A Review of Lessons Learned After Nearly 3 Decades of Environmental Dredging in the USA

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Overview

• Environmental dredging - removal of sediments for environmental cleanup
  - In 30 years what we have learned?
    • Examine some trends
    • Review some key observations & data
    • Important lessons learned
  - Looking forward
Sediment Cleanup in the USA

• Federal and state regulatory programs with common elements
  - Investigation of potential risks
  - Cleanup alternative evaluation
  - Implementation and monitoring

• More than 30 years of remedy implementation
  - Information from more than 100 sites reviewed

• Lessons learned from experience; feedback and adaptation takes time

• Advancements in technology
Environmental Dredging Volumes

Source: Doody, Penniman, and Gehl, 2011

[Graph showing environmental dredging volumes from 1981 to 2010 with a peak at 5,970,000 m³ in 2003.]
Constituents Driving Cleanup

Pre-2000
- PCB: 13
- PAHs: 15
- Metals (including Hg): 20
- Dioxin: 4
- DDT: 5

n = 57

Post-2000
- PCB: 7
- PAHs: 11
- Metals (including Hg): 19
- Dioxin: 2
- DDT: 3

n = 42

Source: Doody, Penniman, and Gehl, 2011
Selected Remedial Approach

Pre-2000
- Removal: 7
- Cap: 7
- MNR: 4
- Hybrid Remedy: 2

n = 47

Post-2000
- Removal: 15
- Cap: 3
- MNR: 3
- Hybrid Remedy: 1

n = 39

Source: Doody, Penniman, and Gehl, 2011
Summary of Trends

- Dredging continues to be predominant sediment remedial technology
- PCBs and PAHs continue to be predominant drivers for cleanup
- Hybrid remedies are becoming more prominent
Review

• What is a hybrid remedy?
  - Use of a combination of approaches for remediation

• What is the predominant remedy selected by EPA for contaminated sediment sites?
  - Sediment removal, or dredging

• What contaminant was most frequently the driver for cleanup?
  - Polychlorinated Biphenyls (PCBs)
2007 National Research Council Review

- Dredging alone achieved cleanup levels at only 3 of 26 sites
- Long-term benefits of dredging not understood or documented
- Dredging rarely capable of achieving long-term risk reduction
  - Resuspension
  - Release
  - Residuals
- Residuals management often needed for risk reduction
Dredging-related Resuspension, Release, and Residual Contaminated Sediments

Source: USACE 2008
“The Four Rs” Literature

Resuspension, Release, Residual, and Risk

Technical Guidelines for Environmental Dredging of Contaminated Sediments
Michael R. Palermo, Paul R. Schroeder, Trudy J. Estes, and Norman R. Francogni
September 2008

In the United States, sediments in lakes, rivers, and estuaries contain contaminants that pose potential risks to human health and the environment. The potential risks from sediments vary widely and are dependent on factors such as the type and extent of contamination, the location of the site, and the exposure pathway. To manage these risks, it is necessary to understand the potential risks from contaminants in sediments and develop appropriate management strategies.

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

Resuspension
Resuspension is the process by which contaminated sediments are resuspended and transported to the water column. This can occur naturally, through wave action, or as a result of human activities such as dredging. Resuspension can lead to increased exposure to contaminants, which can pose risks to human health and the environment.

Release
Release refers to the movement of contaminants from the sediment matrix to the aqueous phase. This can occur through physical, chemical, or biological mechanisms. Release can increase the bioavailability of contaminants, making them more available for uptake by organisms and increasing the potential for adverse effects.

Residual
Residual refers to the amount of contaminants that remain in the sediment after a remediation effort. The residual contamination can persist for a long time and can pose a risk to human health and the environment. Residual contamination can also affect the ability of the ecosystem to recover from a contamination event.

Risk
Risk assessment is the process of evaluating the potential risks to human health and the environment from contaminants in sediments. Risk assessment involves identifying sources of exposure, estimating the magnitude of the exposure, and assessing the potential for adverse effects. Risk assessment can help determine the level of protective measures needed to manage the risks.

The Four Rs are important considerations in the planning and implementation of sediment management strategies. Understanding the Four Rs is essential for developing effective and efficient strategies for the management of contaminated sediments.
# Dredging Release Case Studies*

<table>
<thead>
<tr>
<th>Project</th>
<th>Environmental Dredging Activity</th>
<th>Best Management Practices</th>
<th>Source of Release Estimate</th>
<th>Contaminant Mass Released</th>
<th>Primary Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995 Grasse River</td>
<td>2,300 m³ hydraulic</td>
<td>Operational BMPs/silt curtains</td>
<td>Caged fish monitoring</td>
<td>Fish tissue concentrations increased 5 to 50x</td>
<td>Alcoa NAS Panel Presentation, Nov. 1999</td>
</tr>
<tr>
<td>1999-2000 Fox River</td>
<td>63,000 m³ hydraulic</td>
<td>Operational BMPs/silt curtains</td>
<td>Water quality monitoring</td>
<td>Average 2% (about 30% dissolved)</td>
<td>Steuer, 2000</td>
</tr>
<tr>
<td>2004 Duwamish/ Diagonal</td>
<td>54,000 m³ mechanical</td>
<td>Operational BMPs</td>
<td>Fate/transport and food web modeling to simulate measured fish tissue PCBs</td>
<td>Midpoint 3% (range: 1 to 6%)</td>
<td>Stern, 2007</td>
</tr>
<tr>
<td>2005 Grasse River</td>
<td>19,000 m³ hydraulic</td>
<td>Operational BMPs/silt curtains</td>
<td>Water quality monitoring</td>
<td>Average 3% (&gt;50% dissolved)</td>
<td>Connolly et al., 2007</td>
</tr>
<tr>
<td>2005 Lower Passaic River</td>
<td>3,000 m³ mechanical</td>
<td>Operational BMPs/rinse tank</td>
<td>Water quality monitoring</td>
<td>Average 3 to 4% (range: 1 to 6%)</td>
<td>Lower Passaic River Restoration Project Team, 2009</td>
</tr>
<tr>
<td>2009 Hudson River</td>
<td>210,000 m³ mechanical</td>
<td>Operational BMPs/silt curtains</td>
<td>Water quality monitoring</td>
<td>Average 3 to 4% (about 80% dissolved)</td>
<td>Anchor QEA and Arcadis, 2010</td>
</tr>
<tr>
<td>2011 Hudson River</td>
<td>280,000 m³ mechanical</td>
<td>Operational BMPs</td>
<td>Water quality monitoring</td>
<td>Average 1% (about 80% dissolved)</td>
<td>GE and Anchor QEA, unpublished data</td>
</tr>
</tbody>
</table>

*Preliminary data summaries; subject to revision
Commencement Bay

Hydraulic Dredging
1993-1994

Hydraulic and Mechanical Dredging
2002-2005
Dredging Increased Fish Tissue PCB Concentrations

Data Sources: TetraTech (1985); West and O’Neill (2007); and WDFW (2012)
Duwamish River

Mechanical Dredging
2003-2005
Dredging Increased Fish Tissue PCB Concentrations

Data Sources: Lower Duwamish Waterway Group (2010) and WDFW (2012)
Generated Residuals

- 18 detailed case study sites
- Dredging operations
  - Hydraulic and mechanical dredges
  - 1,800 to 300,000 cubic meters
  - 0.2 to 2 meter dredge cuts (total)
  - One to four production passes
  - All used BMPs
- Pre-dredge sediments
  - Variable debris, slopes, and geology
  - Variable contaminant depth profiles
### Generated Residuals Case Studies*

<table>
<thead>
<tr>
<th>Site</th>
<th>Dredge Volume (cubic meters)</th>
<th>Date</th>
<th>Primary Equipment Type</th>
<th>Generated Residual Mass (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fox River SMU 56/57, WI</td>
<td>24,000</td>
<td>1999</td>
<td>0.25-meter horizontal auger</td>
<td>4</td>
</tr>
<tr>
<td>Lavaca Bay Pilot, TX</td>
<td>8,000</td>
<td>1999</td>
<td>0.35-meter cutterhead</td>
<td>4</td>
</tr>
<tr>
<td>New Bedford PDFT, MA</td>
<td>2,000</td>
<td>2000</td>
<td>3.5-m$^3$ horizontal profile grab</td>
<td>6</td>
</tr>
<tr>
<td>Reynolds Aluminum, NY</td>
<td>49,000</td>
<td>2001</td>
<td>4-m$^3$ cable arm$^TM$</td>
<td>4</td>
</tr>
<tr>
<td>Middle Waterway, WA</td>
<td>69,000</td>
<td>2003/04</td>
<td>4.5-, 9-, 12-m$^3$ clamshell</td>
<td>4</td>
</tr>
<tr>
<td>Hylebos Segment 5, WA</td>
<td>299,000</td>
<td>2003/04</td>
<td>15-m$^3$ clamshell</td>
<td>2</td>
</tr>
<tr>
<td>Hylebos Segment 3/4, WA</td>
<td>153,000</td>
<td>2004</td>
<td>15-m$^3$ clamshell</td>
<td>5</td>
</tr>
<tr>
<td>Hylebos Segment 1/2, WA</td>
<td>306,000</td>
<td>2003/06</td>
<td>Clamshell/horizontal profile grab</td>
<td>3</td>
</tr>
<tr>
<td>Todd Shipyards, WA</td>
<td>92,000</td>
<td>2004/05</td>
<td>Cable arm$^TM$/clamshell</td>
<td>2</td>
</tr>
<tr>
<td>Fox River OU 1A, WI</td>
<td>42,000</td>
<td>2005</td>
<td>0.2-meter cutterhead</td>
<td>9</td>
</tr>
<tr>
<td>Fox River OU 1C/D2S, WI</td>
<td>13,000</td>
<td>2005</td>
<td>0.2-meter cutterhead</td>
<td>5</td>
</tr>
<tr>
<td>East Waterway, WA</td>
<td>199,000</td>
<td>2003/05</td>
<td>Cable arm$^TM$/clamshell</td>
<td>1</td>
</tr>
<tr>
<td>Grasse River ROPS, NY</td>
<td>20,000</td>
<td>2005</td>
<td>0.25-meter horizontal auger</td>
<td>11</td>
</tr>
<tr>
<td>St. Louis Interlake Duluth Tar, MN</td>
<td>92,000</td>
<td>2007</td>
<td>Flat-bottom bucket</td>
<td>7</td>
</tr>
<tr>
<td>Fox River OU 1, WI</td>
<td>115,000</td>
<td>2007</td>
<td>0.2-meter vicvac$^TM$</td>
<td>7</td>
</tr>
<tr>
<td>Willamette River T-4, OR</td>
<td>10,000</td>
<td>2008</td>
<td>15 m$^3$ cable arm$^TM$</td>
<td>4</td>
</tr>
<tr>
<td>Hudson River High Confidence, NY</td>
<td>222,000</td>
<td>2009</td>
<td>Enclosed clamshell</td>
<td>9</td>
</tr>
<tr>
<td>Fox River OU 3, WI</td>
<td>100,000</td>
<td>2009</td>
<td>0.2-meter cutterhead</td>
<td>7</td>
</tr>
</tbody>
</table>

*Preliminary data summaries; subject to revision*
Generated Residuals Case Studies*

*Preliminary data summaries; subject to revision
Post-dredge Residuals Management

Pre-2005
- Removal: 43
- Removal and Backfill/Cover: 20
- Removal and Cap: 4

Post-2005
- Removal: 10
- Removal and Backfill/Cover: 9
- Removal and Cap: 3

67 Remedies Included from 58 Decision Documents
22 Remedies Included from 17 Decision Documents

Source: Doody, Penniman, and Gehl, 2011
Factors Controlling 4 Rs

- Site characteristics
  - Debris and underlying geology
  - Geotechnical properties (e.g., dry density and potential for fluidized mud)
- No discernible equipment relationships to contain residuals or control releases
  - Mechanical dredges
  - Hydraulic dredges
- Use of BMPs
- Operator experience
- Magnitude of chemical concentrations
Review

• What are the 4 Rs?
  - Resuspension, Residuals, Release, and Risk

• What percent mass loss of contaminants to the water column has been observed at dredging sites?
  - 1% to 4%

• What generated residuals mass has been observed at dredging sites?
  - 1% to 11%
Dredging Remedy Costs

- Costs compiled for more than 100 completed dredging projects
- Key factors affecting costs
  - Disposal method (local vs. off site)
  - Treatment (e.g., incineration)
  - Project size

Summary of Environmental Dredging Construction Costs

<table>
<thead>
<tr>
<th>Tier</th>
<th>Dredging Volume Range (m$^3$)</th>
<th>Range of Observed Costs and Average ($/m^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500 to 10,000</td>
<td>260 to 3,800 (1,400 average)</td>
</tr>
<tr>
<td>2</td>
<td>10,000 to 75,000</td>
<td>50 to 1,030 (380 average)</td>
</tr>
<tr>
<td>3</td>
<td>Greater than 75,000</td>
<td>25 to 1,260 (330 average)</td>
</tr>
</tbody>
</table>
Advances Over 30 Years

• Recognized 4 Rs
  - Residuals covers being employed
  - Resuspension controls focus on solids (dissolved contaminant transport inevitable)
  - Need to consider in remedy evaluation

• Equipment improvements
  - Environmental buckets, shrouds
  - Positioning equipment
  - Integration of dredge plans into operator controls

• Dredging not the only answer
  - Capping, in situ treatment, MNR
Applying Lessons Learned

• Estimate anticipated residuals and releases to decide where best to implement dredging versus other remedial technologies (hybrid approach)

• Dredge Plan is key
  - Identify depth of contamination and geology using appropriate sampling, data evaluation, bathymetric surveying, and other tools

• Plan for residuals management (e.g., additional dredge passes versus sand cover or engineered cap) and include costs in remedy evaluations and design documents
Looking Forward

• Use of environmental dredging will continue
• Focus on net risk reduction
• Use of hybrid remedies seems likely
• Sites with sediment removal need to consider residuals/adaptive management approaches during planning and design phases
Looking Forward (cont.)

- Continued development of improved construction technologies
  - Specialized dredging technologies
  - Improved material placement technologies for residual covers and caps
  - Improved material placement technologies for in situ treatment methods
Resources


- ITRC sediment remediation guidance (to be issued)


Questions?