

Case Studies of Environmental Dredging Residuals and Management Implications

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ABSTRACT: One of the more significant limitations currently associated with assessing the effectiveness of environmental dredging is the uncertainty associated with estimating the nature and extent of residual contamination following removal. Residuals can be composed of both “generated residuals” left by the dredging operation and “undisturbed residuals” remaining below the cutline due to dredging inaccuracies or other factors. No removal technology can remove every particle of contaminated sediment, and field results to date for completed environmental dredging pilots and full-scale projects suggest that post-dredging generated residual contamination levels have often not met desired cleanup action levels. However, currently there is no commonly accepted method to predict the degree of generated residual sediment resulting from different dredges applied to different environmental settings. In the absence of suitable predictive models, the use of mass balance measurements from a series of well-documented dredging projects can be used to develop initial “bounding-level” expectations of dredge-generated residuals. Mass balance data meeting general minimum criteria to support residuals calculations are available from a range of environmental dredging projects. In many cases, generated residuals were differentiated from undisturbed residuals based on visual observations and detailed geotechnical measurements (e.g., dry density in core sections). This paper summarizes a series of case histories that have characterized the amount of generated residuals, relative to the mass of contaminant dredged. Environmental dredging residual data are evaluated relative to operational factors and key site characteristics such as the presence of hardpan/bedrock, debris, and relatively low dry density sediment. Management implications are also discussed.

INTRODUCTION

Contaminated sediments pose potential risks to human health and the environment at many sites nationwide, and the problem has received growing attention in recent years. One of the advantages commonly attributed to the removal of contaminated sediments via dredging, relative to other remedial technologies such as capping or monitored natural recovery is greater confidence in the long-term effectiveness of the cleanup, assuming that risk-based action levels can be achieved. However, there are also significant limitations to environmental dredging: implementation of environmental dredging is usually more complex and costly than other sediment management approaches and uncertainties associated with its long-term effectiveness have been underestimated (Bridges et al., in preparation).

Initial reviews of dredge residual data have suggested that dredging accomplishes significant contaminant mass removal, but a veneer of contaminated sediments typically covers the post-dredging surface at many sites after the initial dredge pass (Herrenkohl et al., 2003; Desrosiers et al., 2005). While additional dredge passes can increase

sediment and contaminant removal, the effectiveness of repetitive dredging passes decreases significantly with each successive re-dredging attempt. In many cases, even after re-dredging, post-dredging sediment concentrations were similar to those prior to dredging, particularly for surface sediments that often pose the greatest environmental risk.

Experience gained with environmental dredging over the last several years has revealed the existence a number of factors that complicate the application of dredging to achieve environmental objectives. There are significant limitations associated with even the most modern dredging equipment, and the inherent distribution of contamination found in many sites—where typically higher concentrations occur in deeper sediments—can make the sediment removal process and achievement of risk-based action levels particularly difficult as well as costly.

Dredging residuals have historically been underestimated at many cleanup sites, even when complicating factors such as debris were not present. Effective planning at prospective sediment removal sites requires realistic estimates of dredging residuals in evaluations of cleanup alternatives. It is logical that the nature and extent of post-dredging sediment residuals are related to dredging equipment, dredging methods, sediment physical characteristics, contaminant distributions, and site conditions. However, currently there is no commonly accepted method to accurately predict post-dredging residual concentrations after the implementation of a dredging remedy. Moreover, while empirically-based estimations of residuals are often recommended, to date such information has been difficult to access.

RESIDUALS DEFINED

Consensus definitions of residuals in the context of environmental dredging were developed at the “4Rs” workshop sponsored by the U.S. Environmental Protection Agency (EPA) and the U.S. Army Engineer Research and Development Center, as presented in Bridges et al. (in preparation), and also presented in a companion paper in these proceedings (Palermo and Patmont, 2007). Dredging residuals are defined as contaminated sediment (at concentrations above the cleanup action level) found at the post-dredge surface of the sediment profile, either within or adjacent to the dredging footprint. Because there are numerous potential sources of residual sediment contaminants, residuals can be broadly grouped into two categories: undisturbed residuals; and generated residuals:

- **Undisturbed Residuals.** Contaminated sediments (at concentrations above the action level) found at the post-dredge sediment surface that have been uncovered but not fully removed as a result of the dredging operation
- **Generated Residuals.** Contaminated post-dredge surface sediments (at concentrations above the action level) that are dislodged or suspended by the dredging operation and are subsequently redeposited on the bottom either within or adjacent to the dredging footprint. While there are numerous potential causes, important documented sources of generated residuals include:
 - Sediments dislodged but left behind by the dredgehead that fall to the bottom without being widely dispersed (“fall back”)
 - Sediment moved by slope failures caused by the process of dredging.

Generated residuals typically accumulate above the dredging cutline in thin layers at relatively low density, while undisturbed residuals remain below the cutline as higher density sediment that may exist as either thin or relatively thick layers. It can be important to distinguish the differences between undisturbed and generated residuals, as they may pose different risks, may require different methods for prediction, and may require different monitoring and management responses. Because of their physical characteristics (discussed below), generated residuals may be particularly difficult to remove with an additional cleanup dredging pass, and may also accumulate up to several hundred feet adjacent to the dredging footprint (Anchor, 2006). Assessment of risks posed by residuals remaining within or adjacent to the dredging footprint may influence decisions regarding subsequent removal or management efforts. Considerations for residuals monitoring, selection of residuals management approaches, and important linkages between the two are presented in a companion paper in these proceedings (Palermo and Patmont, 2007).

CASE STUDIES OF ENVIRONMENTAL DREDGING RESIDUALS

Data characterizing post-dredge residual concentrations are available for more than 50 environmental dredging projects, but the basis for monitoring residuals has varied considerably across such projects. In many cases, measurements of residual concentrations have been based on analyses of a specified surficial sediment thickness collected by grab sampling. The ability of sampling equipment to capture a fluffy (i.e., low dry density) thin veneer of residual sediment and the method of handling the sample can affect monitoring results. Moreover, there have been relatively few studies that have differentiated undisturbed and generated residuals.

Currently there is no commonly accepted method to predict the degree of undisturbed or generated residuals resulting from a given dredge type removing different sediments. In the absence of predictive models, residuals measurements from a series of relatively well-documented dredging projects can be used to develop initial “bounding-level” expectations for similar dredging projects. A wide range of environmental dredging projects conducted in the U.S. over the past 10 years have been reviewed by Anchor Environmental and others, focusing on compilation and analysis of the following information:

- Physical and chemical characterization of the dredge prism using detailed pre-dredge coring data
- Basis of design for the dredge plan and complicating factors (e.g., debris, slope, and underlying hardpan/bedrock)
- Removal equipment and operational practices
- Bathymetric surveys during and following dredging operations, and comparison with dredge plans
- Sediment removal volume, mass, and chemical concentrations
- Physical and chemical characterization of post-dredge surface and near-surface sediments using both surface grab and core section samples

- Differentiation of undisturbed and generated residuals based on visual observations and geotechnical measurements of post-dredge core sections, supplemented with bathymetric data (e.g., elevation of the post-dredge surface relative to the dredge plan) and focused chemical analyses.

To support reliable residuals evaluations, carefully defined pre-dredging sediment profiles, including both physical and chemical characteristics, need to be compared to similar post-dredging sediment profiles collected in a manner that reflects the specific dredging operation. These sediment profiles are not easily performed, and are often beyond the scope of pre- and post-dredging sediment sampling required for typical remedial dredging projects. Further, detailed operational records of environmental dredging actions often do not contain step-by-step logs of dredging actions, instead focusing on longer time intervals and highlighting only significant events. For some projects, these data gaps can pose significant limitations to evaluation and interpretation of environmental dredging residuals.

Mass balance-based evaluation methods rely on the statistical precision of sediment quality characterization data. Pre- and post-dredge sediment quality data collected within dredging areas often exhibit considerable variability between replicate sediment samples (e.g., coefficients of variation often exceeding 100 percent). In order to support reliable mass balance calculations, a sufficient number of samples are needed when sampling such a distribution to ensure reliable concentration estimates (i.e., the resulting average pre- or post-dredge concentration should be well within 50 percent of the true average concentration; $p=0.05$). For some environmental dredging projects, this statistical requirement was a limiting factor determining acceptability of data for use in developing reliable bounding-level estimates of dredge residuals.

Data sets supporting reliable mass balance-based evaluations of undisturbed and/or generated residuals are currently available from at least eleven (11) environmental dredging projects performed in different areas of the U.S., including the following:

- **Massachusetts:**
 - New Bedford Harbor Pre-Design Field Demonstration (FWENC, 2002)
- **New York:**
 - St. Lawrence River / Reynolds Remedial Action (Esterline et al., 2002)
- **Texas:**
 - Lavaca Bay Chlor-Alkali Process Area Treatability Study (Alcoa, 2001)
- **Washington:**
 - Hylebos Waterway Segment 5 Remedial Action (Anchor, 2004a)
 - Hylebos Waterway Segment 3/4 Remedial Action (Anchor, 2004b)
 - Hylebos Waterway Segment 1/2 Remedial Action (DOF, 2006)
 - Middle Waterway Remedial Action (Anchor, 2005)
 - Todd Shipyards Remedial Action (Floyd/Snider, 2005)
- **Wisconsin:**
 - Fox River Sediment Management Unit 56/57 Pre-Design Demonstration Project (Fort James, 2001; Montgomery Watson, 2001)
 - Fox River Operable Unit 1 Subarea A Remedial Action (Fox et al., 2006)
 - Fox River OU 1 Subarea C/D2S Remedial Action (Fox et al., 2006)

A summary of general information available for each environmental dredging project listed above is provided in Table 1. The subject projects span a range of physical settings (river, estuary, and variable slope/debris conditions), dredge volumes (2,300 to 400,000 cubic yards), dredge depths (1 to 7 feet), dredge types (mechanical and hydraulic), and chemical conditions (see below). All of the subject projects utilized a series of operational controls and best management practices (e.g., minimizing dredge overcut and spillage) to reduce residual generation to the extent practicable. Based on visual observations and geotechnical measurements of post-dredge core sections, a veneer of generated residuals ranging from 1 to 9 centimeters (cm; average = 5 cm) remained at all of the subject environmental dredging sites even after the final cleanup dredging pass. Relative to underlying undisturbed sediments, the generated residual layer was comprised of comparatively soft, unconsolidated surface sediments with low dry density (ranging from 0.1 to 0.5 gm/cm³).

Final post-dredge surface (0 to 10 cm) chemical concentrations of target chemicals (e.g., polychlorinated biphenyls [PCBs] and mercury), which typically included a combination of both generated residuals and underlying undisturbed sediments, averaged approximately 50 percent of the pre-dredge surface concentration (range: 10 to 100 percent). Depth-weighted average chemical concentrations of target chemicals in the dredge prisms, along with corresponding generated residual concentrations, ranged between approximately 2 and 280 times the cleanup goal (Table 1). Not surprisingly, projects with the greatest sediment concentration “exceedance factor” (calculated as the quotient of the depth-weighted average chemical concentration in the dredge prism divided by the cleanup goal) experienced more difficulty attaining the cleanup goal, often leading to multiple cleanup passes and/or placement of sand layers over the final post-dredge surface before the project was ultimately completed.

Given the widely varying sediment chemical concentrations, dredge depths, and operational conditions of the subject environmental dredging projects (Table 1), simple concentration-based comparisons do not accurately account for important differences between projects. In order to develop bounding-level estimates of residuals that may be more appropriate for general use in environmental dredging projects, generated residuals were calculated and reported in this paper as the percentage of the contaminant mass dredged in the last production dredging cut. Such a mass balance-based approach normalizes for differing sediment concentrations and dredging depths/operations between the subject case studies, consistent with the observation that the depth-averaged constituent concentration of sediment dredged during a single production dredging pass is a reasonable estimate of the generated residual sediment concentration resulting from that dredge pass. For projects utilizing multiple production cuts (e.g., to remove relatively thick deposits), the iterative mass balance calculations assumed that generated residual sediment concentrations resulting from successive dredge passes were influenced by residual sediment volumes and concentrations from earlier production passes.

The results of the mass balance estimates of generated residuals are summarized in Table 1. For the eleven environmental dredging projects listed above, final generated residuals ranged from approximately 2 to 9 percent (average = 4 percent) of the mass of contaminant dredged during the last production cut. Similar generated residual percentages

TABLE 1. Summary of Sediment Sites with Comprehensive Dredged Residual Characterization Data Sets.

	Lavaca Bay Pt Comfort, TX	Fox River SMU 56/57 Green Bay, WI	New Bedford Harbor MA	St. Lawrence River Massena, NY	Middle Waterway Tacoma, WA	Hylebos Segment 5 Tacoma, WA	Hylebos Seg. 3 & 4 Tacoma, WA	Hylebos Seg. 1 & 2 Tacoma, WA	Todd Shipyards Seattle, WA	Fox River OU 1A Appleton, WI	Fox River OU 1C/D/S Appleton, WI
Dredge Prism Sediment Characteristics:											
Avg. Total Solids (% wet)	58%	41%	41%	70%	69%	56%	59%	49%	67%	42%	31%
Avg. Dry Density (gms/cm ³)	0.88	0.53	0.54	1.20	1.17	0.85	0.90	0.69	1.11	0.56	0.38
Geotechnical Description	Plastic Silt / Clay	Plastic / Liquid Organic Silt	Plastic Organic Silt	Plastic / Liquid Organic Silt	Plastic Organic Silt/Sand	Plastic Organic Silt/Sand	Plastic Organic Silt/Sand	Plastic Organic Silt/Sand	Plastic Silt/Sand	Plastic / Liquid Organic Silt	Plastic / Liquid Organic Silt
Typical Slope	> 10H:1V	4H:1V	>50H:1V	-6H:1V	>8H:1V	>10H:1V	4H:1V to flat	7H:1V to flat	2H:1V to 10H:1V	>10H:1V	>10H:1V
Relative Abundance of Debris	Low	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate	Low	Low
Primary Indicator Chemical	Mercury	PCBs	PCBs	PCBs	Mercury	HCBd	PCBs	PCBs	Mercury	PCBs	PCBs
Cleanup Goal (ppm)	0.50	1.0	10	1.0	0.59	0.011	0.30	0.30	0.59	1.0	1.0
Avg. Chemical Concentrations (ppm):											
Dredge Prism (incl. overdredge)	0.87	110	403	280	3.0	0.19	2.9	1.6	5.4	15	8.5
Exceedance Factor	2	110	40	280	5	17	10	5	9	15	9
Surface (0-10 cm) Samples:											
Before Dredging	0.82	4.4	850	59	2.2	0.071	0.63	0.69	1.4	14	6.4
After Dredging	0.60	2.6	160	54	2.3	0.004	0.22	0.23	0.90	2.7	1.1
Final Post-Dredge Residual (cm)	7	9	5	3	8	2	8	7	2	2	1
Dredging Characteristics:											
Dredge Volume (cy)	10,000	82,000	2,300	87,000	90,000	390,000	200,000	400,000	120,000	54,000	17,000
Avg. Dredge Depth (ft)	4.9	6.7	2.6	2.5	7.1	4.1	4.9	5.9	3.0	0.9	1.0
Bottom of Dredge Prism	Native Clay	Native Clay	Native Clay	Native Gravel	Native Sand	Native Sand	Native Sand	Native Sand	Native Silt/Sand	Hard Clay	Medium Silt
Dredging Period	Jan - Feb '99	Sep '99 - Sep '00	Aug-00	Apr - Nov '01	Jul '03 - Feb '04	Jul '03 - Feb '04	Jul '04 - Oct '04	Aug '03 - Jan '06	Jul '04 - Feb '05	May - Nov '05	May - Nov '05
Primary Dredge Type	14-in Cutterhead	10 & 12-in Horizontal Auger	4.5 cy HPG Clamshell	5.5 cy Cable Arm TM	Clamshell	20 cy Clamshell	20 cy Clamshell	Clamshell and Bean	Cable Arm TM Clamshell	8-in Cutterhead	8-in Cutterhead
Typical # of Production Passes	2	4	1	1	1	1	1	2	1	1	1
Final Cleanup Action	N/A	Redredge & 0.5-ft Cover	N/A	Up to 10 Redredge Passes	Redredge & 0.5:1 to 2 ft Cover	Redredge & 0.5:1 to 2 Passes	Redredge 1 to 2 Passes	Redredge 1 to 2 Passes	1 to 2-ft Cap	Pending	Pending
Calculated Dredged Contaminant Remaining as Generated Residuals^(a):											
Mass Balance Calculation	4.0%	4.2%	6.3%	3.6%	3.6%	1.7%	5.1%	3.4%	1.9%	8.7%	4.5%

NOTES:
(a) Generated residuals calculated based on indicator chemical mass balances using pre- and post-dredge sediment sampling data and dredge prism characteristics, relative to the contaminant mass in the last production cut.

were observed for both mechanical and hydraulic dredges. The available data suggest that multiple sources contribute to generated residuals, including resuspension, sloughing, and other factors. However, on a mass basis, sediment resuspension from the dredgehead appears to explain only a portion of the observed generated residuals, suggesting that other sources such as cut slope failure/sloughing are likely quantitatively more important. The available mass balance data also indicate that the presence of hardpan/bedrock, debris, and relatively low dry density sediment results in higher generated residuals (Figure 1). The mass balance estimates derived from these projects, when combined with site-specific data on sediment concentrations, dredge cuts, dry density, and key operational factors (e.g., debris, hardpan/bedrock, and in-situ dry density) can provide bounding-level predictions of generated residual concentrations and thicknesses for other environmental dredging projects.

As discussed above, undisturbed residuals are defined as contaminated sediments (at concentrations above the action level) found at the post-dredge sediment surface that have been uncovered but not fully removed as a result of the dredging operation. Undisturbed residuals can result from incomplete characterization of the horizontal and vertical extent of contaminants, development of dredge plans that intentionally do not target complete removal of contaminated sediments (e.g., due to engineering limitations), inappropriate selection of the target dredge design elevation, and/or inaccuracies in meeting targeted dredging elevations. While some undisturbed residuals remained within the dredge prism at many of the eleven case study projects listed above, post-dredge sediment characterization data at these sites indicated that the contaminant mass represented by undisturbed residuals was minor in comparison to that of generated residuals. Based on these data, detailed estimation of undisturbed residuals at environmental dredging projects may or may not be necessary, depending on the site.

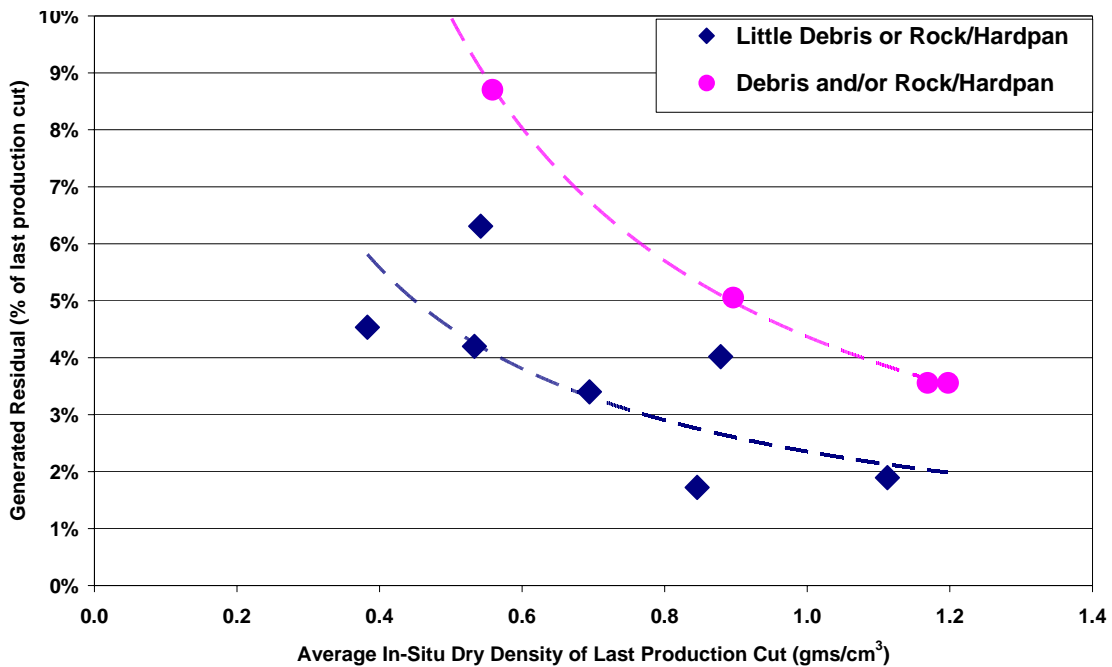


FIGURE 1. Case study summary of generated residuals.

Additional data sets with further information on environmental dredging residuals are expected to be made available in 2007. Refinements to the generated residual predictive approach outlined above may occur as additional case study data are compiled and analyzed. The uncertainty of predictions and the consequences of uncertainty will need to be assessed as predictive models are refined.

ENVIRONMENTAL DREDGING MANAGEMENT IMPLICATIONS

Dealing with residual sediment generated during dredging should be anticipated and considered in contaminated sediment remedy selection and remedial design. Early in the evaluation process, objective analyses should be performed of what realistically can be achieved via dredging, considering the case study data discussed above on generated residuals, as well as site-specific factors. An important factor in evaluating prospective site-specific risk reduction is the estimation of residual concentrations that will likely remain within the biologically active surficial sediment layer.

Developing a multiple pronged strategy that anticipates residuals and establishes a phased approach to proactively respond to residuals is likely to be central to a successful environmental dredging project. As discussed in Palermo and Patmont (2007), there is a linkage between environmental dredging performance standards for residuals, approaches and tools for monitoring residuals, and selection of options for residuals management. The selection of a residuals management approach depends on the nature and extent of generated and undisturbed residuals, as well as an engineering/operational assessment of site conditions related to potential management actions. One or more options for managing residuals may be required, as follows:

- **Monitored Natural Recovery (MNR)** refers to a remedial approach in which natural processes such as sedimentation, sediment mixing, and degradation reduce contaminant concentrations over time. Particularly in depositional areas of environmental dredging sites where future net sedimentation can be reasonably forecasted, MNR can reduce residual concentrations in acceptable time frames.
- **Residual Sand Cover.** Sand covers have been successfully used at a range of environmental dredging projects (Table 1). Where sufficiently thin and low concentration residuals are present, possible short- and long-term mixing of the sand cover into underlying residuals will still ensure attainment of the action level. The placement of a sand cover can thus accelerate the natural recovery process in the biologically active zone. At some sites, sand covers have also provided longer-term physical and chemical isolation of underlying residuals.
- **Engineered Isolation Cap.** Engineered caps have been implemented in several environmental dredging case studies to provide more certain control of undisturbed and/or generated residuals (Table 1). Considerations for evaluating engineered caps as a residuals management option are identical to those for design of engineered caps as a primary remedial option (Palermo, 2005; EPA, 2005).
- **Cleanup Dredging Pass.** At some of the case study sites (Table 1), a final dredge pass was incorporated into the project in an attempt to reduce residual layers. Such an action is often referred to as a cleanup pass, and is usually conducted in such a way as to attempt to remove only a thin surficial layer of material, with the intent of reducing the residuals layer(s) and a minimal thickness of underlying

clean material. However, performance requirements for multiple passes of the dredge to achieve a very low residual concentration have often been inefficient and costly, with little or no discernable benefit in the form of reduced generated residual concentrations or thicknesses. Placement of a residual cover or cap of clean material has provided greater certainty in achieving residual performance standards at the case study project sites.

- **Additional Production Passes.** Additional production dredging may be required for thicker layers of contaminated sediments, and particularly for undisturbed residuals. For the case studies listed in Table 1, additional production cuts were typically only implemented in limited instances where the original production dredge cutline elevation left more than one or two feet of undisturbed residuals.

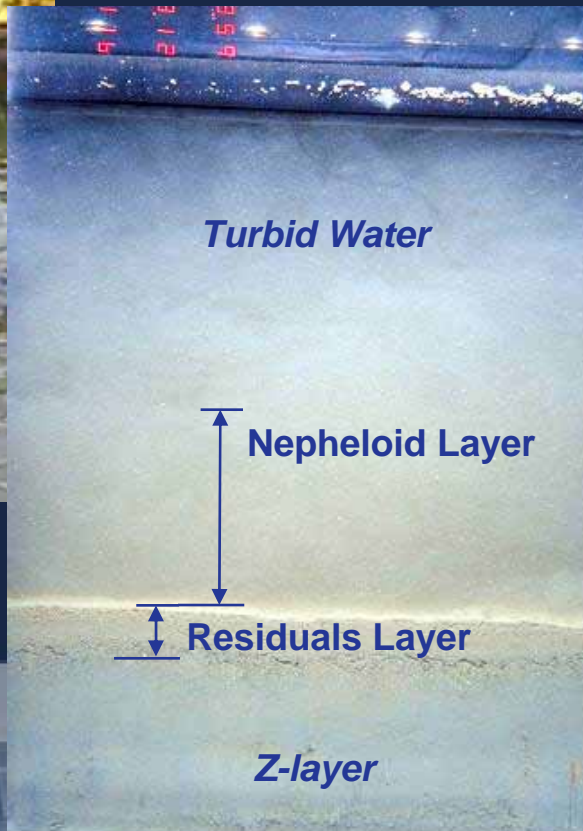
In some cases, a project-specific “decision tree” may be developed with specific rules for selection of the management option based on the nature of the residual layers as defined by post-dredging verification sampling. An example of how these considerations can potentially be applied to a specific project is found in a companion paper in these proceedings (Fox et al., 2007) that describes a preliminary decision tree for residuals management now under consideration for the Fox River site.

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Case Studies of Environmental Dredging Residuals and Management Implications



Conference on
Remediation of
Contaminated Sediments
(Savannah, Georgia)

Clay Patmont
and
Mike Palermo

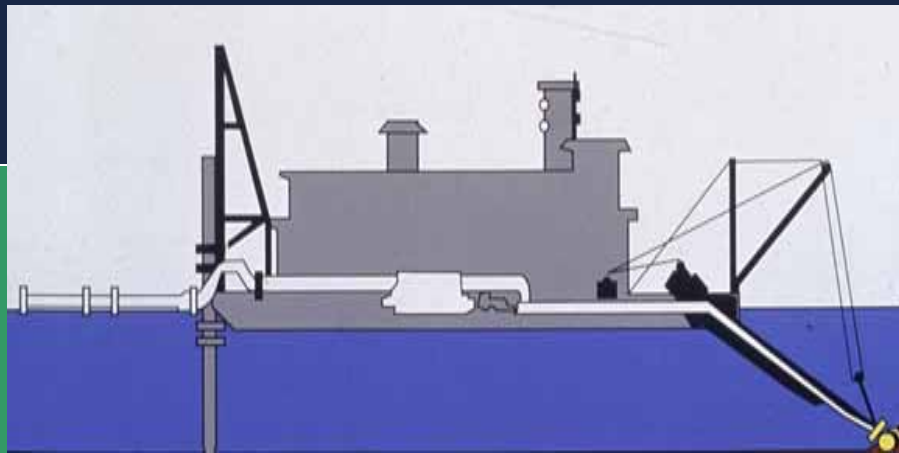
January, 2007

Outline

- Dredge residual definitions
- Mass balance analyses
- Case study data
 - 11 dredging projects with detailed data
- Summary of case studies
- Design and management implications



Conceptual Illustration of Environmental Dredging and Processes



Release
(Air)

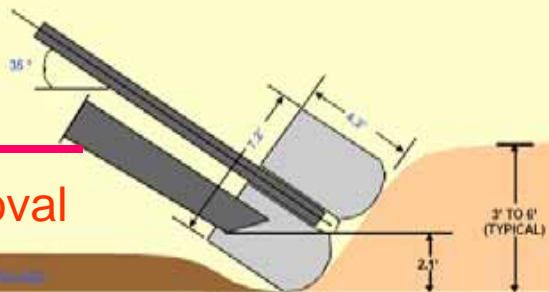
Release
(Water)

Resuspension

Residual
(Sediment)

Removal

Residual



Dredge Residual Definitions

Mass and concentration of contaminated sediment remaining in the vicinity of the dredge area

1. Undisturbed residuals – contaminated sediments uncovered as a result of dredging
 - Incomplete sediment characterization or design
 - Engineering limitations (e.g., bedrock & side slopes)
2. Generated residuals – contaminated sediment dislodged but not removed by dredging
 - “Fallback”, sloughing, and resettling
 - Focus of this discussion



Dredge Residual Definitions, cont'd

- Vertical segmentation
 - Surface water
 - Nepheloid layer
 - “Fluff” layer
 - Generated residuals *
 - Undisturbed residuals *
 - Subsurface sediment
- Horizontal segmentation
 - Near field (within dredge prism) *
 - Intermediate field (within ~200' of dredge boundary)
 - Far field
- Temporal variations

* Focus of recent dredge monitoring efforts



Generated Residuals Defined

Dislodged contaminated sediments that either:

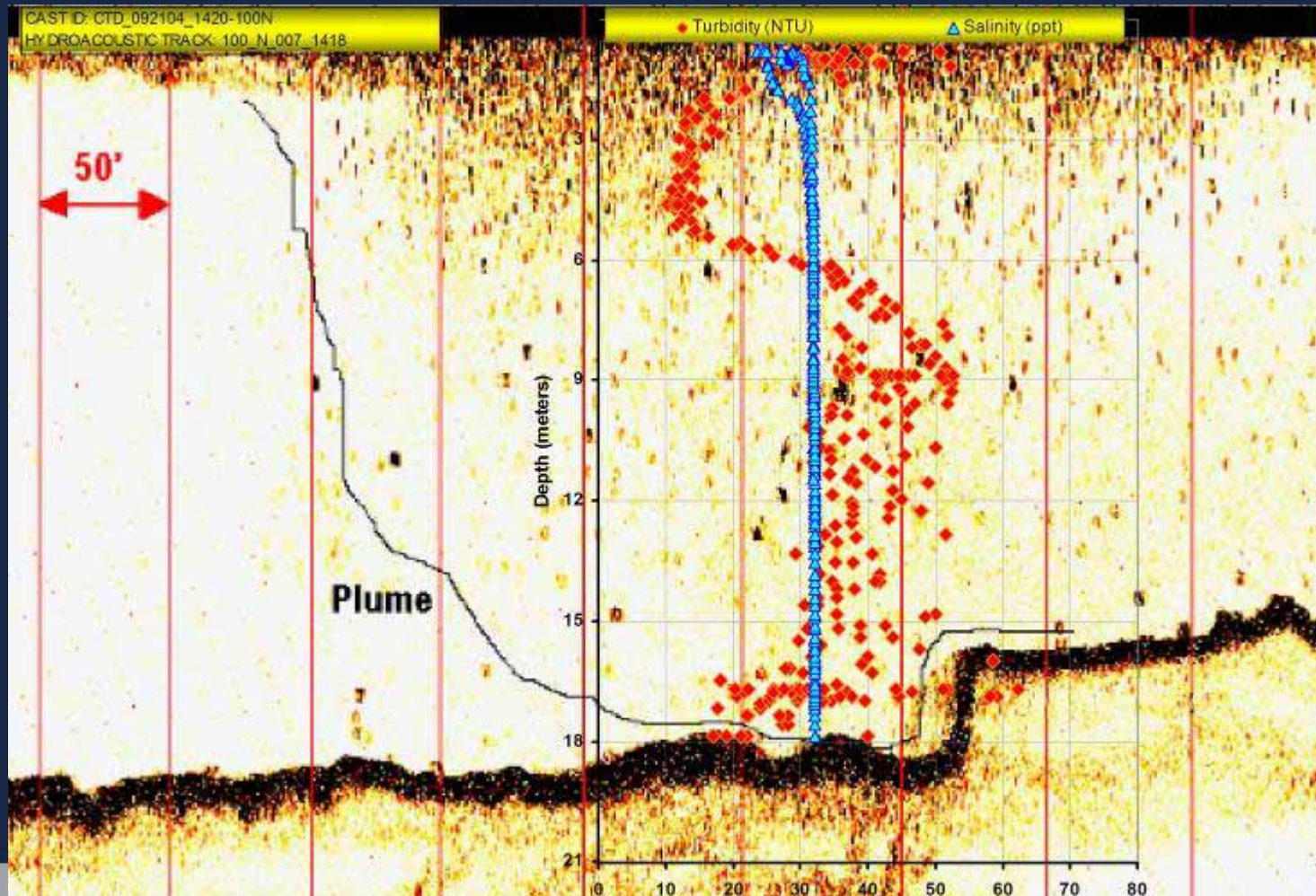
- Remain within the dredge prism after dredging; or
- Have been spread to non-cleanup areas as a result of dredging



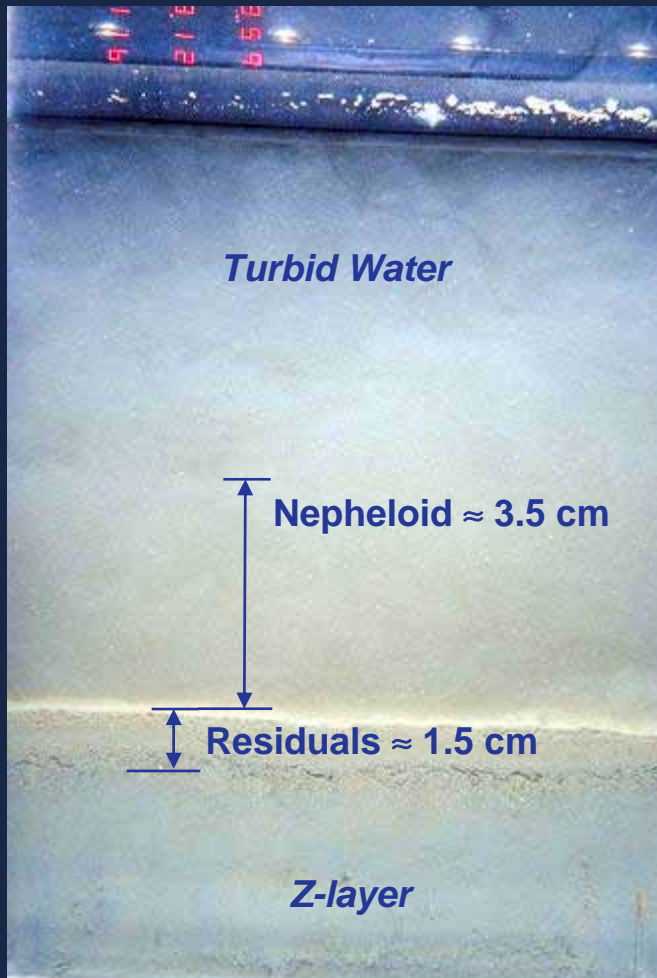
Primary Sources of Generated Residuals



Hydroacoustic Signature of Turbidity Plume During Dredging



Generated Residual Characteristics



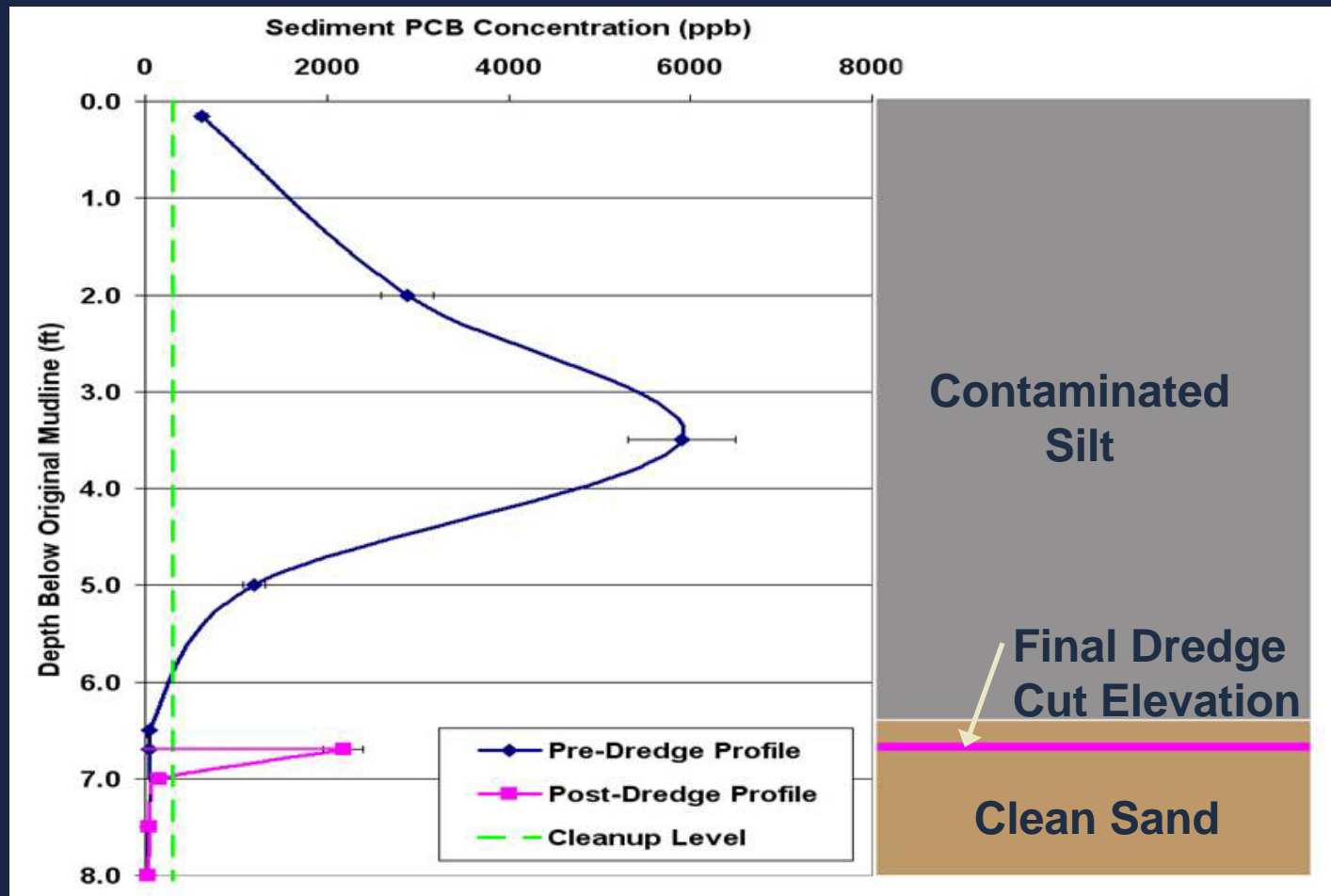
Typical physical properties

- Fine-grained
- Unconsolidated
- High moisture content
- Surface layer may be comprised of fluid mud or “fluff” layer

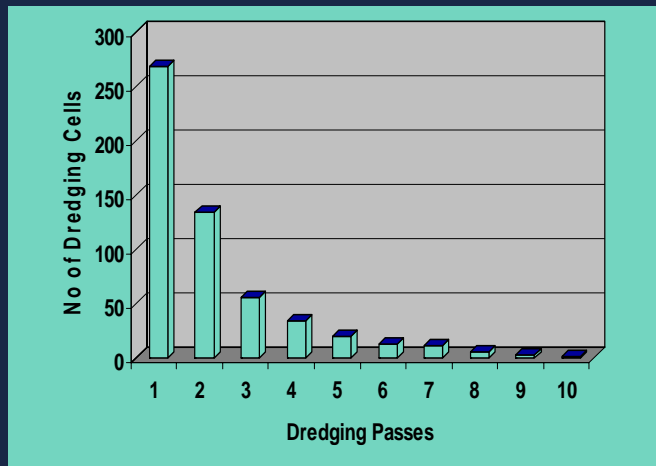
Typical chemical properties

- Constituent concentrations in the generated residual layer (dry weight basis) approximate the depth averaged concentration in the last production pass

Pre- and Post-Dredge Sampling Data *Hylebos Waterway Middle – PCB Deposit*



Production and Cleanup Pass Dredging



- Dredging to design depth includes:
 - Production dredging passes
 - High spot removal (referred as the “initial cleanup pass”)
- Confirmation sampling
- Some projects have attempted additional cleanup pass dredging to try to remove remaining residuals, often with poor results



Case Study Data Required for Generated Residual Mass Balance Evaluation

- Dredge prism characterization (pre-dredge cores)
- Dredge plan basis of design (bottom of cut, debris)
- Equipment and operational practices
 - Production and cleanup passes
- Post-dredge bathymetric surveys
- Sediment and chemical mass removed
- Post-dredge sediment characterization
- Undisturbed versus generated residuals



Case Study Data, continued

- More than 50 environmental dredging projects with useful data
- Variable data collection between projects
 - Pre- and post-dredge characterization
 - Undisturbed versus generated residuals
 - Statistical requirements (sample size)
- 11 case studies met generated residual mass balance requirements
- Additional data collection underway



Generated Residual Case Studies

11 projects with sufficient data for mass balance analysis:

- Fox River SMU 56/57 Pilot Project, WI
- Lavaca Bay Pilot Project, TX
- New Bedford Harbor Pilot Project, MA
- Reynolds Aluminum, NY
- 3 Hylebos Waterway Projects, WA (Mouth, Middle & Head)
- Middle Waterway, WA
- Todd Shipyards, WA
- 2 Fox River OU 1 Projects, WI (Subarea A and C/D2S)



Generated Residual Case Studies

	Lavaca Bay Pt Comfort, TX	Fox River SMU 56/57 Green Bay, WI	New Bedford Harbor MA	St. Lawrence River Massena, NY	Middle Waterway Tacoma, WA	Hylebos Segment 5 Tacoma, WA	Hylebos Seg. 3 & 4 Tacoma, WA	Hylebos Seg. 1 & 2 Tacoma, WA	Todd Shipyards Seattle, WA	Fox River OU 1A Appleton, WI	Fox River OU 1C/D2S Appleton, WI
Dredge Prism Sediment Characteristics:											
Avg. Total Solids (% wet)	58%	41%	41%	70%	69%	56%	59%	49%	67%	42%	31%
Avg. Dry Density (gms/cm ³)	0.88	0.53	0.54	1.20	1.17	0.85	0.90	0.69	1.11	0.56	0.38
Geotechnical Description	Plastic Silt / Clay	Plastic / Liquid Organic Silt	Plastic Organic Silt	Plastic / Liquid Organic Silt	Plastic Organic Silt/Sand	Plastic Organic Silt/Sand	Plastic Organic Silt/Sand	Plastic Organic Silt/Sand	Plastic Silt/Sand	Plastic / Liquid Organic Silt	Plastic / Liquid Organic Silt
Typical Slope	> 10H:1V	4H:1V	>50H:1V	~6H:1V	>8H:1V	>10H:1V	4H:1V to flat	7H:1V to flat	2H:1V to 10H:1V	>10H:1V	>10H:1V
Relative Abundance of Debris	Low	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate	Low	Low
Primary Indicator Chemical	Mercury	PCBs	PCBs	PCBs	Mercury	HCBD	PCBs	PCBs	Mercury	PCBs	PCBs
Cleanup Goal (ppm)	0.50	1.0	10	1.0	0.59	0.011	0.30	0.30	0.59	1.0	1.0
Avg. Chemical Concentrations (ppm):											
Dredge Prism (incl. overdredge)	0.87	110	403	280	3.0	0.19	2.9	1.6	5.4	15	8.5
Exceedance Factor	2	110	40	280	5	17	10	5	9	15	9
Surface (0-10 cm) Samples:											
Before Dredging	0.82	4.4	850	59	2.2	0.071	0.63	0.69	1.4	14	6.4
After Dredging	0.60	2.6	160	54	2.3	0.004	0.22	0.23	0.90	2.7	1.1
Final Post-Dredge Residual (cm)											
Generated Residuals	7	9	5	3	8	2	8	7	2	2	1
Dredging Characteristics:											
Dredge Volume (cy)	10,000	82,000	2,300	87,000	90,000	390,000	200,000	400,000	120,000	54,000	17,000
Avg. Dredge Depth (ft)	4.9	6.7	2.6	2.5	7.1	4.1	4.9	5.9	3.0	0.9	1.0
Bottom of Dredge Prism	Native Clay	Native Clay	Native Clay	Native Gravel	Native Sand	Native Sand	Native Sand	Native Sand	Native Silt/Sand	Hard Clay	Medium Silt
Dredging Period	Jan - Feb '99	Sep '99 - Sep '00	Aug-00	Apr - Nov '01	Jul '03 - Feb '04	Jul '03 - Feb '04	Jul '04 - Oct '04	Aug '03 - Jan '06	Jul '04 - Feb '05	May - Nov '05	May - Nov '05
Primary Dredge Type	14-in Cutterhead	10 & 12-in Horizontal Auger	4.5 cy HPG Clamshell	5.5 cy Cable Arm™	Clamshell	20 cy Clamshell	20 cy Clamshell	Clamshell and Bean	Cable Arm™/ Clamshell	8-in Cutterhead	8-in Cutterhead
Typical # of Production Passes	2	4	1	1	1	1	1	2	1	1	1
Final Cleanup Action	N/A	Redredge & 0.5-ft Cover	N/A	Up to 10 Redredge Passes	Redredge & 0.5-1 ft Cover	1 to 2 Redredge Passes	1 to 2 Redredge Passes	1 to 2 Redredge Passes	1 to 2-ft Cap	Pending	Pending
Calculated Dredged Contaminant Remaining as Generated Residuals ^(a):											
Mass Balance Calculation	4.0%	4.2%	6.3%	3.6%	3.6%	1.7%	5.1%	3.4%	1.9%	8.7%	4.5%

(a) Calculated as the ratio of the generated residual mass to the dredged sediment mass in the last production cut



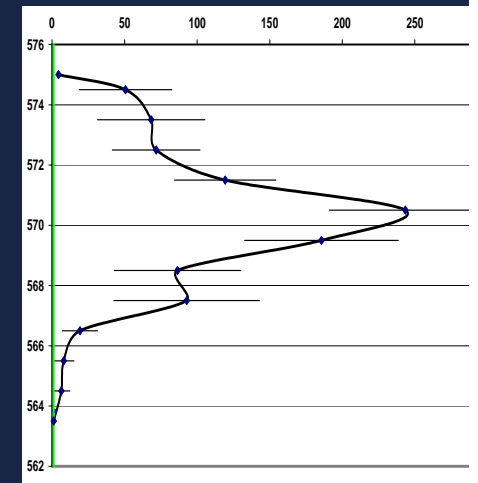
Case Studies – Variable Conditions

Dredging Operations

- Hydraulic and mechanical dredges
- 2,300 to 400,000 cubic yards
- 1 to 7 foot dredge cuts (total)
- 1 to 4 production passes
- All used operational controls and BMPs

Pre-Dredge Sediment Characteristics

- Dry density 0.4 to 1.2 gm/cm³
- Variable debris, slopes, and geology
- Variable contaminant depth profiles
- Dredge prism 2 to 280 times the action levels



Generated Residual Case Studies

Generated Residual Characteristics

- 1 to 9 cm thickness (average = 5 cm)
- Dry density 0.1 to 0.5 gm/cm³
- Dry weight concentrations approximate the depth averaged level in the last production pass

Final Post-Dredge Surface (0 to 10 cm)

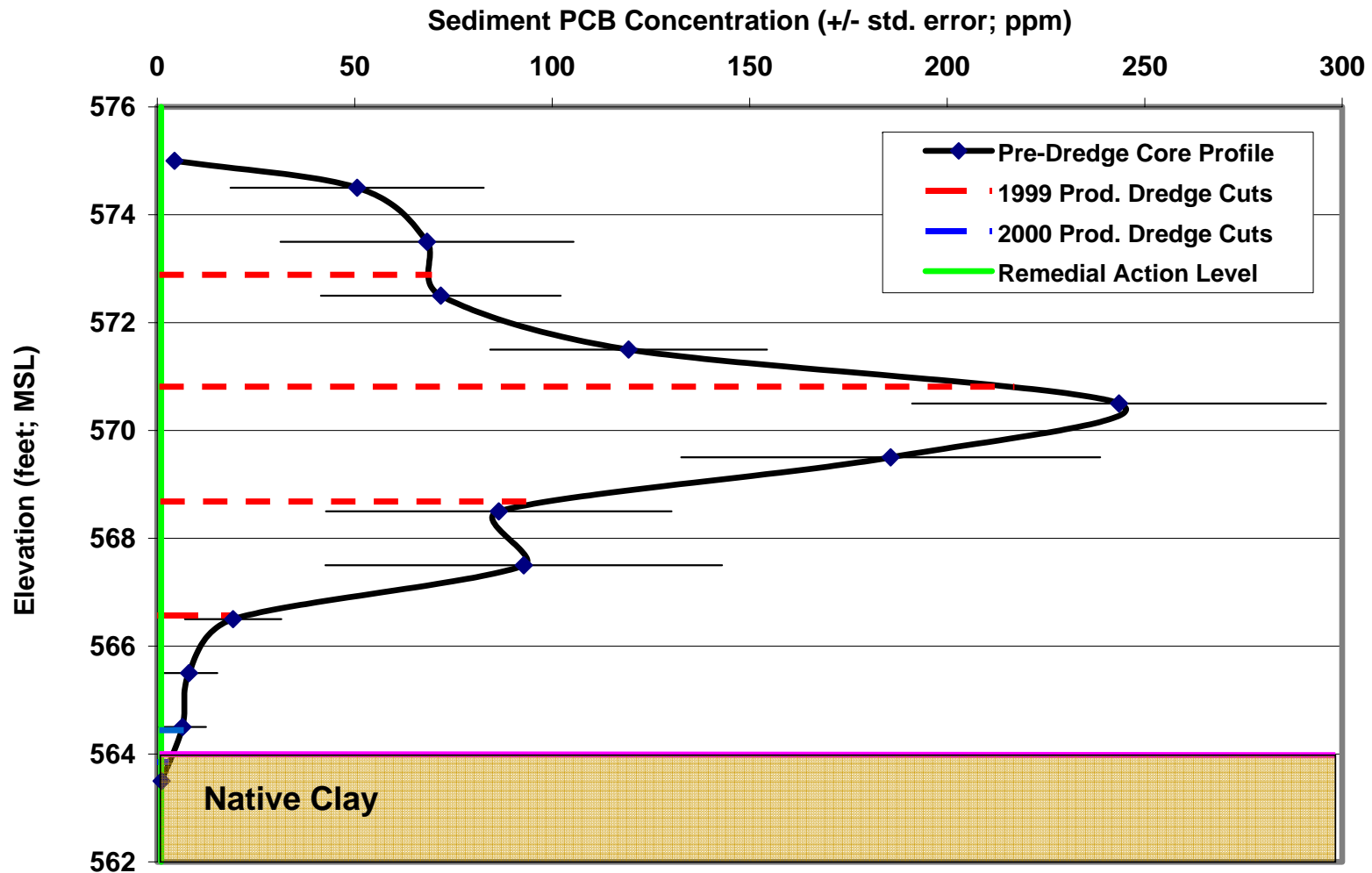
- Target chemical concentrations 10 to 100 percent of pre-dredge surface (average = 50 percent)

Mass Balances Based on Last Production Cut

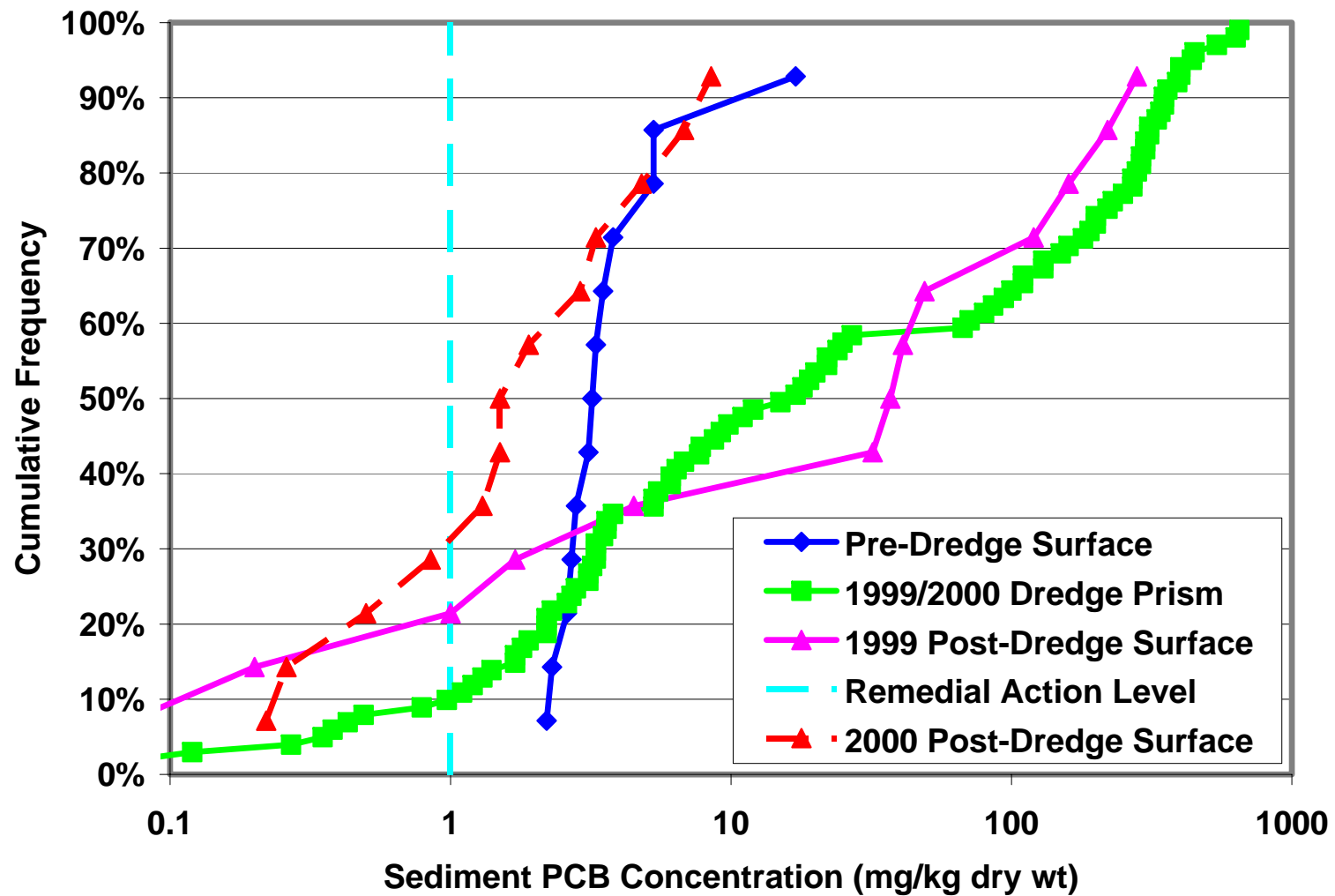
- Normalizes for differing dredge depths and profiles



Fox River SMU 56/57 Pre-Dredge PCB Profile



Fox River SMU 56/57 PCB Concentrations



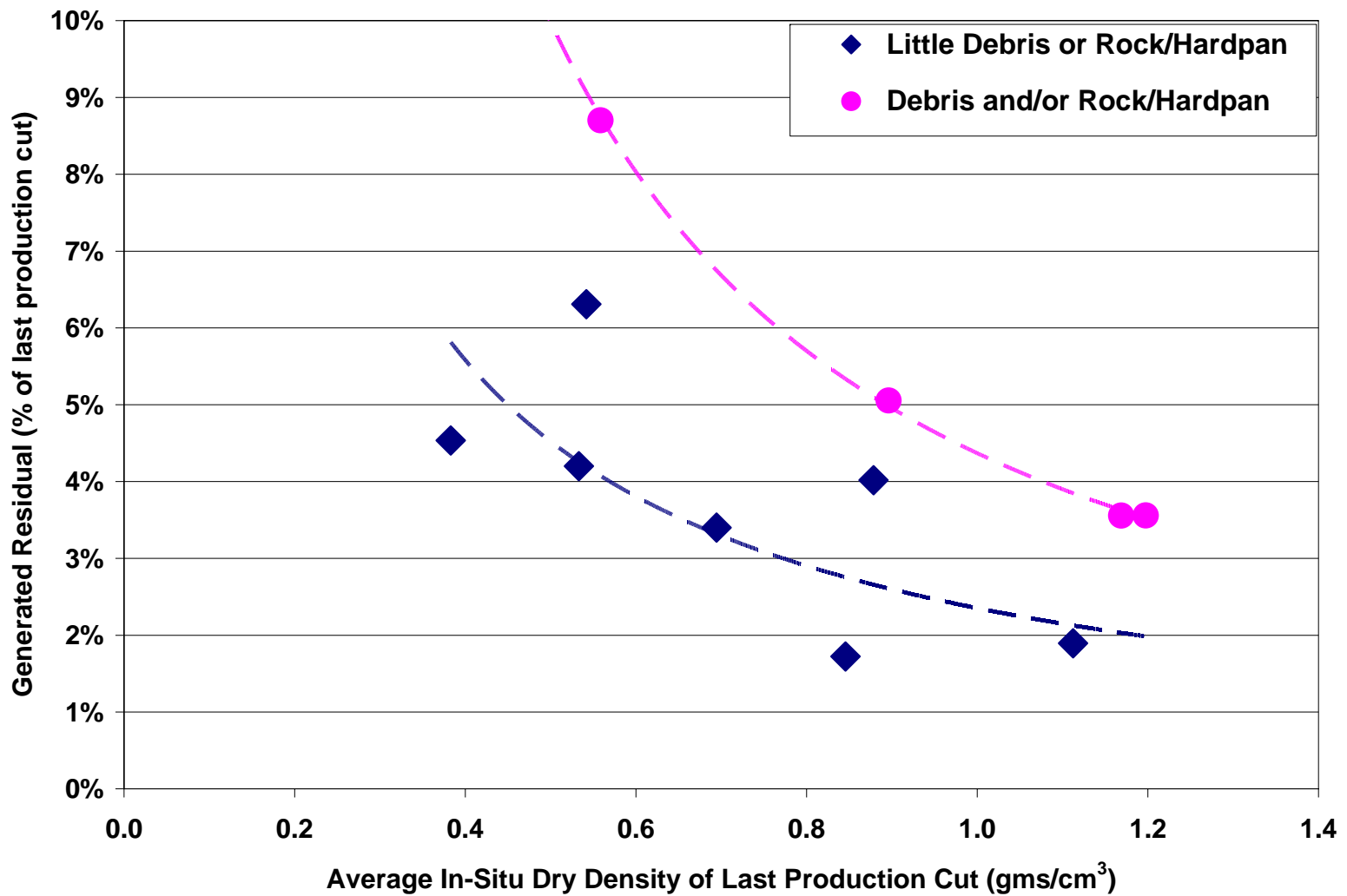
Generated Residual Case Studies

Site	Dredge Volume (cy)	Date	Equipment Type	Generated Residual Mass (%) ¹
Fox River 56/57 Pilot	31,000	1999	10" Horizontal Auger	4
Lavaca Bay Pilot	10,000	1999	14" Cutterhead	4
New Bedford Harbor	2,300	2000	4.5 cy Horiz. Profile Grab	6
Reynolds Aluminum	63,000	2001	5.5 cy Cable Arm™	4
Middle Waterway	90,000	2003/ 04	6-12-16 cy Clamshell	4
Hylebos Wtwy. Mouth	390,000	2003/ 04	20 cy Clamshell	2
Hylebos Wtwy. Middle	200,000	2004	20 cy Clamshell	5
Hylebos Wtwy. Head	400,000	2003/ 06	Clamshell and Bean	3
Todd Shipyards	120,000	2004/ 05	Cable Arm™/Clamshell	2
Fox River OU 1A	54,000	2005	8" Cutterhead	9
Fox River OU 1C/D2S	17,000	2005	8" Cutterhead	5

¹ Calculated as the ratio of the generated residual mass to the dredged sediment mass in the last production cut



Case Study Summary of Generated Residuals



Generated Residuals: *Controlling Factors*

- Site characteristics
 - Debris & underlying geology
 - Geotechnical properties
 - Low dry density and potential for fluidized mud
 - Generated residuals have very low dry density
- Magnitude of chemical exceedance determines level of concern
- Developing database
 - Additional project data expected in 2007



Generated Residuals:

Management Implications

- Case study mass balances provide basis for bounding-level predictions of concentrations that will likely remain within the biologically active surficial sediment layer after dredging
- Post-dredge residual management options
 - Monitored natural recovery (for lower risk areas)
 - Sand cover (frequently used to achieve action levels)
 - Isolation cap (dredge-and-cap to optimize design)
 - Re-dredging (effective only in certain situations)



Summary

- *Residuals happen*
 - 2 to 9% generated residual mass – several controlling factors
 - Undisturbed residuals can provide an additional complication
 - Dredging residuals can result in continued or increased risk
- *Plan accordingly*
 - RI/FS: Develop realistic estimates of dredge residuals
 - RD: Develop and optimize dredge and cap/cover plans that anticipate likely residuals
 - RA: Post-dredge monitoring and decision tree

