Contaminated Sediments Remediation

Tab V

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Keywords: Remediation, Environmental Dredging, In situ Capping, Contaminated Sediments

Corps Perspective on Contaminted Sediments

- 150 years navigation dredging experience
- $200M in applied research
- Regulatory agency for navigation
- Supporting agency for cleanup
- Responsible party for some projects
- The Corps has a unique perspective …. a vested interest in a balanced approach to management…

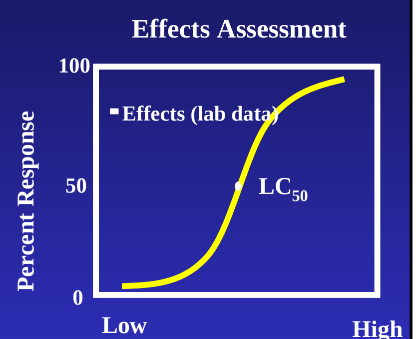
10 Principles for Effective Sediment Remedies

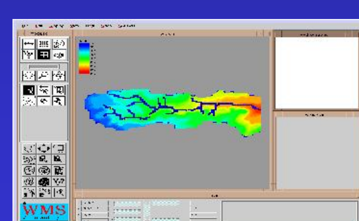
1. All decisions should be risk-based
2. Control sources
3. Set realistic RAOs, RGs, and CULs
4. Compare effectiveness of options on an equal footing
5. Evaluate Spatial and Temporal aspects of exposure
6. Tailor operations to achieve Short Term Effectiveness
7. Design for Long Term Effectiveness and Permanence
8. Develop site-specific, project-specific, and sediment specific remedies
9. Optimize effectiveness by combining options
10. Monitor to document effectiveness

first presented at EPA Forum May 2001

All decisions should be risk-based

- **Risk reduction is the overall objective**
- **Baseline risk assessment**
- **Incremental risk reduction**
- **Present risk and future risk**
- **Comparative risk assessments for remedies**





Control Sources

- Sources should be fully characterized
- Source controls should be considered the first component of the remedy
- Source control component should be in place prior to other components

Set realistic RAOs, RGs, and CULs

- Remedial Action Objectives (RAOs)
  - Specific to receptors
  - Example RAO - Reduce cancer risk for fishermen
- Remediation Goals (RGs)
  - Tied to receptors and pathways
  - Example RG – tissue level in benthic biota
- Cleanup levels (CULs)
  - Consider NCP Criteria (National Oil and Hazardous Substances Pollution Contingency Plan)
  - Example CUL – sediment concentration in biologically active zone

Compare effectiveness of options on an equal footing

- A definite challenge
- All components of the remedy must be considered
- Evaluate effectiveness and permanence over comparable time periods
- Comparative Risk Assessment for Remedy Options

Evaluate spatial and temporal aspects of exposure

- Most sites have aerial and vertical COC gradients
- Consider background and proximate area
- Surficial sediment layers present on-going risk
- Risk is proportional to area of surficial contamination
- Deeper buried sediments present potential future risk
- Not all contamination can or should be remediated
- Contamination gradients change over time
- Risk is proportional to the time of exposure
- Dredging or capping “restarts the clock”

Tailor operations to achieve short-term effectiveness

- Capping
  - Resuspension
  - Mixing
  - Consolidation

- Dredging/ Treatment/ Disposal
  - Resuspension
  - Residuals
  - Disposal releases/ emissions
- Accept short-term sacrifices for long-term gains
- Place in context with other on-going processes

Design for long-term effectiveness and permanence

- **Capping**
  - Design to maintain CULs
  - Erosion
  - Seismic stability
  - Groundwater flow
  - Long-term diffusion

- **Dredging and Disposal**
  - Target for mass removal or to achieve CULs
  - Disposal site releases and emissions
  - Permanence of controls
- **Design for episodic events appropriately**

Develop site-specific, project-specific, and sediment-specific remedies

- Project Specific
  - regulatory framework, volume, area, thickness, etc.
- Site Specific
  - water depth, hydrodynamics, climate, infrastructure, proximate resources
- Sediment Specific
  - debris, physical/chemical properties, COCs
- One Size Does Not Fit All

Optimize effectiveness by combining options

- Combinations often most acceptable to all parties
- Combinations provide a balance of effectiveness and costs
- Combinations help offset disadvantages of respective single options
- Example
  - Dredging hotspots followed by thin capping of residuals
  - Capping of nearby mid-level contamination
  - Monitored Natural Recovery (MNR) for larger adjacent areas of low-level contamination

Monitor to document success

- Historically, few remedies have been adequately monitored
- Dredging
  - About 30 well documented projects
  - Effectiveness of the removal easy to document
  - Long time needed to confirm effectiveness for receptors
- Capping
  - Few capping remedies have been implemented
  - Long time required to confirm effectiveness
- Treatment
  - Limited projects of in-situ sediment treatment
  - Spatial and temporal effectiveness requires confirmation
- Deliberate effort needed to build a base of field experiences

Environmental Dredging Case Studies

- Black River, OH
- Ford Outfall/Raisin, MI
- Grasse River, NY
- GM/ Massena, NY
- N. Bedford Harbor, MA
- Marathon Battery, NY
- Manistique Harbor, MI
- Minamata Bay, Japan
- Lake Jarnsjon, Swdn
- Port of Portland, OR
- P of V Columbia R., OR
- PSNS Bremerton, WA
- Sitcum Waterway, WA
- Sheboygan River, WI
- W. Eagle Harbor, WA
- Waukegan Harbor, IL
- Fox River, WI
- Bayou Bonfouca, LA
- Collingwood Harbor, CN

Remediation Guidance

- ARCS Remediation Guidance Document
  http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/EPA-905-B94-003.html
- EPA Superfund Sediment Guidance
  http://www.epa.gov/superfund/resources/sediment/guidance.htm
  - Draft Jan 2005/ FR Notice
    - RI/FS Considerations
    - MNR
    - In-Situ Capping
    - Treatment
    - Dredging and Excavation
    - Remedy Selection
    - Monitoring

Sediment Remediation Alternatives

- No Action
- Monitored Natural Recovery
- Environmental Dredging
- In-Situ Capping
- Engineered Monitored Natural Recovery
- In-Situ Treatment

Monitored Natural Recovery

- Advantages
  - Actions limited to monitoring and institutional controls
  - No disruption to waterbody
  - Cost Effective
- Disadvantages
  - Sediments remain in the aquatic environment
  - Processes act slowly
  - Subject to episodic storms, floods, etc.
  - Long term monitoring/ institutional controls required

Environmental Dredging

- Advantages
  - Mass removal
  - Proven technology
  - Easily implemented
- Disadvantages
  - Effectiveness reduced by resuspension and release
  - Effectiveness reduced by residual
  - Disposal is expensive

In-Situ Capping

- Advantages
  - Easily to implement
  - Containment in place
  - Cost Effective
- Disadvantages
  - Emerging technology
  - Sediments remain in the aquatic environment
  - Water depths reduced
  - Subject to episodic storms, floods, etc.
  - Long term monitoring/ maintenance required

Engineered Natural Recovery

- ➢Thin layer placement
- ➢Additives to enhance natural processes

Advantages
  - No disruption to waterbody
  - Cost Effective
- Disadvantages
  - Sediments remain in the aquatic environment
  - Processes are optimized
  - Subject to episodic storms, floods, etc.
  - Long term monitoring/ institutional controls required

In-situ Sediment Treatment

- Advantages
  - Permanence
  - Reduced toxicity, mobility and volume
  - Potential reduction in cost and implementation time
  - SARA preference
- Disadvantages
  - Technology unproven
  - Suitable only for low-level contamination
  - Short-term impacts of amendments
  - Time to achieve remediation goal and cleanup level

Remedy Effectiveness – First things that come to mind

- Dredging
  - Can I get it all out?
  - Will I resuspend too much?
- Capping
  - Will it work?
  - Will it stay in place?
- Treatment
  - Will it work in place?
  - Is it timely?

GOOD QUESTIONS, BUT THERE’S MORE TO IT.

Navigation vs Environmental Dredging

- Navigation
  - Costs
  - Timeliness
  - Environmental Impact

- Remediation
  - Long-term Effectiveness
  - Short-term Environmental Impa
  - Costs

Considerations for Environmental Dredging

- Goal: Meet RAOs, RGs, and CULs
- Sediment Resuspension
- Contaminant Release
- Residual Sediment
- Production/Efficiency of Removal
- Precision/Horizontal and Vertical Tolerances
- Compatibility with Treatment and/or Disposal

Objectives, Goals, and Standards

- All cleanup decisions should be RISK-BASED
- Remedial Action Objectives (RAOs)
  - e.g., reduction in cancer risk to fish consumers
- Remediation Goals (RGs)
  - e.g, reduction in fish tissue concentrations
- Cleanup Levels (CULs) *(set to achieve RGs and RAOs)*
  - e.g., max or max normalized [COC] in surficial sediment
  - Tied to a surface area and surficial thickness, e.g. SWAC approaches, and dependent on method for confirmation

Remedial projects are designed to achieve CULs, and thereby <u>indirectly</u> RGs and RAOs.

Objectives, Goals, and Standards

Performance Standards may include or be based on:

- Mass removal (easy)
- Removal to elevation/ area (easy)
- Limits on surficial sediment concentration (difficult)
- Limits on resuspension (moderate)
- Limits on releases (moderate)
- Limitations on solids/ throughput (moderate)

Equipment Availability and Selection

- Mechanical vs. Hydraulic
- Conventional vs. Specialty
- Smaller sizes used compared to navigation for precision and compatibility
- Selection depends on a number of factors
  – Inherent capabilities of equipment
  – Site and sediment conditions

Environmental Dredging Equipment

Conventional Clam

Enclosed Bucket

Articulated Fixed-Arm

Conventional Cutterhead

Horizontal Auger

Pneumatic

Diver-Assisted

Specialty Dredges for Cleanup

Factors for Equipment Selection

- Production
- Percent solids
- Vertical Accuracy
- Horizontal Accuracy
- Max Dredging Depth
- Min Dredging Depth
- Sediment Resuspension
- Contaminant release control
- Residual/ Cleanup Levels
- Transport by pipeline
- Transport by barge
- Positioning Control
- Maneuverability
- Portability/Access
- Availability
- Debris/ Loose Rock/ Vegetation
- Hardpan/ Rock Bottom
- Flexibility for Varying Conditions
- Thin Lift/ Residual Removal

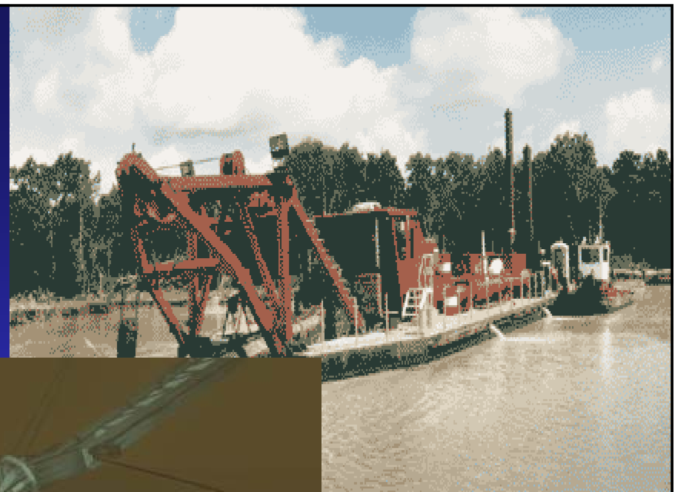
Production

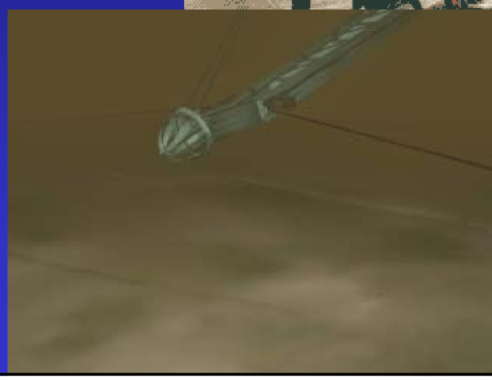
- Production = removal rate, e.g. cy/hr
- Hydraulic production = f [Pumping capacity/ solids content; sediment density; effective dredging time]
- Mechanical production = f [Bucket size; effective bucket fill; cycle time; effective dredging time]
- Constraints on production
  - Thickness of cut; control measures, access, etc.
- Constraints related to treatment/disposal capacity
- Sustained/ Effective Production rates for Environmental Dredging have been LOW.
- Most completed projects involved comparatively small volumes.

Removal Precision

- Efficiency = f [Production and Precision]
- Precision = removal of CS without removing clean material
  - Positioning only locates the dredgehead
  - Attainable precision now at +/- several inches
- Precision of positioning may outstrip that for sediment characterization

What is Dredging Resuspension/ Release/ Residual?





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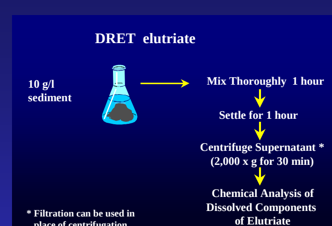
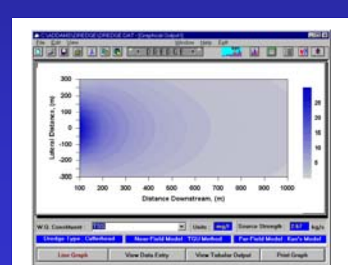
Sediment Resuspension

- Dislodged sediment dispersed to the water column and subject to plume transport
- All dredges resuspend sediment
- Models available for “source strength” and transport
- Field measurement methods are not consistent
- Field experience indicates resuspension generally less than 1% of the mass removed
- Place resuspension in context with other sources
- Resuspension is near field and can be controlled

Contaminant Release

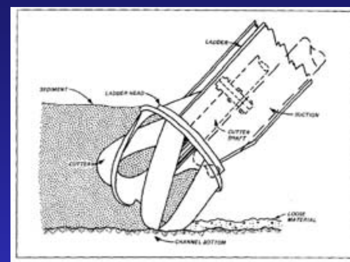
- Resuspension results in releases
- Dissolved release to water column
  - Released porewater
  - Desorption from resuspended particles
- Volatile release from water to air
- Tests/models are available
- Dissolved and volatile releases subject to far field transport – need to evaluate risks accordingly
- Sediments can be removed without excessive release
- Releases can be controlled by limiting resuspension

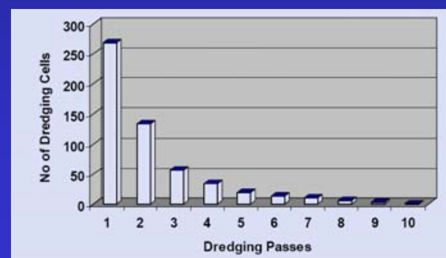




Residual Sediment

- All dredges leave residual sediment
- No standard predictive method
- Field measurement methods are not consistent
- May be as large as 10 to 25% of volume dredged
- Multiple cleanup passes show diminishing returns; residual caps are a management option





Transport for Treatment/Disposal

- Transport distance
- Optimal water content for process train
- Transport must be compatible with treatment/disposal
- Hydraulic - pipeline transport is inherent with removal (batch transport not efficient)
- Mechanical - batch transport is another step in the process train, but reslurry/pipeline is possible.

Summary

- Evaluate risks – Balance capabilities and limitations with environmental controls
- Suitable equipment is available
- Mass removal with acceptable precision is attainable
- Resuspension can be controlled
- Release is a far field problem – evaluate risks
- Residual is a major issue for effectiveness and cost – limit cleanup passes and allow for residual cap
- Dredging/transport must be compatible with treatment/disposal
- Detailed/comprehensive guidance on environmental dredging is lacking but under development

Technical Guidance for Environmental Dredging

- EPA Guidance (OERR)
- Environmental Dredging Processes
  - Removal
  - Residual
  - Resuspension
  - Release
- Removal Objectives and Targets
- Environmental Dredging Equipment and Techniques
- Operations, Sequencing, Management Units
- Pilot Studies
- Contracting Considerations
- Monitoring

Environmental Dredging Bottom Line

- No universal solution
- Conventional equipment can be used
- Specialty equipment is available
- All dredges will resuspend some sediment
- Resuspension can be predicted and controlled in most situations but at an increased cost to the project
- All decisions are inherently risk-based

In-Situ Capping

- Advantages
  - Easily to implement
  - Containment in place
  - Cost Effective
- Disadvantages
  - Emerging technology
  - Sediments remain in the aquatic environment
  - Water depths reduced
  - Subject to episodic storms, floods, etc.
  - Long term monitoring/ maintenance required

What’s Important for Capping?

- Sediment/ Site Characteristics
- Project Design
  - Cap Design; Materials
- Placement Equipment and Methods
  - Mixing
  - Resuspension
  - Positioning
  - Site Controls
- Monitoring

Capping Issues

- Cap performance criteria
- Opportunities for active capping
- Controlled placement in thin layers
- Long-term containment of contaminants
- Erosion due to wind-driven waves or stream flow
- Ice scour
- Influence of habitat on cap performance (SAV or bioturbation)
- Ground water upwelling
- Gas ebullition
- Mobilization of NAPL
- Sediment slope stability
- Incorporation of habitat values into cap design

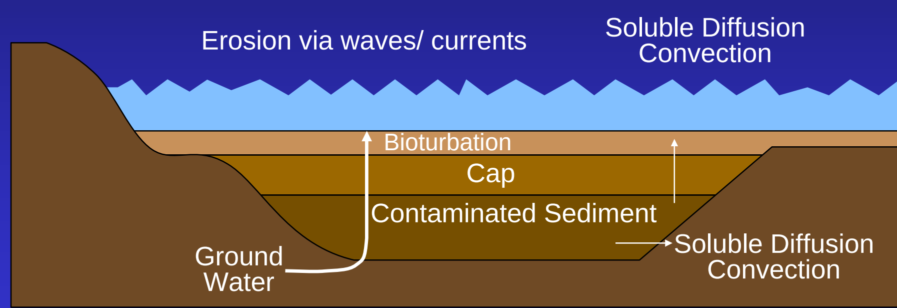
Capping Materials

- Granular materials
  - sediments
  - soils
  - quarry run materials
- Amendments
  - Adsorbents
  - Reactants
- Fabrics and membranes
- Armor stone

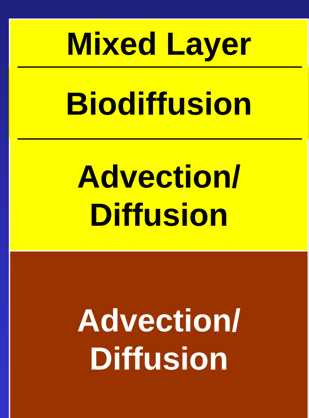
Site Conditions/Boundaries

- Water depths
- Bathymetry
- Hydrodynamics
- Geotechnical
- Biological
- Jurisdictional
- Operational

Migration Pathways for Capping

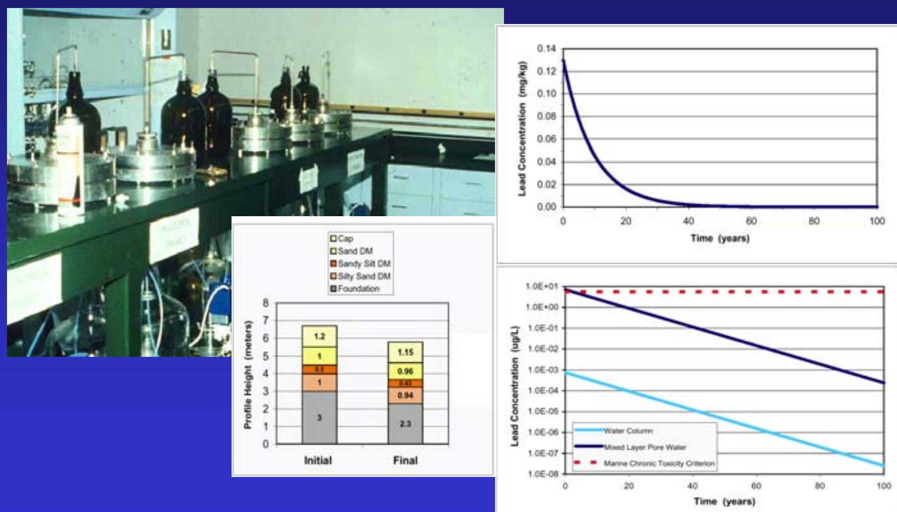


Cap Design



- Advection/ Diffusion
- Bioturbation
- Erosion
- Consolidation
- Operational factors

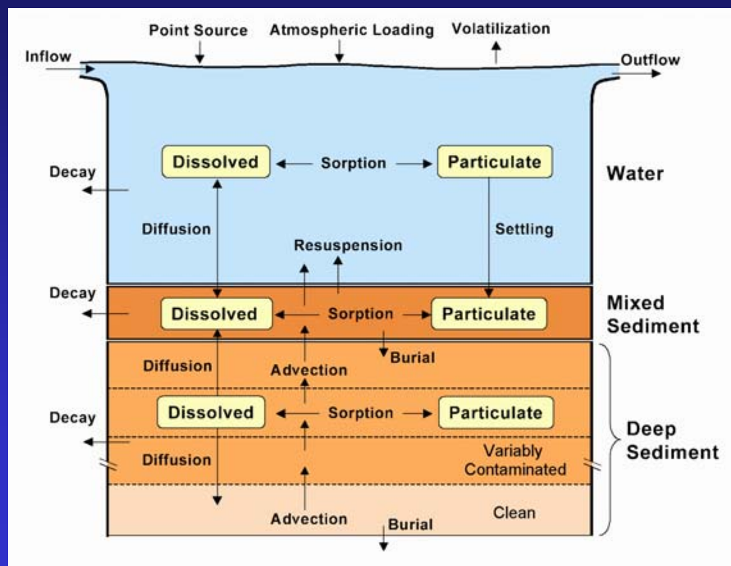
Laboratory Testing and Modeling for Cap Effectiveness



CAP

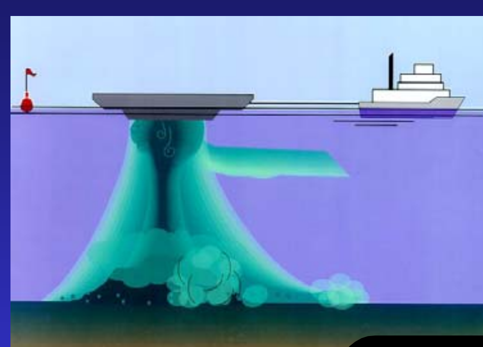
- Extension of the RECOVERY model
  (USACE contaminated sediment-water interaction model)
- Couples consolidation predictions by the PSDDF model with contaminant transport
  (PSDDF is USACE dredged material consolidation model)
- Addresses short-term advection and long-term diffusion of contaminants
- Assumes reversible linear equilibrium sorption and first order decay kinetics

Schematic of CAP Processes



FATE Models

- STFATE
- MDFATE
- LTFATE
- CDFATE
- SSFATE
- DREDGE
- RECOVERY/CAP



Cap Placement Methods

- Barge
  - conventional - spreading - pumpout
- Hopper
  - conventional - spreading- pumpout
- Pipeline
  - diffuser - sand box - baffle plate
- Direct mechanical placement
- Other innovative methods

Cap Placement by Hopper, NY Mud Dump

Submerged Diffuser

Eagle Harbor

In-Situ Management with Capping

- Sand caps easy to place and effective
  - Contain sediment
  - Retard contaminant migration
  - Physically separate organisms from contamination
- Greater effectiveness possible with “active” caps
  - Encourage fate processes such as sequestration or degradation of contaminants beneath cap
  - Discourage recontamination of cap
  - Encourage degradation to eliminate negative consequences of subsequent cap loss
- Potential for habitat development

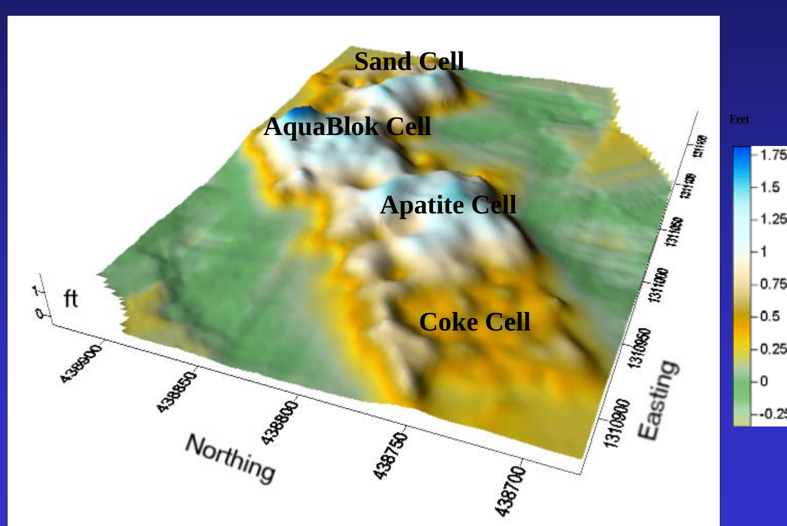
Potential Amendments to Reduce Bioavailability

- Aquablok
  - Control of seepage and advective contaminant transport
- Coke
  - Encourages sorption-related retardation
- Activated Carbon
  - Encourages sorption-related retardation and sequestration
- Organoclay sorbent
  - Encourages sorption-related retardation
- XAD-2/Ambersorb
  - Encourages sorption-related retardation and sequestration

Potential Amendments to Reduce Bioavailability

- Phosphate mineral (Apatite)
  - Encourages sorption and reaction of metals
- Zero-valent iron
  - Encourages dechlorination and metal reduction
- BionSoil
  - Encourage degradation of organic contaminants
- High value materials can be placed in laminated mat

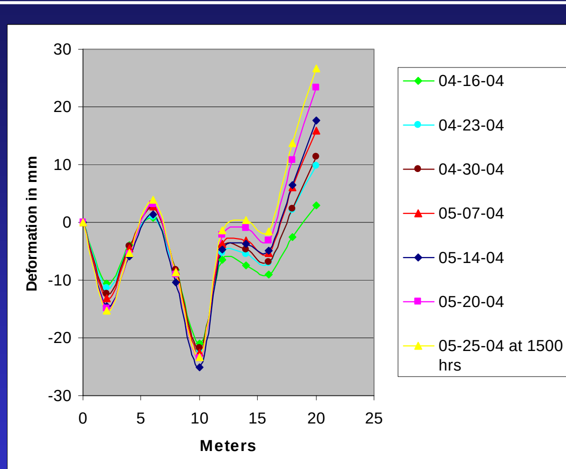
Cap Placement in Anacostia



Cap Thicknesses

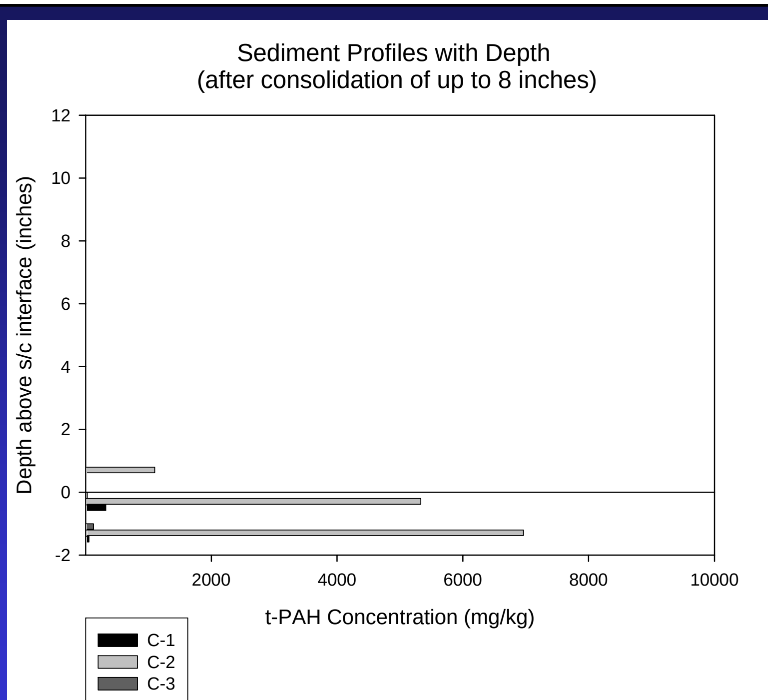
Cap	Target Thickness -in	Observed in±σ
Sand	12	8.9±3.2
Aquablok Sand	4 6	4.5±2.0 5.3±1.8
Apatite Sand	6 6	4.9±1.2 4.5±1.2
Coke Sand	1 6	1 (mat) -

Gas Release in Anacostia

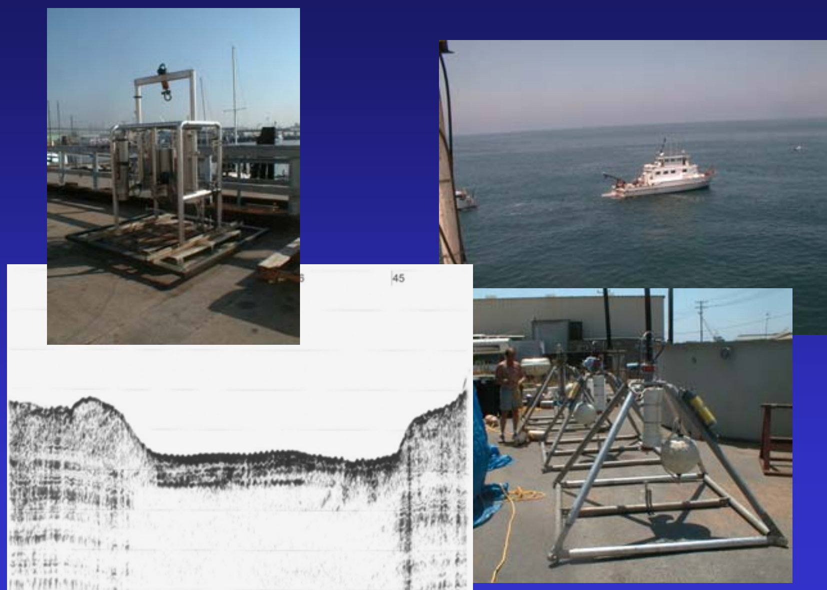


Anacostia River Sediment Capping Research Project
Washington, D.C.

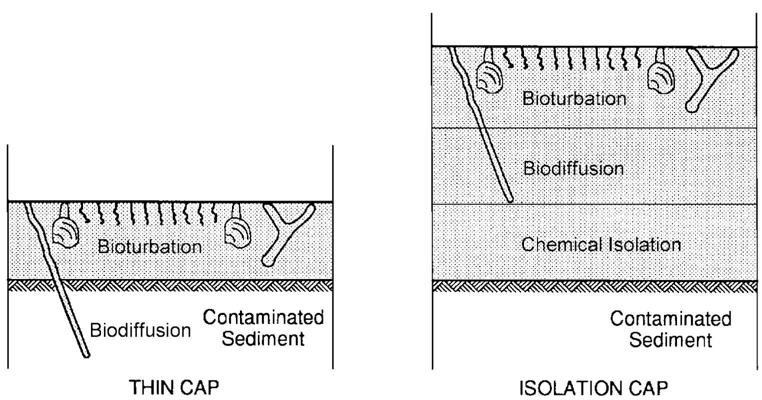
HydroQual, Inc.

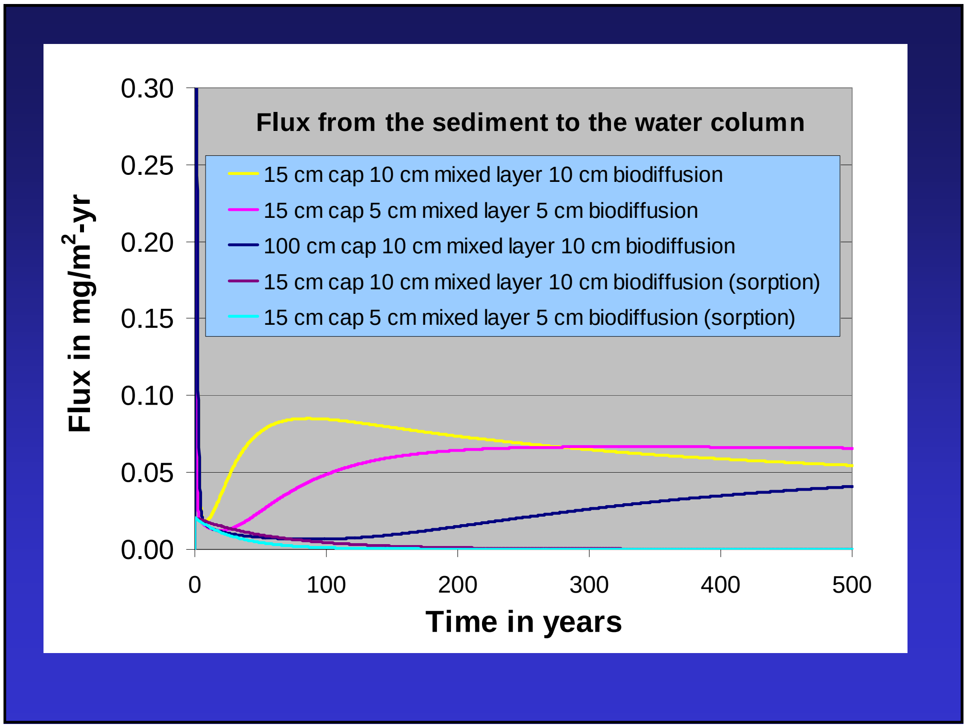


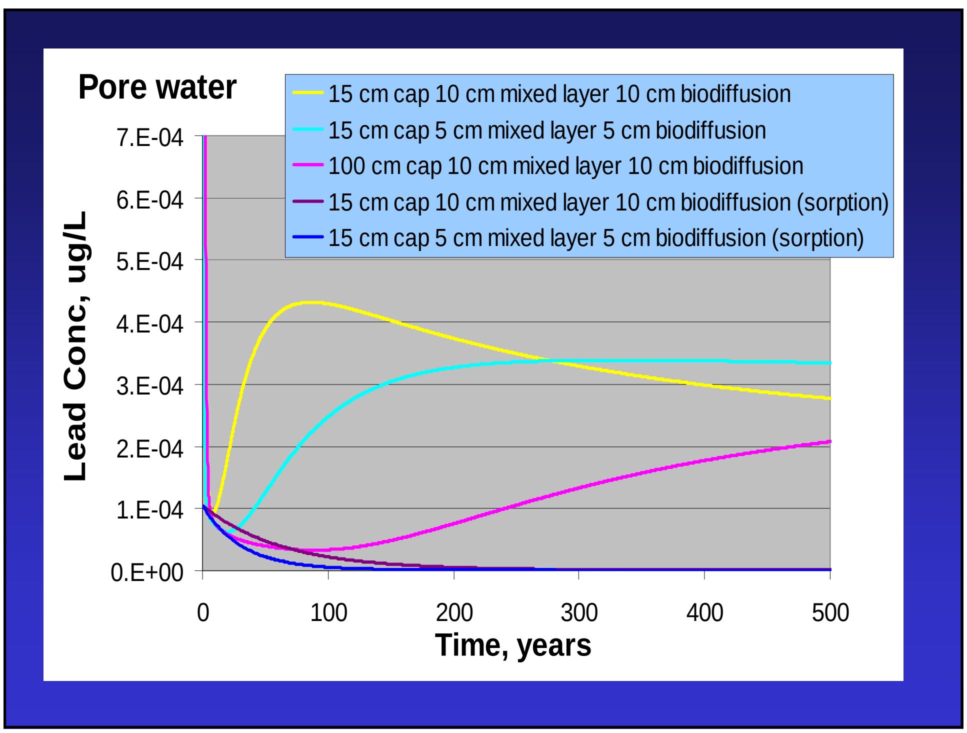
Monitoring



Monitored Engineered Recovery




Flux from the sediment to the water column
15 cm cap 10 cm mixed layer 10 cm biodiffusion
15 cm cap 5 cm mixed layer 5 cm biodiffusion
100 cm cap 10 cm mixed layer 10 cm biodiffusion
15 cm cap 10 cm mixed layer 10 cm biodiffusion (sorption)
15 cm cap 5 cm mixed layer 5 cm biodiffusion (sorption)
Flux in mg/m2-yr
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
100
200
300
400
500
Time in years


Pore water
15 cm cap 10 cm mixed layer 10 cm biodiffusion
15 cm cap 5 cm mixed layer 5 cm biodiffusion
100 cm cap 10 cm mixed layer 10 cm biodiffusion
15 cm cap 10 cm mixed layer 10 cm biodiffusion (sorption)
15 cm cap 5 cm mixed layer 5 cm biodiffusion (sorption)
Lead Conc, ug/L
7.E-04
6.E-04
5.E-04
4.E-04
3.E-04
2.E-04
1.E-04
0.E+00
0
100
200
300
400
500
Time, years

Capping Guidance Documents

- **ARCS In-Situ Capping Guidance EPA 905-B96-004 Oct 96**
  - http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/EPA-905-B94-003-toc.html
- **USACE Guidance for Subaqueous Dredged Material Capping Jun 98**
  - http://el.erdc.usace.army.mil/dots/doer/pdf/trdoer1.pdf

Take Home Message

- Caps must be engineered
- Caps can be effective containment options
- Reactive caps can reduce isolation requirements

In-situ Sediment Treatment

- Abiotic Degradation
- Sequestration
- Reactive Caps
- Bioremediation
- Phytoremediation

In-situ Treatment Technologies

Technology	Maturity	Treatment Locale	Cost	Challenges
Abiotic Degradation	Lab	Delivery Depth	High	Delivery, % Removal
Sequestration	Lab	Delivery Depth	Med	Delivery, Permanence
Reactive Caps	Demo	Surface Flux	Low	Permanence, Effectiveness
Bioremediation	Lab	Delivery Depth	Med	Delivery, % Removal
Phytoremediation	Demo	Shallow Waters	Low	% Removal

In-situ Sediment Treatment

- Add nutrients to accelerate biodegradation
- Add chemical to convert contaminants to less toxic form
- Add solidification / stabilization agents to reduce sediment and contaminant mobility

Take Home Message

- Evaluate options on a comparable basis
- Balance costs vs. degree of environmental protection
- Combinations of options often most efficient
- Solutions are
  - Project specific
  - Site specific
  - Sediment specific