EPA/OSRTI Sediment Remedies: Capping – Technical Considerations for Evaluation and Implementation

Capping Materials and Design

Danny Reible
Environment and Water Resources
The University of Texas at Austin
Ph:512-471-4642
Email: reible@mail.utexas.edu

EPA Sediment Remedies Internet Seminar

A-1

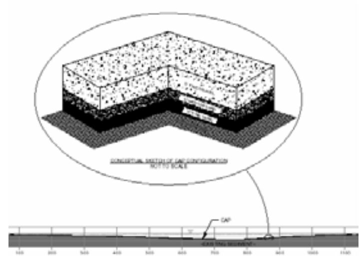
In-Situ Options

- Treatment
  - Limited options, largely unproven
    - Most sediment contaminants strongly sorbed
      - Most abiotic and biotic fate processes require desorption
    - Most sediments contaminants exhibit minimal or only partial degradation
  - Few delivery options that don't compromise basic advantage of in-situ approaches (minimal disturbance of sediment)
- Capping
  - Demonstrated implementability and performance
  - Provides opportunities for reagent addition and habitat modification
  - Lack of degradation of contaminants in underlying sediment gives rise to potential for long-term risks

A-2

Cap Functions/ Design Objectives

- Risk Reduction
  - Stabilize sediments
  - Physically isolate sediment contaminants
  - Reduce contaminant flux to benthos and water column
  - Improve quality of aquatic habitat
  - Improve surficial substrate



A-3

In-Situ Capping

- Advantages
  - Quick risk reduction
  - Easy to implement
  - Cost Effective
  - Potential for Enhancement
- Disadvantages
  - Sediments remain in the aquatic environment
  - Water depths reduced
  - Subject to episodic storms, floods, etc.
  - Long term monitoring/ maintenance required
  - Institutional controls required

A-4

Most Common Reasons for Selection of Capping as Remedy

- Cost per risk reduction
- Rapid implementation risk reduction
- Concerns over risks associated with dredging (resuspension/residual)
  - Capping alone (highly contaminated buried sediment)
  - Capping in conjunction with dredging (residuals control)
- Lack of dredged material disposal alternatives
- Desirability of fill
  - Habitat improvements
  - Economic motivation

A-5

U.S. EPA Guidance
In-Situ Capping – Chapter 5.0

- As of 2004, capping had been selected as a component of the remedy for 15 Superfund sites
- Chapter 5.0 of U.S. EPA's Contaminated Sediment Guidance provides detailed information and guidance on the appropriate factors for evaluating remedy selection and on remedial design and construction

A-6

Highlight Box 5-1

Highlight 5-1: Some Site Conditions Especially Conducive to In-Situ Capping
• Suitable types and quantities of cap material are readily available
• Anticipated infrastructure needs (e.g., piers, pilings, buried cables) are compatible with cap
• Water depth is adequate to accommodate cap with anticipated uses (e.g., navigation, flood control)
• Incidence of cap-disrupting human behavior, such as large boat anchoring, is low or controllable
• Long-term risk reduction outweighs habitat disruption, and/or habitat improvements are provided by the cap
• Hydrodynamic conditions (e.g., floods, ice scour) are not likely to compromise cap or can be accommodated in design
• Rates of ground water flow in cap area are low and not likely to create unacceptable contaminant releases
• Sediment has sufficient strength to support cap (e.g., higher density/lower water content, depending on placement method)
• Contaminants have low rates of flux through cap
• Contamination covers contiguous areas (e.g., to simplify capping)

A-7

In-Situ Capping – Advantages

- Capping typically quickly reduces exposure
- Capping requires less infrastructure in terms of material handling, dewatering, treatment and disposal
- Capping often provides a clean substrate for recolonization
- Contaminant resuspension and the risks associated with dispersion and volatilization of contaminated materials during construction are typically lower for in-situ capping
- Risks associated with transport and disposal of contaminated sediment are avoided
- Most capping projects use conventional equipment
- Capping may be implemented more quickly and may be less expensive than dredging
- In-situ capping may be less disruptive of local communities than dredging

A-8

In-Situ Capping – Limitations

- Contaminated sediment remains in the aquatic environment which can be dispersed if the cap is significantly disturbed
- Contaminants might move through the cap (However, in order to be considered protective, a cap need not achieve zero release, but must prevent unacceptable risk exposure.)
- In some environments, it can be difficult to place a cap without significant contaminant losses from compaction and disruption of underlying sediment
- In shallow waterbodies, it may be necessary to develop institutional controls (ICs) to protect the cap from disturbances such as boat anchoring and keel drag

A-9

Other Capping Considerations

- Capping should not be presumptively considered or disqualified from use in "high or low" energy or concentration areas
  - Instead, the Guidance encourages evaluation of the potential protectiveness of capping on a site-specific basis
  - Appropriate design features will result in a protective remedy in a variety of flow and concentration conditions
- Caps are capable of meeting the permanency preference of CERCLA based on site-specific circumstances

A-10

Other Capping Considerations

- In preparing a feasibility study to evaluate in-situ capping for a site, project managers should consider the following:
  - Identify candidate capping materials physically and chemically compatible with the environment in which they will be placed;
  - Evaluate geotechnical considerations including consolidation of compressible materials and potential interactions and compatibility among cap components;
  - Assess placement methods that will minimize short-term risk from release of contaminated pore water and resuspension of contaminated sediment during cap placement; and
  - Identify performance objectives and monitoring methods for cap placement and long-term assessment of cap integrity and biota effects

A-11

Highlight Box 5-4

Highlight 5-4: Some Key Points to Remember When Considering In-Situ Capping

- Source control generally should be implemented to prevent recontamination
- In-situ caps generally reduce risk through three primary functions: physical isolation, stabilization, and reduction of contaminant transport
- Caps may be most suitable where water depth is adequate, slopes are moderate, ground water flow gradients are low or contaminants are not mobile, substrates are capable of supporting a cap, and an adequate source of cap material is available
- Evaluation of capping alternatives and design of caps should consider buried infrastructure, such as water, sewer, electric and phone lines, and fuel pipelines
- Alteration of substrate and depth from capping should be evaluated for effects on aquatic biota
- Evaluation of a capping project in natural riverine environments, should include consideration of a fluvial system's inherent dynamics, especially the effects of channel migration, flow variability including extreme events, and ice scour
- Evaluation of capping alternatives should include consideration of cap disruption from human and natural sources, including at a minimum, the 100-year flood and other events such as seismic disturbances with a similar probability of occurrence
- Selection of cap placement methods should minimize the resuspension of contaminated sediment and releases of dissolved contaminants from compacted sediment
- Use of experienced contractors skilled in marine construction techniques is very important to placement of an effective cap
- Monitor in-situ caps during and after placement to evaluate long-term integrity of the cap, recolonization by biota, and evidence of recontamination
- Maintenance of in-situ caps is expected periodically

Remedy Selection Considerations

- "A risk management process should be used to select a remedy design to reduce key human and ecological risks effectively."
- "Another important risk management function generally is to compare and contrast the cost and benefits of various remedies."

(Sediment Guidance, p. 7-1)

A-13

Remedy Selection Considerations

- The Guidance encourages project managers to use the concept of comparing net risk reduction between alternatives a part of the remedy selection process.
- Highlight 7-4 covers elements of comparative net risk for MNR, capping and dredging

(Sediment Guidance, p. 7-13)

A-14

Highlight Box 7-4

Highlight 7-4: Sample Elements for Comparative Evaluation of Net Risk Reduction

Elements Potentially Reducing Risk

- Reduced exposure to bioavailable/bioaccessible contaminants
- Removal of bioavailable/bioaccessible contaminants
- Removal or containment of buried contaminants that are likely to become bioaccessible

Elements Potentially Continuing or Increasing Risk

For MNR:

- Continued exposure to contaminants already at sediment surface and in food chain
- Potential for undesirable changes in the site's natural processes (e.g., lower sedimentation rate)
- Potential for contaminant exposure due to erosion or human disturbance

For In-Situ Capping:

- Contaminant releases during capping
- Continued exposure to contaminants currently in the food chain
- Other community impacts (e.g., accidents, noise, residential or commercial disruption)
- Worker risk during transport of cap materials and cap placement
- Releases from contaminants remaining outside of capped area
- Potential contaminant movement through cap
- Disruption of benthic community

For Dredging or Excavation:

- Contaminant releases during sediment removal, transport, or disposal
- Continued exposure to contaminants currently in the food chain
- Other community impacts (e.g., accidents, noise, residential or commercial disruption)
- Worker risk during sediment removal and handling
- Residual contamination following sediment removal
- Releases from contaminants remaining outside dredged/excavated area
- Disruption of benthic community

A-15

Performance Monitoring - Capping

- Performance objectives for an in-situ cap relate to its ability to provide sufficient physical and chemical isolation and stabilization of contaminated sediment to reduce exposure and risk to protective levels.
- Broader RAOs for the site such as decreases in contaminant concentrations in biota or reduced toxicity should be monitored when applicable.

A-16

Performance Monitoring – Capping

- The following processes should be considered when evaluating the performance of a cap, and in developing a cap monitoring program:
  - Erosion or other physical disturbances of cap;
  - Contaminant flux into cap material and into the surface water from underlying contaminated sediment (e.g., ground water advection, molecular diffusion); and
  - Recolonization of cap surface and resulting bioturbation.

A-17

Performance Monitoring – Capping

- Performance monitoring of a cap should be related to the design standards and remedial action objectives related to the site.
- Generally, physical monitoring is initially conducted on a more frequent schedule than chemical or biological monitoring because it is less expensive to perform.

A-18

Performance Monitoring – Capping

- In some cases, physical measurement of cap integrity and water column chemical measurement may be sufficient for routine monitoring.
- General considerations related to monitoring caps and an example of cap monitoring elements are presented in Chapter 8, Remedial Action and Long-Term Monitoring.

A-19

Cap Siting – Screening

- Navigation/Future Use
  - Conduct analysis similar to that used to define bridge heights and navigation depths
- Contaminant Stability
  - Significance of advection, deep bioturbation or other “fast” transport processes
- Sediment Stability
  - Conduct morphological analysis similar to bridge design
  - Supplement with geophysical measurements and assessments
  - Assess potential for exposure and risk of buried contaminants
- Buried Infrastructure
  - Evaluate need for access and danger of removal options
- Debris
  - Evaluate advantages of avoiding difficulties (resuspension/residual) of debris removal
- Water Depth
  - Evaluate both positive and negative aspects of depth reductions

A-20

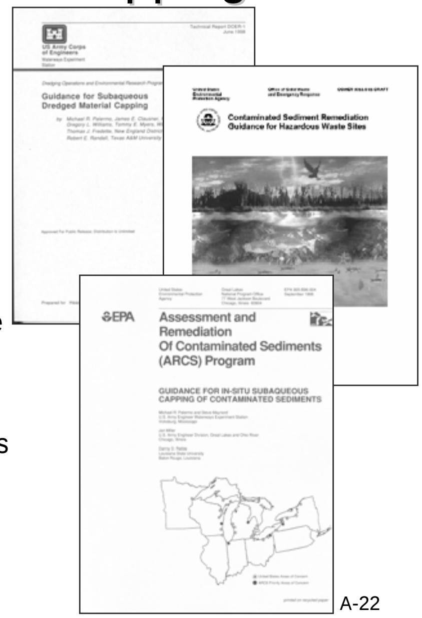
Sand caps

- Majority of existing caps
- Effective for contaminants strongly sorbed to solid phase of underlying sediment
- Easy to place with minimal intermixing
- Generally erosion resistant compared to existing bottom but, if necessary, can be supplemented with armoring layer
- Often provides much-needed diversity to bottom substrate
- Drives sediment layer anaerobic

A-21

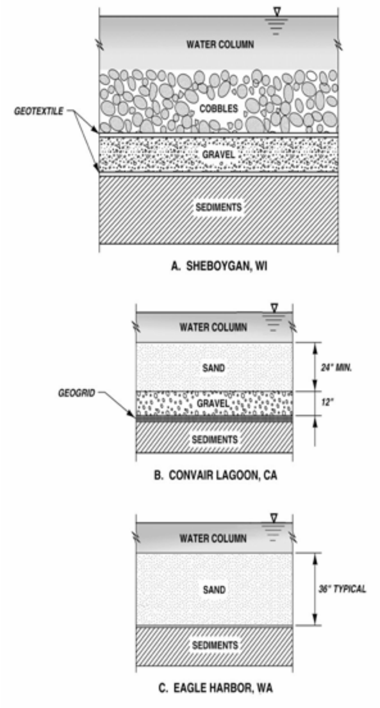
Technical Guidance for Capping

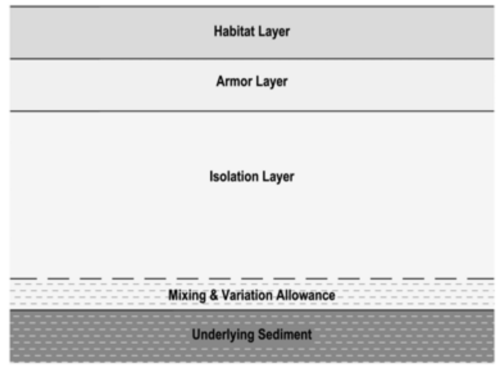
- USACE guidance for DM capping (1998)
  - http://www.wes.army.mil/el/dots/doer/pdf/trdoer1.pdf
- EPA (ARCS) guidance for ISC (1998)
  - http://www.epa.gov/glnpo/sediment/iscmain/index.html
- EPA Sediment Guidance (2005)
  - http://www.epa.gov/superfund/resources/sediment/guidanchtm



A-22

Cap Designs





A-23

Cap Design – Component Layers

- Intermixing layer
  - Intermixing of cap layer with underlying sediment
- Consolidation layer
  - Chemical expression into cap due to consolidation of sediment (typically much less than porewater expression due to sorption)
  - Not important to steady state conditions
- Isolation layer
  - Designed to physical separate “fast” surficial transport processes from contaminated layer
- Armoring layer
  - Layer to ensure long-term stability of isolation layer
- Biologically active layer
  - Layer subject to bioturbation in which control of flux or concentration is desired
  - Typically combined with armoring layer and any habitat enhancement

A-24

Design Standards for Capping

- Bioturbation defines zone of exposure
- Isolation cap design is typically based on maintaining cleanup level (CUL) in the zone of exposure
- Maintaining CUL in biologically active zone should be the basis of design standard for capping
- Points of compliance and timeframe are important
- Caution: Sediment-based CUL may not adequately reflect bioavailability
  - High surficial organic carbon may lead to high modeled organic contaminant levels (e.g. exceedance of CUL) although it may actually reduce bioavailability
  - Pore water concentrations developing tool to assess bioavailability and ultimately cap performance

A-25

Cap Design and Construction

- Geotechnical considerations
  - Bearing Capacity
  - Stability of caps placed on slopes
    - Sand limit of stability 1:1.88 slope
  - Stability of the overall sediment deposits
- Cap construction and placement methods
  - Availability of materials and equipment
  - Contaminant releases during construction

A-26

***(Specific DEC Concern) Show equipment photo here**

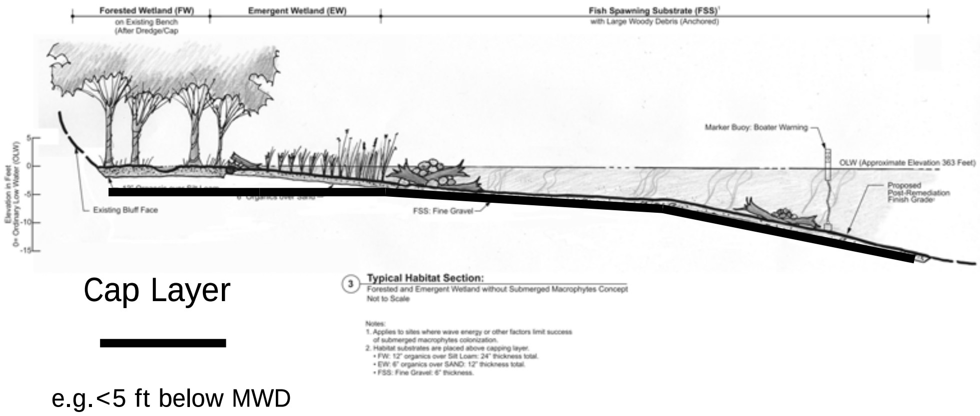
***(Specific DEC Concern) – resuspension less than for dredging and only surficial few inches exposed to resupension**

Habitat and Armoring Layers

- Habitat Enhancements
  - What do you want the river to look like?
    - Useful but rarely conducted exercise
    - Thinking often one-dimensional (depth, water surface area)
    - Conservatism understandable but take advantage of your opportunities!
- Armoring Layers
  - Generally focused on threshold of resuspension
  - Should be focused on area and depth scoured

A-27

Potential Habitat with Cap



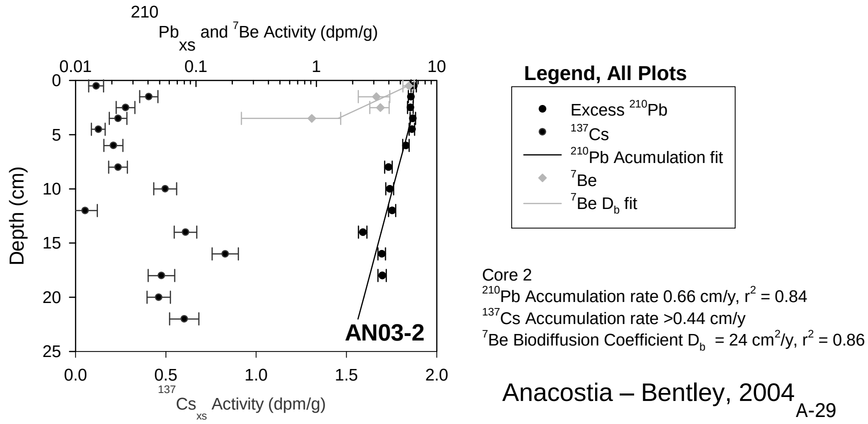
Modified from Davis, 2004

M

A-28

Sediment Stability Geochronology/Bioturbation

Pb-210 profiles suggest deposition rate of 0.6-1.0 cm/yr
Cs-137 profiles suggest deposition rate >0.44->0.84 cm/yr
Be-7 profiles suggest biodiffusion coefficient of 24-34 cm²/yr



Anacostia – Bentley, 2004

A-29

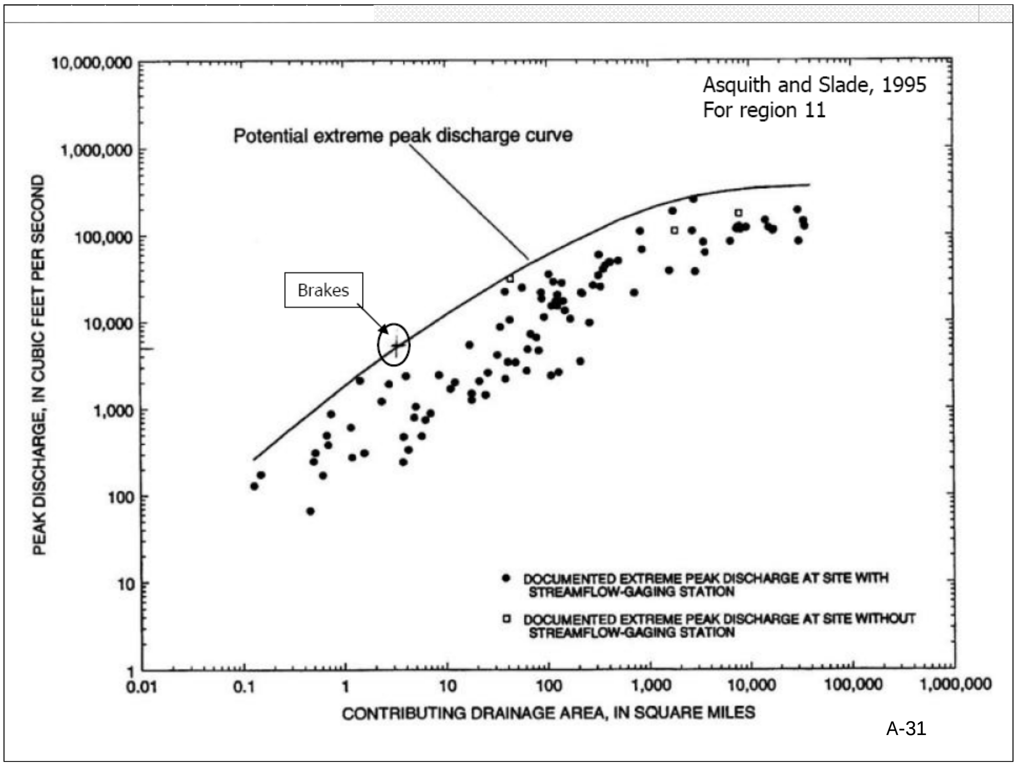
Shear Stress Computations

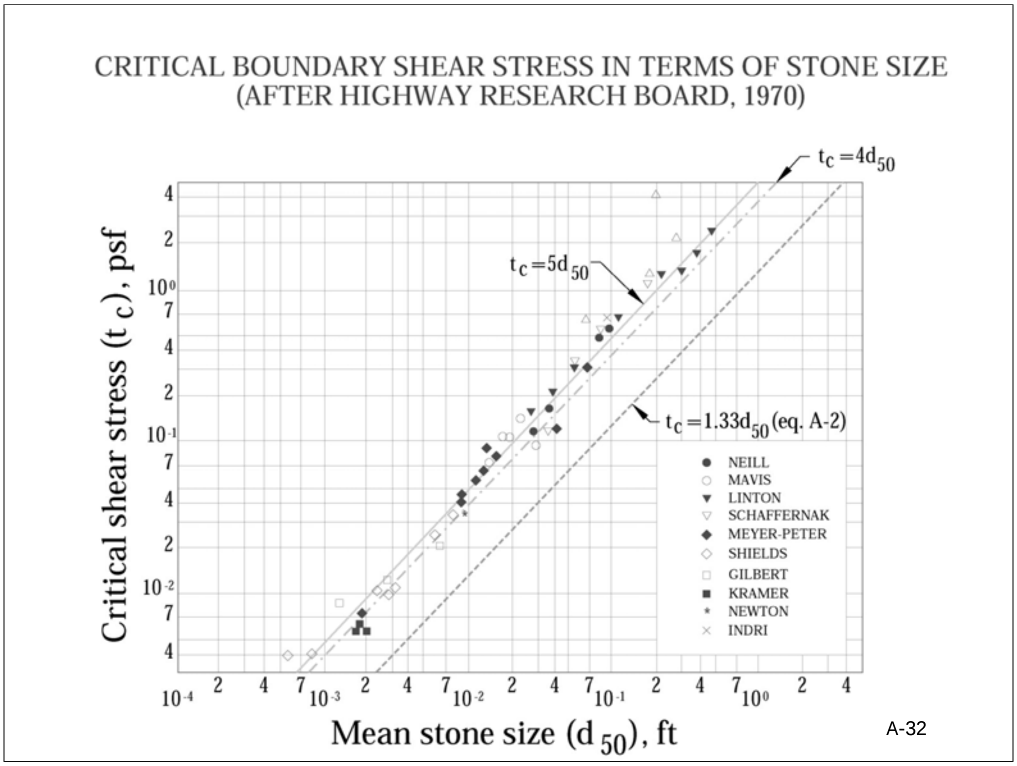
For wide channels the Shear Stress, τ, at a specific cross-section is calculated by:

$$\tau \approx \gamma_w \cdot D \cdot S$$

- γ_w is the unit weight of water;
- D is the hydraulic radius of the river (for a wide channel equals the depth)
- S is the slope of the River
- τ assumed proportional to flow conservative (overestimates τ)

A-30


Asquith and Slade, 1995
For region 11
Potential extreme peak discharge curve
Brakes
PEAK DISCHARGE, IN CUBIC FEET PER SECOND
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
0.01
0.1
1
10
100
1,000
10,000
100,000
1,000,000
CONTRIBUTING DRAINAGE AREA, IN SQUARE MILES
DOCUMENTED EXTREME PEAK DISCHARGE AT SITE WITH STREAMFLOW-GAGING STATION
DOCUMENTED EXTREME PEAK DISCHARGE AT SITE WITHOUT STREAMFLOW-GAGING STATION
A-31


CRITICAL BOUNDARY SHEAR STRESS IN TERMS OF STONE SIZE
(AFTER HIGHWAY RESEARCH BOARD, 1970)
$t_c = 4d_{50}$
$t_c = 5d_{50}$
$t_c = 1.33d_{50}$ (eq. A-2)
NEILL
MAVIS
LINTON
SCHAFFERNAK
MEYER-PETER
SHIELDS
GILBERT
KRAMER
NEWTON
INDRI
Critical shear stress (t_c), psf
Mean stone size (d_{50}), ft
A-32

Cap Armoring Criteria

- Top layer stability
  - Design velocity or stresses (e.g. 100 year flood)
  - d_{50}(ft) = 1/4 τ_c (lb/ft^2) (Highway Research Board)
- Non-uniform size distribution $d_{85}/d_{15} > 4$
- Angular shape
- Maximum particle size <2 d_{50}
- Minimum particle size > 0.05 d_{50}
- Thickness > 1.5 d_{50}
- Adjacent layers: d_{50} (layer 1) / d_{50} (layer 2) < 20
  - To avoid washout of finer material
- Transition zone length: 5 times cap thickness

A-33

Cap Design Models

- Focus on sediment criteria in bioturbation layer
  - Comparison of concentration at steady state to PEC or ER-L
  - Evaluation of time required to achieve steady state
- Chemical fate and transport model options
  - Simple Transient and Steady State Models
  - Numerical Model
- Should consider all relevant transport processes
- Designed to predict concentrations which can be used to indicate cap effectiveness or compare to cap monitoring field samples

A-34

Simple Steady State and Transient Models

- Objectives
  - Transient - How long is the cap expected to contain effectively all contaminants?
  - Steady State – At long time, how protective is the cap?
- Conservative Assumptions
  - Constant concentration in underlying sediment
  - No reactive fate processes
  - Contamination of cap by consolidation
    - Consolidation will only express porewater and transient chemical migration
    - Steady state performance unaffected by sediment consolidation
  - Failure to recognize that isolated failure does not negate cap effectiveness
    - Cap effectiveness proportional to area covered
    - Small area losses or isolated penetrations do not compromise overall cap performance

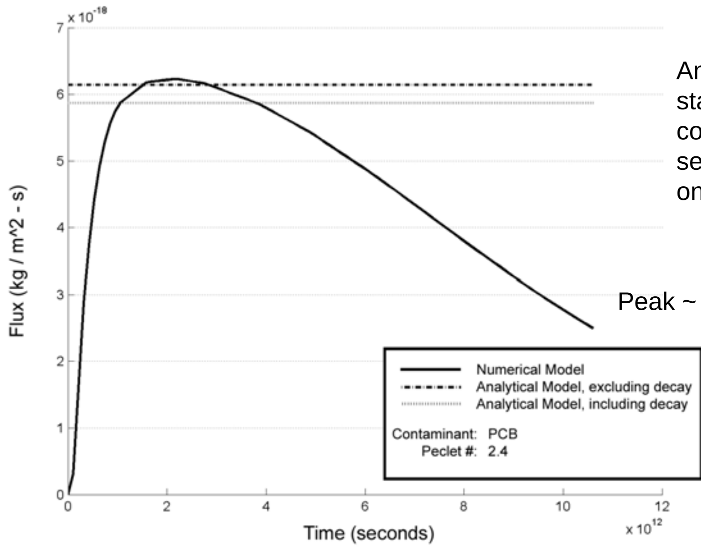
A-35

Alternative – Numerical Models

- Boudreaux- Diagenetic Model, Springer (1996)
- USACE Recovery/CAP
- HSRC – Accessible over the internet
- Allow variations in chemical and physical properties with time and space
- Require additional data to take advantage of additional capabilities

A-36

Model Predicted Flux



Analytical model is steady state model assuming constant concentration in sediment and advection only (no diffusion)

Peak ~ 60,000 yrs

A-37

Model Parameters

- Effective bioturbation mass transfer coefficients
  - Typical conservative value 1 cm/yr
  - 90% of freshwater measurements (Thoms et al., 1995) exceed 0.1 cm/yr
  - Marine systems similar although expressed by fewer, larger organisms
- Seepage velocity
  - Measured via tracers or seepage meters or estimated via groundwater models
  - Typically higher near shore and negligible off shore but can be highly variable
  - 1 cm/yr Advection ~ Diffusion
  - 1-100 **m**/yr Advection ~ Bioturbation for moderately sorbing component
- Concentration in underlying sediment
  - Porewater data or sediment data converted to porewater concentrations
- Diffusion coefficient in sediment
  - Influenced by temperature, sediment porosity and tortuosity
- Partitioning coefficient and retardation factor
  - Sampling data (porewater/sediment) used in underlying sediment
  - Literature values used in cap layers until specific cap material selected
- Fraction organic carbon
  - 0.1%, 1%, 5% typically ranges in bioturbation layer
  - 0.01%-0.1% assumed in chemical isolation layer (if sand used)
- Contaminant reactivity
  - Zero or conservative literature values for anaerobic half-lives typically used

A-38

Velocity – In SMU 1 and 2 the recommended barrier wall is assumed to reduce velocity to 1 cm/yr, we evaluated a maximum velocity as double the assumed groundwater velocity with a barrier in place and for 0 cm/yr assuming the wall controls all upwelling in SMU 1 and 2. In the other SMUs we evaluated the maximum velocity predicted for each SMU which was typically found within 20 feet of the shore line. We also looked at velocities within 300 feet from shore and then greater than 300 feet from shore where the velocities were expected to be less than 2 cm/yr.

Concentrations – Average concentrations and maximum concentrations were evaluated in each SMU. Porewater sampling data was used where available. This was in SMU 1 and 7. In the other SMUs initial porewater concentrations were calculate from maximum and average sediment concentrations in the upper 100 cm, the area which is expected to have the most significant impact on the cap. We also looked at the maximum sediment concentrations at all depths, in most cases the sediment concentrations in the upper meter contained the maximum concentrations in those cases where the concentration at depth was higher we found no?? Exceedences (Caryn to double check-I did this in Atlanta but not since then). Sediment concentrations were divided by a site specific partitioning coefficient which was developed based on a Koc value determined from the porewater sampling and a SMU specific foc value developed from sampling results.

Current Issues in Cap Design

- Extremely soft sediments
  - Control resuspension and limit differential loading by placement in thin lifts with enough water column to allow gravity settling
  - Subsequent consolidation improves support for subsequent layers
- NAPL/gas release
  - Gas generally a concern only w/NAPL present & immediately after placement
  - NAPL mobilization in soft, high fluid content sediments?
    - All remedial alternatives difficult with NAPL in sediments
  - Sand can serve as capillary barrier to collect NAPL
  - Control of NAPL migration (onshore hydraulic control) generally a prerequisite to adequate sediment management
- Seepage
  - Concerns greatest nearshore and in heterogeneous systems
  - Understand/control of seepage generally important for successful cap
- Design flow
  - Sometimes difficult to define (100 yr flood, wind-driven seiche, ice, waves?)
  - Reaching threshold of erosion cap doesn't mean loss of cap effectiveness!
- Active Capping

A-39

Active Capping

- Potentially greater effectiveness than with sand can be achieved with “active” caps
  - Encourage fate processes such as sequestration or degradation of contaminants beneath cap
  - Discourage recontamination of cap
- Feasible if high value components are placed in thin layer in a controllable manner

A-40

Potential Active Cap Materials

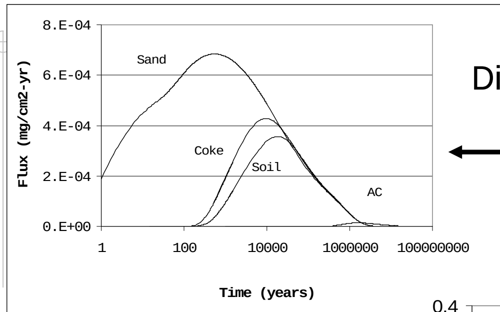
Demonstrated

- Activated Carbon or other carbon sequestration agent
- Organoclays for NAPL control
  - Demonstrated (e.g. McCormick and Baxter)
  - Significant swelling and permeability reduction
  - Design balancing capacity with permeability reduction
- Phosphate additives for metals
  - Rock phosphate (e.g. apatite) demonstrated
  - Phytic acid, injectable into sediments
- Zero valent iron
- Biopolymers
  - Can bind metals and organics
  - Can be injected into sediments

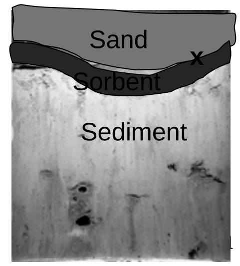
Speculative

A-41

2,4,5-PCB Isolation Provided by Sorbent-amended Thin Layer (1.25-cm) Caps

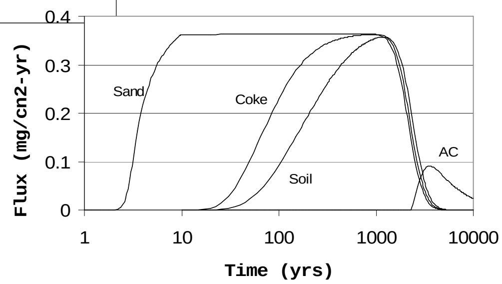


Diffusion Only



times

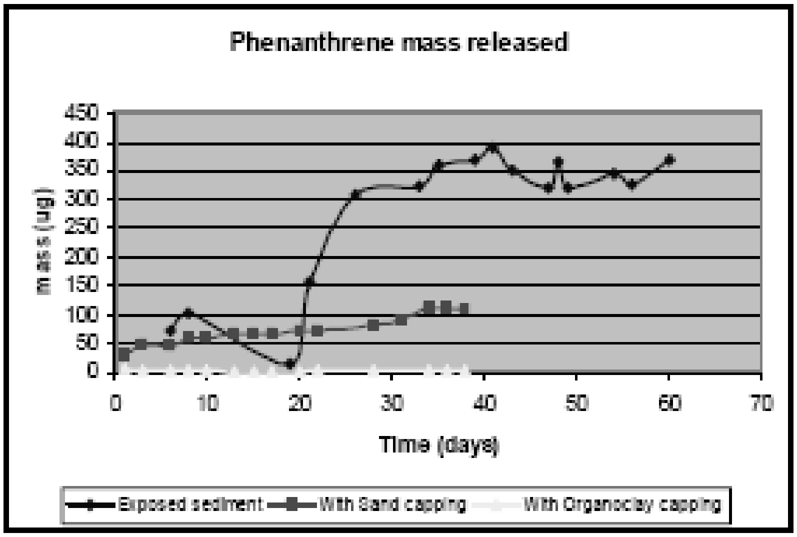
Advection and Diffusion



(Murphy et al., 2005)

A-42

Organoclay for NAPL containment



A-43

Potential Cap Technologies Anacostia Demonstration

- Aquablok for control of seepage and advective contaminant transport
- Zero-valent iron to encourage dechlorination and metal reduction
- Coke breeze to encourage sequestration of contaminants
- Phosphate mineral (Apatite) to encourage sorption and reaction of metals
- BionSoil to encourage degradation of organic contaminants
- Natural organic sorbent to encourage sorption-related retardation (reduction in advective-diffusive transport)

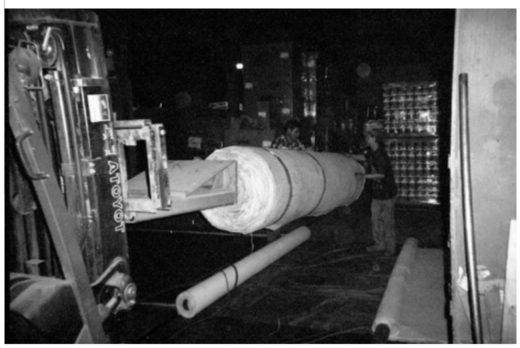
A-44

In-Situ Treatment/Active Caps Fundamental Concerns

- Difficulty in introducing reagents into sediments
- Difficulty of placing high-value materials in aqueous environment
- Limited lifetime of high-value reagents in aqueous environment
- Cost of treatment/active capping
  - Potentially erase cost benefits of capping/in-situ treatment
- Reactive Core Mat approach may be a means of addressing first three concerns

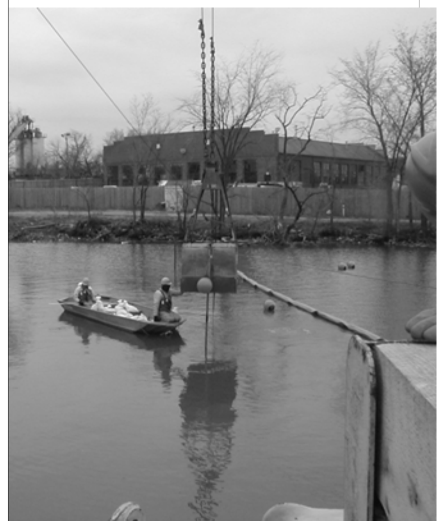
A-45

Reactive Core Mat (RCM) Production



A-46

RCM Placement



A-47

RCM Properties and Costs

- Thickness
  - ~0.5 in. (1.25cm)
- Loading
  - ~0.8-1.0 lb/ft^2 (3.4 kg/m^2)
- Twelve 10' x 100' rolls produced
  - ~6.5 tons of (10 x 40 mesh coke)

- Costs
  - Materials ($2700)
  - Lamination ($1750)
  - Labor ($2850)
  - Coke ($950)
  - Shipping ($2900)
  - Total <u>($11,100)</u> ($1.11/ft^2)

If activated carbon ~ $2.00/ft^2
If iron - $1.25/ft^2 (bulk iron)
$3.62/ft^2 (10% nano-iron)

A-48

Capping Operations

EPA/OSRTI Sediment Remedies: Capping – Technical Considerations for Evaluation and Implementation

Michael R. Palermo, PhD

Mike Palermo Consulting

Email: mike@mikepalermo.com

EPA Sediment Remedies Internet Seminar

B-1

Cap Implementation - Outline

- Implementation = Placement/Construction
- Design and Implementation are inter-related

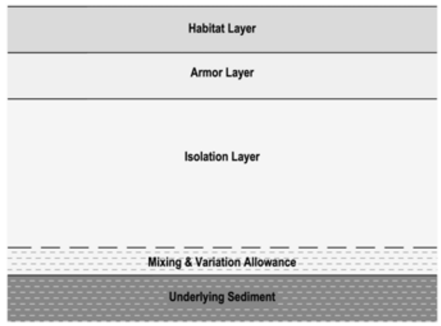
Outline

- Processes Critical for Successful Implementation
- Equipment for Cap Placement
- Capping Operations Plan
- Cap Construction
- Cap Monitoring and Management

B-2

Cap Design and Cap Placement are Strongly Related

- Selection of placement method will depend on selection of cap materials, and thicknesses of layers
- Placement results will influence the effectiveness of the various layers



B-3

Processes Critical to Successful Cap Implementation

- Control Sources First
- Equipment Selection for Placement
- Resuspension During Placement
- Slope Stability
- Bearing Capacity/ Displacement
- Mixing
- Consolidation
- Operational Capabilities

B-4

Resuspension During Placement

- Data collected at a few sites.
- Comparatively less than dredging resuspension.
- Can be managed and controlled.

Reference work sponsored by EPA Cincinnati Lab.

B-5

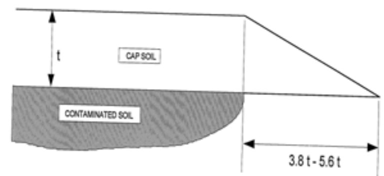
Capping Resuspension

- Limited data thus far
  - Boston Harbor, Eagle Harbor, PV Shelf, Soda Lake, Anacostia, Pacific Sound Resources
- No significant releases
- No predictive method
- Capping resuspension is less than dredging resuspension
  - Rates of resuspension are lower
  - Sediment mass subject to resuspension is lower

B-6

Slope Stability

- Cap Placement on Slopes
  - Field experience the key
- Cap Stability at Edges
  - Overlap the CS deposit with full cap thickness
  - Taper edges, include a buffer



B-7

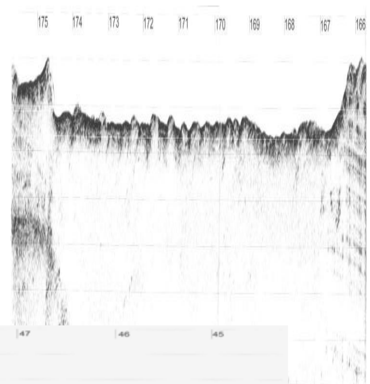
Placement to Avoid Displacement

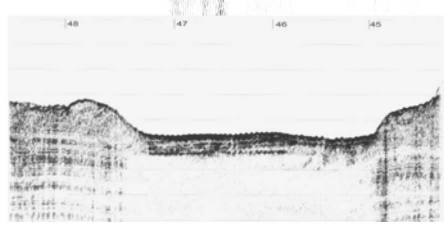
- The Capping Placement Rule of Thumb:
  - Place cap in thin layers
  - Gradually build up the required cap thickness
- How Thin?
  - Not over 6 inches per lift
  - 1 to 2 inch lifts have been placed

B-8

Bearing Capacity/ Displacement

- Controlled placement is key
- Gradual buildup helps avoid large-scale displacements
- Buildup over wide areas

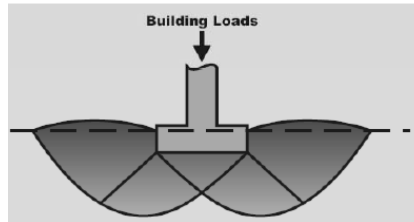




B-9

Approach to Define Maximum Lift

- Based on geotechnical bearing capacity
- “Punching” failure mode
- Max differential lift thickness if defined



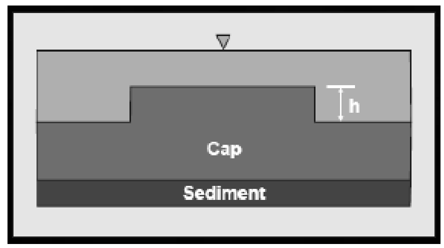
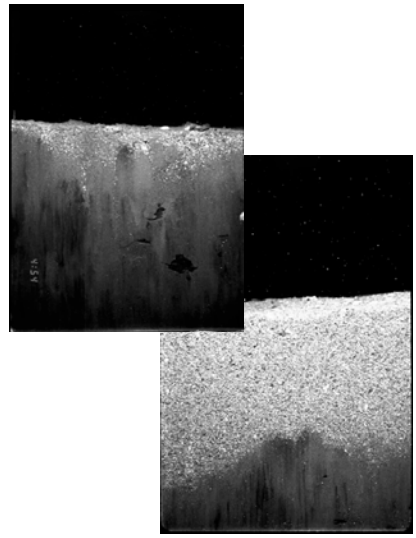


Figure after Anchor Environmental

B-10

Mixing Due to Placement

- Some surficial mixing of cap and CS will occur
- Placement of thin layers helps to minimize mixing
- Consider mixed layer in design



B-11

Consolidation

- Consider consolidation in monitoring placement operations and cap thickness over time.
- Use post-consolidation conditions for long term design evaluations.

B-12

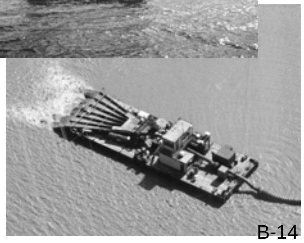
Operational Capabilities

- Ability to place thin lifts
- Ability to place uniform thicknesses
- Ability to monitor placement

B-13

Placement Equipment and Techniques

- Conventional Placement
  - Hopper dredge
  - Pipeline
  - Barge
- Spreading Methods
- Submerged discharges



B-14

Placement Approach

Approach would depend on:

- Geotechnical properties of the CS
- Thickness of the cap component
- Water depth
- Hydrodynamics
- Slopes

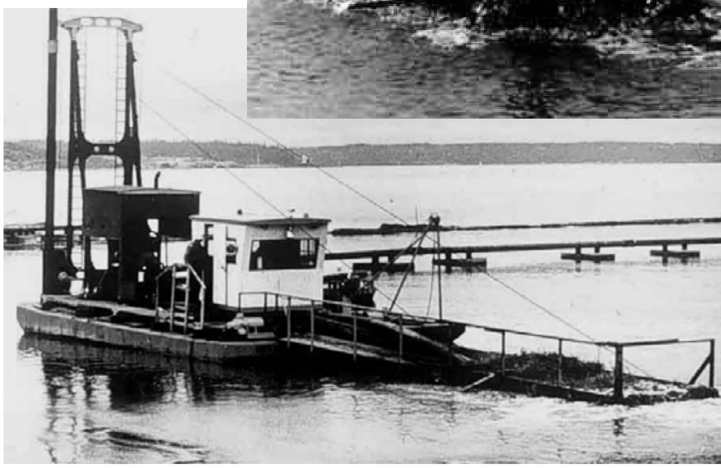
B-15

Denny Way CSO

B-16

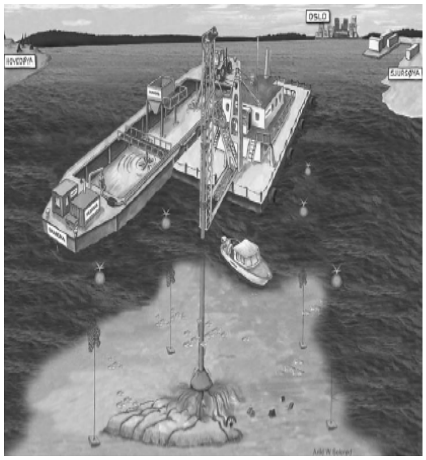
Simpson-Kraft

Sand Box



B-17

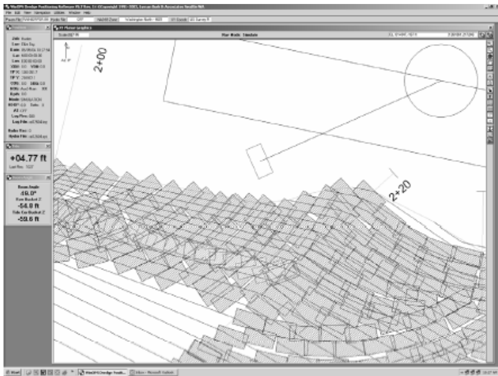
Bjoervika Pilot Project (Norway)

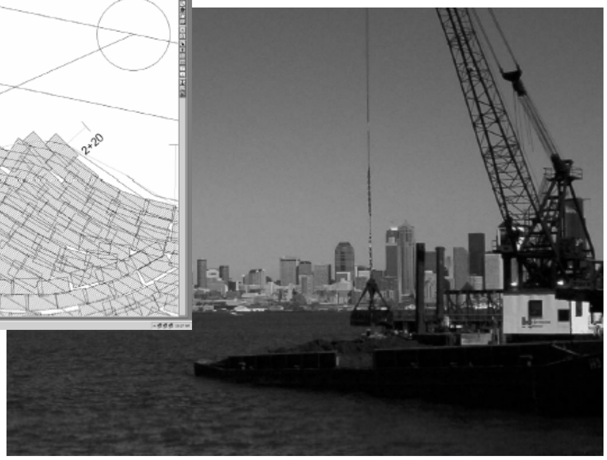


B-18

90 m water depth

Pacific Sound Resources (Seattle)



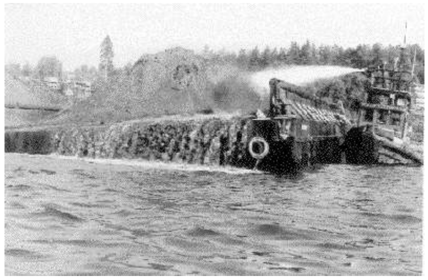


B-19

Sheboygan

Demo

B-20



Eagle Harbor

B-21

Hamilton Harbor

B-22

Pine Street

B-23

Mock’s Pond

B-24

Mock’s Pond

•Fabric, 2ft sand

•8 lifts of 3 in.

•8 in pipeline

•16 ft diffuser

•Photos by RETEC

Soda Lake (Pilot)

B-25

Tremie Placement

B-26

Lake Ketelmeer (Netherlands)

B-27

Todd Shipyard, Seattle
Under Pier Capping

B-28

PPT by Hartman

Thea Foss Waterway

- Impermeable Cap
- Photos DOF/ Hartman

B-29

Clamshell Placement - Anacostia

B-30

We employed conventional and simple placement techniques, even to place relatively thin caps

Cap Thicknesses

(Measured by core samples)

Cap	Target Thickness -in	Observed in±σ
Sand	12	9.3±3.2
Aquablok Sand	4 6	5.8±1.9 5.3±1.8
Apatite Sand	6 6	5.2±1.8 4.4±1.6
Coke Sand	1 6	1 (mat) 6.4±1.4

B-31

A summary of cap thicknesses and standard deviations as measured by hand cores after placement

RCM Placement - Anacostia

B-32

Cap Placement – McCormick & Baxter

B-33

Conveyor Placement- M&B

B-34

Armor- M&B

B-35

Armor Placement – M&B

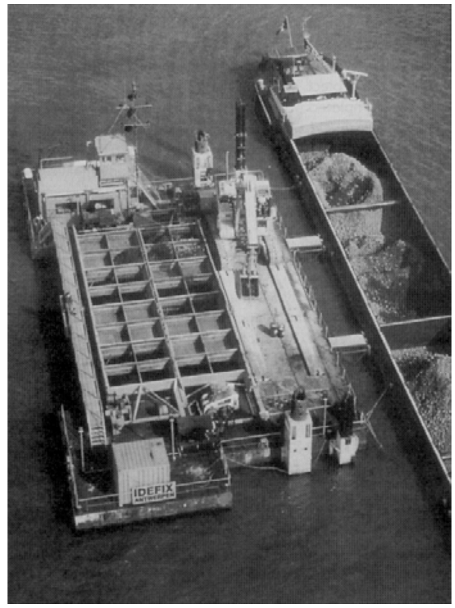
B-36

Controls for Resuspension

- Operational Mods
  - Rate of placement
  - Method of placement
- Containments
  - Silt Curtains
  - Sheet piles, etc.

B-37

Stone Placement



B-38

Capping Operations Plan

Lay out in detail how the cap will be constructed.

- Specific areas for cap placement
- Equipment and Placement Methods
- Sequence of placement (components and by area)
- Logistics
  - Sources for cap material
  - Transport of cap material to the site (rail, truck, barge, etc.)
  - Access and Staging Areas
  - Scheduling and Time Constraints (daily, weekly, seasonal)
- Construction Monitoring

B-39

Cap Monitoring and Management Plan

- Construction/ Long Term/ Severe Event
- Approaches - Bathy and Cores
- Cap Construction
  - Resuspension; cap thickness; mixing and displacement
- Long Term
  - Physical stability; chemical isolation;
- Severe Event –
  - Triggers for storms, ice, etc.
- Written plan – with management actions

B-40

Questions?

B-41

Thank You

After viewing the links to additional resources, please complete our online feedback form.

Thank You

Links to Additional Resources

B-42