ow} C_{pw} \sim K_{ow} \frac{C_{PDMS}}{K_{PDMS}}$$

- Organism kinetics ≠ Passive Sampler Kinetics



Case Study – Hunters Point

- In –situ treatment
  - Bulk solid concentration doesn’t change
  - Porewater can provide indication of performance

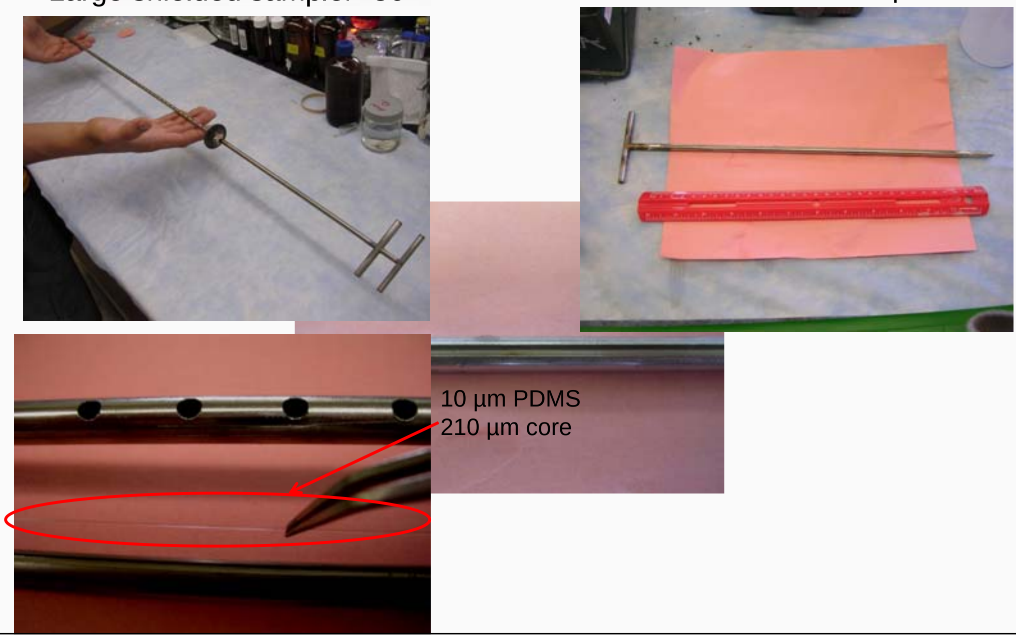
Hunter’s Point

- Stanford demonstration of activated carbon treatment
- Neanthes organisms exposed to PCB contaminated sediments
- Measurements by POM, PDMS as well as conventional measures

Profiling SPME

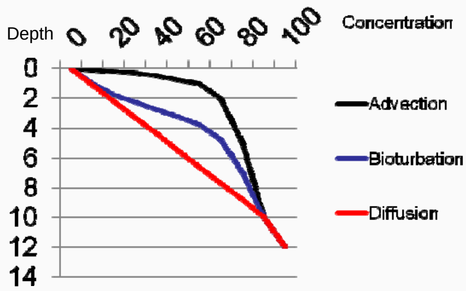
Large shielded sampler- 36”

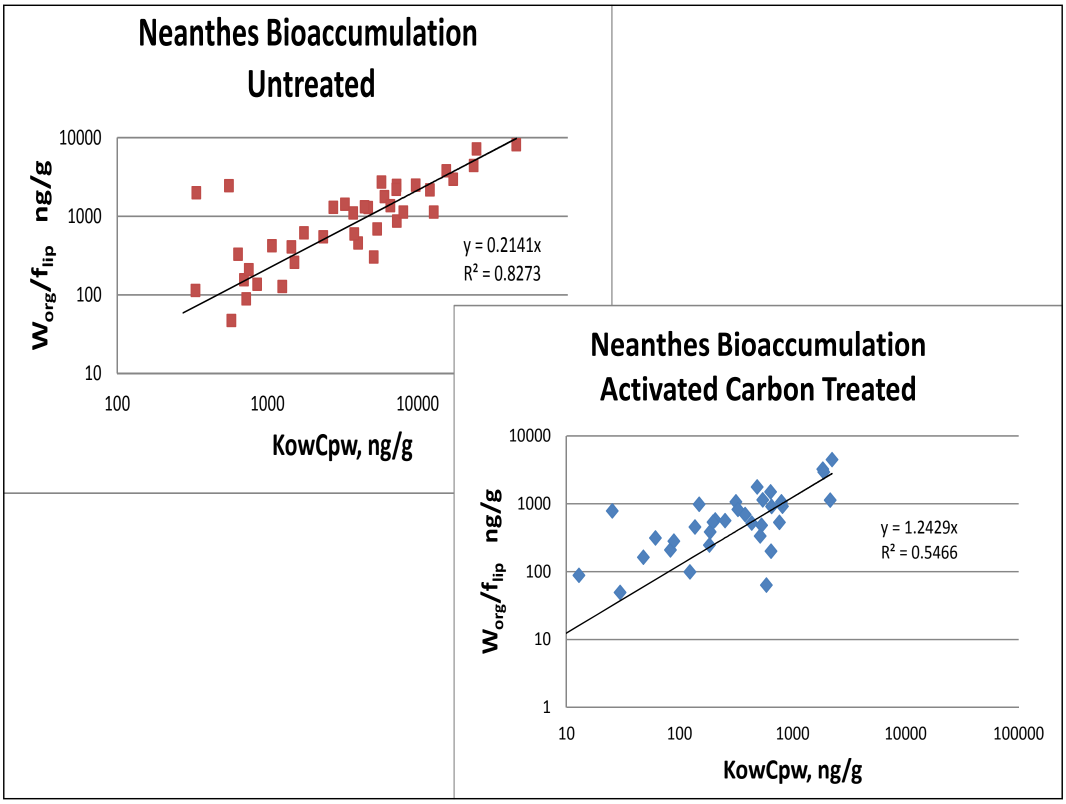
Small unshielded sampler- 14”



Why Profiling Passive Sampling?

- Avoids concerns about contaminant disturbance/dynamics associated with porewater extraction
- Provides in-situ profile with up to 1 cm vertical resolution depending on detection limits
  - Profiles provide rate/mechanism information
- Disadvantages
  - Deployment time
  - Interpretation





- AC treatment reduced porewater concentration
- Porewater concentration related to body burdens in organism (but treated sediment shows BCF~K_{ow} while untreated shows BCF~0.2 K_{ow})
- Bioaccumulation Differences
  - Differences in organism activity/kinetics?
    - Slower kinetics or reduced organism ingestion in untreated?
  - Differences in exposure?
    - Organisms at surface, PDMS buried 2-4 cm into sediment

PDMS/SPME as passive sampler

- Commercial fabrication readily available in variety of dimensions
- Easy analysis - wipe fiber, rinse and insert in autosampling vial with injection solvent
- Concentrates porewater for hydrophobic contaminants (Log Kow≥ 4)
  - Little advantage and special handling required for volatile, less hydrophobic compounds
- Slow kinetics for very hydrophobic (Log Koc≥6)
- Kinetics governed by surface area to volume ratio
- Detection limit governed by volume of sorbent

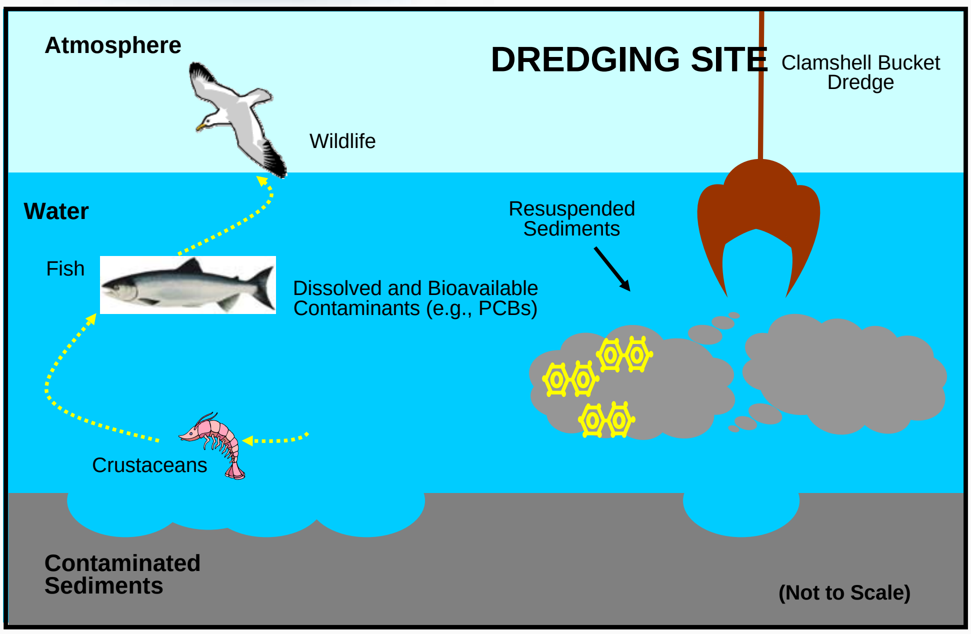
Status – Porewater Measurements

- Ex-situ
  - Standardized approach with EPA Method 8272
    - Laboratory generation of pore water, colloidal separation and analysis using SPME
  - Standardized approach developing with sediment
- In-situ (DGT-inorganics, SPME-organics)
  - Provides profile information
  - Not standardized due to site specific kinetics of sorbent uptake
  - Useful with “expert” guidance as part of a WOE approach

Case Study

New Bedford Harbor

Conceptual Model of Relationship Between Released Dissolved Contaminants and Aquatic Life



Materials and Methods

Site Description

- New Bedford Harbor
  - New Bedford, Massachusetts, USA
  - Superfund Site
  - Tidal estuary
- Two stations
  - NBH2 (low tide depth 3.4 m)
  - NBH4 (low tide depth 2.6 m)
- Sediments contaminated with very high PCB concentrations:
  - NBH2 ~ 100 mg/Kg Total PCBs
  - NBH4 ~ 10 mg/Kg Total PCBs

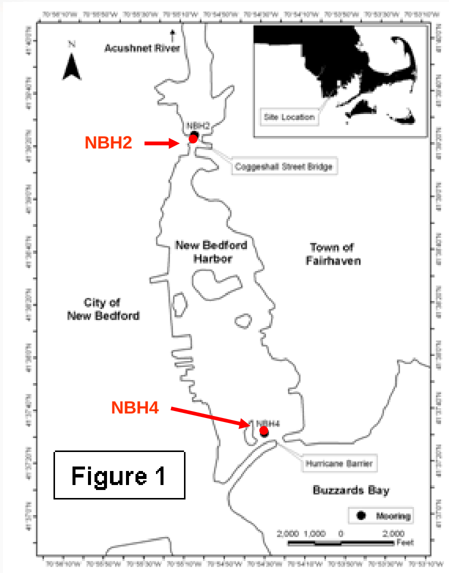


Figure 1

U.S. EPA Region 1 Biological Technical Assistance Group January 29, 2009

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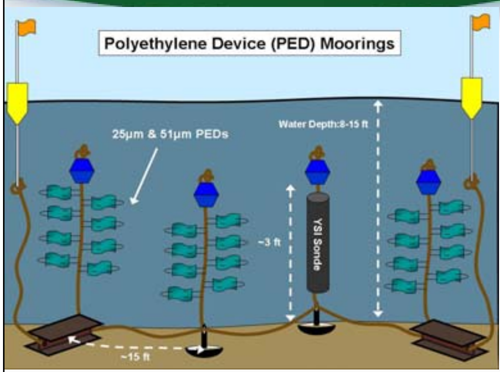
Materials and Methods

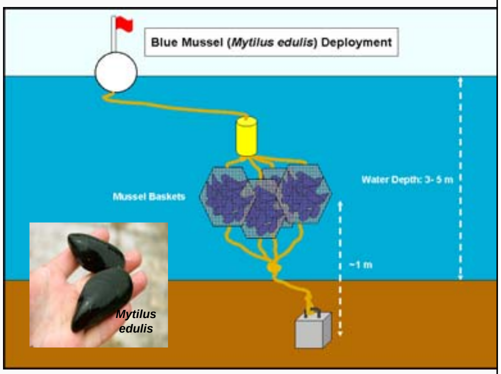
Sampler Temporal Sampling Designs

- Fall 2007
  - PEDs deployed in four temporal intervals:
    - 0-7 days; 0-14 days; 0-21 days; 0-28 days
  - Blue mussels (*Mytilus edulis*)
    - 0 - 32 days
- Total water samples collected in both Fall and Winter 2007

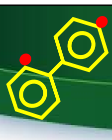
Materials and Methods



Sampler Deployments



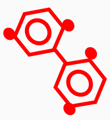
Materials and Methods



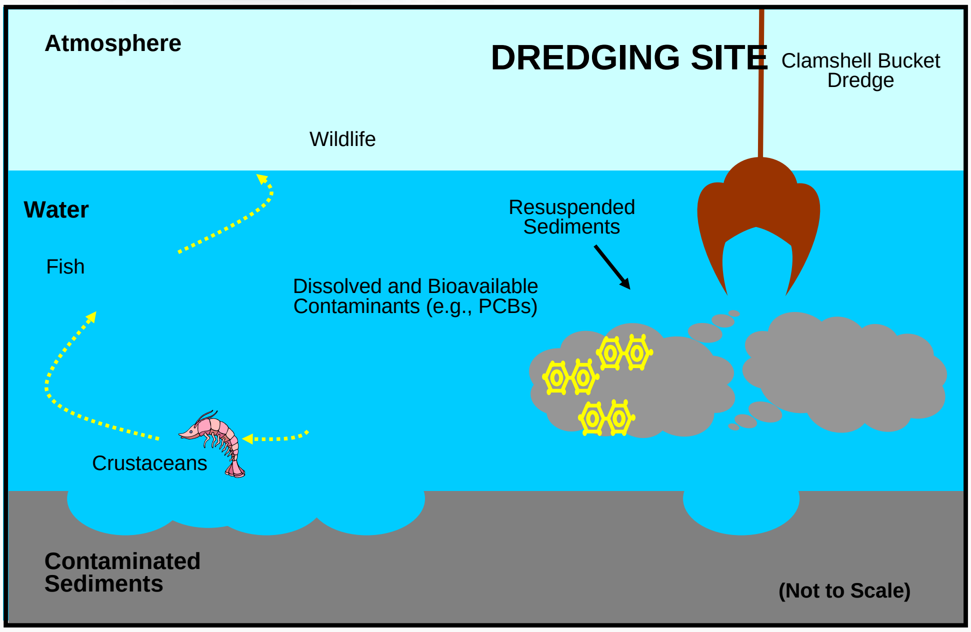

PCB Analyses

- All samples analyzed for 18 PCB congeners
- Emphasize PCB8, PCB18, PCB52 and PCB118
- Focus on NBH2 results

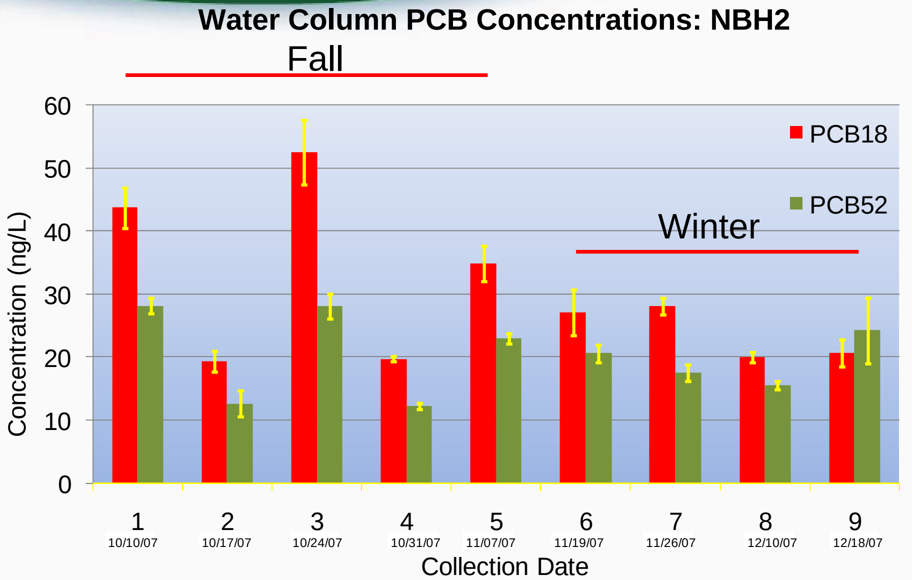
PCB	Structure	Log K_{OW}	Solubility (µg/L)
PCB8	Di-Cl	5.07	640
PCB18	Tri-Cl	5.24	450
PCB52	Tetra-Cl	5.84	33
PCB118	Penta-Cl	6.74	2



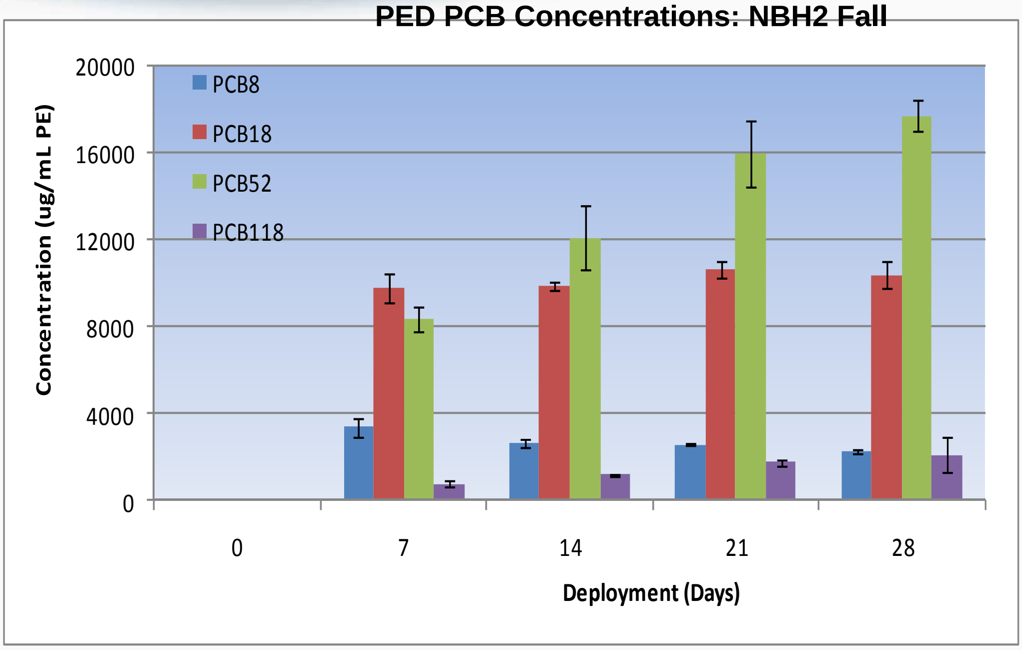

Conceptual Model of Relationship Between Released Dissolved Contaminants and Aquatic Life



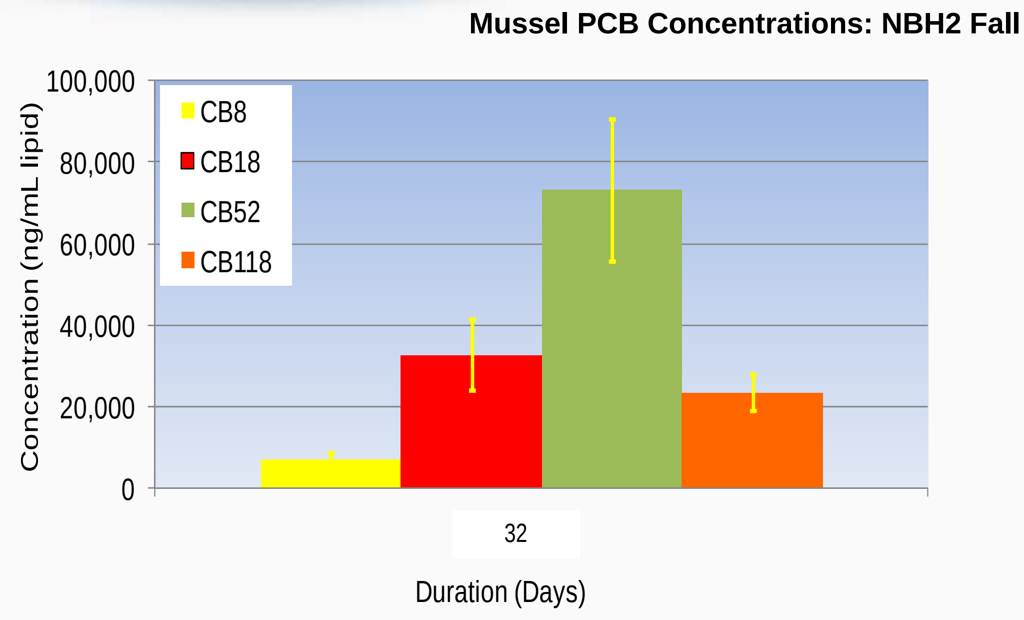
Results and Discussion



Results and Discussion

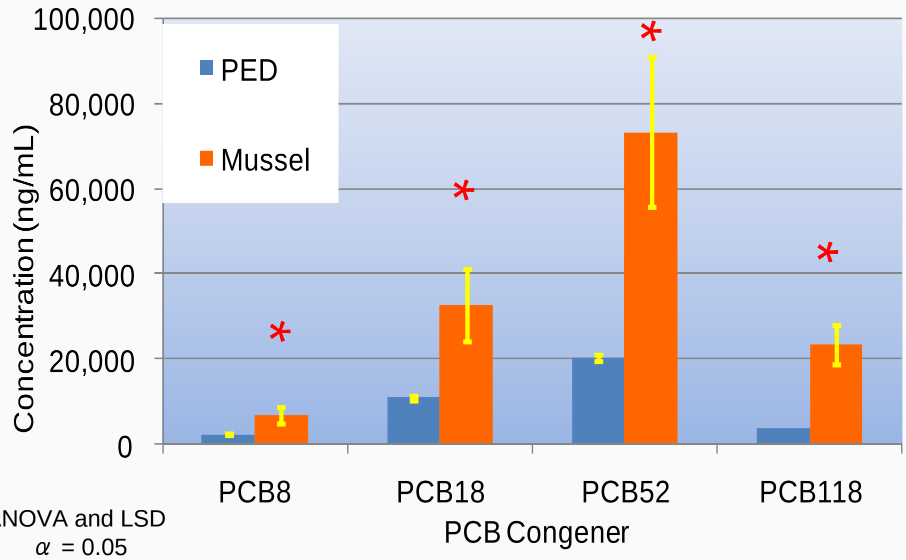


Results and Discussion



Results and Discussion

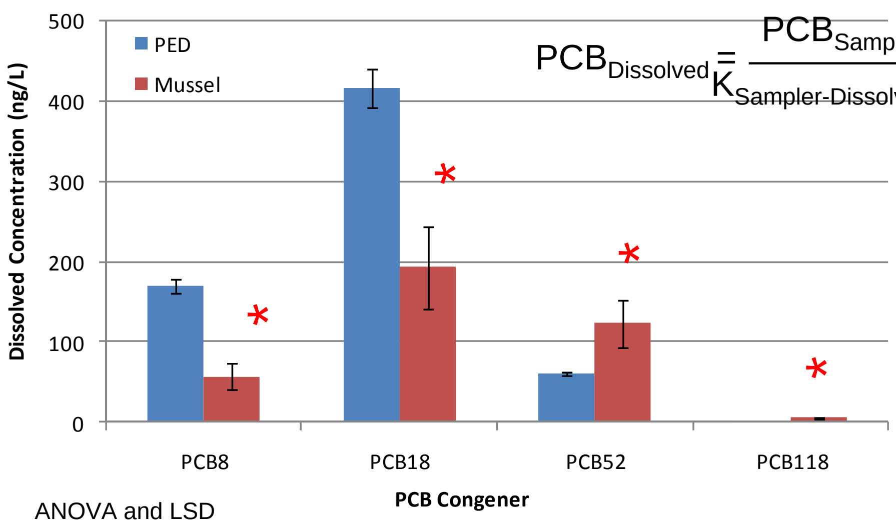
PED_{Eq} and Mussel PCB Concentrations: NBH2 Fall Day 28/32



ANOVA and LSD
$\alpha = 0.05$

Results and Discussion

PED_{Eq}- and Mussel-based Dissolved PCB Concentrations: NBH2 Fall Day 28/32



$$PCB_{Dissolved} = \frac{PCB_{Sampler}}{K_{Sampler\text{-}Dissolved}}$$

ANOVA and LSD
$\alpha = 0.05$

Summary

- Water column concentrations of PCBs shown to vary during the deployment time period
- Over the deployment time period, PED PCB concentrations continued to increase especially for higher molecular weight congeners
- Concentrations of PCBs accumulated by the PEDs and mussels were different by a factor of about four
- Estimated water column dissolved concentrations were different by a factor of about two varying by PCB congener

Overall Summary

- Passive samplers continue to show utility as useful cost-effective tools for quantifying dissolved and bioavailable concentrations of organic contaminants
- Applicable to a wide range of scientific and regulatory questions
  - Complement/predict biomonitoring data
  - Sediment-water column interactions
  - Release of dissolved contaminants into the water column from contaminated sediments
- Challenges remain regarding determining equilibrium and understanding the relationships between sampler and animal uptake

Conclusions

- Porewater concentrations often better indication of remedy performance
- Inorganics measurable with DGT (special resins and diffusion layer for Hg)
- Hydrophobic organics measurable with SPME using PDMS, POM, PE
  - Similar sorbents, different geometries and uptake kinetics
- Measurements indicate rate, magnitude of transport through cap

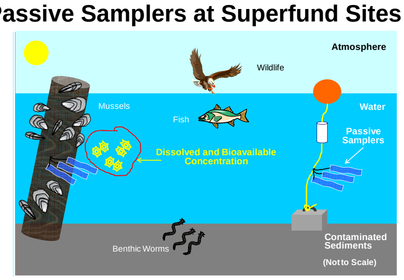
Passive Sampler Application

SAMS guidance document in preparation for using passive samplers at Superfund sites

Office of Superfund Remediation and Technology Innovation
and
Office of Research and Development

Sediment Assessment and Monitoring Sheet (SAMS)

Guidance for the Application of Passive Samplers at Superfund Sites



OSWER Directive 9200.1-96FS

February 2012

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- Robert Burgess, EPA ORD NHEERL
- Danny Reible, University of Texas
- Joe Schubauer-Berigain, EPA ORD NRMRL

55

Discussion

Taiwan-EPA Contaminated Sediment Workshop June 14-15, 2011: U.S. EPA's Approach to Understanding Sediment Site Conditions, Characterizing Contamination, and Reducing Uncertainties in Making Decisions to Manage Risks from Contaminated Sediments

Sediment Ecotoxicity Testing: What Works, Where, and Why?

Marc S. Greenberg, Ph.D.
U.S. EPA OSWER OSRTI Environmental Response Team
2890 Woodbridge Ave.
Edison, NJ 08837
732-452-6413
greenberg.marc@epa.gov

Acknowledgements

Jeffery A. Steevens, Army Engineer Research and Development Center, Vicksburg, MS

Christopher G. Ingersoll, Columbia Environmental Research Center, U.S. Geological Survey

Donald D. MacDonald, MESL, Nanaimo, BC, CAN

EPA 2005 Sediments Guidance

- **Toxicity tests typically provide an integrated measurement of the cumulative effects of all contaminants.**
- **For toxicity tests to be useful, it is important to have demonstrated a concentration-response relationship.**
- **However, no single endpoint can quantify all possible risks**
  - combination of physical, chemical, and biological endpoints usually provides best overall approach for measuring risk reduction and assessing the long-term effectiveness of a remedial action

U.S. Environmental Protection Agency 3

Sediment Toxicity Testing—Use of Data

- **Site-specific exposure-response relationships useful to informing risk managers**
- **PRG footprint for benthic toxicity can be developed**
- **Provides pre-remedial baseline data**
  - Useful if benthic toxicity will be part of long-term monitoring plan

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Sediment Toxicity Testing—*Needs*

- **Samples for testing span a range of exposure concentrations (gradient needed)**
- **Choose appropriate test species**
  - Freshwater or marine system?
- **Choose appropriate endpoints**
  - Survival, Growth, Reproduction
  - Acute, chronic?
- **Follow defensible methods of collection, storage, manipulation of sediments, and toxicity testing**
  - EPA and ASTM

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Sediment Toxicity Testing—*Needs*

- **Measure COPCs and potentially confounding factors!**
  - Metals present? SEM, AVS
  - PAHs? Σ ESB-TU model (34 parent & alkylated PAHs)
  - Ammonia, pH, H_2S
    - Whole sediment and pore water
  - TOC, grain size
  - Other pore-water
    - DOC, major cations and anions, pH

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Table 4. Spearman Rank Correlation for Toxicity Data and the Sedim
Chemistry Data[1]

Variable	**Toxicity endpoint** *Hyalella azteca* survival	*Hyalella azteca* length
Pore-water ammonia (total)	-0.26 (26)	-0.72 (15)*
Pore-water ammonia (unionized)	-0.37 (26)	-0.45 (15)
Grain size	0.36 (25)	0.14 (15)
TOC	-0.05 (29)	0.04 (18)
SEM-AVS	-0.30 (29)	-0.43 (18)
Toxic units metals	-0.11 (27)	-0.031 (17)
Total PCBs	-0.66 (25)*	-0.57 (15)
Total PAHs	-0.64 (29)*	-0.38 (18)
Average PEC quotient for metals	-0.74 (29)*	-0.49 (18)
Mean PEC quotient	-0.77 (29)*	-0.57 (18)

[1] Asterisk indicates significant correlations

Bulk Sediment Toxicity Tests-
Considerations for you and your team

Zumwalt Water Splitting Chamber

Sediment Toxicity Test Manifold

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Bulk Sediment Toxicity Tests

ADVANTAGES

- **Limited manipulation of sediment and porewater.**
- **Most realistic laboratory exposure to sediment dwelling organisms, includes most accumulation routes.**
- **Greatest acceptance by regulatory and scientific community. Typically used in sediment quality evaluations, including dredging material evaluation, environmental monitoring, site characterization and risk assessment.**
- **Allow assessment of variety of endpoints: Survival, growth, reproduction, etc.**

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Sediment phases evaluated in toxicity tests

–Whole-sediment tests*
- Sediment and associated pore water that have had minimal manipulation

–Pore-water tests*
- Water occupying space between sediment particles
- Isolate by centrifugation, peepers, suction
- Test water phase and manipulate samples

–Elutriate tests
- Sediment resuspension associated with dredging
- Test water phase

–Organic extracts
- Solvent extract sediment (e.g., DMSO)

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Advantages of whole-sediment toxicity tests (USEPA, ASTM)

- –Provide a direct measure of benthic effects
- –Limited special equipment is required
- –Methods are rapid and costs known
- –Legal and scientific precedence exist for use
- –Can be applied to all chemicals of concern
- –Testing field-collected samples reflects effects of all contaminants and interactions
- –Amenable to field validation
- –Tests with spiked chemicals and manipulations of whole sediment (i.e., TIEs) provide data on cause and effect

Disadvantages of whole-sediment toxicity tests (USEPA, ASTM)

- –Collection, handling, storage can alter bioavailability
- –Spiked sediment may not represent field sediments
- –Geochemistry of sediment can affect responses
- –Indigenous animals in field sediments
- –Route of exposure may be uncertain
- –Testing field samples may not identify cause and effect
- –Limited availability or application of chronic methods
- –Challenges in predicting ecological effects
- –Do not directly address human health effects

Large Number of Animals & Tests Available

Freshwater Bulk Sediment Tests

Ideal sed tox test organism should:

1. Have demonstrated relative sensitivity to a range of contaminants of interest
2. Have interlaboratory comparisons of procedures
3. Be in direct contact with sediment.
4. Be readily available from culture or through field collection; easily maintained in the laboratory.
5. Be easily identified.

Whole-sediment toxicity and bioaccumulation tests for freshwater habitats (USEPA 2000, ASTM 2003a,b)

– *Hyalella azteca* (amphipod)
- Duration: 10 to 42 days
- Metrics: Survival, growth, reproduction

– *Chironomus dilutus* (midge; formerly *C. tentans*)
- Duration: 10 to 60 days
- Metrics: Survival, growth, reproduction, emergence

10-d tests for S & G most common for H.a. & C.d.

– *Lumbriculus variegatus* (oligochaete)
- Duration: 28 days
- Metrics: Bioaccumulation and behavioral observations

– Other organisms (ASTM 2003a): *Tubifex tubifex, Diporeia* spp., cladocerans, mayflies

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Whole-sediment toxicity and bioaccumulation tests for estuarine and marine habitats (USEPA 1994, 2001; ASTM 2003c)

– Amphipods
- Acute (4 species)
  - Duration: 10 days
  - Metrics: Survival (and reburial)
- Chronic (*Leptocheirus plumulosus*)
  - Duration: 28 days
  - Metrics: Survival, growth, reproduction

– Polychaetes and mollusks
- Duration:10 to 28 days
- Metrics: Bioaccumulation, behavior

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Sediment Chronic/Sublethal Tests

- Sediment toxicity typically evaluated using acute tests which measure lethality following short-term exposures
  - Advantages
    - Short term
    - Low maintenance
    - Low cost
  - Disadvantages
    - May lack adequate sensitivity to detect subtle effects of low to moderate-level contamination

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Hyalella Acute vs Sublethal Endpoints

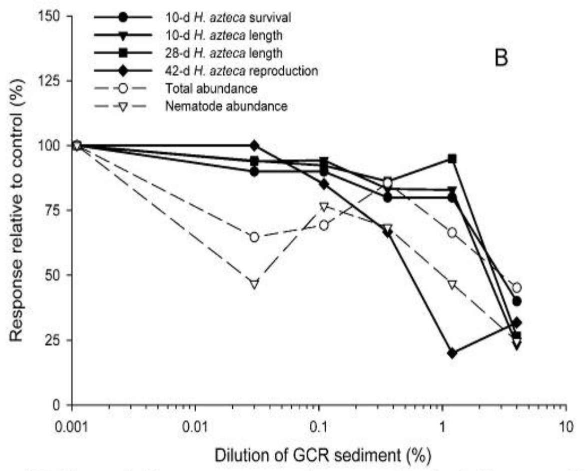

Fig. 1. Responses of *Hyalella azteca* in laboratory exposures compared to responses of taxa in colonizing trays containing a gradient of dichlorodiphenyldichloroethane (DDD) spiked in sediment (**A**) or dilutions of Grand Calumet River (GCR) sediment (**B**). Only field endpoints with significant treatment effects and select endpoints for the *H. azteca* tests are included.

Take home message: Chronic FW bioassays provide additional sensitivity and information about chronic effects

Sediments from Calumet River

Ingersoll C. G., et al. (2005) A field assessment of long-term laboratory sediment toxicity tests with the amphipod *Hyalella azteca*. Environmental Toxicology and Chemistry, 24 (11): 2853-2870

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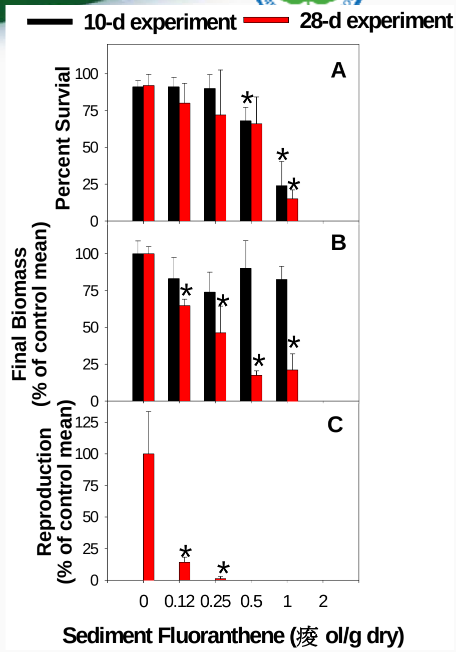
Leptocheirus Acute vs. Chronic Tests

Ten-day and 28-day exposure to sediments spiked with fluoranthene.



Take home message: In general acute marine bioassays are as sensitive as chronic for survival, but without all the failure, variability, and interpretation issues of other endpoints.

Porewater Extraction & Testing

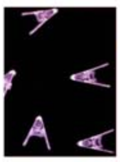
In situ

- Suction
- Peepers (equilibration)

Laboratory

- Centrifugation
- Vacuum filtration
- Pressure filtration

Unfertilized and Fertilized Sea Urchin Egg

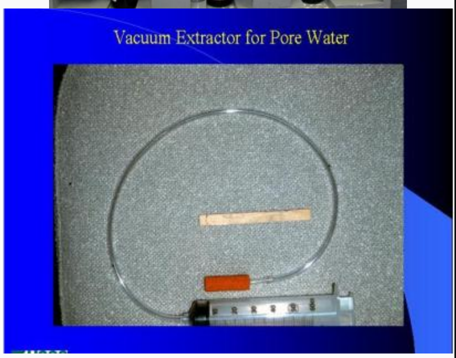


Sea Urchin echinoplutei

Red fish (survival)

Macro-alga germination, growth

Sea Urchin Test Setup



Advantages of pore-water toxicity tests

– Can appear to be more sensitive compared to whole-sediment toxicity tests
– Estimate chronic or sublethal effects often in short duration exposures (1 to 4 days)
– Screening
– Impacts on water column species
– Equilibrium partitioning studies
– Toxicity identification evaluations (TIEs)

Bay et al. (2003)

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Disadvantages of pore-water toxicity tests

– Ecological relevance
– Species not adapted to pore-water environment
– Results often non-discriminatory
– Do not address other exposure routes
– Sample handling artifacts
  - Oxidation and precipitation
  - Loss of chemical to sampling apparatus
– Exposure duration (snapshot in time)
– Limited volume of pore water available
  - Biomass loading problems of test organisms
  - Static conditions
  - Limited chemistry
– Lack of standard methods

Bay et al. (2003)

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Recommendations for Sediment Toxicity Tests (Take Home Messages)

1. **Focus on whole sediment toxicity tests**
   - Freshwater: Acute and Chronic *Hyalella azteca*
   - Freshwater: Acute and Chronic *Chironomus dilutis*
   - Marine: Acute amphipod, *Leptocheirus*
   - Marine: Chronic, *Neanthes*
   - *Note: don't use mysids—not much contact with sediment*
2. **Carefully consider odd tests/unusual animals: elutriate, sediment water interface, pore water tests (all have confounding factors that can muddle conclusions)**
3. **Be sure to confirm the lab can actually run the test and has a successful track record**

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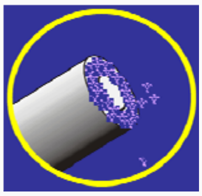
Passive samplers for estimating pore water concentrations

- **Technologies**
  - For organics: POM, SPME
  - For metals: Diffuse Gradients in Thin Films (DGT)



- **Uses**
  1. As a line of evidence (LOE) for **bioavailability** of CoC; **direct measure of pore water concentration**
  2. Use to help guide selection of samples for bioassay
- **Benefits: relatively easy and inexpensive; majority of cost is from chemical analysis**
- **Don't use alone to predict bioaccumulation; calibrate to your site using direct measurements or bioassay**

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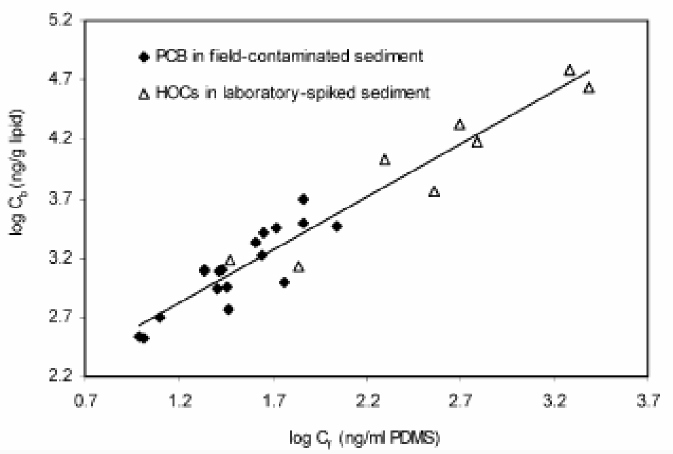
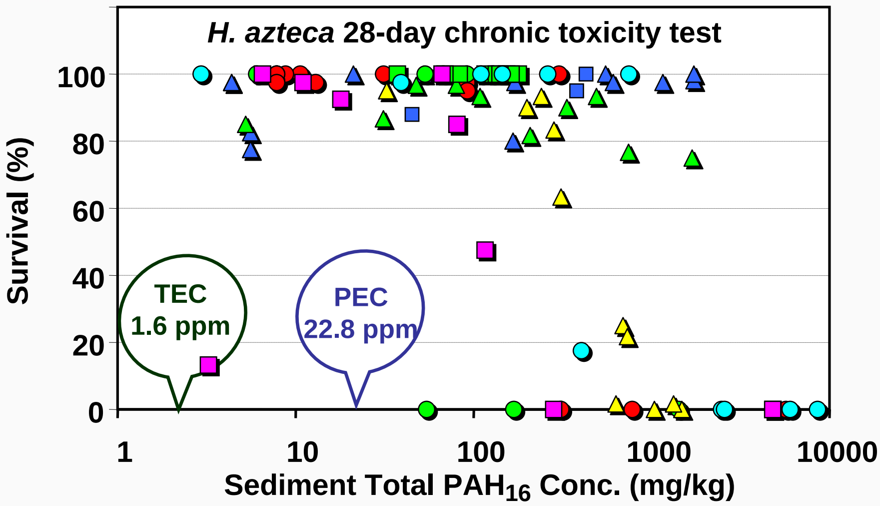
SPME Concentration Predictive of Body Burden in aquatic worms



- Field-contaminated sediments
- HOC laboratory-spiked sediments
- *Lumbriculus variegatus*

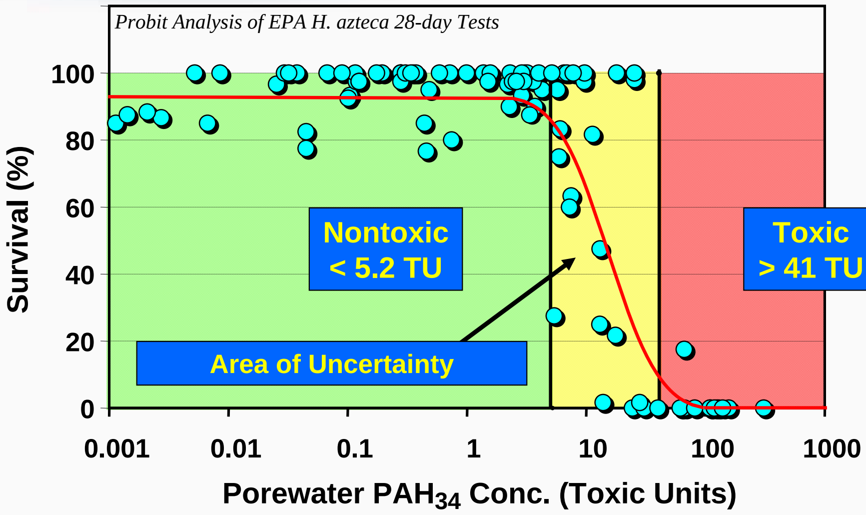
You et al. 2006, Environ. Sci. Technol. 40: 6348

Poor Relationship Between the bulk Total PAH$_{16}$ and Toxicity



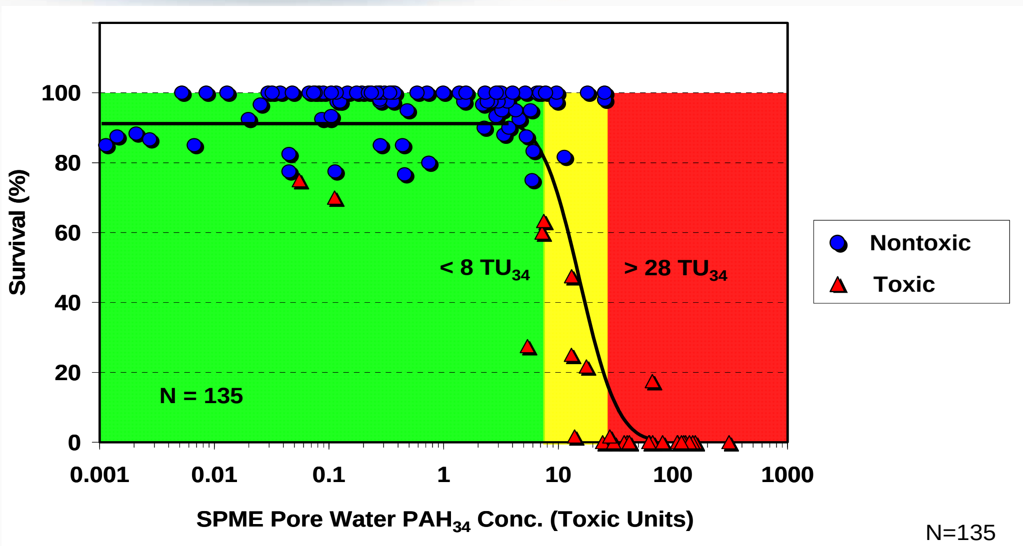
Adapted from Kreitinger et al., 2006; 2009

Enhanced Predictability by Measuring Dissolved [PAH] in Porewater



Adapted from Kreitinger et al., 2006; 2009

Enhanced Predictability by Measuring Dissolved [PAH] in Porewater



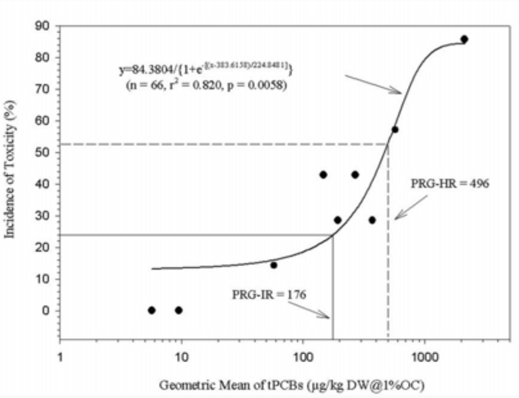
N=135

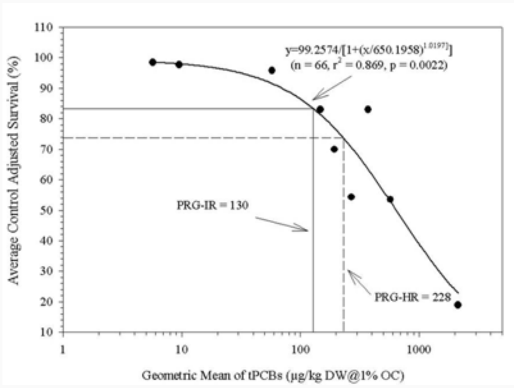
Adapted from Kreitinger et al., 2006; 2009

Sediment Toxicity Testing—Use of Data

Indiana Harbor sediments

- **Develop site-specific relationships between whole-sediment chemistry and whole-sediment toxicity**

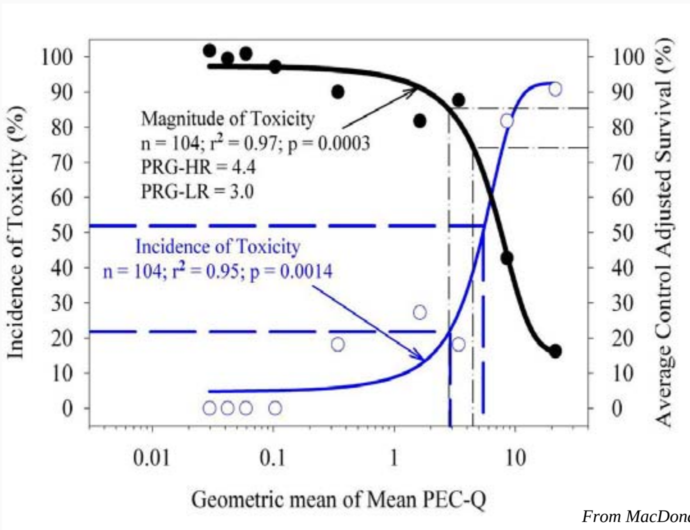




From MacDonald et al., SETAC 2005

Sediment Toxicity Testing—Use of Data

- **Develop site-specific relationships between whole-sediment chemistry and whole-sediment toxicity.**



From MacDonald et al., SETAC 2005

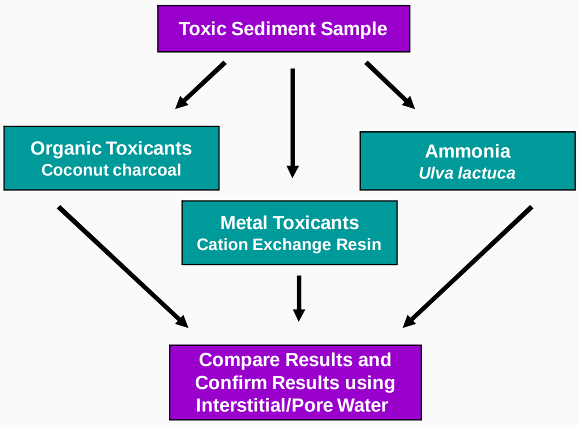
Parting Thoughts on Testing

- **Lots of options for testing sediments for adverse effects on survival, growth, and reproduction of ecologically relevant organisms**
- **Many standardized methods exist**
- **No matter what you do, it needs to be tied back to the sediment contaminant(s) to be useful**
  - Have the meeting on **what toxic means** and **how the data will be analyzed** before you run the tests!
  - Test sediments over a concentration gradient or you will not be able to develop a concentration-response relationship for use in decisions

EXTRA TIME?

Toxicity Reduction/Identification Evaluation

- **TRE / TIE developed and effectively used within WET testing and water column toxicity**
- **Recent development of TIE guidance for sediments (led by Ho, Burgess, Tjeerdema)**



Sediment TIE manipulations

AMMONIA

- **Zeolite (Besser, 1998);**
  - Sorbs ammonia from sediment
  - Effective in freshwater systems
- ***Ulva lactuca* (Burgess 2003)**
  - Reduces ammonia from overlying water
  - Effective in marine systems

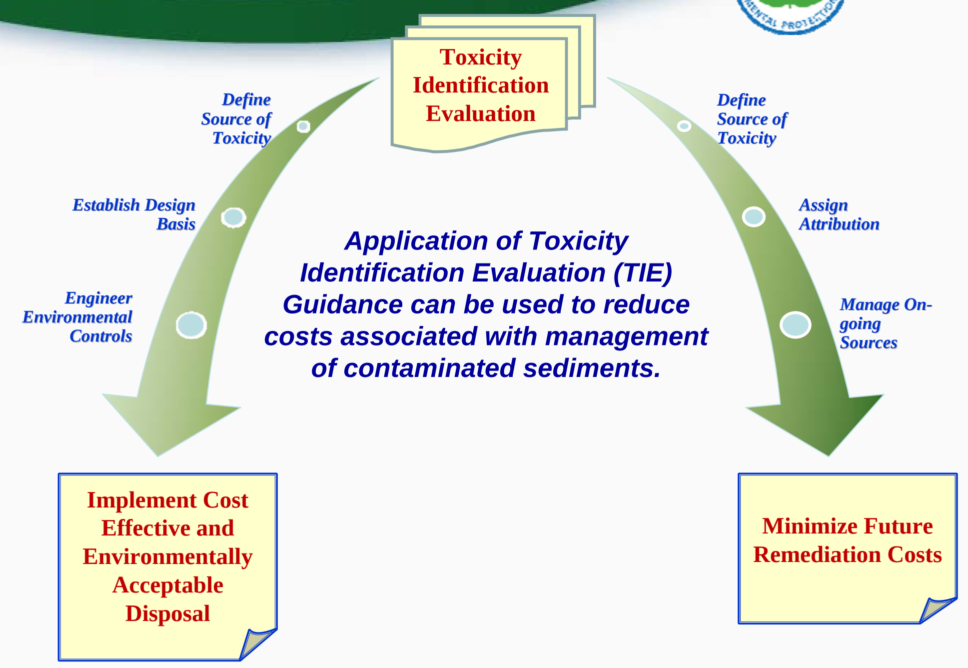
ORGANICS

- **Coconut charcoal (Lebo, 2000)**
  - Sorbs HOCs
- **Ambersorb (Kosian, 1999)**
  - Adsorbs HOCs
  - Can isolate from sediment and then eluted with solvent

- Eluate can be added to water and toxicity assessed

METALS

- **Cation X-Δ resin (Burgess, 2000)**
- **SIR-300 sorbs metals (1° cationic)**
  - Can strip metal from resin using acid.
  - Acid solution can be added back to water to assess toxicity.



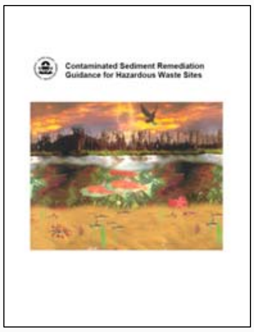
Recommendations for TIE

- TIE can be used to identify a risk driver
- It has limitations when toxicity is marginal— (i.e., 20-50 % mortality); difficult to see differences between treatments
- Running a TIE on a single sample requires around 10 to 15 gallons of sediment for midge and amphipod bioassays
- Need to collect material when you collect initial material (expensive) or recollect and retest (even more expensive)
- Don’t use a TIE unless it is critical to decisions

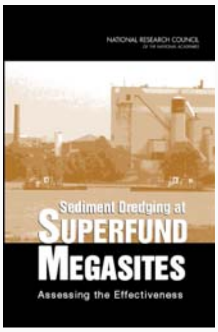
Monitoring Objectives and Baseline Data Acquisition

Stephen Ells
US EPA
ells.steve@epa.gov
and
Karl Gustavson
Army Engineer Research and Development Center
Karl.E.Gustavson@usace.mil

Primary Resources



USEPA. 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. EPA-540-R-05-012.



NRC. 2007. Sediment Dredging at Superfund Megasites. Assessing the Effectiveness.

Navy SPAWAR. Long-Term Monitoring Strategies for Contaminated Sediment Management. Final Guidance Document. Feb. 2010.

Introduction

- A successful sediment remedy is one where selected sediment chemical or biological cleanup levels have been met and maintained over time and risks reduced to acceptable levels (EPA 2005, p.8-1).
- Must be able to measure remedy performance and effectiveness to learn and improve cleanup responses

3

Introduction

Key metrics for US approach to evaluate remedy effectiveness:

- short- and long-term remedy performance (reduction and maintenance of sediment contaminant levels)
- short- and long-term risk reduction (e.g., decreases in fish tissue levels or benthic toxicity).

(EPA 2005, p. 8-1)

4

Types of Monitoring

- **Baseline monitoring** establishes a pre-remediation basis for comparison during subsequent monitoring.
- **Construction monitoring** evaluates parameters directly related to the construction.
- **Performance monitoring** evaluates specifically whether the remedy is performing as designed.
- **Remedial goal monitoring** evaluates whether contaminant exposures and corresponding risk are reduced to acceptable levels.

5

Remedial Goal vs. Performance Monitoring

- Distinguishes whether remedial technology worked from whether entire remedy worked.

	Dredging	Capping	MNR
Performance Monitoring	Removal of targeted mass to targeted concentrations	Cap is isolating contaminants	MNR processes occurring; decreased exposure
Remedial Goal Monitoring	Fish tissue contamination / benthic toxicity	Fish tissue contamination / benthic toxicity	Fish tissue contamination / benthic toxicity

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Monitoring Timeframes

"***Baseline*** data needed for interpretation of the monitoring data should be collected…"

"Monitor ***during and after*** sediment remediation to assess and document remedy effectiveness."

(EPA 2002, Contaminated Sediment Management Principles)

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Monitoring Timeframes

- ***Baseline, pre-remediation:*** Establishes trends in the pre-remedy condition for comparison to post-remediation conditions.
- ***During remediation:*** Remedies can increase exposures and risks. Such increases – transient or otherwise – are important to understanding the level of protection afforded by the remedy as well as trends in the post-remedy timeframe.

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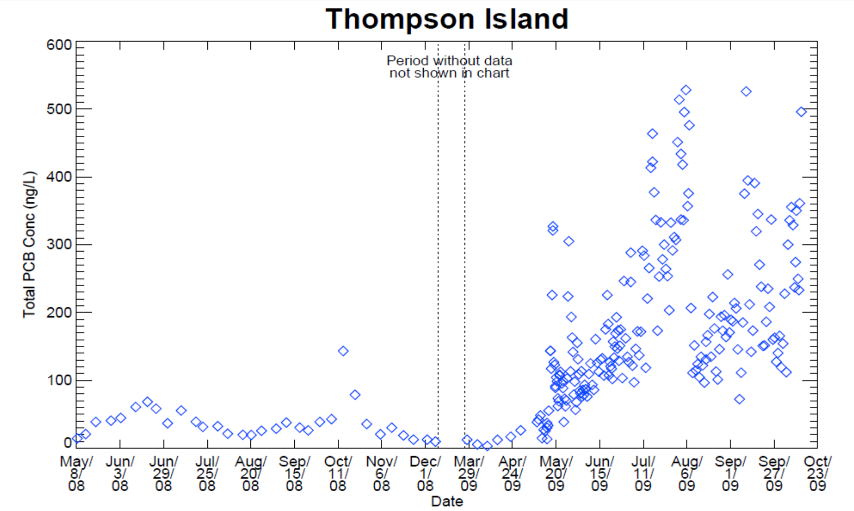
Timeframes: Baseline and During Remediation in Hudson River Water Column



Source: Bridges et al. 2010

9

Monitoring Timeframes

- ***Immediately following remediation:*** "Time = 0" monitoring gives context to later points on rate of change or mechanisms influencing remedy effectiveness, such as recontamination.
- ***Long-term:*** Provides the basis for establishing whether performance standards and remedial action objectives have been achieved.

10

Effective Compared to What?

A Basis for Comparison in Evaluations of Effectiveness

- Need to document where you've been and where you're going….
- Three critical elements
  - Objectives to clearly establish goals of remediation
  - Baseline to indicate effect of remediation
  - A monitoring plan that can answer whether objectives were achieved.

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Objectives

Clearly establish goals of remediation

- Need for quantitative statements that describe specific expectations of the remedy.
- Quantitative goals are project-specific (e.g., risk-based, background, achievable).
- Identify the what, where, when, and how.
  - *Sediments (exposures):* Post-cleanup, surface sediment samples (top 10 cm) within [a specified area] will achieve a SWAC of 50 ug/kg dw.
  - *Fish:* Adult largemouth bass in [a specified area] will attain contaminant fillet concentrations of 20 ug/kg ww within 10 years of implementation.

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Fish Tissue Objectives

- Human health risk at sites with PCB-contaminated sediments primarily stems from consumption of fish tissue.
- Assumption that fish tissue contaminants derive from sediment contaminants.
- So, sediment remediation is conducted to decrease that risk.

➢ **Means that fish tissue is the primary determinant of remedy effectiveness – whether our goals were achieved.**

Baseline Data Collection

Basis for Effectiveness Evaluations

- Why needed?
  - Baseline data permit evaluation of improvement in the conditions… the purpose of the remedy.
  - Baseline data provide the "no action" scenario.
  - Remediated areas cannot represent an unremediated condition.

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Baseline Data Collection

Basis for Effectiveness Evaluations

- What would have happened minus the remediation?
- Two options; compare to
  - Pre-remediation data
  - Contaminated, unremediated area (uncommon)
- Static conditions cannot be assumed, so trends are preferred.

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Site Examples

US *long-term monitoring data sets*

•Portage Creek, MI

•Tabbs Creek, VA

•Cumberland Bay, NY

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Portage Cr. (Allied Paper Site)

- PCBs
- 1998/1999: diverted creek; removed 146,000 cy to 1 PPM (cleanup level).
- Yearling and adult suckers; YOY and adult carp; various fish in 1993, 1999, 2000, 2001, 2002, 2006. State data on adult carp from 1986, 1987, 1988.
- Post-remediation sediments were below cleanup level.

Image: Google Earth

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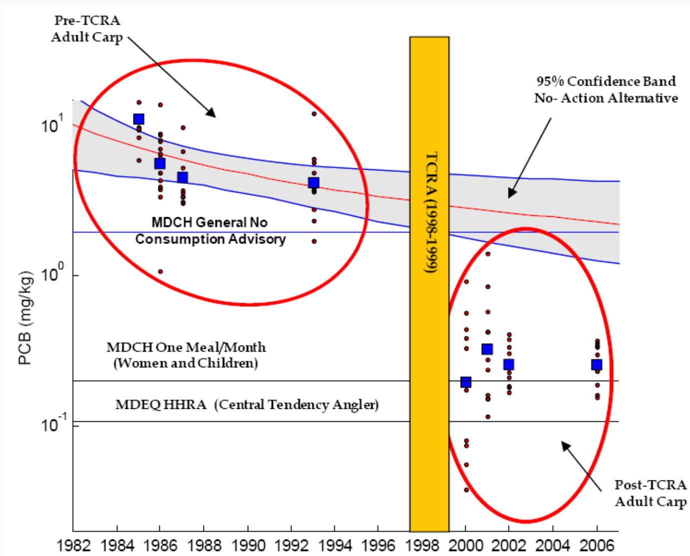
Portage Cr. MI

(Allied Paper Site)

•Pre-remediation trend and extrapolation analysis

•No specified objectives in Superfund (State's "trigger values" shown)

•Time = 0 post-remediation, but no long-term sediment data



Source: CDM 2009

Tabbs Creek, VA

- PCBs/PCTs
- 1999/2000: Dredged 12,371 tons of sediment, backfilled.
- Remove all sediments greater than 5 ppm of total PCBs and PCTs.
- Mummichog sampling in 2000, 2002, 2003, 2004, 2005, 2006, 2007.
  - Three replicate, composite, whole body samples (20 individuals per composite)
- Sediments not sampled post-remediation.

Image: Google Earth

"Because this remedy will not leave hazardous substances on-site above health-based levels, a long-term monitoring and five year review of the remedial action will not be necessary".
(ROD, 1998)

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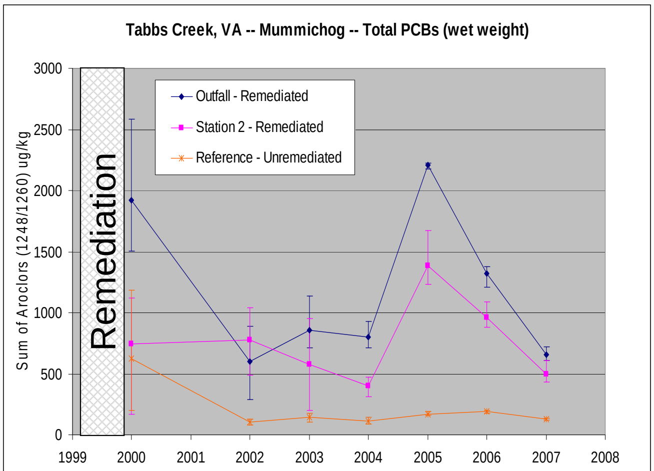
Tabbs Cr. VA

NASA Langley Res. Cntr.

•No pre-remediation data

•No specified objectives; but uncontaminated reference

•No associated sediment data



Error Bars: Range of Data

Source: Data from Final Year 7 Post Remedial Biomonitoring Report for Tabbs Creek NASA Langley Research Center, Hampton, Virginia. October 8, 2009

Cumberland Bay, NY

- PCBs
- 1999/2000: Dredged 195,000 cy to remove all contaminated sediments.
- Yellow perch and rock bass sampling. Fall yellow perch sampling in 1994 and 1997 (pre) and annually from 2000-2009.
- Sediments sampled following remediation indicated residual contamination.

Image: Google Earth

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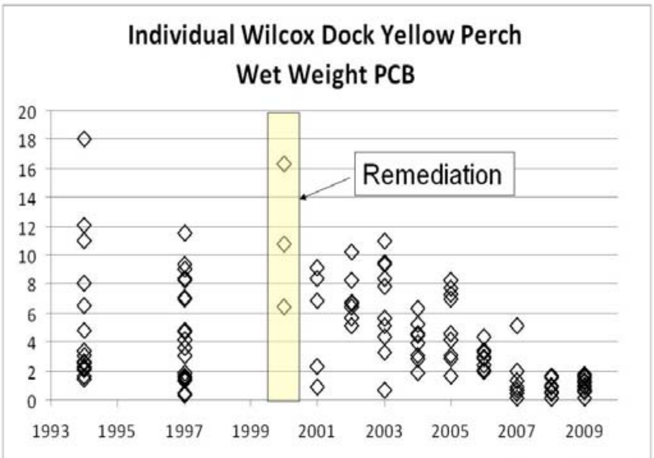
Cumberland Bay

- Pre- and during-remediation data
- No specified objectives; but uncontaminated reference
- Post-remediation data, but no long-term sediment data



Source: Michael Kane, NYSDEC

22

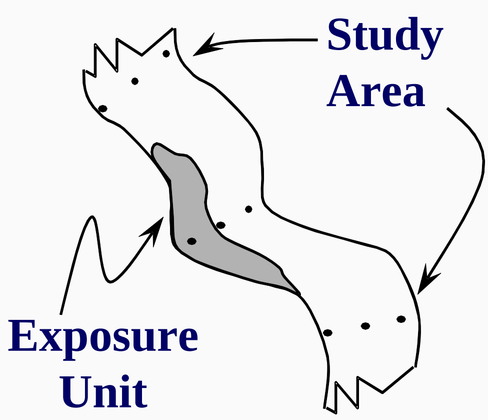
Taiwan-EPA Contaminated Sediment Workshop June 14-15, 2011: U.S. EPA's Approach to Understanding Sediment Site Conditions, Characterizing Contamination, and Reducing Uncertainties in Making Decisions to Manage Risks from Contaminated Sediments

Surface Weighted Average Concentration (SWAC)

Marc S. Greenberg, Ph.D.
U.S. EPA OSWER OSRTI Environmental Response Team
2890 Woodbridge Ave.
Edison, NJ 08837
732-452-6413
greenberg.marc@epa.gov

What is a SWAC

- Arithmetic average concentration over an exposure unit
  - Conceptually equivalent to EPC, however, common EPC methods (Pro UCL) require unbiased data and multiple samples within EUs.
  - 95% UCL on the mean necessary because of uncertainties (RAGs guidance: EPA, 1992)
  - Uncertainty in SWAC should inform remedy selection



When is it appropriate to calculate SWAC?

- CSM information
  - How did the material come to be there-N&E?
  - What is the nature of the exposure?
  - Is there spatial continuity in the data
- Useful method when large area needs to be covered with limited sampling relative to the area's size
  - Standard methods would require very large number of samples
  - May not be acceptable in all circumstances
  - Maximize data utility, efficient use of sampling effort
  - Phased approaches

What do you want to do with a SWAC ?

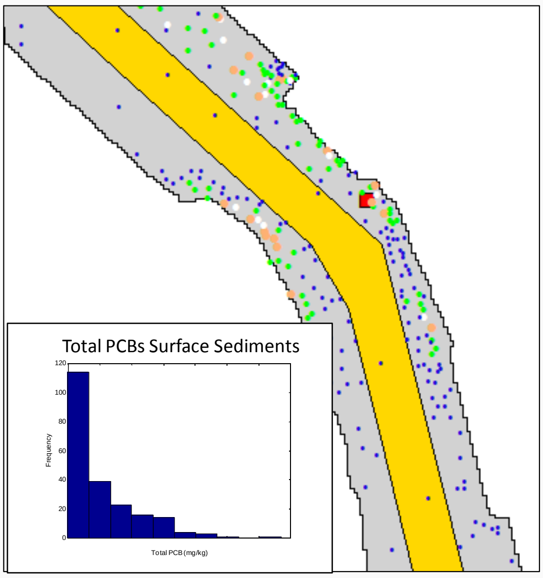
- Average concentration over an area of interest
  - Evaluate remedial options relative to action levels
  - Remedial footprint
  - Post-remedial surface concentration
    - Confirmation sampling
    - Performance standard
    - Clean-up Goal (risk-based)
  - Exposure area
    - human use
    - ecological habitat
  - Differences/similarities between geomorphically distinct areas

Problem Statement

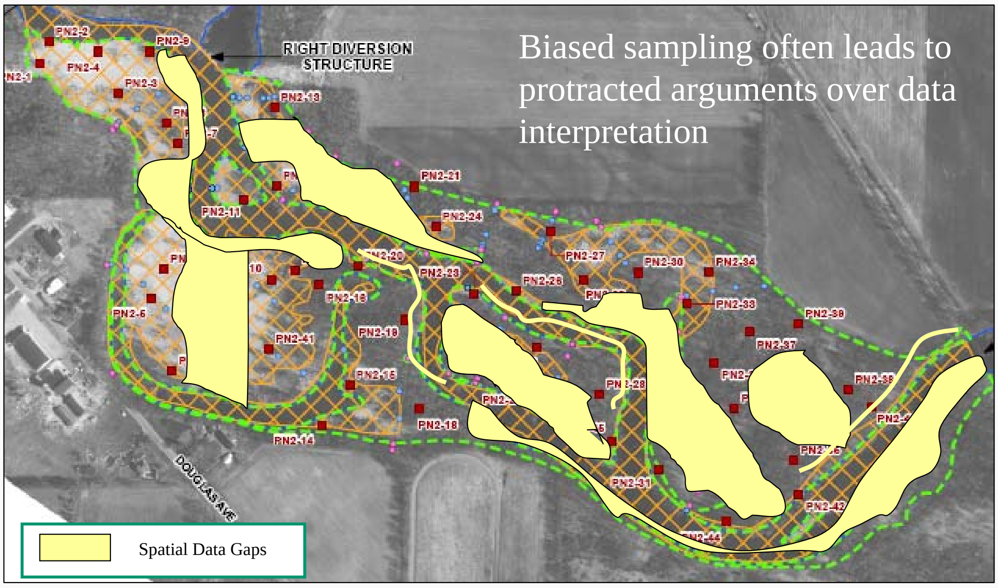
- More commonly used and proposed for risk characterization and remedy selection
- Methods inconsistently applied across sites
- Methods not often transparently described
- Need systematic approach to application of SWAC
  - Built in uncertainty analysis
  - Methods to handle real data (non-normal/log-normal, biased, etc)

Technical Issues…….

- Skewed distributions
  - 16 methods in Pro-UCL
- Biased sampling Designs
  - Pro-UCL methods not directly applicable
- Lack of replicate samples within exposure units of interest
- Interpolation is used to correct for bias
- UCLs are often left behind



Biased Sampling



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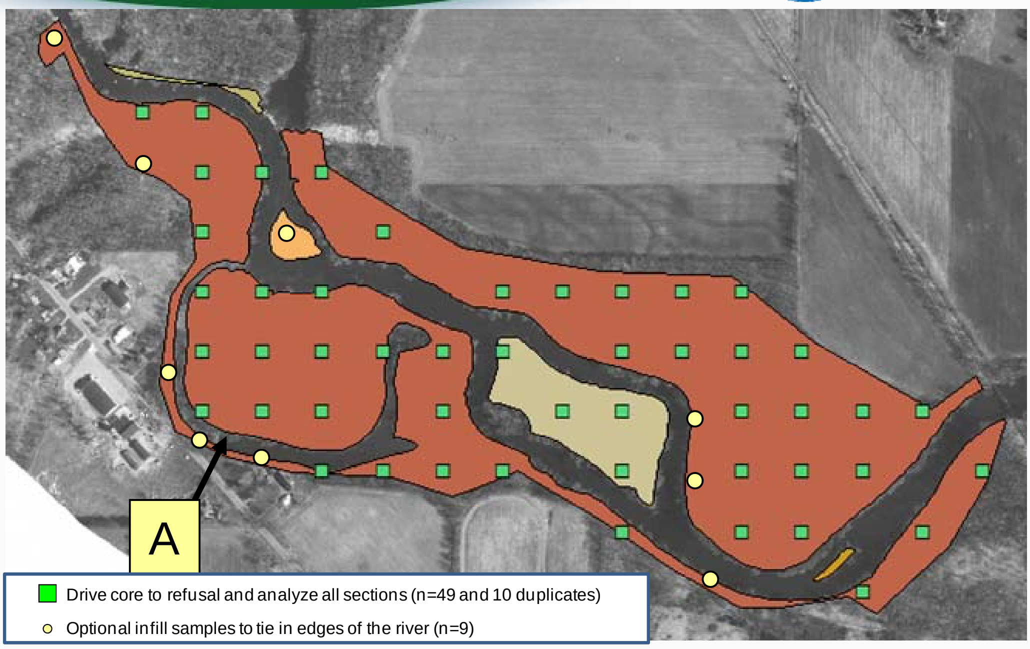
Systematic Sampling Design



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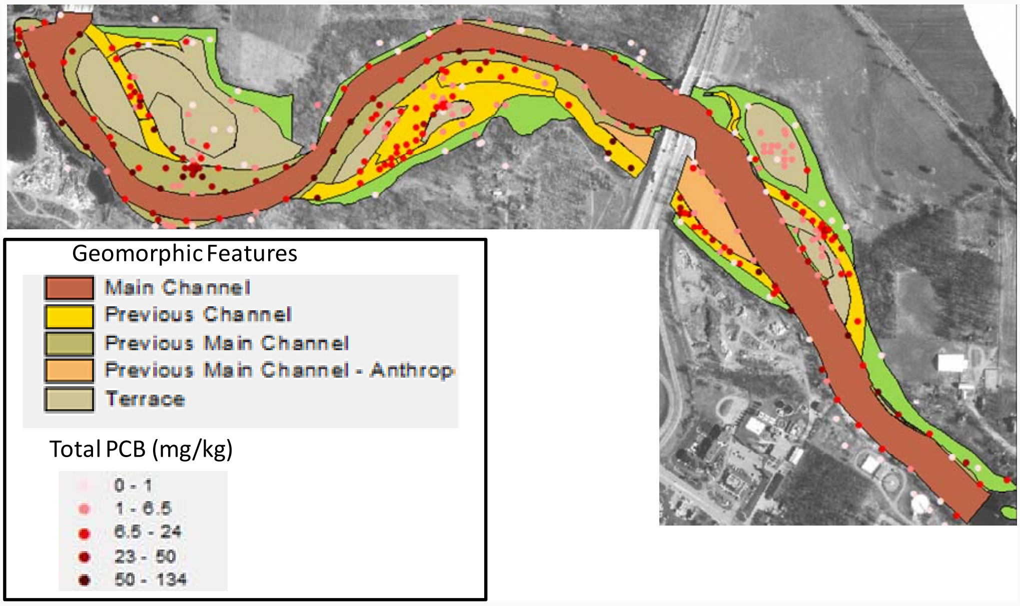
Stratified Sampling
Based on Geomorphology

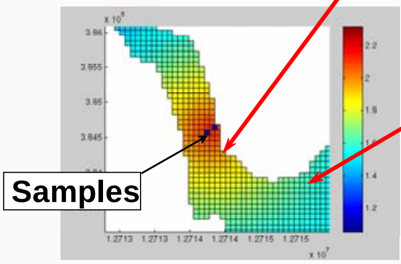


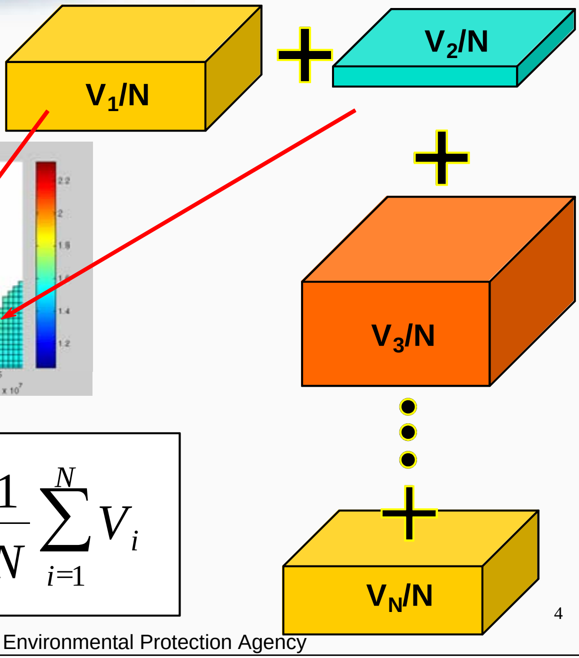
SWAC Estimation:

Interpolation Methods

Interpolation Used to Reduce Bias

Average of Grid =

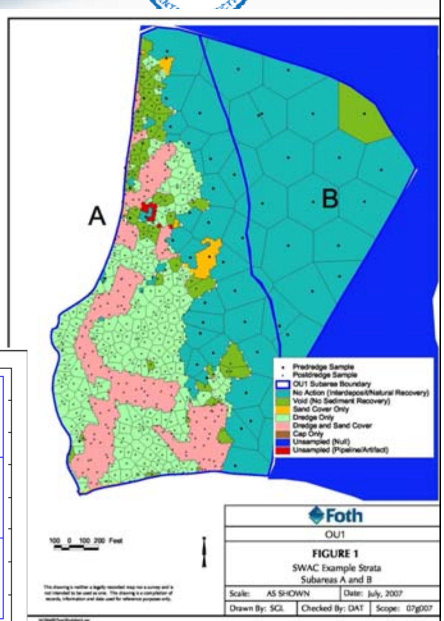


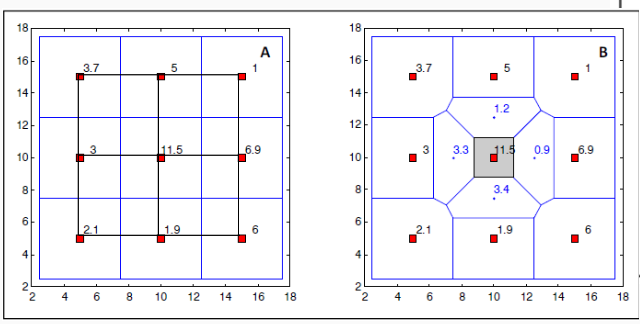


$$SWAC = \frac{1}{N}\sum_{i=1}^{N} V_i$$

Thiessen Polygons

- Sampling weights are proportional to the area of the Thiessen polygon.





Common Interpolation Methods

- Linear interpolation methods
  - Thiessen polygons
  - Inverse distance weighting (IDW)
  - Natural neighbor (NN)
  - Kriging
- Nonlinear methods
  - Linear methods applied to transformed data
  - Splines
  - Minimum curvature methods

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Uncertainty of SWAC

- Interpolated values subject to sampling error
  - Kriging methods quantify prediction errors for unsampled locations
  - Uncertainty in other interpolators can also be quantified
  - Influence of estimation error on SWAC not widely applied
- The variogram
  - Useful to select methods
  - Necessary to estimate uncertainty

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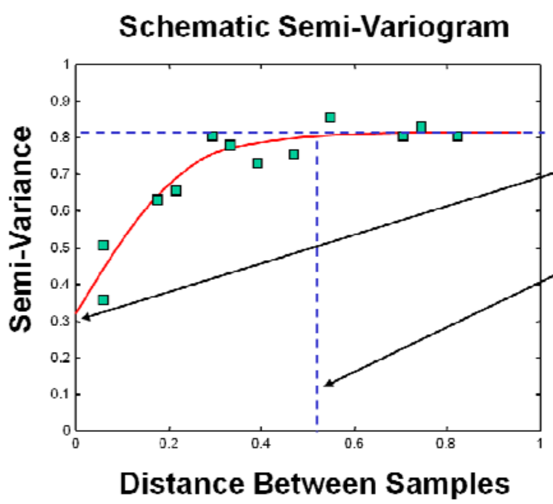
Semivariogram Basics

Semivariance is a measure of the degree of spatial dependence between samples



Sill ~ Total variance among distant samples. For completely independent data this simplifies to sample variance S^2

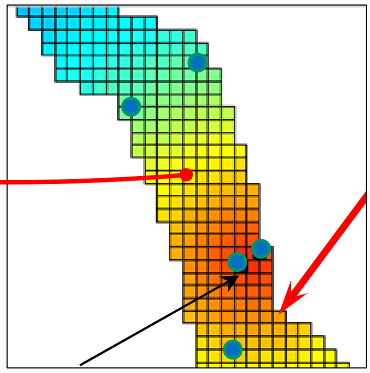
Nugget Effect ~ Measure of small scale spatial heterogeneity.

Range of Influence ~ Distance at which samples are uncorrelated.

- Quantitative approach to evaluate influence of sample data at un-sampled locations
- High nugget effect indicates that small changes in location may be associated with large changes in variable of interest.

SWAC is a Weighted Average

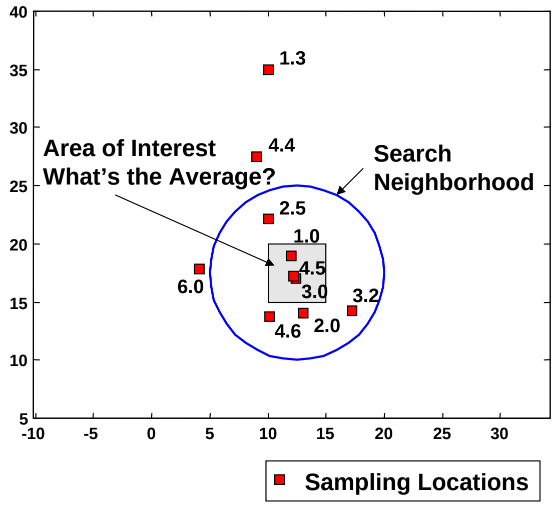
$$\hat{v}_i = \sum_{j=1}^{n} a_{ij} v_j ; i = 1, 2, \ldots, N$$



Grid Location	Sampling Location				
	1	2	3	…….	n
1	a_{11}	a_{12}	a_{13}	……	a_{1n}
2	a_{21}	a_{22}	a_{23}	……	a_{2n}
3	a_{31}	a_{32}	a_{33}	……	a_{3n}
4	a_{41}	a_{42}	a_{43}	……	a_{4n}
.	.	.	.		.
.	.	.	.		.
.	.	.	.		.
N	a_{N1}	a_{N2}	a_{N3}	……	a_{Nn}

$$SWAC = \frac{1}{N}\sum_{i=1}^{N}\hat{v}_i = \frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{n} a_{ij} v_j = \sum_{j=1}^{n}\bar{a}_j v_j$$

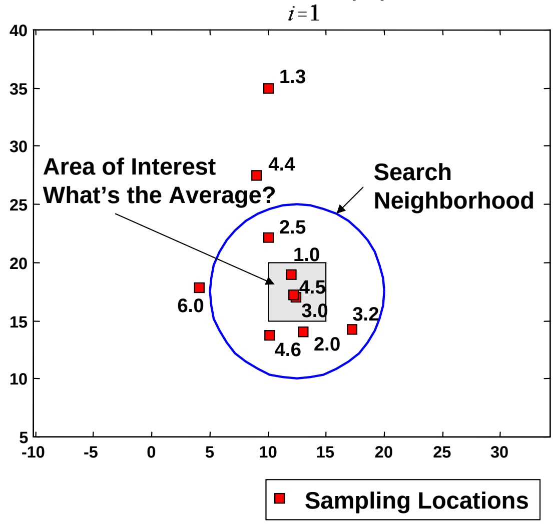
Standard Problem:



- A variable such as contaminant concentration or total biomass is to be studied.
- Measurements are made at a sample of locations within the study area.
- Because data are from a sample, statistical methods are necessary to make inference to the population.
- Particular interest is in estimation of the variable at unsampled locations.
  - Interest may be at the point scale for contouring.
  - For regulatory decision making some larger exposure unit may be more useful.

Interpolation: Weighted Averaging

$$\bar{V} = \sum_{i=1}^{n} a_i v_i$$



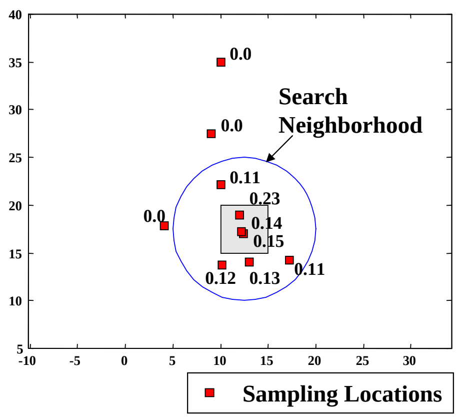
- To estimate the mean value within the gray area "block" one could
  - average the data within the block,
  - or use data outside the block as well.
- Intuitively one might expect sample information to decrease with increasing distance from the block.
- Weighting samples as a function of distance to the block sounds reasonable.
- Is this appropriate for all sample data?
- How should the weights decay with distance?

Properties of Kriging Estimates

- Geostatistical method that uses known values and a semivariogram to predict the values at some unmeasured locations
- Kriging takes into account:
  - Proximity of sample locations to estimation of block or point.
  - Proximity of sample locations to each other.
  - Heterogeneity of the sample data (through the variogram).
- Unlike most other interpolators, estimation error is readily available
- Both interpolation and estimation error are informed by semivariogram

Example Block Kriging Weights

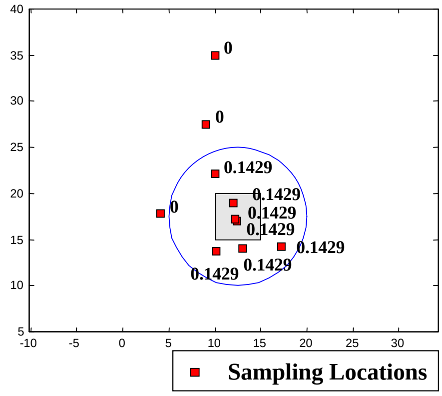
Variogram Parameters:
Nugget=0.0
Range =3.0
Sill=2.59



- Samples outside specified search neighborhood have zero weight.
- Samples in the block have higher weights than those outside the block.
- Clustered samples in the block have total weight similar to that of an un-clustered sample in the block.

Example Block Kriging Weights

Variogram Parameters:
Nugget=2.59
Range =0.0
Sill=2.59

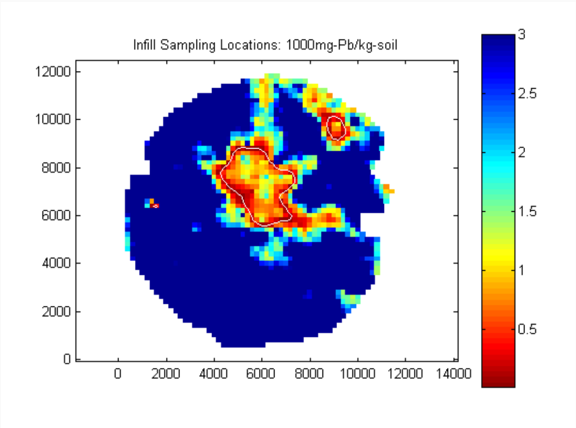


- Nugget and sill equal indicates no spatial auto-correlation.
- Sample weights are all equal.
- The block Kriging estimator simplifies to the mean.
- When samples are spatially independent, the best estimate is simply the mean.
- The variogram indicates that the data may be too sparse or too heterogeneous to defend local scale inferences.

Communicating Uncertainty

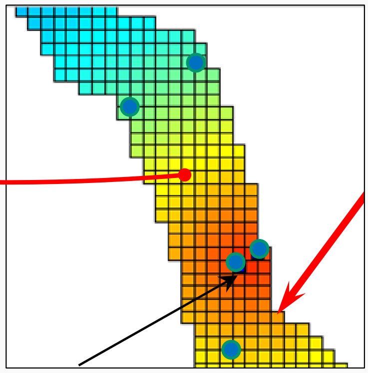
- Uncertainty in estimated values at unsampled locations is often not communicated
- Methods are not routinely available for IDW, NN and TP
- Kriging is often discounted due to difficulties in finding a reasonable variogram
- Communication of uncertainty is usually limited

$$\lambda = \frac{|\hat{V} - RAL|}{\sqrt{MSPE}}$$



SWAC is a Weighted Average

$$\hat{v}_i = \sum_{j=1}^{n} a_{ij} v_j ; i = 1, 2, ..., N$$



Grid Location	Sampling Location 1	2	3	…….	n
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3	a_{31}	a_{32}	a_{33}	……	a_{3n}
4	a_{41}	a_{42}	a_{43}	……	a_{4n}
.	.	.	.		.
.	.	.	.		.
.	.	.	.		.
N	a_{N1}	a_{N2}	a_{N3}	……	a_{Nn}

$$SWAC = \frac{1}{N}\sum_{i=1}^{N} \hat{v}_i = \frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{n} a_{ij} v_j = \sum_{j=1}^{n} \bar{a}_j v_j$$

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Error estimation for SWAC: Mean Squared Prediction Error

- SWAC can be expressed as a weighted average of the sample data
- Sampling error is given by the mean squared prediction error
- Estimating uncertainty in SWAC is based on the variogram
  - Covariance terms are derived from the semi-variogram.

$$MSPE = \bar{\boldsymbol{a}}^T C \bar{\boldsymbol{a}} + C_{BB} - 2\bar{\boldsymbol{a}}^T \boldsymbol{C}_B$$

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Prediction Error: Linear Interpolators

Kriging, NN, IDW and TP are Linear interpolators:

$$\hat{V} = \sum_{i=1}^{n} a_i v_i$$

Confidence intervals are based on mean squared prediction error:

$$MSPE = E\left\{\left(V - \sum a_i v_i\right)^2\right\}$$

$$UCL = \hat{v} + 1.96 \times \sqrt{MSPE}$$

Prediction Error Details

$$MSPE = \boldsymbol{a}^T C \boldsymbol{a} + C_{BB} - 2\boldsymbol{a}^T C_B,$$

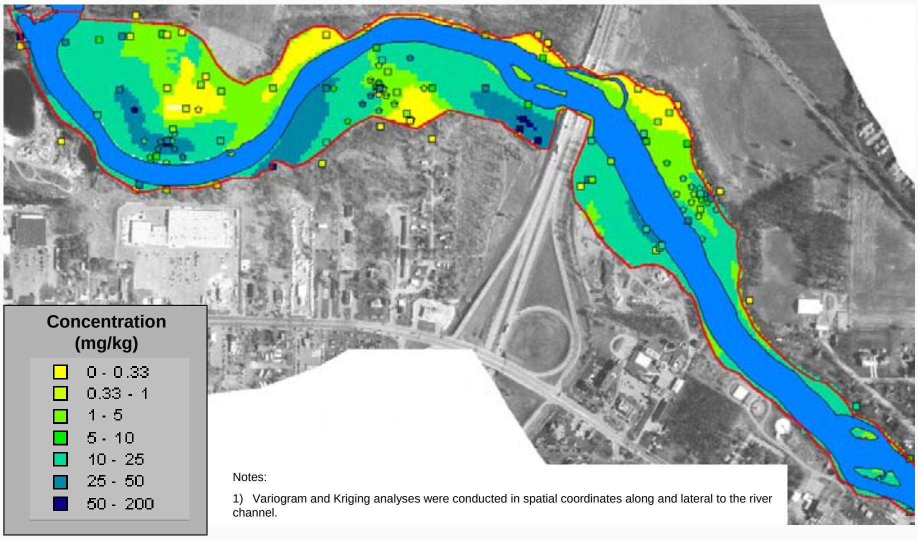
$$C_{BB} = \frac{1}{B^2}\int_B\int_B C(\boldsymbol{x},\boldsymbol{x}')\,d\boldsymbol{x}\,d\boldsymbol{x}',$$ Average covariance among all points in the block B.

$$C_{ij} = Cov(\boldsymbol{x}_i,\boldsymbol{x}_j)$$ ~ Covariance matrix of the data.

$$C_B(i) = \frac{1}{|B|}\int_B C(\boldsymbol{x},\boldsymbol{x}_i)\,d\boldsymbol{x}$$ Average covariance between the data and the region B.

Covariance terms are derived from the semi-variogram.

Surface PCB Concentration



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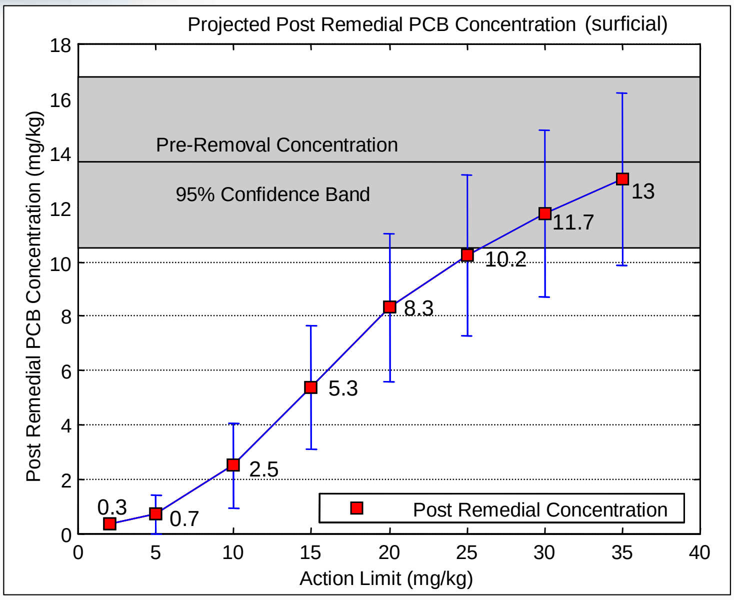
How is the SWAC Used?

- Determination of Remedial Action Level (RAL) and remedy footprint
- Each RAL/SWAC associated with a remedial footprint



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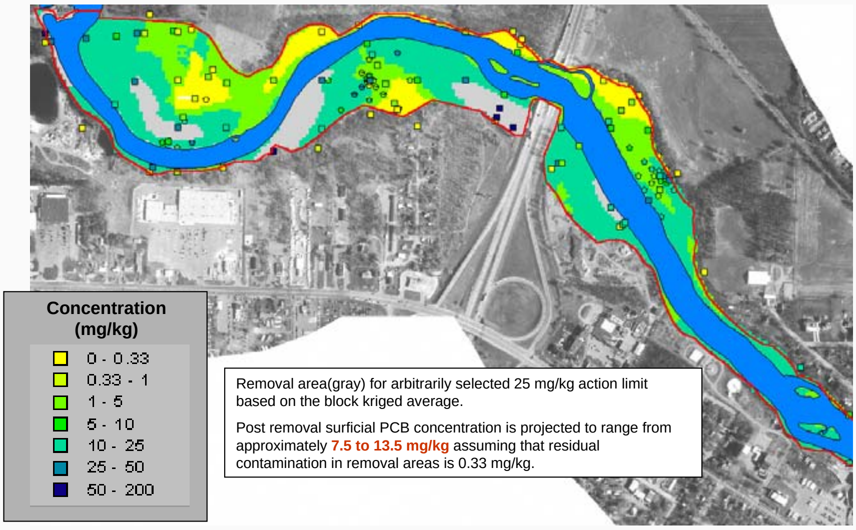
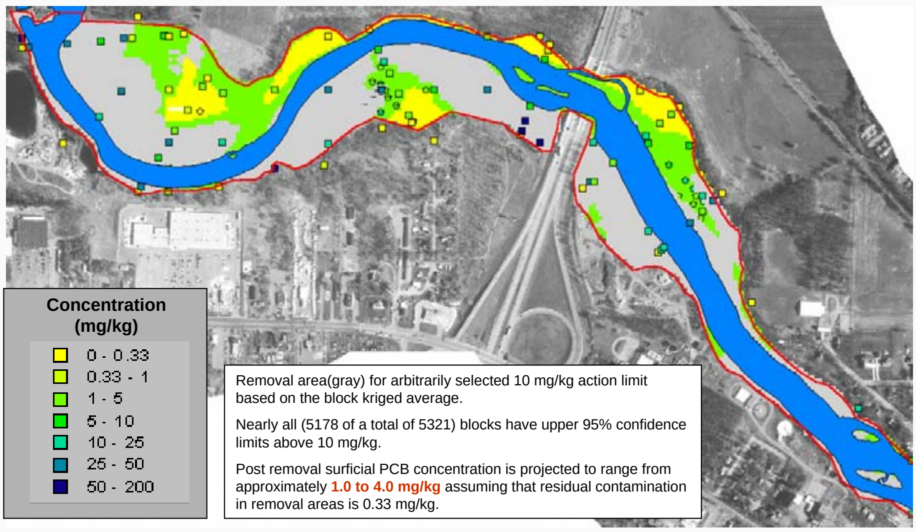
Remedial Footprint for 25 mg/kg RAL



Removal area(gray) for arbitrarily selected 25 mg/kg action limit based on the block kriged average.

Post removal surficial PCB concentration is projected to range from approximately **7.5 to 13.5 mg/kg** assuming that residual contamination in removal areas is 0.33 mg/kg.

Remedial Footprint for 10 mg/kg RAL

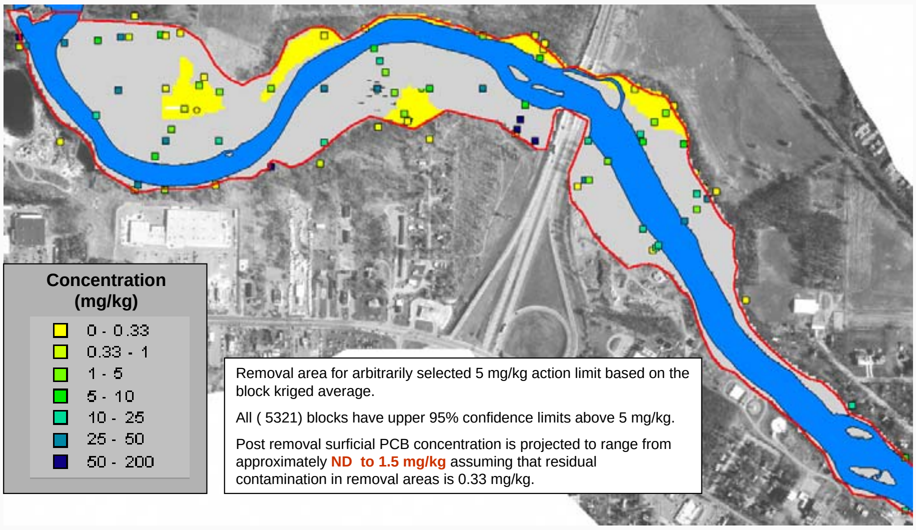


Removal area(gray) for arbitrarily selected 10 mg/kg action limit based on the block kriged average.

Nearly all (5178 of a total of 5321) blocks have upper 95% confidence limits above 10 mg/kg.

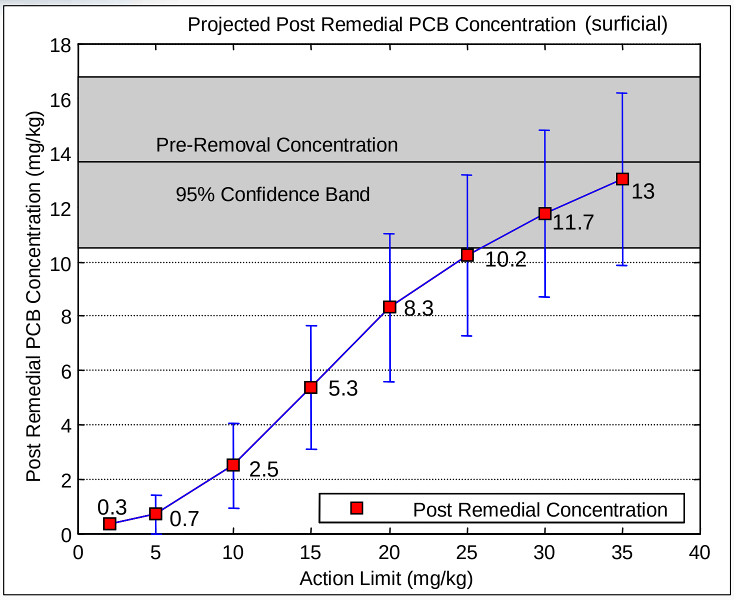
Post removal surficial PCB concentration is projected to range from approximately **1.0 to 4.0 mg/kg** assuming that residual contamination in removal areas is 0.33 mg/kg.

Remedial Footprint for 5 mg/kg RAL



How is the SWAC Used?

- **Determination of Remedial Action Level (RAL) and remedy footprint**
- **Each RAL/SWAC associated with a remedial footprint**



Interpolation Method Considerations

- Kriging explicitly requires variogram model
  - Variogram estimation requires data to be within less than a range of influence
  - At large sites data are frequently more widely spaced
  - Sample data may be too sparse to reliably interpolate
- Frustration with variogram often leads to use of IDW, NN, Thiessen Polygons
  - Corrects global mean for biased sampling
  - MSPE can still be used to estimate uncertainty
  - Remedy selection may be unreliable when variogram analysis not conducted
- Differences among methods usually much less important than sampling error associated with sampling density

Parting Thoughts: SWAC - General Steps

1. Sample design and implementation
2. Variogram analysis—semivariogram
3. Interpolate if appropriate
4. Uncertainty estimates
5. Document the method choice decisions and results (beyond just tables)

Evaluating Dredge Residuals

Marc A. Mills, Ph.D.
USEPA
Office of Research and Development

Issues with Environmental Dredging

The Four Rs of Environmental Dredging: Resuspension, Release, Residual, and Risk

1. sediment **resuspension resulting from dredging** operations,
2. **release of contaminants from bedded and suspended sediments** in connection with dredging,
3. **residual contaminated sediment** produced by and/or remaining after dredging, and
4. the environmental **risks that are the target of and associated with dredging**

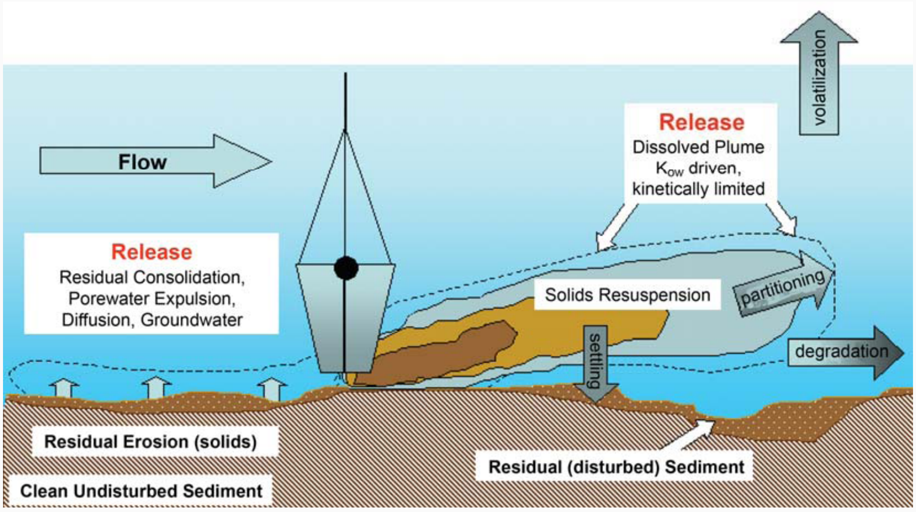
Resuspension

- **<u>Resuspension</u>** as defined with environmental dredging: the processes by which the dredge and associated operations dislodge bedded sediment and disperse them into the water column
- Operations responsible include:
  - Dredge actions
  - Spillage
  - Prop wash from associated vessels
  - Movement of dredge or support barges
  - Debris removal

Resuspension

- Resuspension pose water quality, ecosystem concerns and potential human health risks
  - Plumes can change aquatic wildlife behavior
  - Expose aquatic wildlife
  - Physical and chemical risks to sedentary organisms

Conceptual model



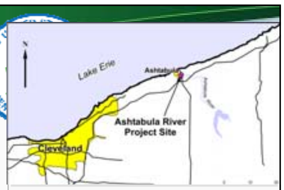
Objective and Approach

Objective: Evaluate existing and innovative tools to measure and predict post-dredge residuals before, during, and after an environmental field dredging project.

Approach

- Predict and Characterize Residuals
  - Field measurement of volume and contaminant characterization in dredging residuals
  - Determine if conventional characterization techniques can be used to measure residuals and evaluate alternative techniques
  - Develop approach for estimating the volume and concentration of post-dredging residuals
- Field measurement of re-suspension during dredging activities
- Evaluate how contaminant mass removal relates to reduced risks to aquatic and human receptors
  - Assess changes in PCB levels in aquatic invertebrates before, during, and after dredging
  - Assess changes in DNA damage and external and liver abnormalities in brown bullheads before, during, and after dredging
  - Evaluation of the bioavailability of contaminants in post-dredging residuals

Site Background

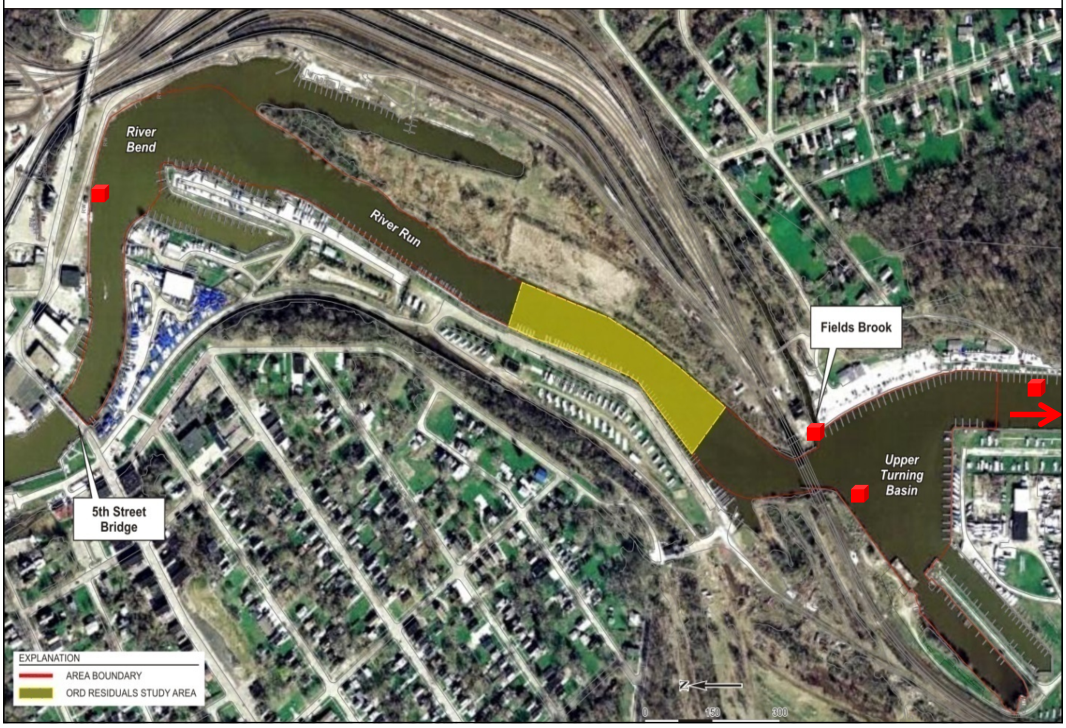


Location in the state of Ohio

Ohio's location in the USA

- **Great Lake Legacy Act remediation action on 5,500-ft of the Ashtabula River, Ohio (AOC - Ashtabula River)**
  - Restrictions on fish and wildlife consumption
  - Degradation of fish and wildlife populations
  - Fish tumors or other deformities
  - Degradation of benthos
  - Restriction on dredging activities
  - Loss of fish and wildlife habitat
- **The Ashtabula River**
  - In extreme northeast Ohio, flowing into Lake Erie's central basin at the City of Ashtabula.
  - Drainage basin covers an area of 137 sq mi, with 8.9 sq mi in western Pennsylvania.
  - Major tributaries include Fields Brook, Hubbard Run, and Ashtabula Creek.
  - The City of Ashtabula, with an estimated population of approximately 21,000 is the only significant urban center in the watershed, the rest of the drainage basin is predominantly rural and agricultural.
  - There is concentrated industrial development around Fields Brook (east of the Ashtabula River) and east of the Ashtabula River mouth.
- **Contaminants**
  - Approximately, 600,000 cu yd of contaminated sediments.
  - PCBs is driver for site. Also includes PAHs, hexachlorobenzene, hexachlorobutadiene, metals, and radionuclides.

Dredging Footprint and ORD Study Areas



4 Phase Study Design

Phase 1 - Pre-dredge characterization

- Sediment cores and water sampling
- Macroinvertebrate and fish sampling
- Surface sediment sampling and SPI
- Semipermeable Membrane Devices (SPMDs)
- Electronic surveys (multi-beam and side scan sonar)

Phase 2 - During Dredging

- Surface sediment samples and water samples to characterize re-suspension
- Macroinvertebrate and fish sampling completed
- Electronic surveys (multi-beam and side scan sonar)

Phase 3 - Post-dredge

- Sediment cores and water samples
- Diver supported characterization of dredge residuals
- Surface sediment sampling and SPI
- Semipermeable Membrane Devices (SPMDs)
- Electronic surveys (multi-beam and side scan sonar)
- Macroinvertebrate and fish sampling

Phase 4 – Annual monitoring - Implemented 2008-2011

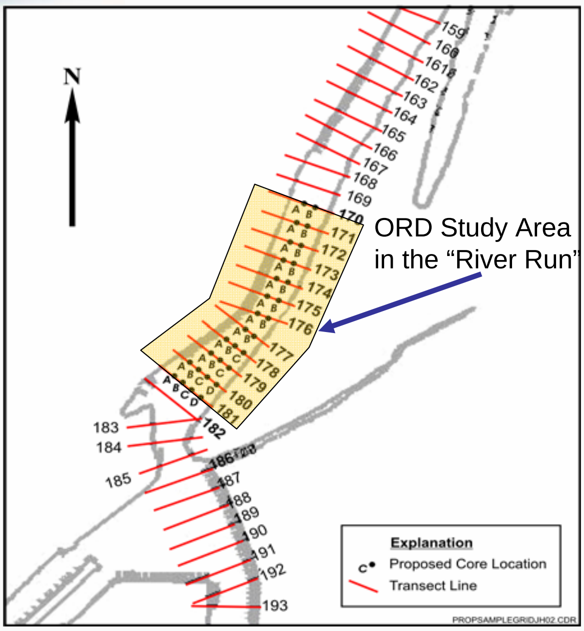
- Sediment/water sampling
- Electronic surveys
- Macroinvertebrate and fish sampling

Physical LOE	Chemical LOE	Biological LOE
Diver assisted probing	Pre- and Post-dredge contaminant profiles	Contaminants in Macrobenthos tissue
Bathymetric surveys	Forensic approaches	Contaminants in Fish tissue
Dredge head position analysis		DNA damage in fish liver and blood
Physical sediment characteristics (grain size, etc)		Examination of external lesions and anomalies in fish
Visual observations of Core Samples		Fish liver histopathology (pre-dredging and post-

Sediment Sampling

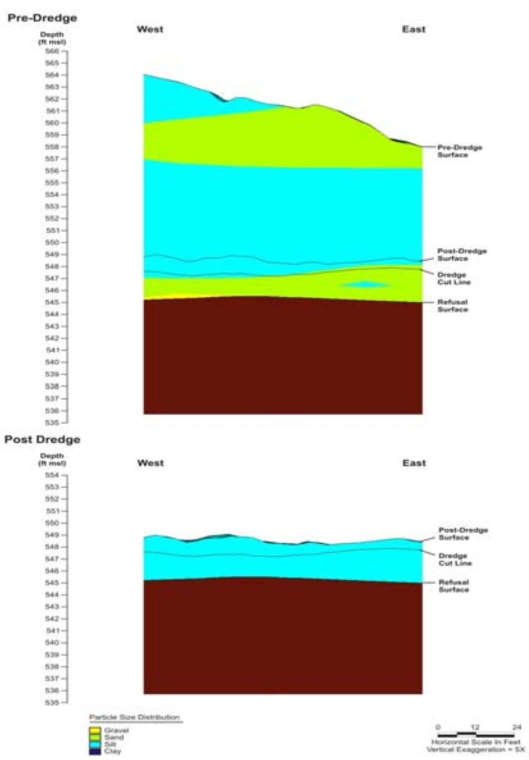
Core Locations Used in Pre- and Post Characterization

- 30 locations located in the “river run” within the dredge area
- 100 ft x 50 ft spacing
- Cores collected to either bedrock or ~5 feet below design cut line pre-dredge action
- Cores samples were collected at these locations post dredging



Vertical Alignment and Physical Examination of Cores

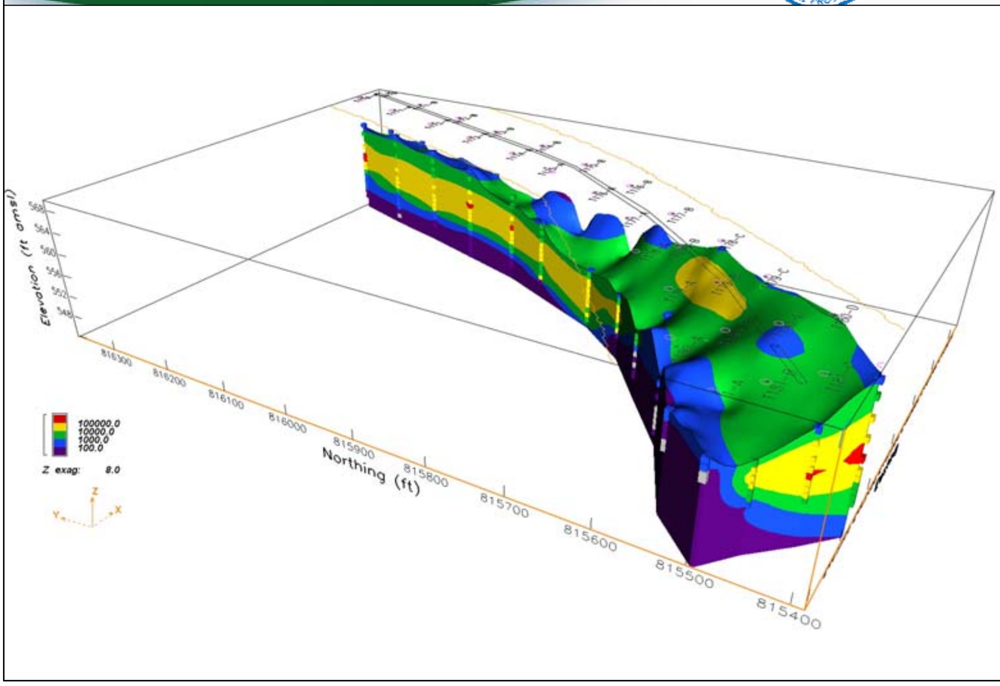
- Vertical – Used water depth, core length, and pre- and post bathymetry
- Pre- and post-dredge geology and color were not necessarily useful in determining core vertical positioning
  - ~1/3 cores had "visual" residuals
  - ~1/3 cores had no "visual" residuals
  - ~1/3 cores were indeterminate for "visual" residuals



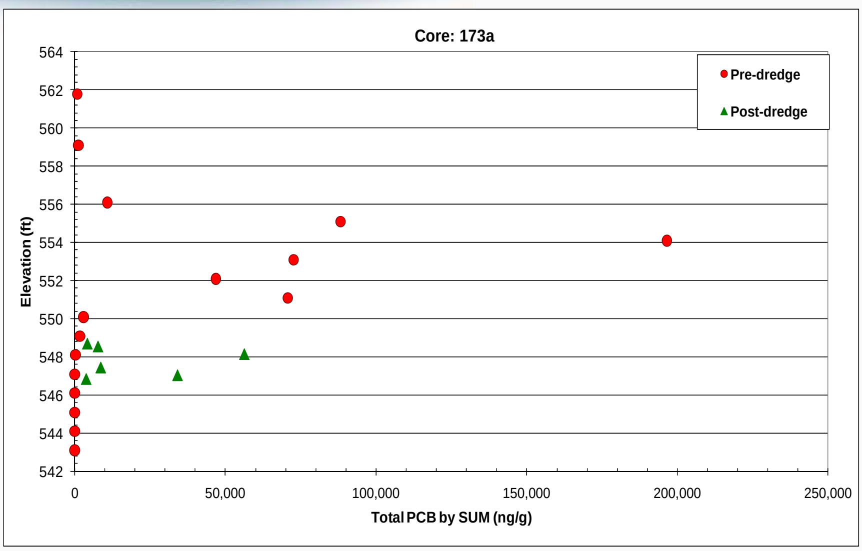
Physical Parameter Analysis

- Gravel, course sand, and medium sand decreased 25%, 75% and 40%, respectively
- Fine sand and clay increased 50% and 7%, respectively
- Avg. dry BD was 20% lower

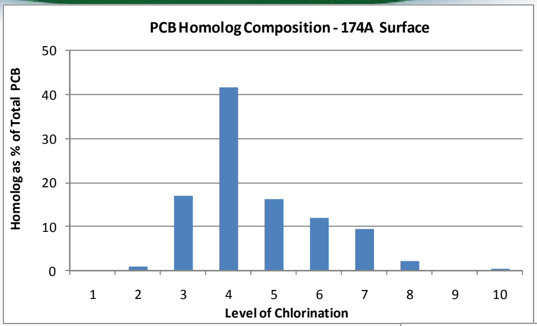
Pre-Dredge PCB Concentrations



Post-Dredge Sediment PCB Concentration vs. Depth

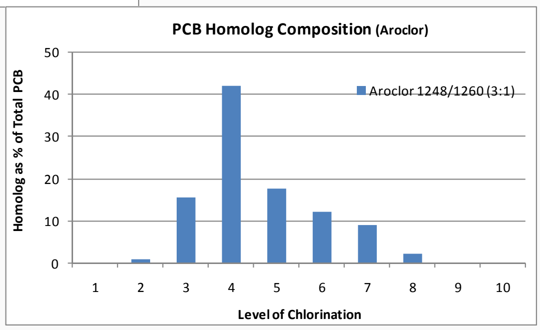


Pre-Dredge Sediment PCB Composition

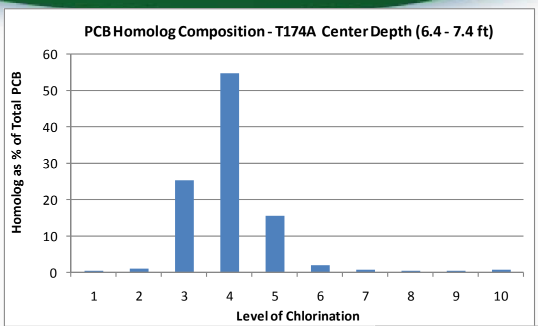


Surface composition is similar to 3:1 Mixture of Aroclor 1248:1260

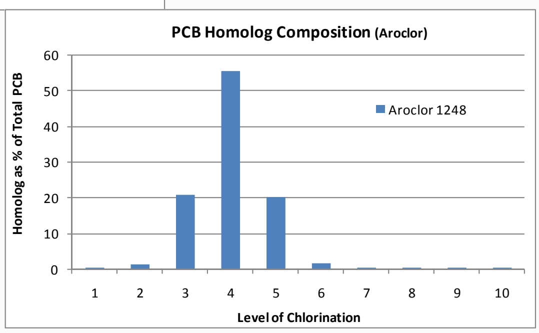
Fields Brook - Aroclor 1248
Strong Brook –Arolcor 1260
Only in surface sediments



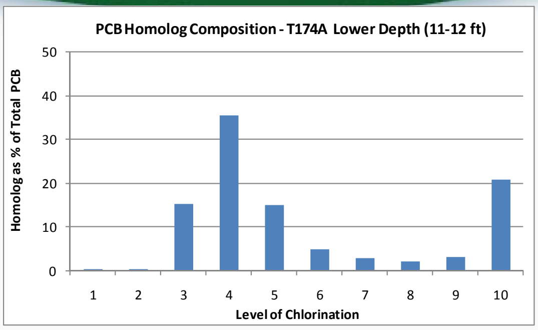
Pre-Dredge Sediment PCB Composition



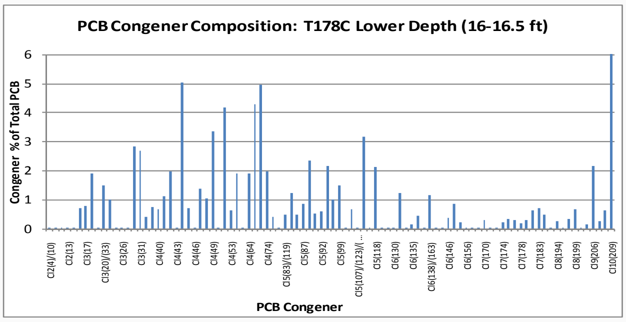
Mid-depth composition is similar to Aroclor 1248



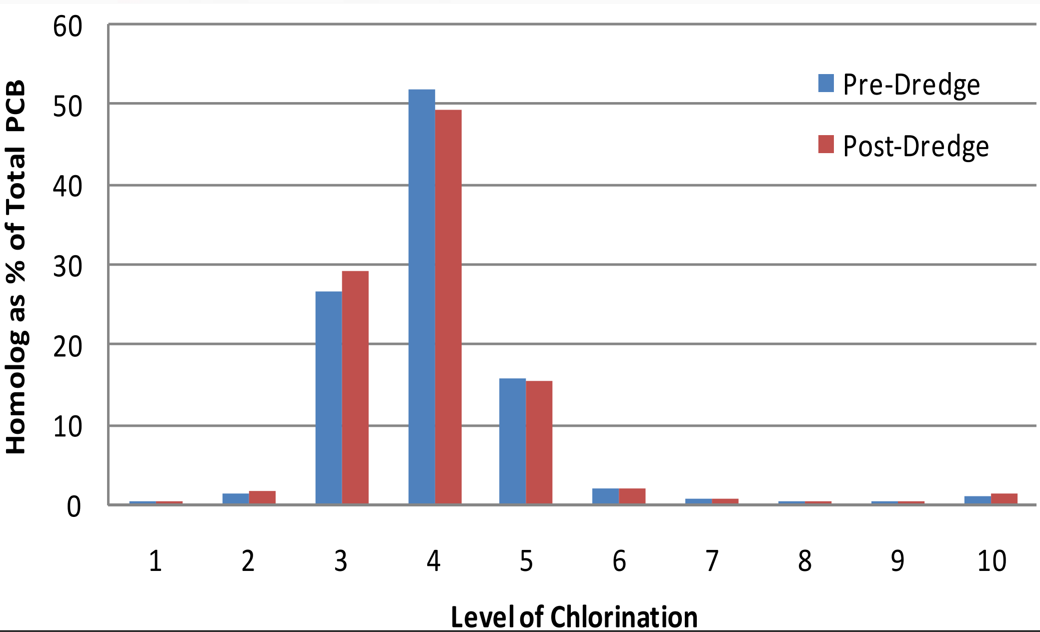
Pre-Dredge Sediment PCB Composition



Deep sediment composition had noticeable contribution of highly – chlorinated PCB congeners (PCB 209)



Pre- vs. Post-Dredge comparison - homolog distribution

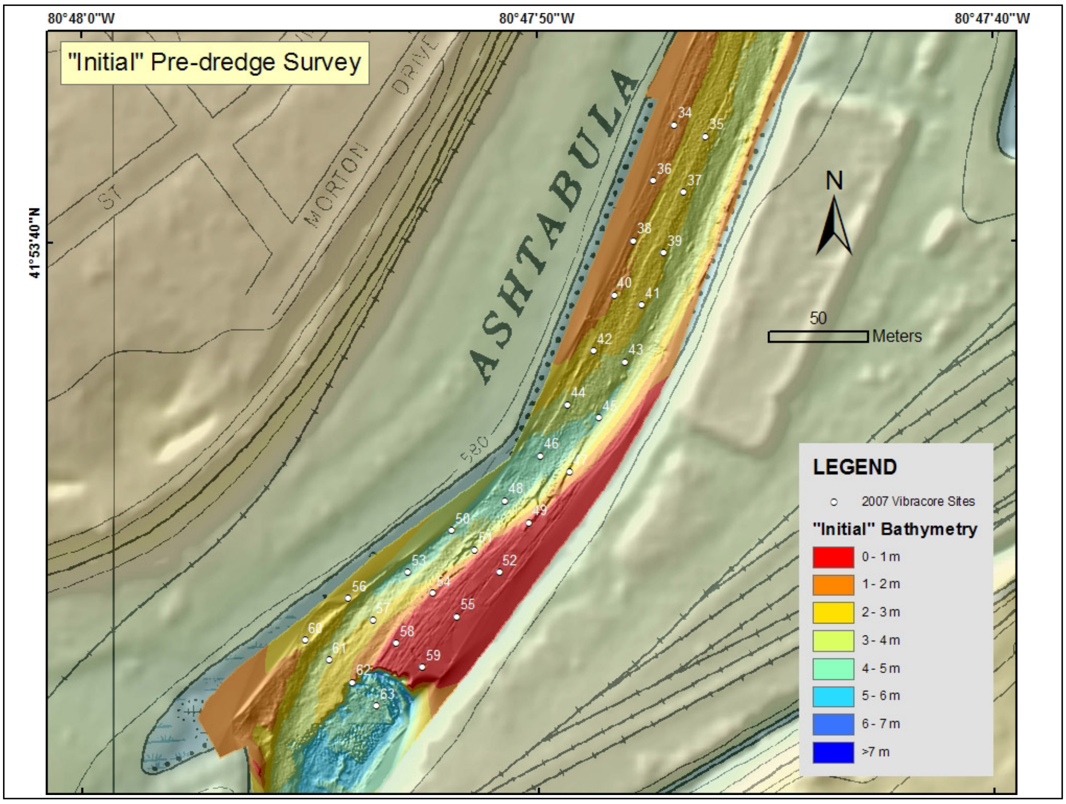


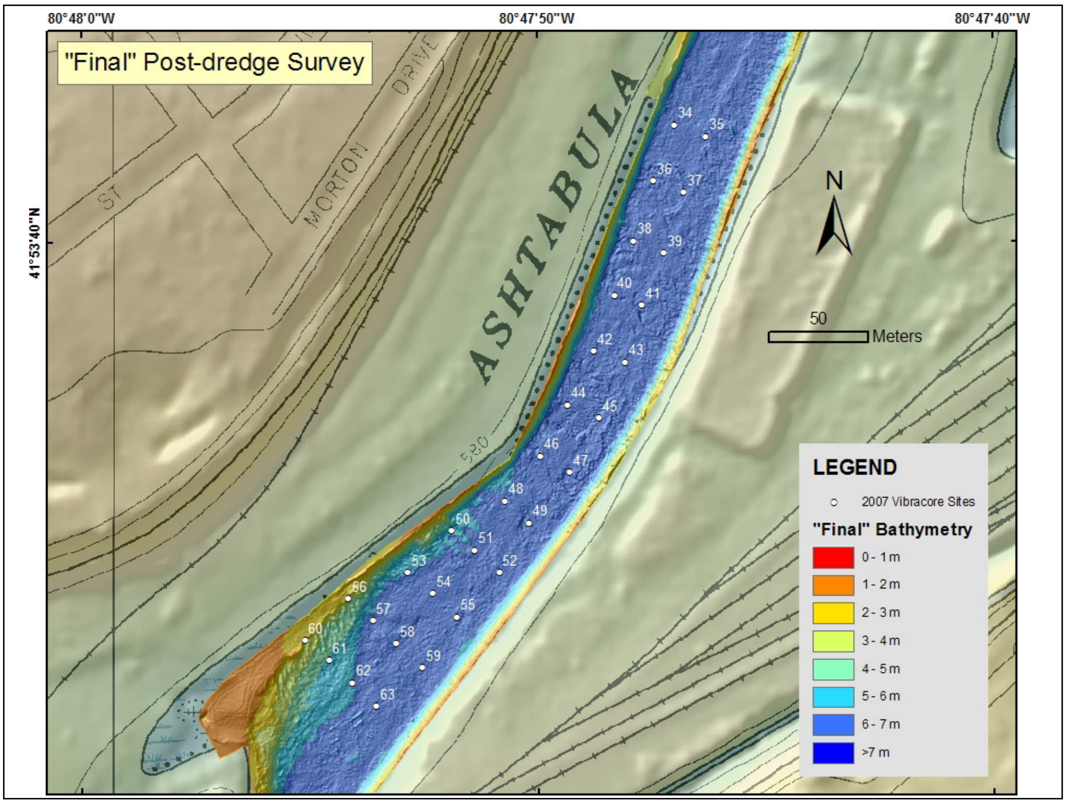
Bathymetry

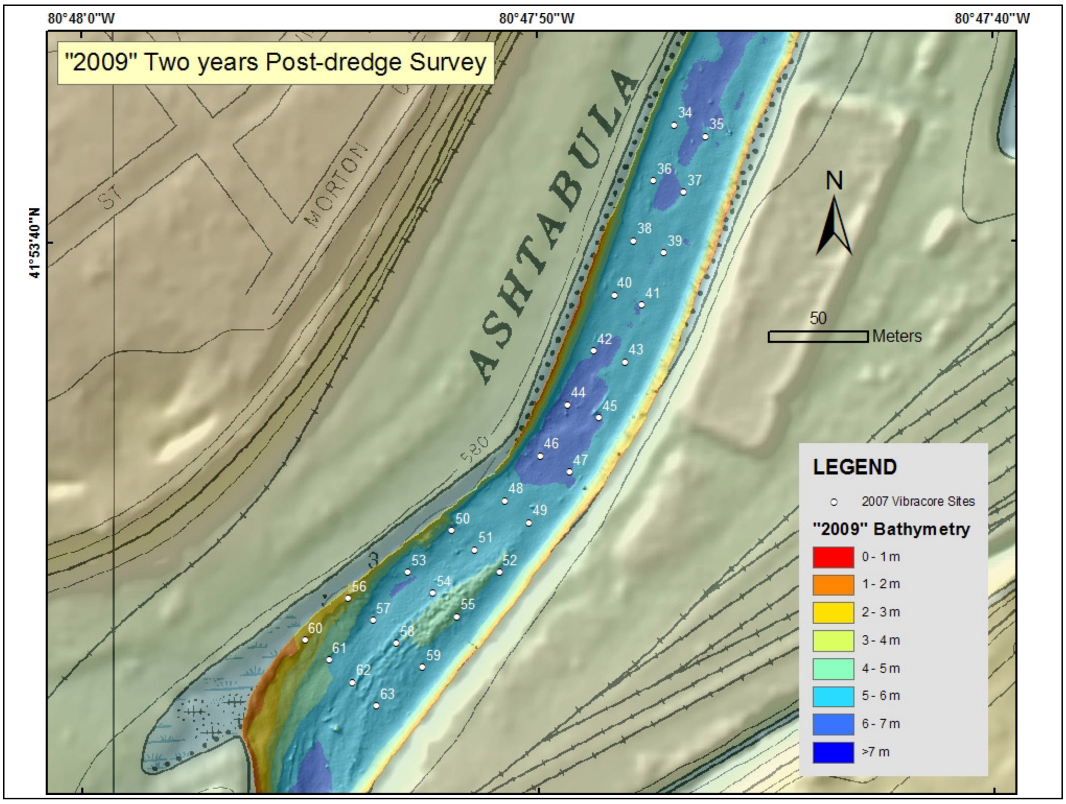
- Multibeam survey
- Surveys conducted
  - Pre-dredge
  - Immediately post dredge (residuals)
  - 2 years post dredge (sedimentation rates)

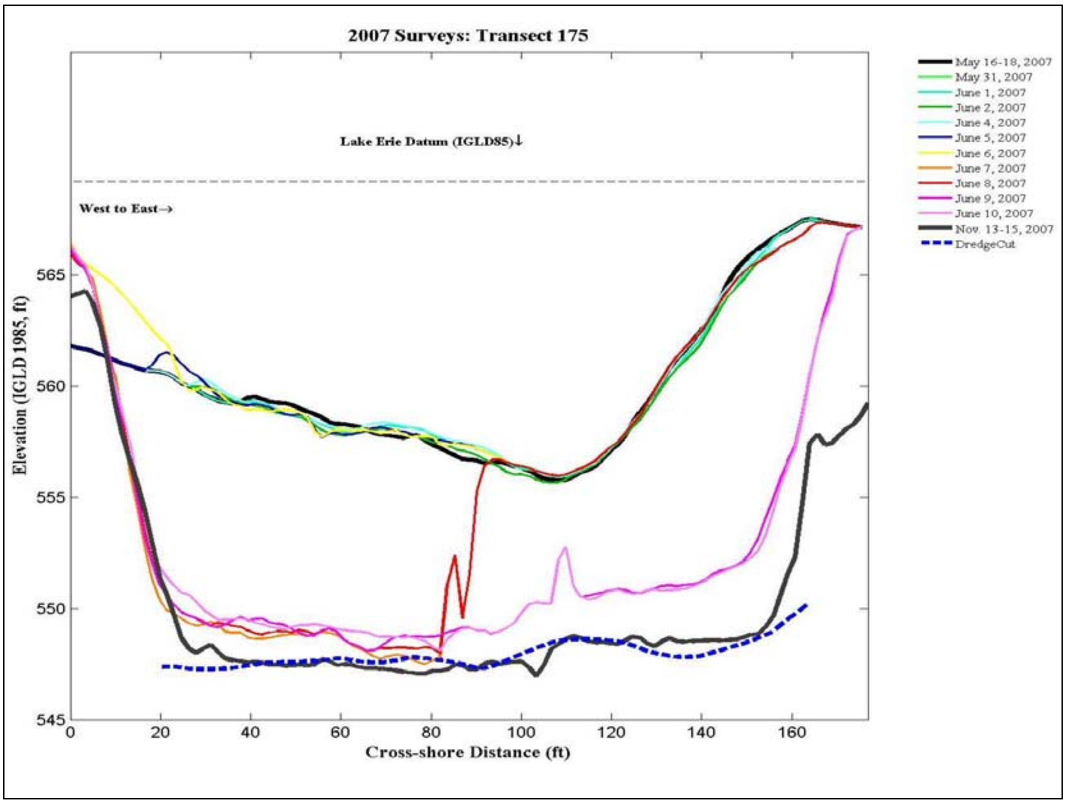
- 200 khz multibeam echo sounder
- 30 beams
- 90º coverage sector
- 3º beam pattern
- Working depth range: 2-100 meters

•Output resolution: 2.5 cm



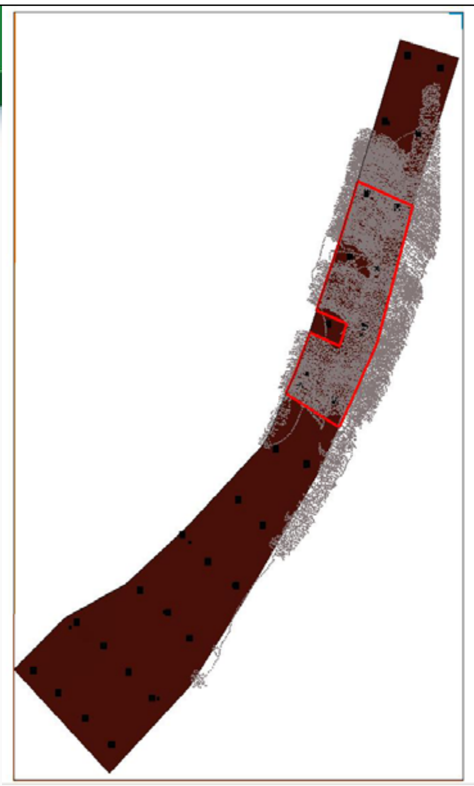

80°48'0"W
80°47'50"W
80°47'40"W
41°53'40"N
"Final" Post-dredge Survey
ASHTABULA
MORTON
DRIVE
ST
N
50
Meters
LEGEND
2007 Vibracore Sites
"Final" Bathymetry
0 - 1 m
1 - 2 m
2 - 3 m
3 - 4 m
4 - 5 m
5 - 6 m
6 - 7 m
>7 m


80°48'0"W
80°47'50"W
80°47'40"W
41°53'40"N
"2009" Two years Post-dredge Survey
ASHTABULA
MORTON
ST
N
50
Meters
LEGEND
2007 Vibracore Sites
"2009" Bathymetry
0 - 1 m
1 - 2 m
2 - 3 m
3 - 4 m
4 - 5 m
5 - 6 m
6 - 7 m
>7 m

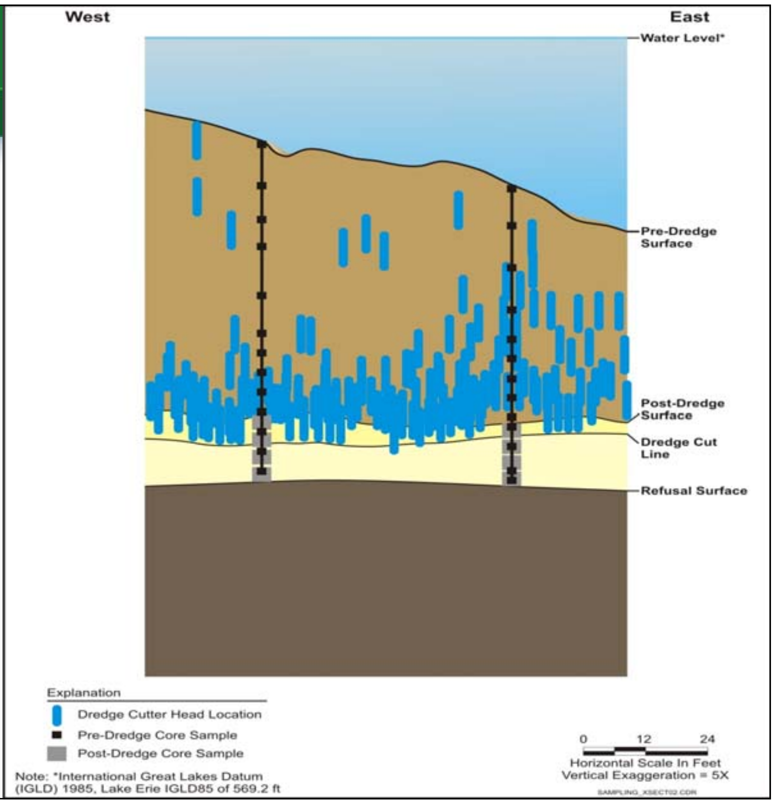


Dredge Cutter Head Positioning

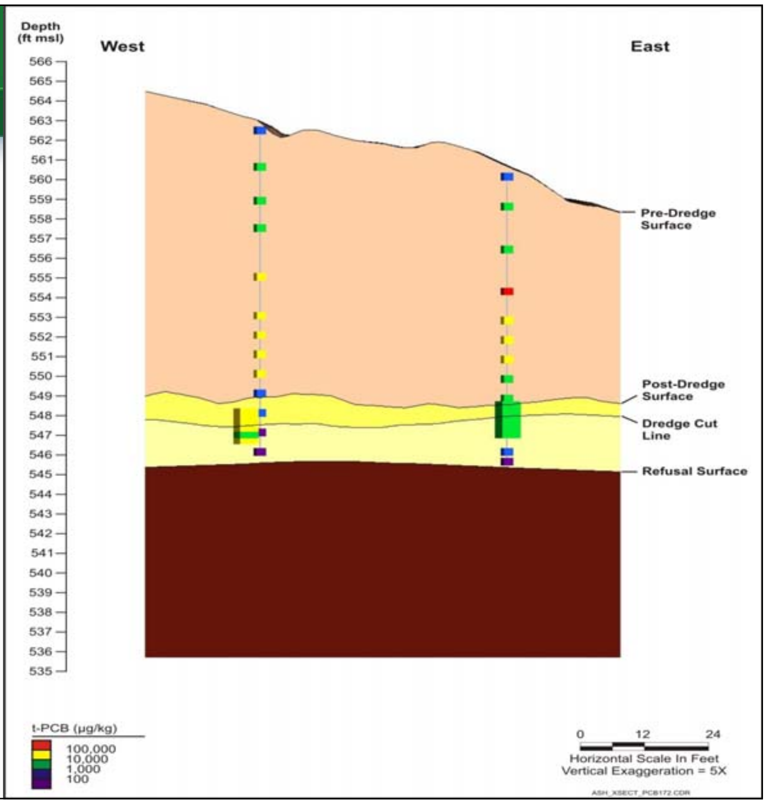
- XYZ cutter head data → uniformly spaced surface
  - 5 x 5 ft to 25 x 25 ft grids tested
  - Used 15 x 15 ft grid
  - Used lowest data points
  - Elevations greater than 559.2 ft and transiting data removed



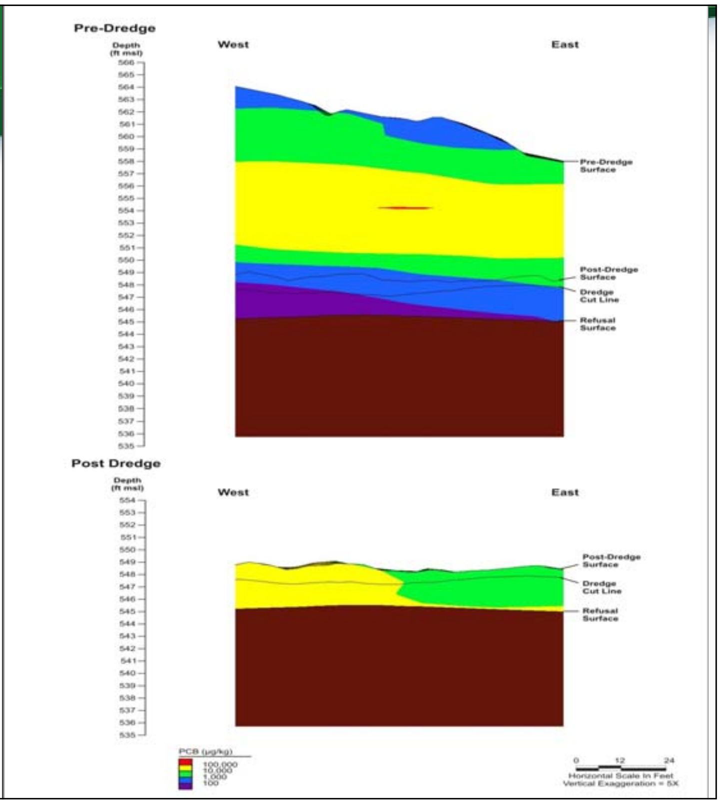
Cross-Section Conceptual View of Post-Dredge Surface



Cross-Section View of T-172



Cross-Section View of T-172 with Pre- and Post-Dredge PCB concentrations



Estimate of Sediment Residual Inventory

Transect ID	Pre-Dredge Inventory			Post-Dredge Inventory		
	Sediment		t-PCBs	Sediment		t-PCBs
	cu yd	kg	kg	cu yd	kg	kg
T172	229	163,071	4.16	17	9,811	0.1
T173	263	185,315	6.12	14	8,167	0.1
T174	96	69,350	1.37	1	530	0.0
T175	197	141,193	4.59	8	4,533	0.0
T172 to T175	13,596	9,669,399	251	625	361,668	3.3

- Independent Transects – Values calculated based on a band of 5 ft band (linear flow) from bank to bank (2.5 ft on each side)
- Study Area – Values calculated based on a band of sediment 400 ft (linear flow) from 175 to 172 and from bank to bank

Estimate of Percent Removal and Residuals

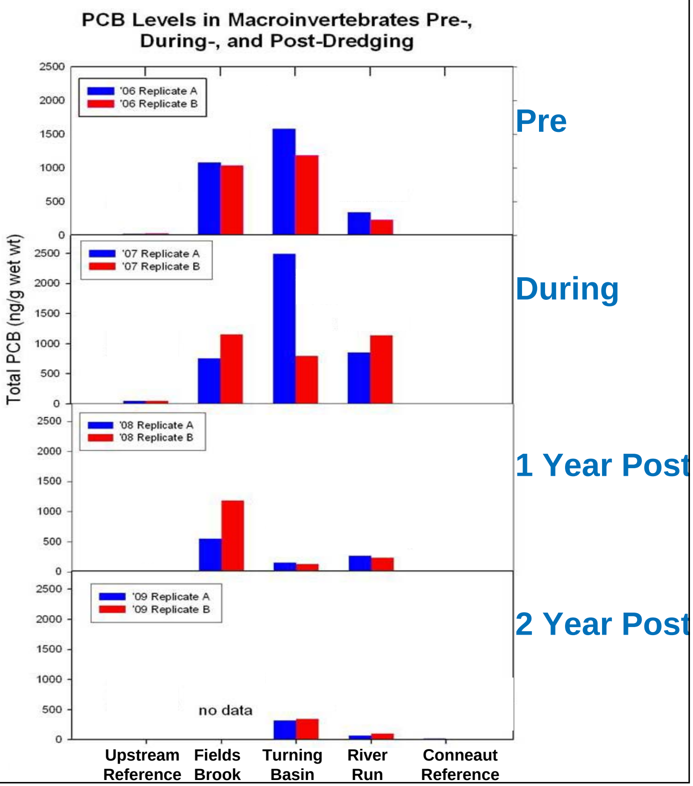
	Removal						Residuals	
	Sediment				t-PCBs		Sediment	t-PCBs
	cyds	kg	% vol	% mass	kg	% mass	% mass	% mass
T172	212	153,261	92.6	94.0	4.04	97.0	6.0	3.0
T173	249	177,148	94.6	95.6	6.03	98.5	4.4	1.5
T174	96	68,820	99.1	99.2	1.37	99.7	0.8	0.3
T175	189	136,661	96.0	96.8	4.55	99.3	3.2	0.7
T172 to T175	12,971	9,307,731	95.4	96.3	248	98.7	3.7	1.3

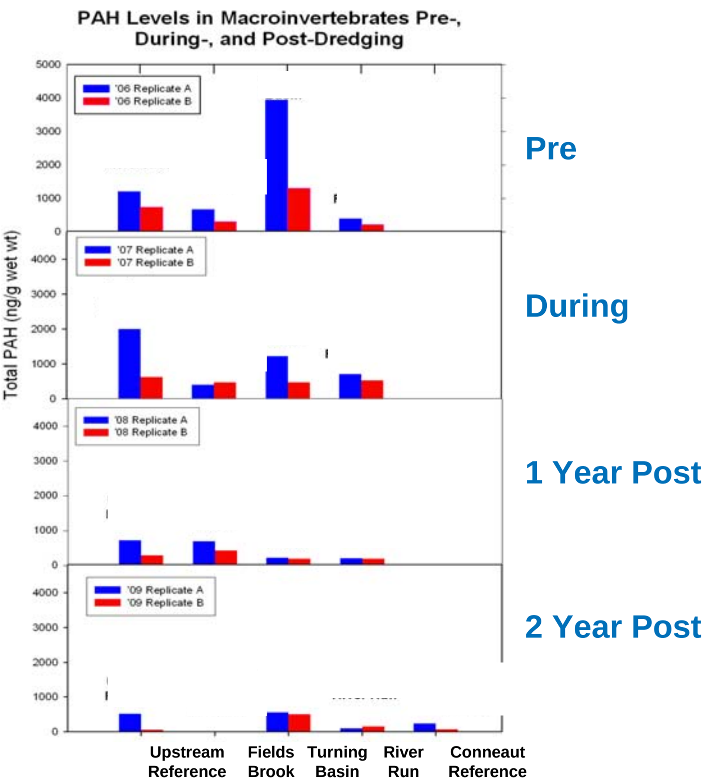
- Independent Transects – Values calculated based on a band of 5 ft band (linear flow) from bank to bank (2.5 ft on each side)
- Study Area – Values calculated based on a band of sediment 400 ft from 175 to 172 and from bank to bank

Biological Monitoring

- Why Sample Macroinvertebrates?
  - **A majority of the benthic invertebrates, i.e. midge larvae, annelids (aquatic worms), mayfly larvae have life cycles** of **30-90 days.**
  - **Body burden values for contaminants in macroinvertebrates provide very recent exposure levels.**
  - **Longer lived fish may take a long time before the benefits of remedies can be detected.**

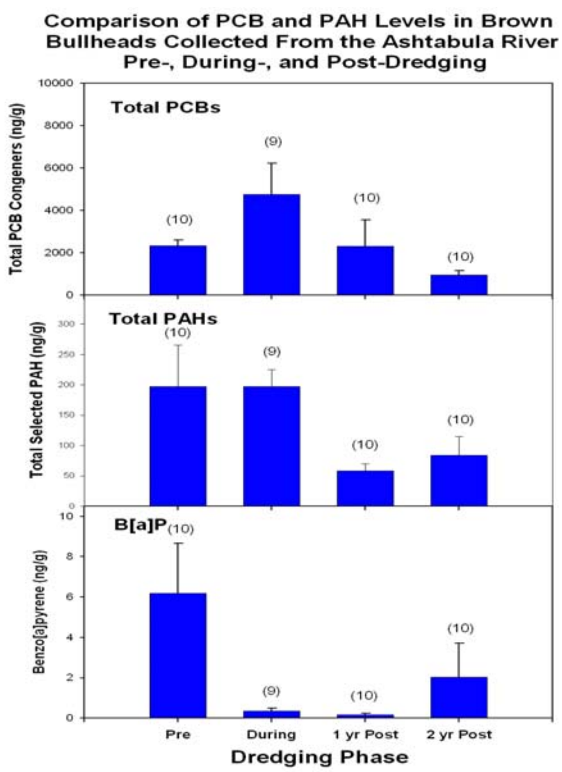
Artificial Substrates (Hester Dendy's) to collect benthic macroinvertebrate tissue.


PCB Levels in Macroinvertebrates Pre-, During-, and Post-Dredging
Total PCB (ng/g wet wt)
'06 Replicate A
'06 Replicate B
Pre
'07 Replicate A
'07 Replicate B
During
'08 Replicate A
'08 Replicate B
1 Year Post
'09 Replicate A
'09 Replicate B
2 Year Post
no data
0
500
1000
1500
2000
2500
Upstream Reference
Fields Brook
Turning Basin
River Run
Conneaut Reference


PAH Levels in Macroinvertebrates Pre-, During-, and Post-Dredging
Total PAH (ng/g wet wt)
'06 Replicate A
'06 Replicate B
Pre
'07 Replicate A
'07 Replicate B
During
'08 Replicate A
'08 Replicate B
1 Year Post
'09 Replicate A
'09 Replicate B
2 Year Post
0
1000
2000
3000
4000
5000
Upstream Reference
Fields Brook
Turning Basin
River Run
Conneaut Reference

Why Brown Bullheads?

- Bottom feeders
- Live and eat in sediments where pollutants accumulate
- Tend to stay in one area
- Metabolize certain carcinogens (PAHs) as humans do.
- Liver tumors in bullheads have been linked to polynuclear aromatic hydrocarbons
- One of two fish species used to assess tumors/other deformities for "beneficial use impairment" for AOCs.



Conclusions

- Vertical Alignment/Physical Examination
  - Color and geology did not appear to be definitive in identifying the maximum dredge cut depth
  - Qualitative assessment could be made regarding the cut depth vicinity using organic carbon and bulk density in post dredge cores
- Sediment PCB Chemistry
  - Pre-dredge sediment inventory closely resembled Aroclor 1248 (predominantly)
  - Generally, the surface sediments following dredging had congener and homolog profiles more similar to the dredge inventory of sediment and were substantially impacted by the overlying sediments
- 2- and 3-D Visualization of PCBs in Pre- and Post Dredge Sediments
  - Confirmed the concentration analysis performed independently; namely that increased post-dredge sediment surface t-PCB concentrations were noted at particular elevations compared to pre-dredge sediments

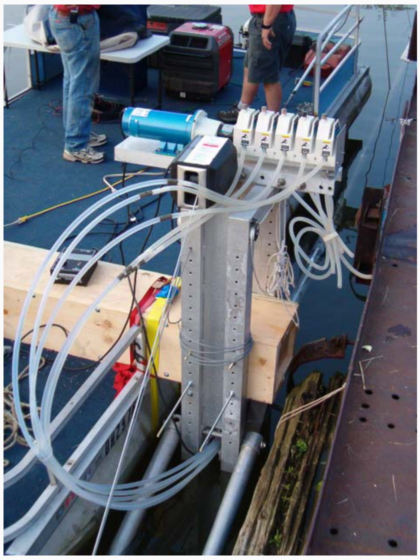
Conclusions

- Bathymetric Surveys
  - MBS proved to be a good tool for determining the elevation from which to vertically align pre- and post-dredge cores
  - Daily surveys provided some evidence of slope failures (although a more focused approach is needed for future efforts)
  - Data and interpretation is sensitive to temporal effects
- Dredge Cutter Head Positioning
  - Used as the primary method to quantify the extent of dredge-induced residuals
  - The dredger used RTK-GPS, electronic compasses, HPR compensators, electronic tide gauges, Hypack™ software, and trained operators; however literature and personal communications with dredgers regarding accuracy, as well as, levels of inaccuracies in other equipment (MBS), results in a accumulation of errors effect (~ 9 -12 in)
  - Sediment and mass t-PCB removals were approximately 96% and 99%
  - Residuals estimated from near 0 – 3% in the limited study area

Conclusions

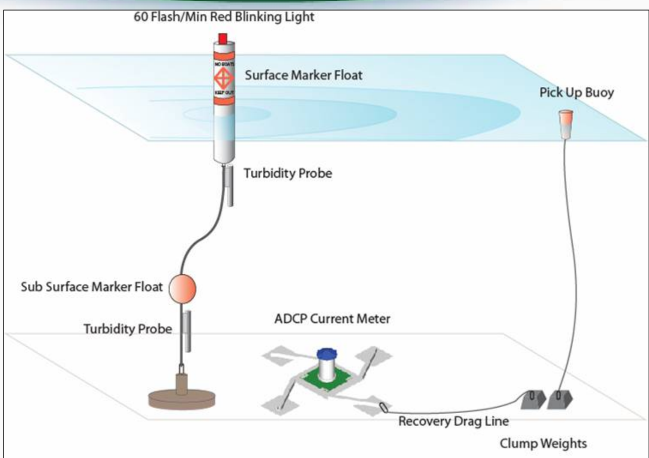
- Biology showed rapid recover
  - Macrobenthos responded quickly to the remediation
    - Need more biomass
    - Need more replicates
    - Need more positions to fully evaluate a site this large
  - Fish also appear to be responding
    - More species would be useful
    - Don't expect the histopath to respond nearly as quickly as the tissue levels

Multi-Depth Water Sampler

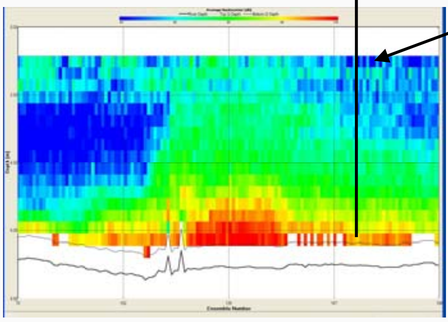


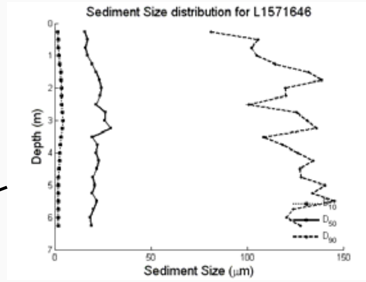
Features:
- Up to 5 Sensor/Water Collection Ports
- 5 lpm water delivery from each port
- Depths of 15 – 30’
- Up to 5 knots tow speed
- Real-time display of contoured data
- Can be deployed on vessels 20’ or greater

Water Quality Deployments

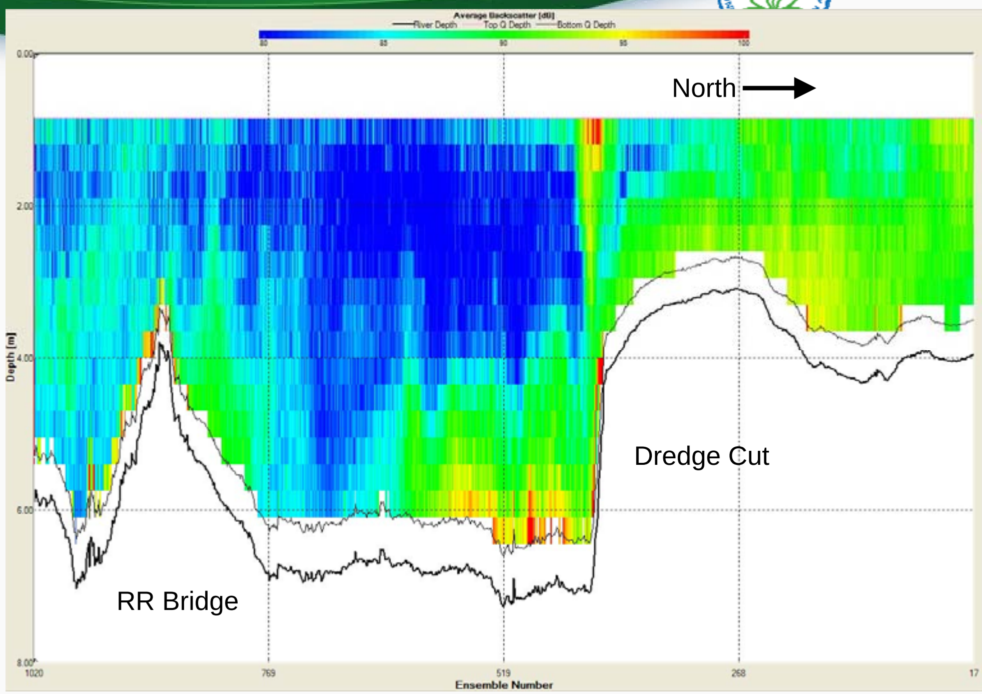


ADCP Backscatter and LISST Data





Longitudinal ADCP Transect



Treatment of Contaminated Sediment

Trudy Estes, P.E., Ph.D. and Daniel Averett, P.E.
Trudy.J.Estes@usace.army.mil
US Army Engineer Research and Development Center
and
Stephen Ells
US EPA
Ells.steve@epa.gov

Topics

- Historical overview
- Type of treatment technologies
  - Target contaminants
  - Issues
  - Demonstrated scale
- Processing specifics
  - Mechanisms of treatment
  - Understanding effectiveness/efficiency
  - Logistical challenges
  - Cost considerations
  - Uncertainty
  - Sediment demonstrations

Four Key Technologies

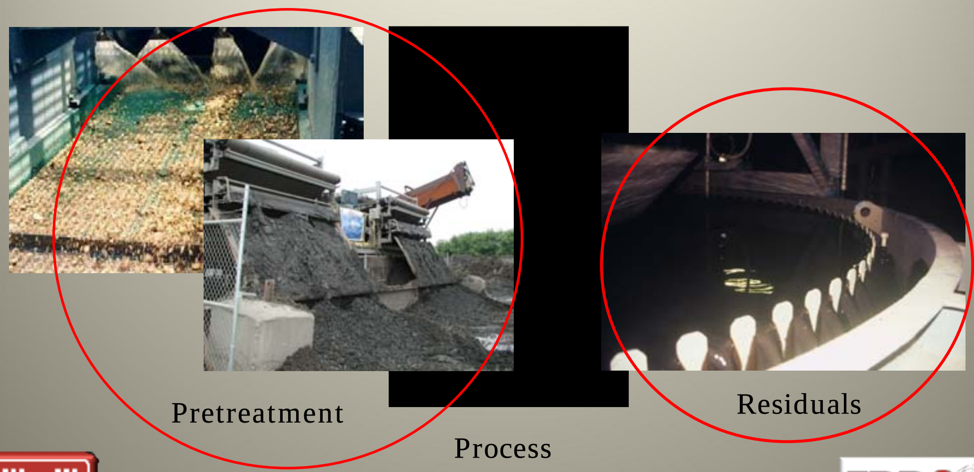
- RK – JCI Upcycle Rotary Kiln
  - Produces light weight aggregate
- GTI –Gas Technology Institute Cement Lock[R]
  - Partial replacement for cement, Ecomelt[R] aggregate
- MIN - Minergy[R] Glass Furnace
  - Glass aggregate, construction fill
- BG – Biogenesis[SM] sediment washing
  - Construction fill, landfill cover

Scale of Sediment Demonstrations

	1994	1996	1999	2000	2001	2003	2004	2005	2006	2007
RK				10						
GTI		X							66.5	
MIN					50					
BG	30		700			330		14.6K		X

(Volumes are in-situ cubic yards)

- Failure of technology developers to consider the “integrated” treatment train



What is treatment?

There are multiple definitions….

- Legal/regulatory definitions
- Public perception
- Risk reduction

And also….

- Ex-situ vs. in-situ processes

Primary Types

- Separation
  - Volume reduction
  - Size & density separation
- Soil washing
  - Phase transfer
  - Extraction & separation
- Stabilization
  - Physical or chemical immobilization of contaminants
- Contaminant destruction
  - Incineration
  - Chemical oxidation

Major Challenges in Sediment Treatment

- Location
  - Access
  - Operational limitations
  - Complete removal
- Heterogeneity
  - Characterization, monitoring & verification
- Debris impacts
  - Dredging costs
  - Dredge/bucket type
  - Follow-on treatment
- Water
  - Sediment water content
  - Associated produced water
- Organic content
- Multiple contaminants
  - Heavy metals
  - Inorganics
  - PAHs
  - PCBs
  - Pesticides
  - Dioxins
  - Nutrients

Issues in Scaling Up

- Pilot/full scale vs. bench testing
  - Greater mass transfer limitations
  - Less efficient mixing, reagent contact
  - Need for supporting dimensional analysis
  - Greater material heterogeneity
  - Often higher concentrations at scale
  - Non-optimized system/equipment at pilot
- Relative scale
  - Treatment capacity vs. dredge production
  - Upland processes usually limiting
  - Surge/storage capacity required

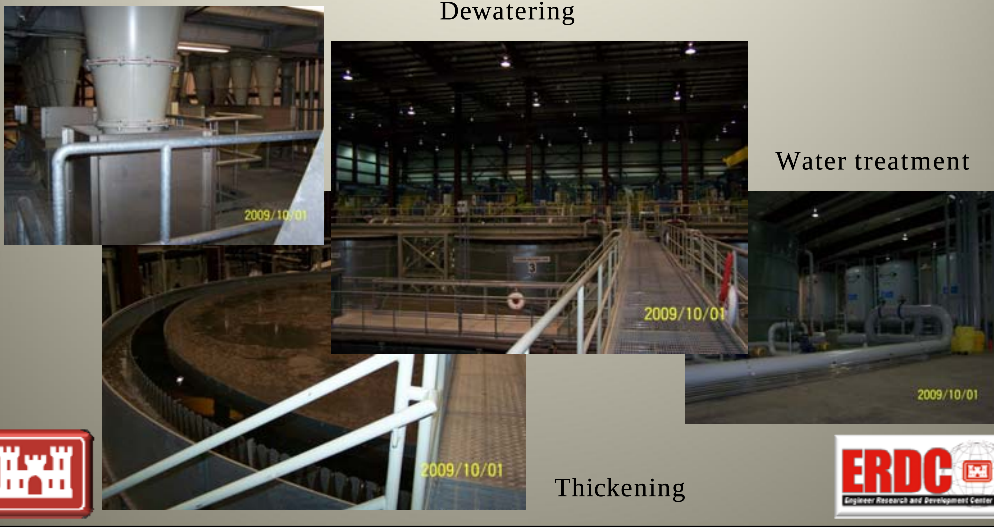
Fox River Separation & Dewatering

Scale required to accommodate small hydraulic dredges...

Size/density separation

Dewatering

Water treatment



Thickening

TREATMENT TYPES

Physical Separation

- Target Contaminants
  - Metals
  - Organic compounds
- No contaminant destruction
- Separate fractions for appropriate management
  - Further treatment (as a pre-treatment process)
  - Disposal
  - Beneficial use
- Wet and dry processes

Soil Washing

- Variation of physical separation
  - Wet process
  - Surfactants
  - Extracting agents
  - Dispersants
- Issues
  - Large wastewater stream
  - Residual sediment fractions requiring disposal

Solidification/Stabilization

- Target contaminants
  - Metals
  - Organic contaminants
- Contaminant destruction
  - Organics - limited (with chem-ox) to none
  - Metals - none
- Typically
  - Ex-situ (but in-situ processes exist)
  - "Cementing" process

- Current in-situ stabilization research
  - Carbon injection
  - Capture of dissolved fraction

Hunter's Point – ESTCP carbon injection demonstration
From: Ghosh, Luthy, Zimmerman, McLeod, Smithenry, Bridges and Millward 2004

In-barge mixing of sediment and pozzolonic agents

Figure 15-10 In situ injection system. (Harmon Environmental Services, Inc.)

From: Chemical Fixation and Solidification of Hazardous wastes, J. R. Conner, Van Nostrand Reinhold, NY.

In-situ injection

Chemical Oxidation

- Target contaminants
  - Organic compounds
- Contaminant destruction
  - Full or partial mineralization
  - Contaminant → CO_2 + H_2O
- Additives
  - Potassium permanganate
  - Hydrogen peroxide
  - Activated sodium persulfate
  - Fenton's reagent
  - Ozone
  - Dissolved oxygen
  - Proprietary mixtures
- Issues
  - Intermediate breakdown products
  - Corrosive, explosive, heat generating chemicals
  - Competition of natural organics for reagents
  - Limited (ex-situ) demonstrated effectiveness in sediments
  - In-situ unlikely to be successful

Thermal Technologies

- Target contaminants
  - Low temp – volatile metals and organics
  - High temp – all contaminants
- Processes
  - Volatilization
  - Incineration
  - Melting of sediment matrix
- Issues
  - Public resistance
  - Energy intensive
  - High capital cost
  - Not mobile
  - Limited demonstrated scale
  - Processing equipment issues

GENERAL CONSIDERATIONS

Treatment Efficiency

- Decontamination vs. efficiency
- Overall process efficiency
  - Total output vs. total input
- Stage efficiency
  - Stage output vs. stage input, *or "where in the process"* the treatment is occurring
- Decontamination efficiency
  - Final sediment concentration vs. initial sediment concentration

Implications of Treatment Efficiencies

- Overall environmental impact
- Utility of additional treatment stages ($$)
- Magnitude of residuals ($$)
- Contaminant levels in treated sediment

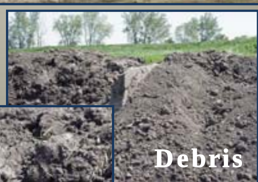
Process Monitoring Challenges

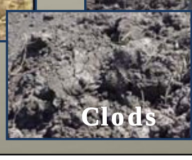
- Mass, mass, mass
  - Solids, liquids, gas and contaminants
- Data interpretation
  - Was it "treatment" or "loss" or "feed variability"?
- Total AND leachable concentrations
- Representative sampling
- Batch vs. continuous processes
  - Average values over time
- Low concentrations in high volume process streams

Physical Separation & Soil Washing

PROCESSING SPECIFICS

Hydrocyclone & Screening Operations





Differentiating between contaminant reduction mechanisms

- Soil washing
  - Oxidation vs. volatilization vs. separation vs. solubilization
- Supporting data
  - Wastewater volume & solids concentration
  - Dissolved and particulate contaminant concentrations
  - Monitoring conservative constituents, such as chlorides, to account for contaminant fate
  - Monitoring for oxidation byproducts
  - Contaminant mass calculations

Solidification/Stabilization S/S

PROCESSING SPECIFICS

Solidification

- Process
  - Elimination of free water
  - Hydration with setting agent or binder
- Binders
  - Cement (portland)
  - Pozzolans[1] (flyash, ground blast furnace slag)
  - Thermoplastics
- Effects
  - Physically altered (cemented) and stable matrix
  - Improved engineering properties
  - Contaminant isolation
  - Reduced resuspension in-situ

[1]Exhibits cementitious properties when combined with lime-rich medium, eg. calcium hydroxide

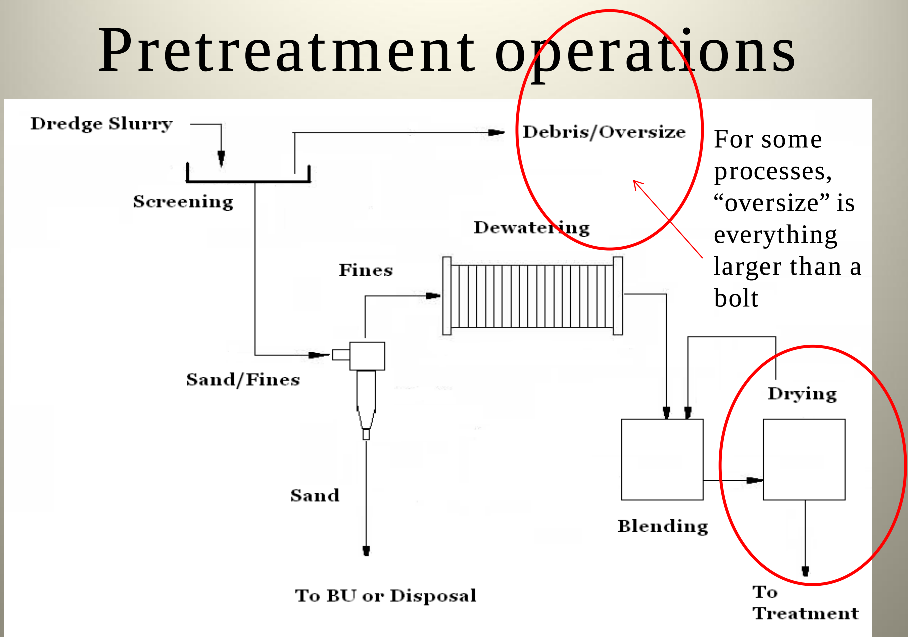
Stabilization

- Process
  - Alteration of contaminant chemical forms
  - Achieved through pH and alkalinity control
- Effects
  - Reduced solubility of cationic metals
  - No contaminant destruction
- Limitations
  - Petroleum hydrocarbons limit hydration
  - Limited applicability to organic compounds
  - Anions more difficult to bind in insoluble compounds
  - Results not always predictable – leach tests required

Thermal

PROCESSING SPECIFICS

Pretreatment operations



Pretreatment requirements vary by process

Soil Washing

PERFORMANCE

Biogenesis

- Physical/chemical processes - organics
  - Phase transfer
  - Size separation
  - Chemical oxidation
  - Filtration
  - Carbon adsorption
- Physical/chemical processes – metals
  - Phase transfer
  - Size separation
  - Chelation
  - Filtration
  - Carbon adsorption

Biogenesis

- Beneficial use product
  - Topsoil component
- Pretreatment
  - Debris removal
  - Screening
- System inputs
  - Sediment
  - Water
  - Surfactants
  - Oxidizers
  - Chelants
  - Polymers
- System outputs
  - Debris
  - Wastewater
  - Fine grained solids
  - Treated sediment

Figure 2-9. BiogensisSM commercial scale, Keasby, NJ (Stern et al. 2009)

Biogenesis Demonstrations

- Brookhaven[1]
  - 700 yd3
  - Stratus Petroleum – Newark Terminal
  - Evaluate general effectiveness
  - Generate design data for scale-up
- Venice 2003-2004[2]
  - 430 yd3
  - Porto Marghera canals
- Lower Passaic 2006
  - 15,000 yd3
  - 40 yd3/hr (250,000 yd3/yr)
  - Process modifications
  - Accompanying bench testing effort to improve PAH removal

1 (BioGenesis & Weston 1999), 2) Biogenesis Italia, LLC et al 2005

Original Process Stages

Table 2-12. BioGenesis[SM] process stages

Stage		Function
Non-Proprietary Stages	Grizzly (or comparable)	Removal of oversize material
	Vibrating Screen	Separation and removal of debris and coarse material (6.4 mm (>0.25 in.))
Proprietary Stages	Pre-processor (BioGenesis[SM] chemical (surfactant) addition and mixing)	Disaggregate sediment particles and outer layer of contaminants
	Aeration, flotation, and skimming	Float and remove lighter organics
	Collision chamber (sediment washer)	Apply high pressure impact technology to remove adsorbed contaminants from sediment particles and transfer into water phase
	Oxidant addition, mixing, and cavitation/oxidation	Oxidize desorbed organic contaminants under (localized) increased temperature and pressure
	Hydrocyclone/dewatering screen	Solid-liquid separation to collect treated coarse grained product
	Filter press and/or centrifuge	Dewater treated sediment for beneficial use
	Water treatment	Remove contaminants from centrate/filtrate

From Estes et. al 2011

Apparent Loss/Treatment Mechanisms NY/NJ Harbor Demo

- Metals
  - Phase transfer & particulate losses to wastewater
  - Hg volatilization
- Organics
  - Material losses during pretreatment
  - Limited phase transfer to wastewater
  - Chemical oxidation?
  - VOCs volatilization
- Losses
  - ≈13% loss of metals
  - ≈ 40% loss of Hg
  - No spent carbon or offgas data to estimate volatilization losses
- PAH Removal
  - ≈50% occurred in preprocessing
  - ≈4% occurred in cavitation/oxidation step
- PCBs Removal
  - 1% occurred in cavitation/oxidation step

Efficiencies NY/NJH Study

Contaminant	Overall efficiency	Decontamination efficiency	Fraction of input in centrifuge solids	Fraction of input in centrate (total and dissolved)
Chromium	11.3%	82.3%	17.7%	71.0%
Lead	4.7%	73.7	26.3	69.0
Nickel	-8.2%	52.9%	47.1%	61.0%
Zinc	22.5%	71.3%	28.6%	48.9%
Mercury	39.8%	95.4%	4.6%	55.6%
Benzo(a)pyrene	54.5%	54.5%	45.5%	0.0%
Fluoranthene	51.0%	69.5%	30.5%	18.5%
Total Metals	12.7%	75.0%	25.0%	62.2%
Total PAHs	61.2%	66.3%	33.7%	5.1%
Total PCBs (Homo-logues)	53.4%	99.8%	0.2%	46.4%
Total Dio-xins/Furans	78.9%	99.9%	0.1%	21.0%

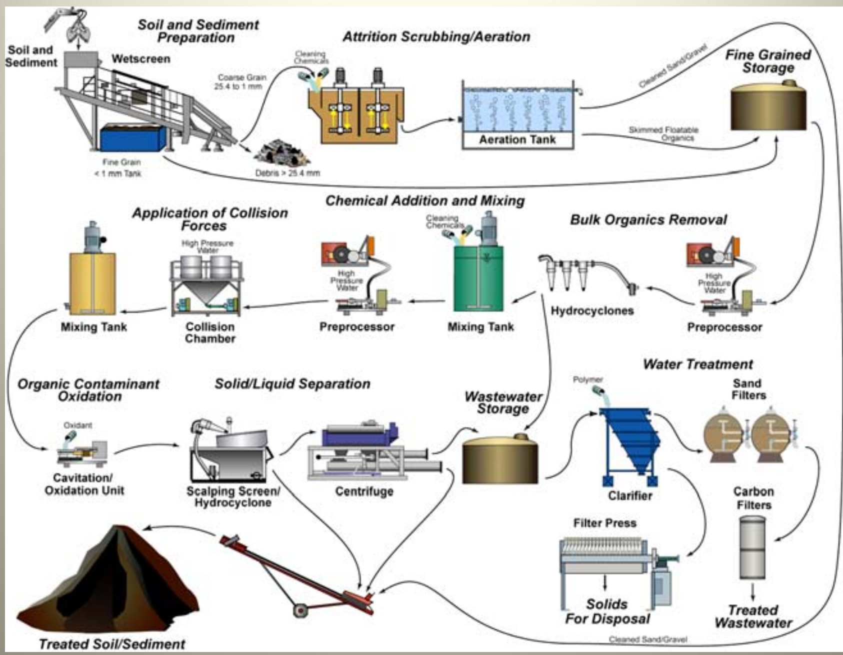
$$E_{overall} = \frac{\sum Mass_{in} - \sum Mass_{out}}{\sum Mass_{in}} * 100$$

Housatonic Bench Testing

- PCBs target contaminant
- 3-5 gal volumes/test run
- Fine & coarse grained sediment and soil
- Multiple treatment cycles

- Process
  - >1" oversize screened
  - +425 um[1] scrubbed to remove fines and organics
  - -425 um[1] (passing 850 um screen), scrubbed, then oxidized & dewatered 3X

From separate coarse and fine sediment samples respectively



Taken from Biogenesis Enterprises Inc. 2008

Treatment Mechanisms

- Coarse fraction
  - Phase transfer (Avg. 41% to wastewater)
  - Size and density separation (Avg. 6% remaining in treated coarse)
- Fine fraction (after 1 cycle)
  - Phase transfer (Avg. 28% to wastewater)
  - Size and density separation (Avg. 2% in cyclone solids and oversize organics)
  - Chemical oxidation/cavitation(Estimated average 12% of PCBs entering this stage remain in centrifuge solids after 1 cycle)
  - Material/PCB mass ($\approx$ 28-29% avg. in 1st cycle both fines and coarse)

After 3 cycles...

- Coarse sediment
  - <10% PCB mass in combined output solids
  - ≈41% inlet PCB mass in wastewater
  - ≈50% PCB mass unaccounted for or destroyed (not adjusted for material losses)
- Fine sediment
  - <3% in treated solids
  - ≈28% inlet PCB mass in wastewater
  - ≈69% PCB mass unaccounted for or destroyed (not adjusted for material losses)

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General Soil Washing Findings

- Chemical oxidation questionable utility
- Wastewater volumes
  - Expect ≈1-2m^3 wastewater/m^3 sediment containing fine solids
  - Expected to require treatment
  - May be recycled in system
- Multiple cycles may be required to achieve adequate treatment
- Beneficial use potential depends on
  - Starting concentrations
  - Proposed application & applicable criteria

ERDC
Engineer Research and Development Center

Thermal Technologies

PERFORMANCE

Cement Lock, Minergy, Rotary Kiln

- Technologies demonstrated on sediments at pilot scale
- Evaluated in Estes et al 2011
- Common treatment mechanisms
  - Volatilization
  - Thermal destruction
  - Vitrification (immobilization)
- Emission controls
  - Particulates
  - Sulfur
  - Nitrogen oxides
  - Volatilized contaminants
- Differences
  - Treatment temperatures
  - Kiln/Furnace type
  - Product properties
  - Pretreatment requirements

Minergy

- Glass furnace technology
- Oxygen & natural gas fueled
- Glass aggregate product
- Primary present application sewage sludge treatment
- Commercial scale plants generating trench fill for municipalities
- Most sediments have suitable mineralogy
- Salinity can be problematic (corrosive)
- Process
  - Oversize & metallic debris removal
  - Dewatering (<50% MC)
  - Drying (<10% MC)
  - Flux addition
  - Melting (1600 deg C) – 6 hr residence time
  - Quenching
  - Offgas capture & treatment

Cement Lock Demonstrations

- 1996 Newtown Creek sediments
  - 3 yd3
- Stratus Petroleum Sediments 2003-2005
  - Phase I pilot
  - 100 tons sediment
  - Not continuous operation
  - Phase II demonstration
- Stratus Petroleum Sediments 2006
  - Phase II confirmation testing
  - 5.1 tons sediment
- Passaic River sediments 2006-2007
  - Extended duration testing – 48 hrs total
  - Slag discharge plugging
  - 16.5 tons sediment
  - 1500 lb/hr

Cement Lock[1]

- Rotary kiln technology
- 2 beneficial use products
  - Ecomelt (cement additive) – slagging or vitrification
  - EcoAggMat (aggregate) – non-slagging or sintering
- Process
  - Debris and oversize (>2in) removal
  - Dewatering
  - Drying
  - Modifiers
  - Kiln treatment (1400-1500 deg C)
  - Quenching
  - Offgas capture & treatment

1) Volcano Partners

Apparent Loss/Treatment Mechanisms – EcoMelt Generator®

Offgas particulates losses?

Majority of TCLP <DL

Analyte	Stage efficiencies (Total analyses-Ecomelt® product)	Stage efficiencies (TCLP leachate-Ecomelt® product)
Total metals[1]	54%	99%
Mercury	60%	60
Lead	93	99.9%
Total PCBs	99.9	NA

[1] Total of As, Ba, Cd, Cr, Co, Cu, Hg, Mn, Ni, Pb, Se, Ag, and Zn

Not conducted for PCBs

From Estes et al 2011 – Stage efficiency of kiln during extended duration tests with Passaic River sediments

Decontamination Efficiency

Analyte	Decontamination efficiencies (Total mass-Ecomelt® product)	Decontamination efficiencies (TCLP leachate mass-Ecomelt® product)
Total metals[1]	54%	99%
Mercury	99.6%	100%
Lead	93%	100%
Total PCBs	99.99%	NA
1) Total of As, Ba, Cd, Cr, Co, Cu, Hg, Mn, Ni, Pb, Se, Ag, and Zn		

From Estes et al 2011 extended duration testing with Passaic River sediments;
TCLP below regulatory limits for all samples
SPLP below detection for most contaminants; 3 samples < NJ Ground Water Quality Criteria for Mn and 1 for Pb

COSTS

Treatment Cost Comparisons

- Non-uniform basis
  - Process scale
  - Capital recovery period
  - Total volume treated
  - Potential costs may not have been considered
  - Value of beneficial use products may/may not have been included
- Extrapolated from small-scale operations
- May be contingent upon
  - Guaranteed total or annual volume
  - Extended performance period (eg. 20 years)
  - Assumed product value
- Beneficial use products
  - Lack demonstrated performance
  - May suffer “stigma”
  - Market must be developed

Adjusted Cost Estimates[1]

- Derived from vendor estimates
- Comprehensive list of standard line items developed
- Missing elements estimated using other vendor’s estimates
- Adjusted to Dec 2009
- Equivalent per cy/in-situ sediment basis
- Different straight line depreciation
  - Rotary Kiln 10 yrs
  - Cement Lock 20 yrs
  - Minergy 15 yrs
  - Biogenesis 10 yrs

ERDC estimates based on vendor reported costs
Estes et al 2011

Normalized Cost Estimates[1]

	Rotary Kiln	Cement Lock	Minergy	BiogenesisSM
Volume Basis (m3)	380,000	380,000	380,000	430,000
Volume Basis of Cost Data (yd3)	500,000	500,000	500,000	560,640
Yrs Straight Line Depreciation	10	20	15	10
Sale of Product	$35.76	$41.81	$0.91	$11.30
Sale of Energy	NA	$19.56	NA	NA
Total Cost	$91.82	$101.16	$71.75	$51.99
Net Cost	$56.06	$39.79	$70.84	$40.69

1) 2009 basis, subject to some uncertainty, typically 30 to 50% under actual cost and as much as 30% over actual for preliminary design

Normalized Cost Estimates

- A relative tool - intended to aid preliminary technology screening
- Values subject to considerable uncertainty
  - Missing information
  - Pilot scale basis
  - Time adjustments
  - Unclear elements of the original estimates

CONCLUSIONS

General Observations

- All processes capable of some level of treatment
- Bench scale testing is usually optimistic – especially with respect to chemical oxidation
- Mass balance is essential for all materials & contaminants in all process streams
  - Mass or volume AND concentration
- Physical separation "effects"
  - Soil washing
    - by design
    - often more significant than other processes
  - Thermal treatment
    - incidental to pretreatment & offgas particulate losses
- Dilution
  - Some concentration reduction may be attributable to process amendments

Obstacles to Commercialization

- Lack of full-scale performance history
- Availability of effective and economical disposal alternatives
- Mutually exclusive requirements for process scale and mobility
- Public acceptance
- Treatment cost uncertainty
- Undemonstrated product market and long-term performance

Technology Selection Criteria

- Pretreatment requirements
- Efficiency
- Residual process streams
- Capacity and scalability
- Cost/economics
  - Capital cost vs. sediment volume
  - Sustained vs. short term demand
- Suitability to sediment properties & target contaminants
- Mobility
- Degree of treatment or risk reduction required
- Technology maturity
- Product market?

References

- Channel, M.G. and Averett, D.E. 1997. "An Evaluation of Solidification/Stabilization for Treatment of New York/New Jersey Harbor Sediments", Waterways Experiment Station, Vicksburg, MS
- Maher, A., Najm, H. and Boile, M. 2005. "Solidification/Stabilization of Soft River Sediments Using Deep Soil Mixing", State of New Jersey, Department of Transportation, Trenton, N.J.
- Harbor Resource Environmental Group, Inc. 2005. "Sediment Decontamination Demonstration Project – Final Report", Submitted to New Jersey Department of Transportation, Office of Maritime Resources, 2005.
- Estes, T.J., Magar, V.S., Averett, D.E., Soler, N.D., Myers, T.E., Glisch, E.J. and Acevedo, D.A. 2011. "Mass Balance, Beneficial Use Products and Cost Comparisons of Four Sediment Treatment Technologies Near Commercialization", USAC Engineer Research and Development Center, Vicksburg, MS.
- Biogenesis Enterprises Inc. 2008. "BIOGENESISS SEDIMENT WASHING TECHNOLOGY Bench-Scale Treatability Study Report Housatonic River – Rest-of-River Site", Springfield, VA.

Disposal Options for Dredged Sediment

Marc Mills, PhD
Edwin F. Barth, PhD, PE, CIH
U.S. Environmental Protection Agency

1

Sediment Properties Important for Dewatering and Disposal Options

- Grain size distribution (LL, PL)
- Particle shape
- % solids
- Hydraulic conductivity
- Compaction/consolidation
- Shear strength
- Organic content, nutrients, pH, salinity
- Toxicity, leachate quality

Dewatering (Geotextile Tube)

- Dredged material pumped to polymer mix tank then to Geotextile Tube
- % solids increased from 5-10% from dredge to 35-50% after Geotextile Tube
- Materials compatibility

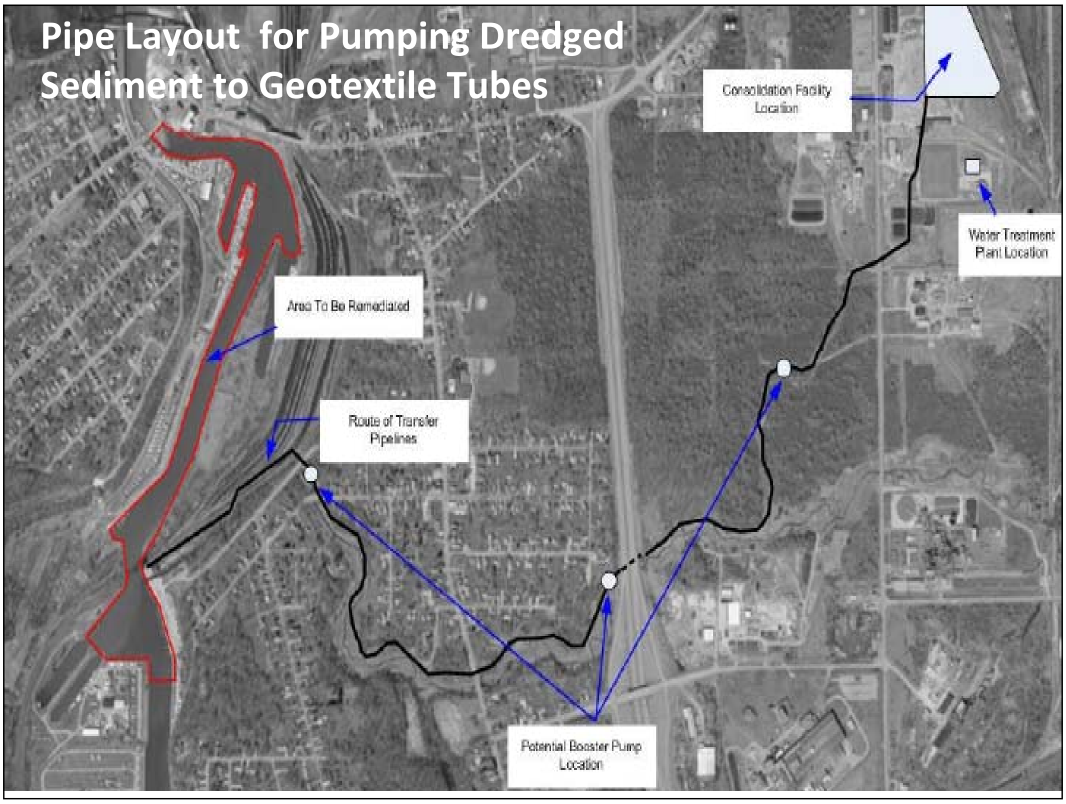
Types of Geotextile Tubes (woven and non-woven)

- Polypropylene
- Polyester
- 35, 45, and 60 ft. circumference (typ.)
- Use polymers for dewatering fine material

Percentage Solids Reduction Wd/Wt

- % solids in-situ sediment (typ.): 40-50%
- % solids hydraulic dredge (typ.): 8-10%
- % solids belt filter press (typ.): 17%
- % solids after Geo.Tube drying (typ.): 45%

Pipe Layout for Pumping Dredged Sediment to Geotextile Tubes



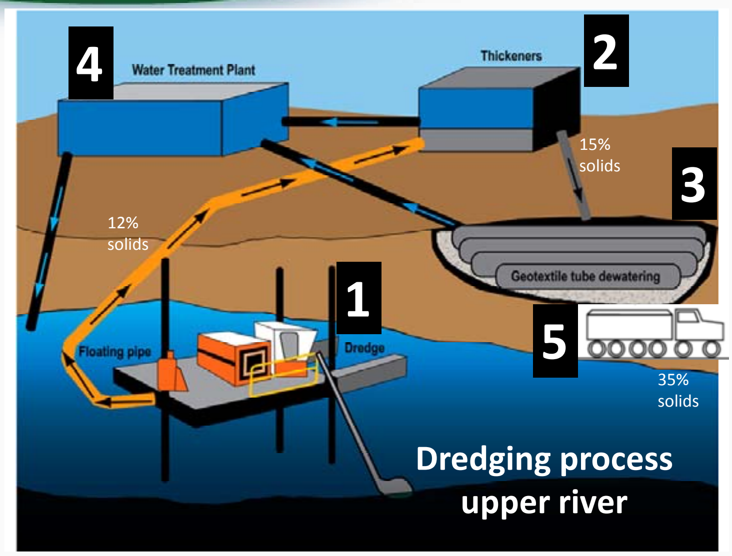
Filled geotubes

Water Treatment Plant

Sand and Carbon Filter Units

Polishing Bag Field

Fox River, WI



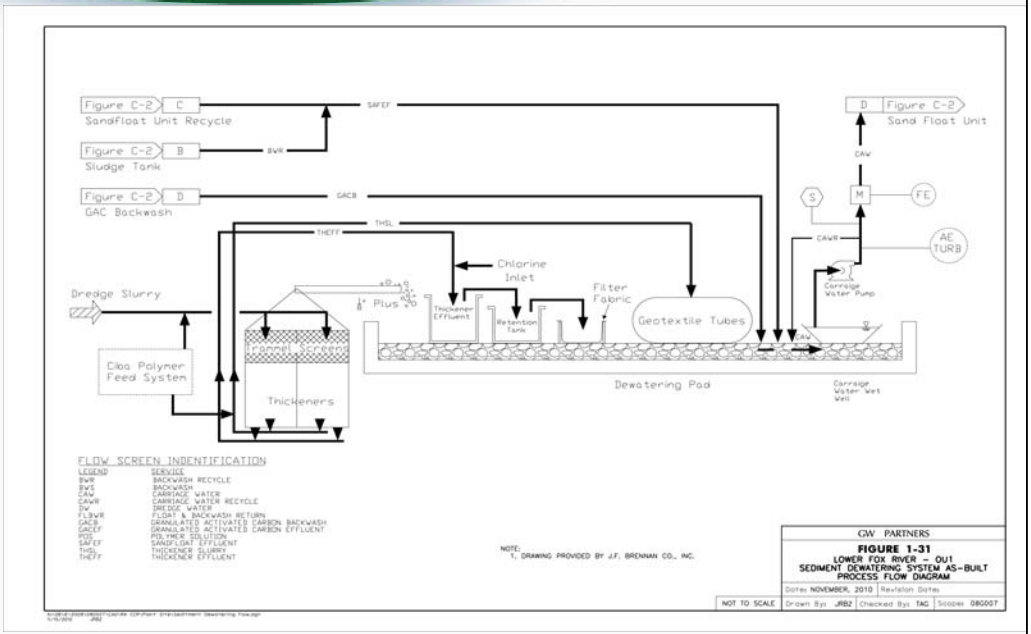


Figure C-2 C
Sandfloat Unit Recycle
Figure C-2 B
Sludge Tank
Figure C-2 D
GAC Backwash
SAFEF
BWR
GACB
THSL
THEFF
D Figure C-2
Sand Float Unit
CAW
S
M
FE
CAWR
AE TURB
Chlorine Inlet
Dredge Slurry
Plus
Thickener Effluent
Retention Tank
Filter Fabric
Geotextile Tubes
Carriage Water Pump
Trommel Screens
Ciba Polymer Feed System
Thickeners
Dewatering Pad
Carriage Water Wet Well
FLOW SCREEN INDENTIFICATION
LEGEND SERVICE
BWR BACKWASH RECYCLE
BWS BACKWASH
CAW CARRIAGE WATER
CAWR CARRIAGE WATER RECYCLE
DW DREDGE WATER
FLBWR FLOAT & BACKWASH RETURN
GACB GRANULATED ACTIVATED CARBON BACKWASH
GACEF GRANULATED ACTIVATED CARBON EFFLUENT
POL POLYMER SOLUTION
SAFEF SANDFLOAT EFFLUENT
THSL THICKENER SLURRY
THEFF THICKENER EFFLUENT
NOTE:
1. DRAWING PROVIDED BY J.F. BRENNAN CO., INC.
GW PARTNERS
FIGURE 1-31
LOWER FOX RIVER – OU1
SEDIMENT DEWATERING SYSTEM AS-BUILT
PROCESS FLOW DIAGRAM
Date: NOVEMBER, 2010
Revision Date:
NOT TO SCALE
Drawn By: JRB2
Checked By: TAG
Scope: 08G007

Containment: CDF or CAD

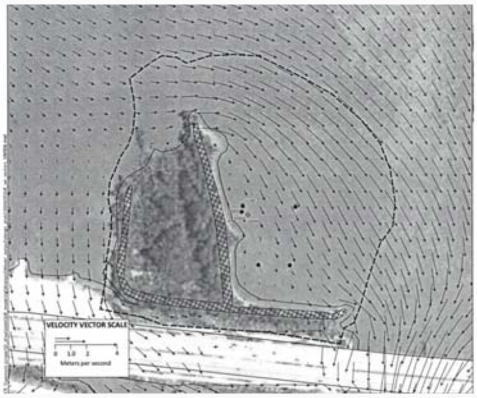
- Horizontal flow isolation by sheet piling and sealant, slurry wall
- VOC loss by volatilization (seasonal)
- Metal mobility by redox changes from dewatering trenches
- Potential Use of Sediment or Land Occupied

CDF or CAD Design Evaluation

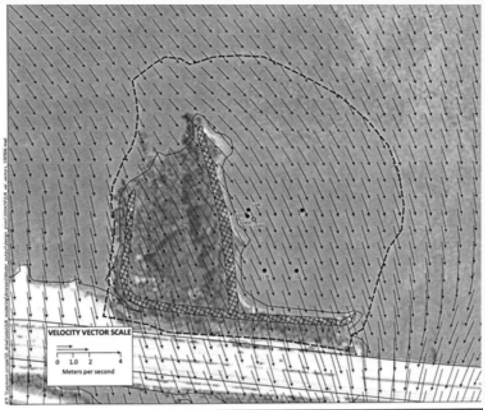
- Hydrodynamic modeling
- Storm event probability (0.01/yr)
- Velocity
- Shear stress (SEDFLUME)
- Elevation (Sheet piling)

CDF or CAD Flow Velocity Evaluation

5 year flooding event

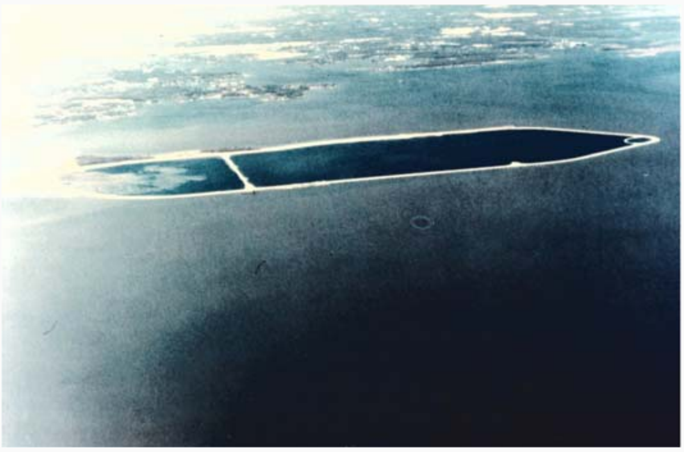


100 year flooding event



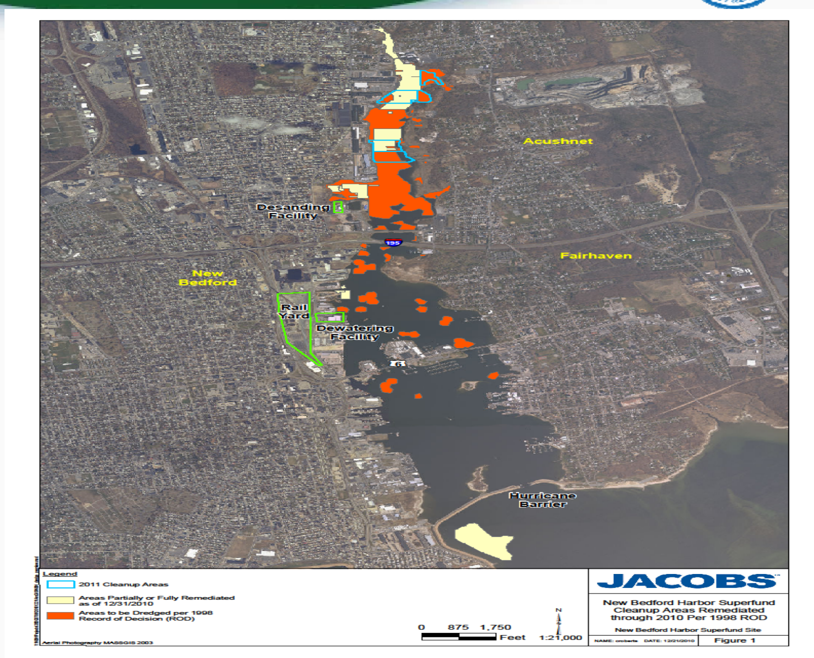
Hart Miller Island CAD

- 1984-2009
- 1100 acres

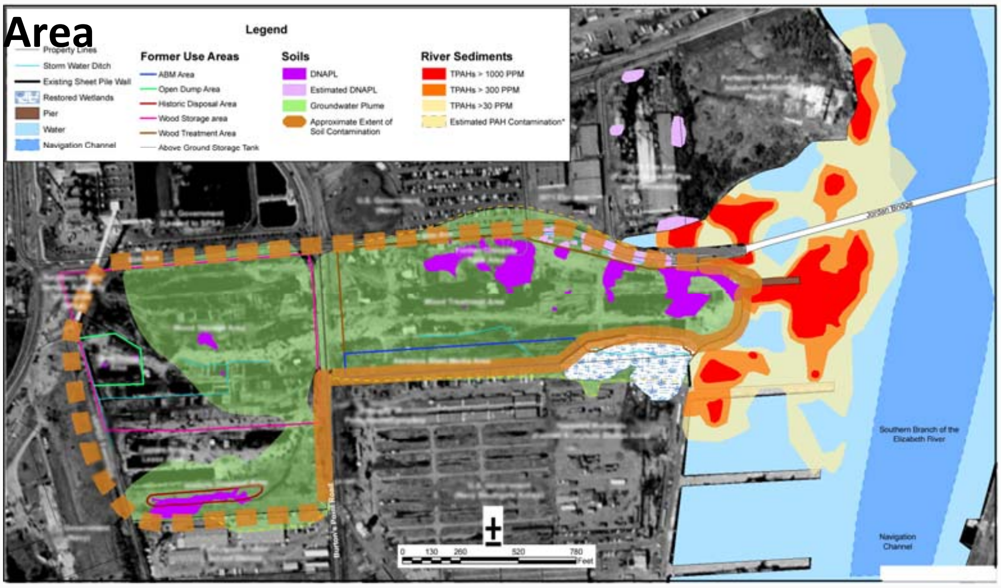


New Bedford Harbor

- Dredged material is being dewatered (BFP) then disposed in upland landfill
- 300,000 CY CAD being planned



Creation of CAD Bordering Soil Remediation Area

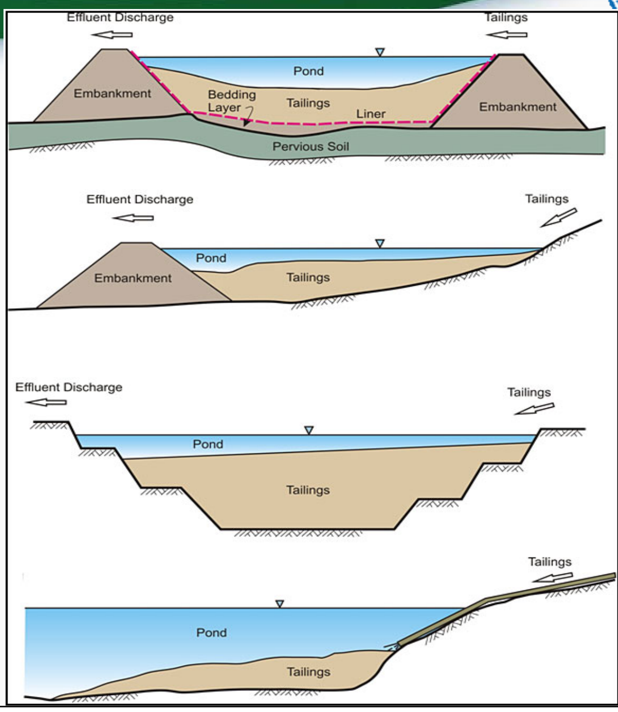


IHC Site – Petroleum Refining Dismantled

IHC: 4.8 MCY Capacity, 168 acres, $200M cost

CDF/Canal Sheet Piling Isolation Structure

Mine Tailings Management



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- Randy Sturgeon, EPA Region III
- Val. Leos, Steve Tzhone, EPA Region VI
- Jennifer Miller, USACE, Chicago, IL
- Jack Fowler, Geotec

Taiwan-EPA Contaminated Sediment Workshop June 14-15, 2011: U.S. EPA's Approach to Understanding Sediment Site Conditions, Characterizing Contamination, and Reducing Uncertainties in Making Decisions to Manage Risks from Contaminated Sediments

Risk-Based Decision-Making:

Linking the RI risk assessment and remedy decision to monitoring of receptors that matter

Marc S. Greenberg, Ph.D.

U.S. EPA OSWER OSRTI Environmental Response Team
2890 Woodbridge Ave.
Edison, NJ 08837
732-452-6413
greenberg.marc@epa.gov

Important Monitoring Considerations

- **Surface water monitoring**
  - Surface water ARARs as Remedial Action Objectives (RAOs)
  - Recent focus on dredging-related issues of residuals, resuspension and contaminant release warrants increased focus on water column
- **Consider using real-time *in situ* biomonitoring approaches**
  - Can be especially useful during remedial actions
  - Acute biological responses using controlled exposures
  - Can conduct in near- and/or far-field
- **Improved understanding of bioavailable fraction**
  - Perspective to residual contamination following dredging (undredged inventory, generated and undisturbed residuals)
  - Supports exposure analysis and knowledge of natural recovery and/or sequestration processes
  - Biouptake studies

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Important Monitoring Considerations

- **Improved understanding of dynamic processes**
  - Important to all remedial options (MNR, capping, dredging)
  - Sediment stability and transport
  - Contaminant flux
  - Supports exposure analysis and knowledge of natural recovery and/or sequestration processes
- **Transparent basis for sampling designs**
  - Data Quality Objectives clarified *(use the ROD!)*
  - Statistical basis
  - Cost of effort

Physical Measurements

Sediment erosion/deposition, ground water and surface water flow rates, and sediment physical characteristics (e.g., particle size, heterogeneity, bulk density)

- ***Sediment Physical Properties***: Fate and transport modeling, sediment characteristics, post-remedy surface sediment features
- ***Water Column Physical Measurements*** *(e.g., turbidity, suspended solids)*: Sediment suspension during remedy implementation
- ***Bathymetry***: Evaluate pre-remedy and post-remedy bottom elevations
- ***Side Scan Sonar Data***: Monitor sediment types and bedforms
- ***Settlement Plate Data***: Changes in cap thickness, cap consolidation
- ***Sediment Profile Camera Data***: Visual surface sediment characteristics, bioturbation/oxidation depths, presence of gas bubbles
- ***Subbottom Profiler Data***: Changes in sediment surface and subsurface composition, presence of gas bubbles

Chemical Measurements

Surface or buried (as appropriate) sediment chemical concentrations, surface water and pore water chemical concentrations, chemical transformations

- Sediment Sampling
  - ***Grab Samples*: Surface sediment chemistry (bulk)**
  - ***Sediment Coring*: Vertical chemical profiles, or contaminant migration through a cap or through naturally deposited clean sediment**
- Surface Water Sampling
  - ***Direct Water Column Measurements*: Dissolved oxygen, pH**
  - ***Surface Water Samples*: Chemical concentrations (dissolved and particulate), water-column releases during remedy construction**
- Pore Water Sampling
  - ***Direct Pore Water Sampling*: Trident probe, piezometers (contam. and flow)**
  - ***Passive Samplers (Peepers)*: Establish pore water equilibrium to measure contaminants**
  - ***Passive Samplers (SPMD/SPME)*: Semi-Permeable Membrane Devices, and solid-phase microextraction measure dissolved contaminants**
  - ***Seepage Meters*: Contaminant flux into the water column**

Biological Measurements

- ***Toxicity Testing***: Measure acute and chronic lethal or sub-lethal contaminant effects on organisms
- ***Tissue Sampling***: Measure bioaccumulation, model trophic transfer potential, and estimate food web effects
- ***Caged Fish/Invertebrate Studies***: Monitor changes in contaminant uptake (bioaccumulation rates) by biota in sediment or water column
- ***Bioavailability studies***: Ex situ and in situ
- ***Consumption Patterns***: Extent of recreational/commercial harvesting of fish/shellfish for human consumption
- ***Synoptic/Observational Analyses***: Abundance/diversity of bottom-dwelling species, fishes, and emergent/submergent vegetation; Sediment Profile Camera; macroinvertebrate recolonization

Sediment Remedy Decisions—Key Biological Information

- **Consumption of contaminated fish by humans and wildlife are most often driving risk-based decisions**
- **Sediment toxicity tests**
  - Often useful line of evidence at sediment sites for developing ecologically protective sediment PRGs (as a risk range)
  - Direct toxicants (acute & chronic measures)
  - PBTs (chronic generally most useful measures)
- **Bioaccumulation**
  - BSAFs, ERA and HHRA uses

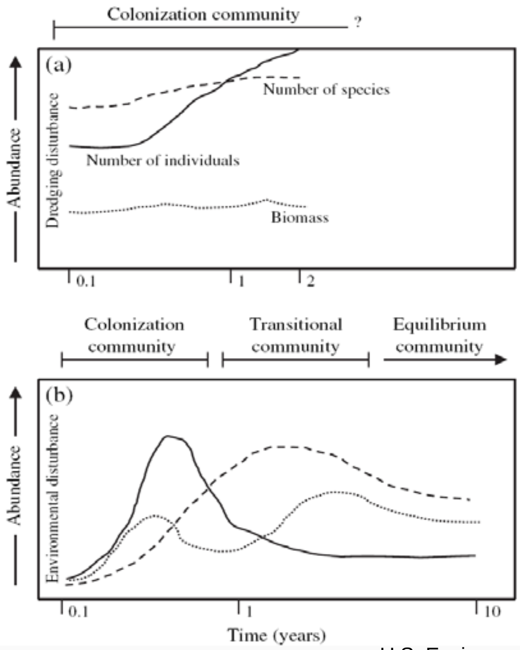
EPA 2005 Sediments Guidance

- **Biological measure employed should match the time frame established for the criteria.**

Examples:

- Acute toxicity tests quantify short-term effects on an organism—may be appropriate for operational monitoring; short period of time or discrete time points following an action
- Changes in species diversity, typically occur over long periods of time—may be more appropriate for use in a long-term monitoring program designed to look at ecological recovery

Benthic macroinvertebrates: Easy to measure; challenges with decisions



Gilkinson KD et al., ICES J. Mar. Sci. 62:925-947 (2005)

- **What is an acceptable benthic recovery or recolonization endpoint?**
- **Commonly thought that the benthic organisms will return quickly following a disturbance.**
  - Can be useful to show remedy effectiveness early
  - Perhaps can consider frequency of short vs. long-term monitoring due to community succession
- **Recommend that decision criteria should be developed during selection of a measure**

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Ketchikan Pulp Company Site

- **Contact: Karen Keeley, Region 10 RPM**
- **Dissolving sulfite pulp mill from 1954 until 1997**
- **Degradation of organic-rich pulping by-product led to contamination by ammonia, sulfide, and 4-methylphenol**
- **2000-2001 remediation: TLP in 27 ac; MNR in 52 ac; dredge approx. 8700 cy.**

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Ketchikan Pulp Company, Ward Cove, AK

Area		Summary: Amphipod % Survival
MNR Shallow-Thin Organic Deposits	•	>90% all stations (2004)
	•	Station 47: 73% (1996), 100% (2004)
MNR Shallow-Thick Organic Deposits	•	Range 20-100% (2004); 1 station 70%, 6/7 stations ≥85% (2007)
	•	Station 38: 0% (1997), 89% (2004); 98% (2007)
MNR Mod/Deep	•	≤60% except 2 stations (1996 & 2004); 8/10 stations ≥90% (2007)
	•	Station 13: 36% (1996), 15% (1997); 46% (2004); 96% (2007)
Thin Layer Placement	•	≥80% all stations (2004); ≥85% all 15 stations (2007)
	•	Station 8: 43% (1996); 99% (2004); 96% (2007)
	•	Station 9: 54% (1996); 91% (2004); 94% (2007)

Data summarized from Exponent 2005; Integral 2009

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Ketchikan Pulp Company, Ward Cove, AK

Summary of Recovery Status for Various Biological Indicators Based on 2007 Data

	Stratum					
	Enhanced Natural Recovery (i.e., TLP)			Monitored Natural Recovery		
Indicator	1	2a	3a	2b	3b	4
Sediment Toxicity	✓	✓	✓	✓	✓	✓
Benthic Community Metrics[b]	100%	100%	100%	33%[c]	100%	100%
Abundance						
Total abundance	✓	✓	✓	--	✓	✓
Taxa abundance						
Molluscs	✓	✓	✓	--	✓	✓
Polychaetes	✓	✓	✓	✓	✓	✓
Arthropods	✓	✓	✓	✓	✓	✓
Richness						
Total richness	✓	✓	✓	--	✓[d]	✓
Taxa richness						
Molluscs	✓	✓	✓	--	✓[d]	✓
Polychaetes	✓	✓	✓	--	✓[d]	✓
Arthropods	✓	✓	✓	✓	✓	✓
SDI	✓	✓	✓	--	✓[d]	✓

Final Remedial Action Report, Integral 2009

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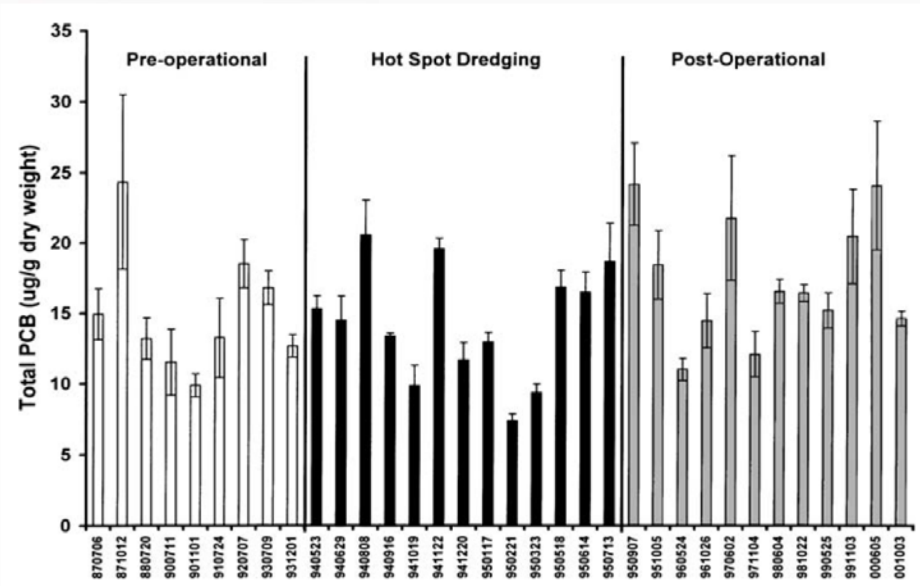
Tissue Monitoring

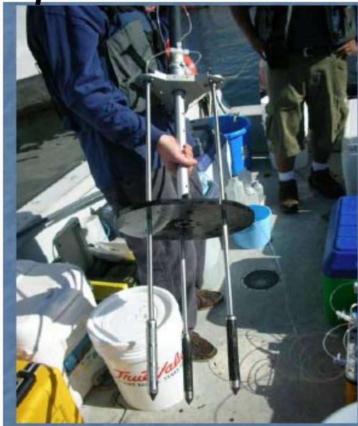
- **Fish (and shellfish) tissues:**
  - Human health consumption risks
  - Risks to wildlife from consumption
- **Other bottom dwelling species**
- **Measure of bioavailability**
  - Tissue data are "direct" (status or change in status)
  - Also good idea to combine with passive sampling

Realities: May not see rapid decreases after hot spot removals



Physicochemical Assessment Tools

Add effects assessment strategies to existing tools for improved site and risk characterization



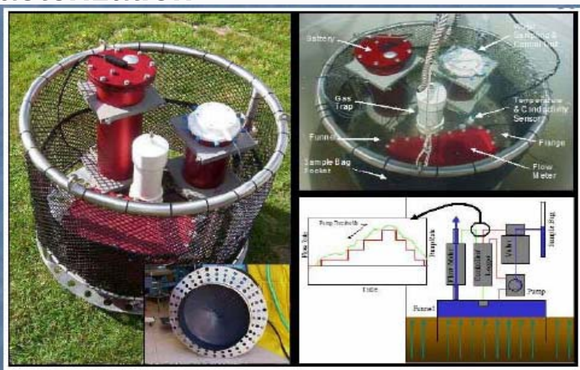


Figure 4. The UltraSeep system showing component layout and schematic of the flow and sampling systems.

Trident Probe
↓
Toxicity Screening

SERDP

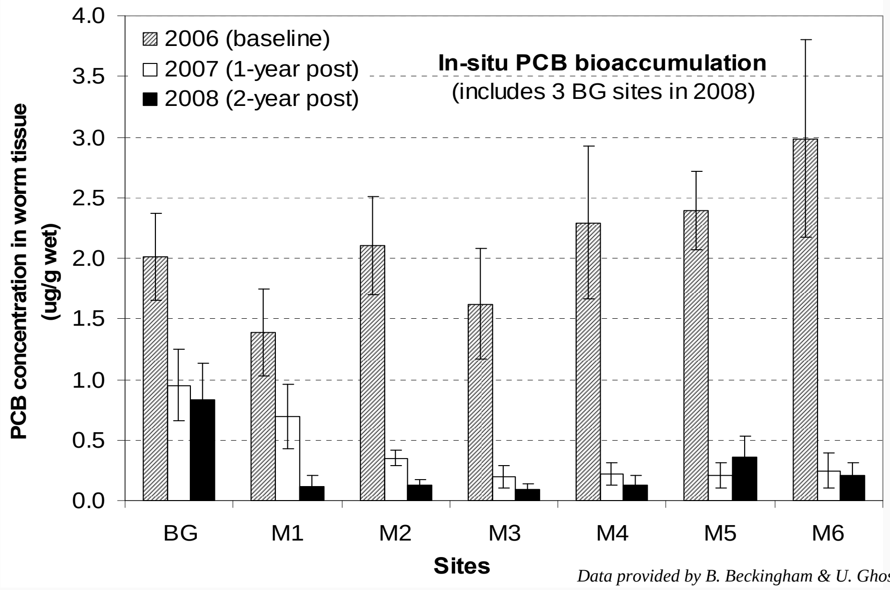
UltraSeep
↓
***In Situ* Bioassays**

Sediment Ecotoxicity Assessment Ring 'SEA Ring'

- ***Toxicity testing***
- ***Bioaccumulation testing***
- ***Passive samplers (SPMEs, DGTs)***
- ***Water quality***

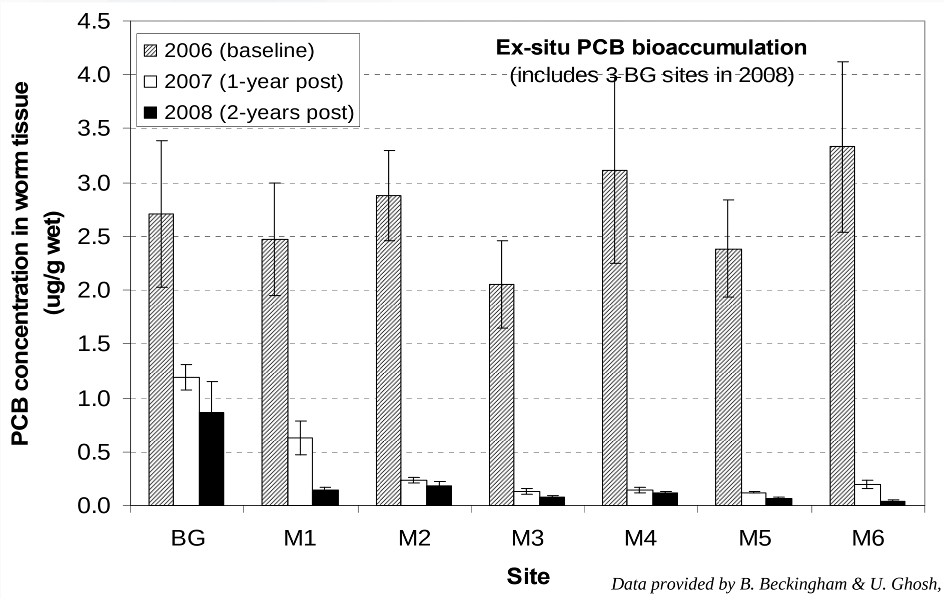
SERDP

Grasse River Activated Carbon Pilot Study
Mixed Tiller Area Worm PCB In-Situ



Data provided by B. Beckingham & U. Ghosh, UMBC

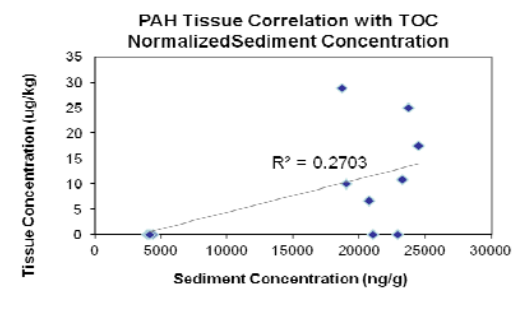
Grasse River Activated Carbon Pilot Study
Mixed Tiller Area Worm PCB Ex-Situ

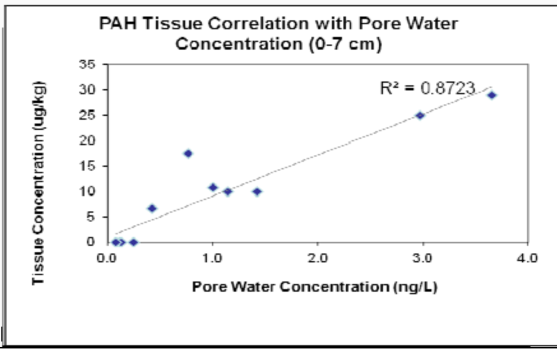


Data provided by B. Beckingham & U. Ghosh, UMBC

Naval Station San Diego: Tissues & Integration of Passive Samplers

- **Good** correlation between *Musculista* tissue and SPME-derived pore water concentrations for PAHs
- **Weak** correlation between TOC-normalized bulk sediment concentration and tissue concentration
- Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene
- **NS21>NS24>NS22>2243**





ental

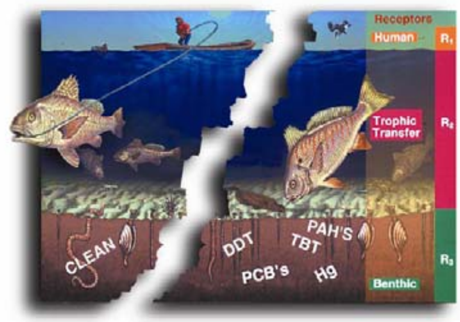
Guidance on designing fish monitoring plans

- **Considerations:**
  - Contaminant Types
  - Fish Species
  - Sex, Age, Lipid Content
  - Sample Type and Size
  - Sampling Frequency
  - Time of Sampling
  - Sample Location
- **Difficult choices!**

Office of Superfund Remediation and Technology Innovation
and
Office of Research and Development

Sediment Assessment and Monitoring Sheet (SAMS) #1

Using Fish Tissue Data to Monitor Remedy Effectiveness



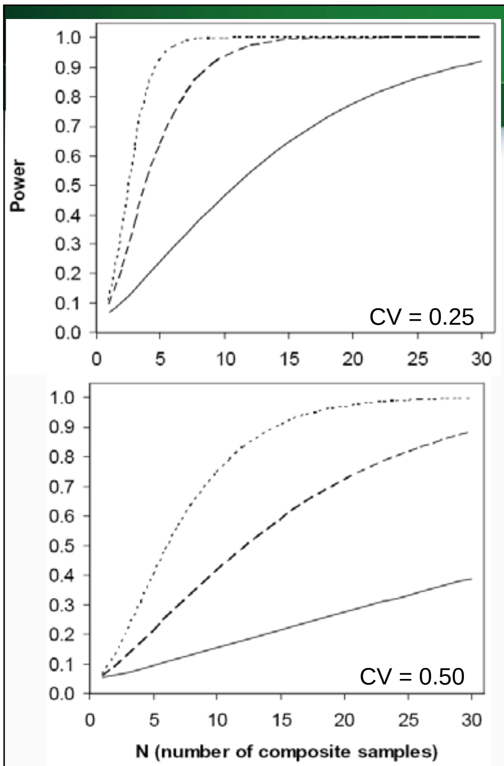
OSWER Directive 9200.1-77D

July 2008

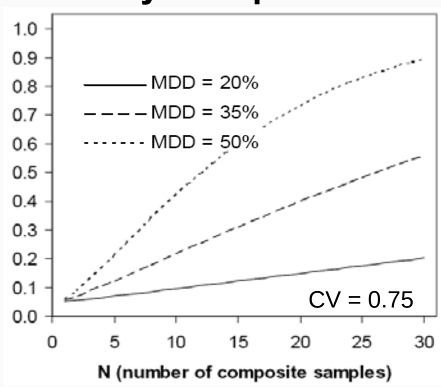
Analysis for Monitoring Timeframes

- Optimize sample design for the monitoring period of interest—*weigh various design options*
- Ensure data adequacy for pre- vs. post- statistical comparisons (*e.g., parametric* tests)
  - **We will use this approach to evaluate changes in fish tissues or sediment concentrations in the short term (*i.e.,* first 5-yrs)**
  - **Determine the *Power* (1-β) of specific comparisons.**
    - **Power is the probability of avoiding Type II error (β)**
      - **Concluding 'no difference' when in fact there is**
- Ensure data adequacy for establishment of a trend to show risk reduction over the **long-term**
  - **Determine whether we will be able to detect a significant slope of reduction if it exists**

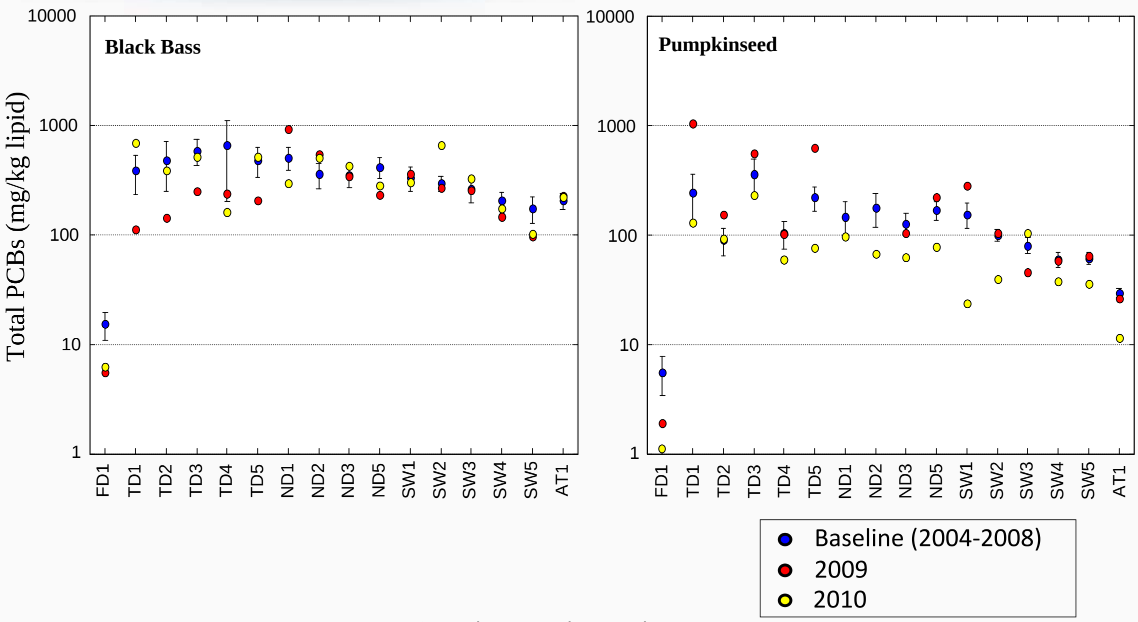
$$C_f^t = C_f^0 e^{-kt}$$



- **Achieving levels of statistical power for realistic detectable decreases**
- **What do you expect?**



Hudson River Bass & Pumpkinseed: Baseline vs. 2009 and 2010



SECTION	STATION	River Mile	Baseline vs 2009 Black Bass	2009 vs 2010 Black Bass	Baseline vs 2010 Black Bass	Baseline vs 2009 PKSD	2009 vs 2010 PKSD	Baseline vs 2010 PKSD
1	ALL	188.5-195	-	+		+	-	-
2	ALL	183.4-188.5	(-)	(+)		+	-	-
3	ALL	168.2-183.2		(+)			-	-
SECTION	STATION							
--	FD1	201.1		+				(-)
1	TD1	194		+		+	(-)	
1	TD2	193	-	+		+	-	
1	TD3	192	-					
1	TD4	190-191					-	
1	TD5	189.3	-	(+)		+	-	-
2	ND1	187				(+)	-	
2	ND2	186.4					-	-
2	ND3	185.5						(-)
2	ND5	183.5	-	+			-	-
3	SW1	181.2					-	-
3	SW2	178.2			(+)		-	-
3	SW3	177.3		(+)			(+)	
3	SW4	172.1					-	-
3	SW5	167.8					-	-
--	AT1	153.2 & 142					-	-

Total PCBs in Fish Tissues:
Baseline vs. 2009 and 2010

(blank)	Neutral p>0.10
-	Decrease btwn 2009 and 2010; p < 0.05
+	Increase btwn 2009 and 2010; p < 0.05
()	0.05< p < 0.10

Trend Analysis: Long-Term Decisions

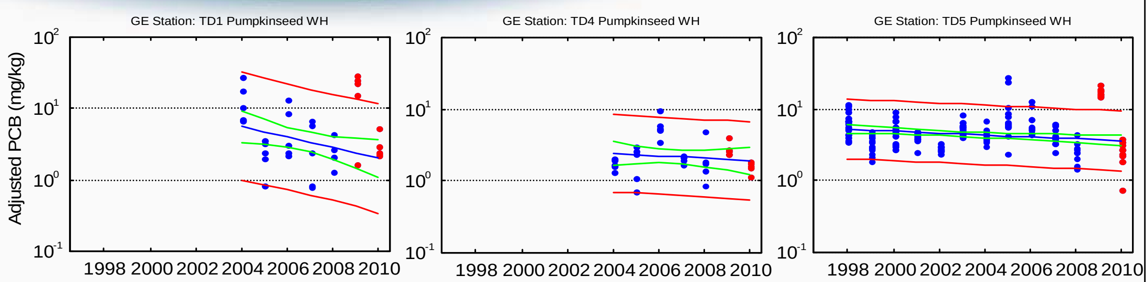
- **Longitudinal data: Temporal trends can be estimated simultaneously; log linear model** (*example equation for fish*)

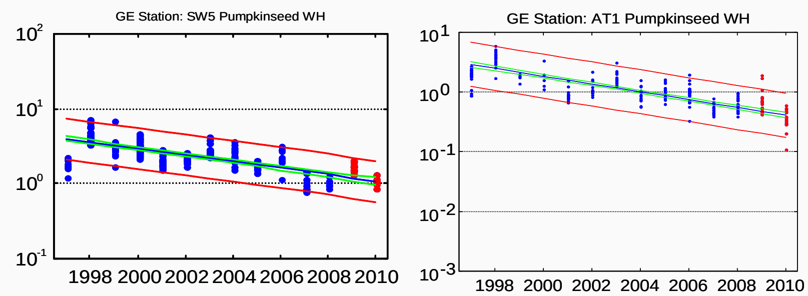
$$Log(C_f) = \beta_0 + \beta_1 Log(f_l) + \beta_2 Year + \beta_3(Sex) + \beta_4(Sex \times Year) + \sum_{k=5}^{8} \beta_k (Species_{k-4}) + \sum_{k=9}^{12} \beta_k (year \times Species_{k-4}) + \varepsilon$$

- **Spatial Variation: Temporal trends can be tested for differences in decay rates among sampling stations** (*example equation for fish*)

$$Log(C_f) = \beta_0 + \beta_1 Log(f_l) + \beta_2 Year + \beta_3(Sex) + \beta_4(Sex \times Year) + \sum_{k=5}^{18} \beta_k (Station_{k-4}) + \sum_{k=19}^{32} \beta_k (Year \times Station_{k-4}) + \varepsilon$$

Annual & spatial patterns in trends can be important





Variability high:
Approx. one order of magnitude range of conc.

- within each yr;
- within & among stations
- Within reach or section

Parting thoughts on monitoring receptors that matter

- Monitoring plan should be linked to RAOs to address effectiveness
- Benthic invertebrates useful in monitoring and demonstrating ecological recovery (short- and long-term; tox and community survey)
- Combined physicochemical and biological measures needed to explain results (i.e., understand exposures)
- Fish are often the most important receptor to monitor at sediment sites—plan accordingly
- Very important to collect baseline data

Location

MRT

Danshui/Beitou (Red line):

Exit 2, National Taiwan University Hospital Station

Blue Line:

Exit 2, Shandao Temple Station

Bus Stop

MRT Shandao Temple Station：

0(south)/15/22/202/212/212(straight)/220/232/232/257/262/265/299/605/671

MRT NTU Hospital Station:

22/15/615/227/648/648(green)/208/208(straight)/37

Workshop on
Characterization and Remediation for
Contaminated Sediment Sites

June 15-16
2011

List of Participants

(Listed on June 8, 2011)

International Participants

Surname	First Name	Country	Institute Organization
Bahari	Azimuddin	Malaysia	Ministry of Natural Res. and Environ.
Beamer	Paloma	USA	U.S. Environ. Protection Agency
Bradham	Karen D.	USA	U.S. Environ. Protection Agency
C. Concepcion	Edwin	Philippines	Department of Environ. and Natural Res.
Ells	Stephen John	USA	U.S. Environ. Protection Agency
Greenberg	Marc Samuel	USA	U.S. Environ. Protection Agency
Hanh	Pham Thi Thuy	Vietnam	Ministry of Natural Res. and Environ.
Hasan	Rashid	India	Ministry of Environment and Forests
Jr	Ernesto D. Adobo	Philippines	Department of Environ. and Natural Res.
Kim	Dong Jin	Korea	Ministry of Environment
Le	Le Thi Hai	Vietnam	Ministry of Natural Res. and Environ.
Mills	Marc Allyn	USA	U.S. Environ. Protection Agency
Mohd Rapi'Ain	Nur Sharliza	Malaysia	Ministry of Natural Res. and Environ.
Nursyamsi	Dedi	Indonesia	Indonesian Agric. Environ. Res. Inst.
Purnama	Aep	Indonesia	State Ministry for Environment
Sitthichai	Aroonkit	Thailand	Ministry of Natural Res. and Environ.
Troche	Luis Alberto	USA	U.S. Environ. Protection Agency
Wangcharoenrung	Chayawee	Thailand	Ministry of Natural Res. and Environ.
Yang	Jae E.	Korea	Kangwon National University
YI	Jin Won	Korea	Ministry of Environment

Local Participants

Surname	Given Name	Chinese Name	Institution
Chang	Fu-Hsiang	張富翔	National Taiwan University
Chang	Yi-Kuo	張益國	Central Taiwan University of Science and Technology
Chang	Yi-Tang	張怡塘	Soochow University
Chang	Ariel	張欣欣	Alterra technical Corporation
Chang	Li-Wen	張力文	Sitech Services, Inc.
Chang	Keng-Jung	張耿榕	TESC
Chang	Wen-Hsin	張文馨	TESC
Chang	Hao-Yen	張顥嚴	National Taiwan University
Chao	Chien-Cheng	趙健呈	National Taiwan University
Chen	Colin S.	陳士賢	National Kaohsiung Normal University
Chen	Fang-Shuan	陳枋萱	MWH Americas Inc. Taiwan Branch Office
Chen	Hsin-Jung	陳信榮	China Steel Corporation
Chen	I-Chun	陳怡君	Industrial Technology Research Institute
Chen	Ching-Yu	陳慶宇	China Environmental Consultants Limited
Chen	Mei-Kuei	陳梅桂	National Taiwan University
Chen	Shen-Yi	陳勝一	National Kaohsiung First University of Science and Technology
Chen	Ching-Yuan	陳敬遠	MEIHO University
Chen	Chiu-Yang	陳秋楊	Ming Chi University of Technology
Chen	Sara	陳虹螢	GITech
Chen	Yue-Sen	陳躍升	FORMOSA PLASTICS CORPORATION
Chen	Yi-Han	陳薏涵	TWEPA
Chen	Zueng-Sang	陳尊賢	National Taiwan University
Cheng	Chih-Hung	鄭志鴻	sinotech engineering consultants, LTD.
Cheng	Shu-Fen	程淑芬	Chao Yang University of Technology
Cheng	Hsiao-Fen	鄭曉芬	Industrial Technology Research Institute (ITRI)
Chin	S-Len	秦詩漣	Billion Beauty Engineering Technologies, Inc.
Chin	Lieng-Chieh	金良杰	Weston Solutions Taiwan, Ltd.
Chiu	Yi-Cheng	邱易成	MWH Americas Inc. Taiwan Branch Office
Chiu	Wei-po	邱韋博	National Dong Hwa University
Chou	His-Ling	周希瓴	Soochou university
Chou	Chih-Hao	周志豪	Jinn Wei Engineering & Construction Co., Ltd
Chu	Jerry	朱家毅	URS International Projects, Taiwan Branch
Chuang	Li-Wei	莊立偉	MWH Americas Inc. Taiwan Branch Office
Chuang	Chien-Tsai	莊見財	FORMOSA PLASTICS CORPORATION
Chung	Yu-Jen	鍾裕仁	Sinotech Engineering Consultants, Inc.
Fan	Joseph	范康登	MWH Taiwan Office
Fan	Huei-Ru	范惠茹	National Taiwan University
Go	Ching-LIn	郭青霖	Feng Chia University
Ho	Chun-Yen	何君艷	Sinotech Engineering consultants, Inc.
Hsieh	Chi-Ying	謝季吟	National Pingtung University of Science and Technology
Hsu	Chum-Ming	許峻銘	CHINA ECOTEK CORPORATION
Hsu	Hui-Tsung	許惠悰	China Medical University
Hu	Ching_Yao	胡景堯	School of public health, Taipie Medical Unversity

Huang	Shu-Chun	黃述鈞	National Taiwan University
Huang	Fu-Chang	黃富昌	Nanya Institute of Technology
Huang	Chih	黃智	Sinotech Engineering Consultants, Inc.
Huang	Tai-Xiang	黃泰祥	National Taiwan University
Huang	Cheng-Chieh	黃正介	National Taiwan University
Hung	Hao-Chun	洪豪駿	TWEPA
kao	Chen-Chi	高振棋	sinotech engineering consultants, LTD.
Ku	Hui Chia	古蕙嘉	ASIA ENVIRONMENTAL TECHNICAL CORP.
Lai	Yun-Jie	賴允傑	APOLLO TECHNOLOGY CO., LTD
Lai	Wei-Ju	賴威宇	National Taiwan University
Lee	Chung-Kung	李中光	Vanung University
Lee	Jyuhn-Hsiarn	李俊賢	National Health Research Institutes
Lee	Chia-Hsing	李家興	National Taiwan University
Li	Xiao-Lan	李曉嵐	APOLLO TECHNOLOGY CO., LTD
Li	Louise	李芸英	ERM-Taiwan
Liang	Chiu-Ping	梁秋萍	COA
Liao	Pei-yu	廖珮瑜	MWH
Lim	Pek-Hoon	林佩雲	Sinotech Engineering Consultants, Inc.
Lin	Yi-Chun	林怡君	Sinotech Engineering Consultants, LTD.
Lin	Shu-Hsin	林淑鑫	TASGEP
Lin	Ting-Hsiang	林鼎祥	GCEP
Lin	Chen-Hau	林正浩	Sinotech Engineering Consultants, Inc.
Lin	Ling-Chu	林玲珠	National Central University
Lin	Chi-Yen	林季燕	National Taiwan University
Lin	Wei-Chou	林威州	Sinotech Engineering Consultants Ltd.
Liou	Tay-ming	劉泰銘	Apollo Technology CO., LTD
Liu	Jung-Hsiu	劉蓉袖	Feng Chia University
Lu	Che-Ming	盧哲明	SGS TAIWAN LIMITED
Ngo	Thi-Thuan	歐婷芳	National Central University
Ni	Chuen-Fa	倪春發	National Central University
Ou	Chiao-Yi	歐喬宜	National Taiwan University
Pan	Shih-Cheng	潘時正	Sinotech Engineering Consultants Ltd.
Sah	jy-gau	薩支高	National Ping-Tung University of Science and Technology
Shan	Hsin-yu	單信瑜	National Chiao Tung University
Shen	Chien-Chuan	沈建全	National Kaohsiung
Shih	Yang-Hsin	施養信	National Taiwan University
Shiu	Huei-Jiuan	許惠娟	Nanya Institute of Technology
Su	Shih-Chang	蘇世昌	KATEC R&D Corp.
Tsai	Chia-Ying	蔡佳穎	National Dong Hwa University
Tsai	Kuo-Sheng	蔡國聖	Bureau Environmental Protection, Keelung City
Tseng	Li-Hsuan	曾立軒	China Medical University
Tsui	Lo	崔砢	Mingchi University of Technology
Tsui	Chun-Chih	崔君至	National Taiwan University
Tsui	Chia-Chi	崔家綺	National Taiwan University
Tung	Brian	董上銘	MWH Taiwan

Tung	Te-Chih	董德志	Industrial Technology Research Institute
Wang	Chin-Wei	王智緯	National Chino Tung University
Wang	Ping-Nan	王炳南	Sinotech Engineering Consultants Ltd.
Wang	Jun-Yu	汪俊育	China Steel Corporation
Wang	Wei-Chi	王瑋琦	China Medical University
Wang	Chang	王彰	Glory Engineering & Technology
Wang	Mei-Sheue	王美雪	Vanung University
Wang	Zih-Sin	王子欣	TWEPA
Wang	James		CETCO
Wei	Hsien-Hsiang	魏顯祥	Sinotech Engineering Consultants Ltd.
Wu	Yeong-Shing	吳勇興	SINOTECH Engineeing Consultants, Inc.
Wu	Sail	吳展帆	MWH Americas Inc. Taiwan Branch Office
Wu	Wan-lin	吳宛霖	National Taiwan University
Wu	Pei-Yao		Industrial Technology Research Institute
Wu	Dickson	吳添貴	Helpful Machinery Service Ltd.
Wu	Jun-Wei	吳俊偉	
Wu	I-Min	吳一民	China Steel Corporation
Yan	Ren-rong	顏瑞容	Alterra technical Corporation
Yang	Shang-Shyng	楊盛行	China University of Science and Technology
Yang	Paul	楊雍衡	Weston Solutions Taiwan, Ltd.
Yang	Hui-Wen	楊惠雯	FCU EES
Yang	Tzong-Deng	楊宗燈	FORMOSA PLASTICS CORPORATION
Yu	Yi-Hsien	余奕賢	National Dong Hwa University
Yu	Cheng-Kang	余政剛	GITech

ROC (Taiwan)
Environmental Protection
Administration

United States
Environmental Protection
Agency

Taiwan Association of
Soil and Groundwater
Environmental Protection

Working Group of
East and Southeastern Asian Countries on
Soil and Groundwater
Pollution and Remediation