Understanding Remediation At Contaminated Sediment Sites: Advantages, Limitations, And Risks Associated With Sediment Management Options

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Overview

- Major Remedies: Dredging, Capping, Monitored Natural Recovery
  - Misperceptions
  - Case studies
  - Advantages
  - Limitations
  - Risks
  - Conditions conducive to conducting each remedy
- Key Sediment Management Considerations
- Lessons Learned

Three Major Remedies

- Dredging
- In-situ capping
- Monitored natural recovery

Dredging

- Common Misperceptions
- Case Studies
- Advantages
- Limitations
- Risks
- Conditions Especially Conducive To Dredging

Dredging Misperception

MISPERCEPTION

- Mass removal immediately and permanently reduces risk

FACT

- "Simple mass removal … may not reduce risk."
  Sediment Dredging At Superfund Megasites: Assessing The Effectiveness. 2007 National Research Council, p. 56.

Dredging Misperception

MISPERCEPTION

- Dredging will allow fish consumption advisories to be lifted immediately

FACT

- Affecting the food chain can take a long time – from several years if all sources are controlled, to many decades if not

Dredging Misperception

MISPERCEPTION

- O&M costs of dredging are vastly lower than capping

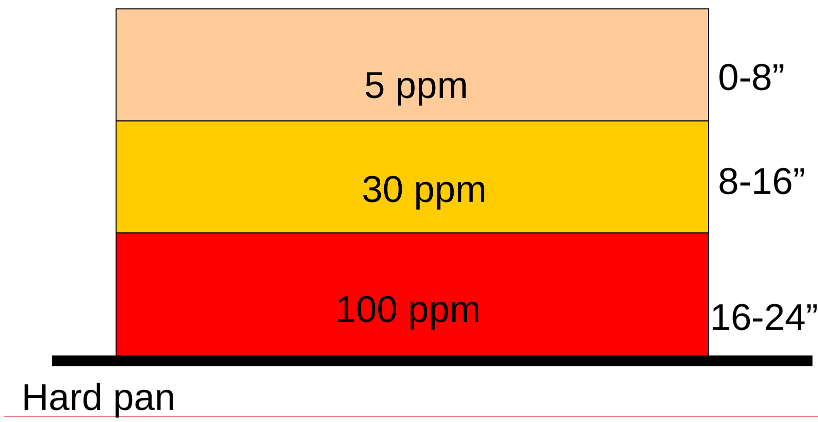
FACT

- Good data are hard to get, but suggest that…
  - O&M costs for dredged areas are lower than capping if the dredging meets risk-based cleanup levels and cap repair is likely to be needed frequently
  - O&M costs for dredged areas are very similar to capping where low risk-based sediment levels are met through MNR after dredging and capped areas won't need much repair
  - O&M costs for dredging go up significantly if it includes on-site disposal units

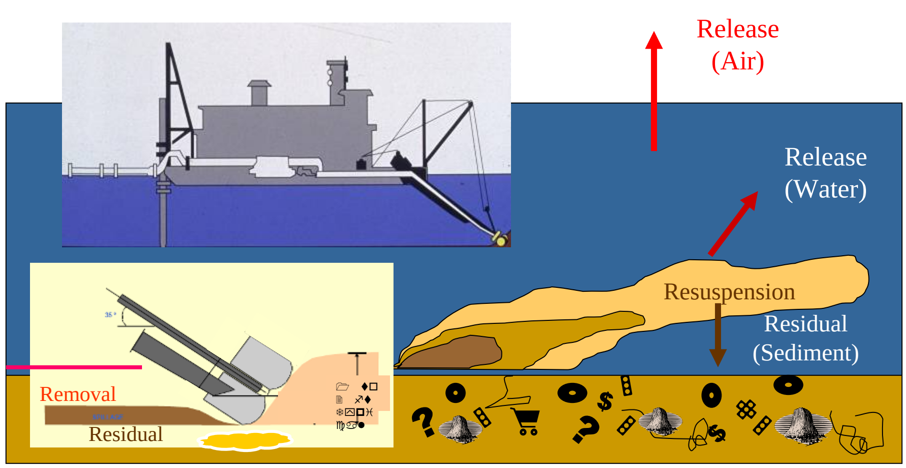
Dredging Lessons From 2007 NRC Report "Sediment Dredging At Superfund Megasites: Assessing The Effectiveness"

- Dredging is effective for mass removal, but mass removal alone may not achieve risk-based goals.
- Dredging will likely have at least short-term adverse effects on the water column and biota.
- Dredging effectiveness is limited by resuspension, release, and residuals.
- Dredging alone is unlikely to be effective in reaching short-term or long-term goals where sites exhibit one or more unfavorable conditions.

Pre-Dredge Contaminant Concentration In Sediment Column



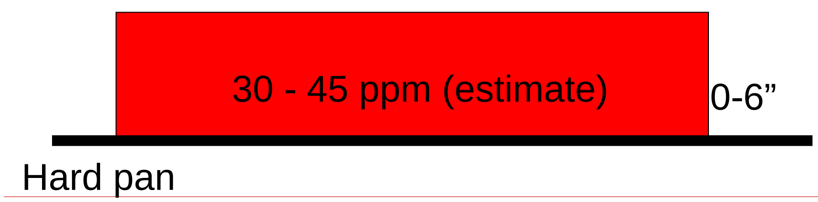
Conceptual Illustration Of Environmental Dredging And Processes



From D. Reible, 2007

Post-Dredge Surficial (0-6”) Sediment Contaminant Concentrations

Hard pan and/or debris prevented dredge from removing all the contaminated sediment. The buried sediment with high concentrations of contaminant was exposed. The surficial concentration went from 5 ppm to ~30 – 45 ppm.



Residuals From Selected Projects

Site (Year(s) Dredged)	Pre-Dredge Prism Average PCB Conc. (ppm)	Pre-Dredge Surficial Average PCB Conc. (ppm)	Post-Dredge Surficial Average PCB Conc. (ppm)
Cumberland Bay (1999, 2000)	33/431 (84)[1]	--	6-7
Fox Deposit N (1998, 1999)	16 (45)[2]	16	14 (21)[2]
Fox SMU 56/57: Yr. 1 (1999) Yr. 2 (2000)	 114 11	 4.4 --	 73 2
GM Massena (1995)	200	548	9.2
Grasse ROPS (2005)	--	4.1	150
Grasse River NTCRA (1995)	1109	518	75
Manistique (1995-2000)	28 (46)[1]	15.1	~18
Reynolds Metals - Massena (2001)	59 (191)[1]	--	0.8 (“well below 5”)[2]
River Raisin (1997)	1369[1]	3020	9.7

[1] These prism average concentrations were calculated from the aggregate pounds of PCBs and volume of sediments removed.
[2] Alternative literature value.

Dredging Case Studies

- Grasse River, NY: 2005 ROPS
- Head of Hylebos, Commencement Bay, WA: 2004 - 2006
- Manistique Harbor, MI: 1995 - 2000

Grasse River, NY – 2005 ROPS (Pilot)

- Project
  - Remedial Options Pilot Study
  - 20,600 cy dredged over 4 months
- Contaminants
  - PCBs
- Project Goals
  - Goals: Dredge 64,000 cy in 3 areas; make progress on river
- Results
  - Dredged only 1/3 of desired volume
  - Residuals issue
    - Pre-dredging average surficial concentration was 4.1 ppm
    - Post-dredging average surficial concentration was 150 ppm
  - 3% of PCBs lost downstream
  - Concentrations of PCBs in fish increased

Grasse River, NY - 2005 ROPS (Pilot)

- Lessons Learned
  - Average surficial concentration increased even though ~100 dredge cuts in each 25 ft x 25 ft unit
  - Complex site bottom conditions hampered ability to remove all targeted sediments with the equipment used and limited productivity
  - Available technology unable to characterize site sub-bottom conditions
  - High residual PCBs due to high PCB concentrations at depths at which obstructions (rocks, boulders, etc.) were encountered
  - Significant downstream loss of PCBs largely due to desorption of PCBs from resuspended sediments

Head of Hylebos, WA

- Project
  - Dredged 404,000 cy from 2004 – 2006
- Contaminants
  - PCBs, PAHs, As
- Project Goals
  - Remedial Goal: 300 ppb (0.3 ppm) PCBs
- Results
  - Average surficial PCB concentrations decreased from 0.69 ppm to 0.07 ppm
  - One area had to be capped
- Lessons Learned
  - Soft black muck over clean sand provided clear visual differentiation between impacted and clean sediment
  - Overdredging feasible
  - Relatively little debris
  - Source control prior to dredging

Manistique Harbor, MI

- Project
  - Dredged 187,500 cy from 1995-2000 (15 acres)
  - Hydraulic and substantial diver-assisted hand dredging
- Contaminants
  - PCBs
- Project Goals
  - Initial goal: Remove sediments with PCB concentrations greater than 10 ppm
  - Revised goal: Remove 95% of total PCB mass and an average PCB concentration not greater than 10 ppm throughout the sediment column
- Results
  - Average surficial concentrations of PCBs increased post dredging from 15.1 ppm to 18 ppm
  - No decrease in fish concentrations
  - Average surficial concentrations were later reduced through deposition due to dam removal and sand placement
- Lessons Learned
  - Fractured bedrock bottom and wood debris led to operational and residuals issues

Dredging Advantages

- Moves contaminants from a potentially mobile environment to one which can potentially be more easily and safely maintained and monitored
- Except for continuing fish consumption advisories, does not limit future water body uses or reduce flood control capacity

Limitations Of Dredging

- Complex and time-consuming to design and implement
- Lack of capacity in disposal facilities
- Resuspension and transport of contaminants
- Release of contaminants to water, leading to an increase in bioavailability
- Residual 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.

Dredging – Elements Potentially Continuing Or Increasing Risk

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

Conditions Especially Conducive To Dredging

- Contaminated sediment is underlain by clean sediment (overdredging is feasible)
- Low incidence of hardpan, bedrock, and/or rocks (overdredging is feasible)
- Low incidence of debris (e.g., logs, scrap materials)
- Low incidence of low dry density sediment (“fluff”)
- Higher contaminant concentrations cover discrete areas
- Water diversion is practical; or current velocity is low or can be minimized to reduce resuspension and downstream transport during dredging

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

Conditions Especially Conducive To Dredging

- Existing shoreline areas and infrastructure can accommodate dredging (e.g., piers, pilings, buried cables)
- Navigational dredging is scheduled or planned
- Suitable area is available for staging and handling of dredged material
- Suitable disposal sites are available
- Long-term risk reduction outweighs sediment disturbance and habitat disruption
- Contaminants are highly correlated with sediment grain size (i.e., to facilitate separation and minimize disposal costs)

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

Capping

- Common Misperceptions
- Case Studies
- Advantages
- Limitations
- Risks
- Conditions Especially Conducive To Capping

Capping Misperception

MISPERCEPTION

- Capping is experimental and not proven

FACT

- Caps have been placed as the final remedy or pilot at over 100 sites worldwide (www.sediments.org /capping-chart.html)

Capping Misperception

MISPERCEPTION

- All caps will fail eventually

FACT

- When caps are eroded, it usually is in localized areas
  - Erosion by water is relatively easy to predict
  - Predicting ice effects can be more difficult (not impossible), but also usually localized
- Models of contaminant movement into caps are based on well-understood mechanisms
- Contaminant movement is highly dependant on rates of ground water advection (if any)

Capping Misperception

MISPERCEPTION

- Ground water flow will make most caps fail

FACT

- Based on site-specific measurement, ground water flow may be, but often is not, a large risk to caps, because …
  - Higher flow rates tend to be in limited areas & to occur for limited time periods
  - Most sediment contaminants are hydrophobic
- Engineering solutions for high flow areas are available

Capping Misperception

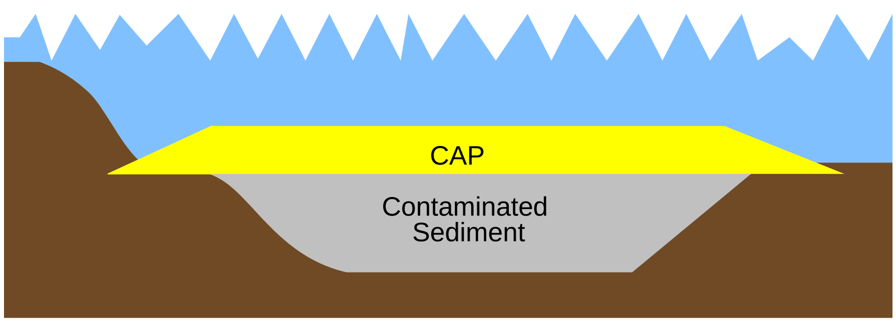
MISPERCEPTION

- You can't cap in rivers

FACT

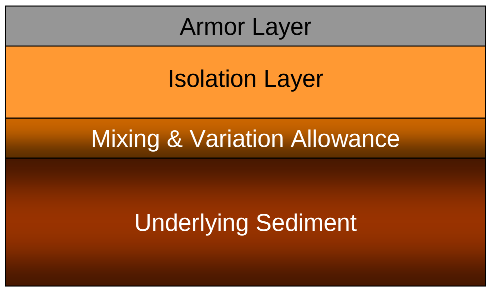
- It depends where you are in the river
- River areas that may be better suited to capping:
  - Outside of main channels
  - Slower flowing channels & back-waters
  - Reaches with higher flows that can be addressed with an engineered armor layer
  - Pool or dam-controlled reaches
  - Reaches with sufficient depth for flood control and navigation after capping
  - Areas with relatively slow rates of ground water advection (or for small areas, might control through design)
  - Areas with stabilized banks or a slow rate of meander migration relative to contaminant degradation

Conceptual Illustration – In-Situ Subaqueous Capping



From D. Reible, 2007

Cap Design



Capping Case Studies

- Anacostia River, Washington DC: 2004
- St. Paul Waterway, WA: 1988

Anacostia River, Washington DC

- Project
  - Freshwater tidal system
  - Reactive capping remedy - 2004
- Contaminants
  - PAHs, PCBs, metals, other
- Project Goals
  - Test innovative “reactive” cap materials (apatite, Aquablok, coke breeze)
- Results
  - Cap successfully contained targeted contaminated sediment
  - Recontaminated in 2 years
- Lessons Learned
  - Source control is key: Deposition of contaminated sediments on top of the cap from urban sources in the area and relocation of unremediated sediments present elsewhere in the waterway

St. Paul Waterway, WA

- Project
  - Early capping project - 1988
  - 17 acres capped in situ plus habitat enhancement
- Contaminants
  - phenols, PAHs, Cu, dioxins, furans
- Project Goals
  - Maintain integrity of the cap
  - Chemically stable
  - Biological recovery within 2 yrs of completion of cap
- 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 benthic and epibenthic organisms and macrophytes
    - Communities indistinguishable from reference area communities
- Lessons Learned
  - Cap provided intertidal habitat in industrial bay

Capping Advantages

- Can achieve greater risk reduction more quickly (almost immediately)
- Creates less short-term risk and fewer quality of life issues
- Can be implemented quicker and at less cost
- Requires much less space for staging, handling, and treatment of sediment
- Can facilitate habitat restoration by using an eco-friendly surface layer

Limitations Of Capping

- Sediments remain in the aquatic environment, but isolated by an engineered barrier
- Water depths reduced
- Must evaluate if subject to episodic storms, floods, etc.
- Long term monitoring/maintenance required
- Institutional controls may be required

Elements Potentially Continuing Or Increasing Risk - Capping

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

Conditions Especially Conducive To Capping

- Sediment has sufficient strength to support cap (e.g., has high density/low water content)
- Rate of contaminant flux through cap is not likely to create unacceptable risk or can be accommodated in cap design

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

Conditions Especially Conducive To Capping

- Anticipated or existing 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) or surcharge capping can be used to maintain adequate water depth
- Suitable types and quantities of cap material are available

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

Conditions Especially Conducive To Capping

- 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
- Rate of ground water flow in cap area is not likely to create unacceptable contaminant releases
- Incidence of cap-disrupting human behavior, such as large boat anchoring, is low or controllable

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

Monitored Natural Recovery

- Common Misperceptions
- Case Studies
- Advantages
- Limitations
- Risks
- Conditions Especially Conducive To Monitored Natural Recovery

MNR Misperception

MISPERCEPTION

- MNR is a "do nothing" remedy

FACT

- Selection of MNR as a remedy recognizes that:
  - Risk is unacceptable
  - Natural processes are the best alternative for reducing risk in this area
  - Resources should be expended to monitor it
- MNR decisions should include a risk-based remediation goal for sediment and an estimated time-frame for achieving it

MNR Misperception

MISPERCEPTION

- We don't need MNR; if risk from sediment is unacceptable, we should address it with an active remedy

FACT

- EPA policy is to consider MNR on a equal footing with dredging and capping
- Where natural processes are working at an acceptable rate, MNR may be the best use of resources and is less disruptive
- Site-specific conditions may make dredging or capping very difficult or unlikely to materially speed up risk reduction
- For large areas of relatively low contamination, dredging or capping may not be cost-effective
- MNR may be needed to reach low risk-based sediment remediation goals even in areas where you dredge or cap

MNR Case Studies

- Bellingham Bay, WA
- Grasse River, NY
- Sitcum Waterway – Area B (Commencement Bay/Nearshore Tideflats), WA

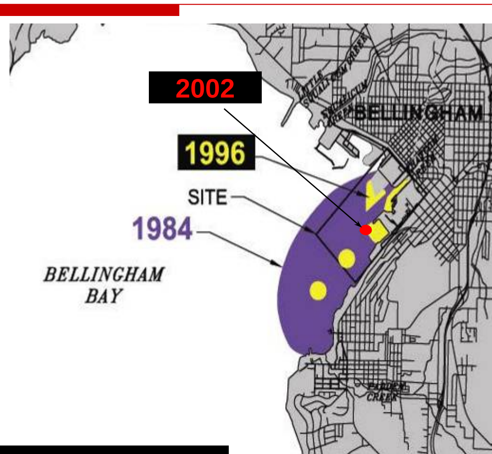
Bellingham Bay, WA

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

Bellingham Bay Natural Recovery Biological Endpoint: Sediment Toxicity

Toxicity tests:

- **Amphipod: toxicity**
- **Larval: acute toxicity & abnormality**
- **Polychaete: chronic toxicity & growth**

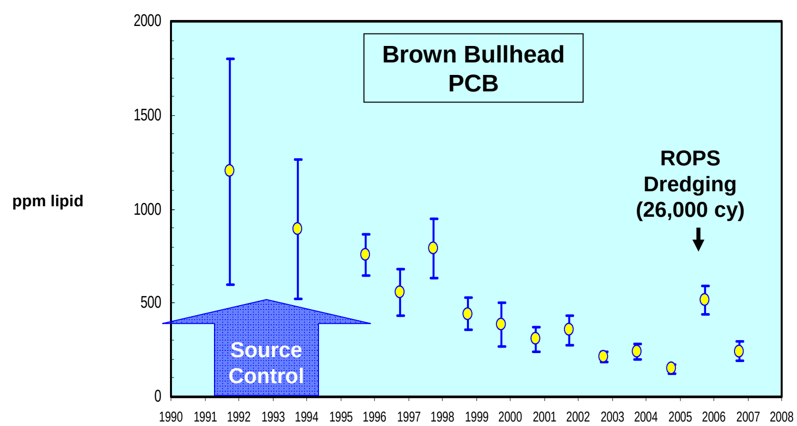


Data Source: Georgia-Pacific (2004)

Grasse River, NY

- Project
  - Upper NY State waterway
- Contaminants
  - PCBs
- Project Goal
  - Reduce PCB concentration in fish tissues
- Results
  - Significant decreases in PCB concentration in fish tissue after upstream source control, except for the year following the 2005 ROPS dredging
- Lessons Learned
  - Dredging caused a significant increase in PCB concentration in fish tissue
  - MNR is the least invasive sediment remedy and it allows the existing eco-system to remain in place

Grasse River Natural Recovery Biological Endpoint: Fish Tissue PCB Levels



Data Source: Alcoa (2007)

Commencement Bay Nearshore/Tideflats, WA

- Project
  - MNR selected for Area B of the Sitcum Waterway in the Commencement Bay/Nearshore Tideflats Site
- Contaminants
  - PAHs, metals
- Project Goals
  - RAO: Achieve acceptable sediment quality in a reasonable time frame
  - Acceptable sediment quality defined as absence of acute or chronic adverse effects on biological resources or significant human health risks
  - Reasonable time frame defined as within 10 years following the completion of other remedies in different portions of the operable units
- Results
  - Monitoring (1998 – 2003) showed that surface sediment concentrations decreased below the SQOs
  - Long term monitoring determined to be complete in the 2004 5-year review report
- Lessons Learned
  - MNR was an integral component of a combination remedy that included dredging, engineered capping, thin layer capping

MNR Advantages

- MNR is the least invasive sediment remedy, and allows the existing eco-system to remain in place
- MNR avoids the disruption to the use of the waterbody, to the surrounding neighborhood and roads, avoids the need for large staging and storage areas, and, in the case of dredging, avoids the need for large treatment areas
- MNR is less costly than dredging and capping (although long-term monitoring costs can be costly as well)
- MNR avoids the need to transport contaminated sediment or capping materials through the neighboring community and beyond

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 or capping design and implementation are considered, this time difference may not be significant
- Long-term liability
- Uncertainty
- 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

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 (e.g., lower sedimentation rate)
- Potential for contaminant exposure due to erosion or human disturbance

Conditions Especially Conducive To MNR

- Anticipated land uses compatible with MNR
- Anticipated water body uses compatible with MNR
- Contaminant concentrations in biota and in the biologically active zone of sediment are moving towards risk-based goals

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

Conditions Especially Conducive To MNR

- Natural recovery reasonably anticipated to reduce risk within an acceptable time frame
- Current human exposure is low or can reasonably be controlled by institutional controls
- Site includes sensitive or unique habitats that could be irreversibly damaged by capping or dredging
- Sediment deposition is occurring in areas of contamination
- Hydrodynamic conditions are not likely to compromise natural recovery

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

Key Sediment Management Considerations

Key Sediment Management Considerations

- Purpose Of Remediation: Reduce Risks To Human And Ecological Receptors
- Control Sources Early
- Significant Uncontrolled Sources Are Key Impediments
  - Historical Contamination
  - On-going Contamination
- Key to Successful Project Outcome Is Control Or Mitigation Of Sources Up Front

Key Sediment Management Considerations

- No presumptive remedy:
  "[T]here is no presumptive remedy for any contaminated sediment site, regardless of the contaminant or level of risk." p. 7-16

  "There should not be necessarily a presumption that removal of contaminated sediments from a water body will be necessarily more effective or permanent than capping or MNR." p. 3-16

- Use a risk management process:
  "A risk management process should be used to select a remedy designed to reduce the key human and ecological risks effectively." p. 7-1

U.S. EPA, 2005. *Contaminated Sediment Remediation Guidance For Hazardous Waste Sites.*

Key Sediment Management Considerations

- Compare costs/benefits:
  "Another important risk management function generally is to compare and contrast the costs and benefits of various remedies." p. 7-1

- Focus on bioavailability:
  "Project managers should keep in mind that deeper contaminated sediment that is not currently bioavailable or bioaccessible, and that analyses have shown to be stable to a reasonable degree, do not necessarily contribute to site risks." p. 7-3

U.S. EPA, 2005. *Contaminated Sediment Remediation Guidance For Hazardous Waste Sites.*

Key Sediment Management Considerations

- Understand how site conditions affect remedy effectiveness:
  "Project managers should evaluate and compare the effectiveness of in-situ (capping and MNR) and ex-situ (dredging) alternatives under the conditions present at the site." p. 3-16

- Use realistic time estimates:
  "The time frame for natural recovery may be slower than that predicted for dredging or in situ capping. However, time frames for various alternatives may overlap when uncertainties are taken into account. In addition, realistic estimates of the longer design and implementation time for active remedies should be factored into the comparison." p. 4-4

U.S. EPA, 2005. *Contaminated Sediment Remediation Guidance For Hazardous Waste Sites.*

Key Sediment Management Considerations

- Consider combination remedies:
  "At many sites, but especially at large sites, the project manager should consider a combination of sediment approaches as the most effective way to manage the risk." p. 7-17

  If site conditions vary significantly across a site, areas should be evaluated separately and a combination remedy should be considered.

- Use comparative net risk:
  "Project managers are encouraged to use the concept of comparing net risk reduction between alternatives as part of their decision-making process for contaminated sediment sites, within the overall framework of the NCP remedy selection criteria." p. 7-13

U.S. EPA, 2005. *Contaminated Sediment Remediation Guidance For Hazardous Waste Sites.*

Key Remedy Selection Question

- After completing the comparative net risk evaluation and applying risk management principles (including an evaluation of costs and benefits), does the proposed sediment management option address the risk-drivers identified in the Conceptual Site Model and the risk-based Remedial Action Objectives identified earlier in the process?

Conclusions

Take Home Message - Dredging

- Dredging can be an effective remedy if conditions are conducive (e.g., low debris or underlain by clean sediment – overdredging is feasible)
- Dredging also has limitations, particularly at sites with debris, rock and hardpan
- Debris, rocks and hard pan significantly affect residuals and decrease the risk reduction potential of this remedy
- All dredges require skilled operators, but:
  - All dredges re-suspend sediment
  - All dredges leave residuals
- Dredging alone is unlikely to be effective in achieving both short-term and long-term cleanup levels at many sites that exhibit conditions unfavorable for dredging
- Is a highly complex and costly integrated train of processes (e.g., removal, transport, rehandling, treatment, disposal)

Take Home Message - Capping

- Capping has been successfully implemented at a number of Superfund sites and its advantages and limitations are better understood
- Can be an effective remedy
- Capping provides immediate exposure control
- Conventional sand caps are easy to implement
- Caps have been placed as the final remedy or pilot at over 100 sites worldwide (www.sediments.org/capping-chart.html)
- Methods are available to address key cap design issues (e.g., erosion control, bioturbation, contaminant flux, etc.)

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 reduce long-term uncertainty
- Enhanced MNR also may be used to reduce uncertainty

SMWG Background

- SMWG formation - May 1998
- Coordinated approach by parties responsible for developing/implementing contaminated sediment management strategies

  Current membership:
  - 45 Members
  - 44 Sponsors

SMWG Mission and Objectives

- ***Our Mission …*** To advance risk-based, scientifically sound approaches for evaluation of sediment management decisions
- ***Our Objectives …*** To collect, develop, analyze, and share data and information on the effectiveness of sediment management technologies and approaches

SMWG Initiatives

- Technical and Administrative Advocacy - National Policy
- Communication of Key Strategies to Members
- Collection and Dissemination of New Developments to Members

Questions?

FOR FURTHER INFORMATION ...

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- Visit the SMWG website: www.smwg.org