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Designing a Dredge Plan to Accommodate Anticipated Residuals

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ABSTRACT: Understanding and appropriately planning for residual contamination that may remain following dredging is a critical component of successful environmental remediation projects. Recent efforts focused on characterizing the effectiveness of environmental dredging projects throughout the United States have led to advances in understanding the processes leading to dredging residuals. Dredging residuals can be classified into two categories: generated (sediment disturbed or resuspended during dredging that settles back to the sediment bed) and undisturbed (undredged contaminated sediment below the dredge cutline). Dealing with residual contamination following environmental dredging should be anticipated and considered in the remedy selection and design process, with dredge plan development aimed at achieving removal goals and facilitating the implementation of appropriate residuals management plans. Careful pre-design characterization and subsequent data analyses, including geostatistical methods, have proven to be useful in reducing the risk of undisturbed residuals at environmental dredging sites. If the predicted concentration and/or thickness of residuals estimated during the design phase indicate that a significant risk may remain following dredging, modifications to dredging and/or development of capping/cover plans can be integrated into the final design to improve the effectiveness of the overall action. Regardless, provisions should be made during the design phase in the form of a residuals management framework that provides for timely evaluation of various management options for the effective management of dredge residuals during construction.

INTRODUCTION

Many environmental dredging projects conducted to date have encountered residual contamination following dredging of targeted sediments. However, experience has shown that additional dredging to remove relatively low-density residual sediments is inefficient and often ineffective. Therefore, remedial design efforts should include appropriate planning for dredging residuals and the development of a residuals management plan prior to the start of remedial dredging. The major steps in the remedial design of a dredge plan to accommodate anticipated dredging residuals include:

1. Identify depth of contamination
2. Design dredge plan to achieve action level
3. Estimate anticipated residuals
4. Optimize dredge plan
5. Plan for residuals management

Each of these steps is described in further detail below.

IDENTIFY EXTENT OF CONTAMINATION

Remedial investigation and characterization of the nature and extent of contamination is a key component of the remedial design process for a contaminated sediment site. Once a remedial action level is set for the project, the extent of contamination is identified through a systematic sampling and analysis program. These activities typically occur during the pre-design phase of a project and may contain subsequent sampling events to fill remaining data gaps and further delineate areas of interest, such as "hot spots" and historic navigational features. Depending on the spatial distribution of contaminants and the distribution/density of the sampling, several geostatistical methods can be used to develop a model defining the extent of contamination including generating a triangular irregular network (TIN), Thiessen polygons, kriging (e.g., ordinary or indicator), and integrating other available geophysical and historical dredging information. For larger projects, several geostatistical approaches may be considered and evaluated to determine the most representative model to define the data set. Additional scientific judgment and interpretation may be applied to the model in order to better characterize the sediment deposit. For example, refinements such as coordinate transformation ("river straightening") based on shoreline geometry and boundary area adjustments to reflect historical channel features could be made to increase the validity of the model. Ultimately, a sound representation of the data is crucial to the project as it serves as the primary basis for dredge plan development.

DESIGN DREDGE PLAN

An engineered dredge plan design is subjective and relies on dredge plan design experience, best professional judgment, and the quality and accuracy of the information available to the design team. Because the dredge plan design relies on multiple sets of data (e.g., bathymetry, contamination depth and extent as defined by geostatistical methods), the precision of each data set affects the level of certainty that the dredge plan encompasses all the contaminated sediments. The primary objective of the dredge plan is to ensure that the contaminated sediment that is defined by the neatline falls within the horizontal and vertical extent of the dredge plan, to the extent practicable.

There are two general approaches that can be followed to design a remedial dredge plan that would specify the limits and grades to which a contractor would be required to remove sediment. One approach is to specify that the contractor must remove sediments to the precise elevations directly derived from the geostatistical model used to identify the extent of contamination. This approach is often called a "neatline" dredge plan. In many cases, a neatline dredge plan would involve a complicated 3 dimensional surface that may or may not mimic the bathymetric contours.

The second dredge plan design approach is to develop a fully engineered dredge plan which is developed based on the designer's evaluation and interpretation of the neatline surface with the goal of generalizing the neatline model (i.e., dredge cut elevations are designed to fall at or just below the neatline). The engineered dredge plan defines the required dredging as a set of regular cells each with a constant dredge elevation (or depth). To date, this engineered dredge plan approach has been more typical than a neatline dredge plan for remedial dredging projects, and may be more readily incorporated into contract specifications.

ESTIMATE RESIDUALS

Typically, remedial objectives for environmental dredging projects include a goal for the removal of a large portion of the volume or mass associated with one or more chemicals of concern (COCs). Many projects measure the effectiveness of the dredging through comparison of post-dredge surface sediment sample COC concentrations with performance standards defined for the project. However, field results for numerous completed environmental dredging projects have shown that residual contamination exceeding the performance standard or cleanup goal exists in post-dredge surface sediment. This residual contamination may be the result of a number of factors including incomplete/inaccurate characterization of the extent of contamination, inappropriate dredge plan design, or processes that occur during dredging (i.e. resuspension/fall back, dredge cut sloughing, etc.).

Although there are numerous potential sources of dredge residuals, the type of residuals can be generally grouped into two categories: "generated residuals" left by the dredging operation and "undisturbed residuals" remaining below the dredge plan or actual dredge cutline due to dredging inaccuracies, accuracy in defining the contaminated surface, or other factors. A workshop recently held at the U.S. Army Engineer Research and Development Center (ERDC) on Relating the "4 Rs" of Environmental Dredging: Resuspension, Release, Residual, and Risk (Bridges et al in preparation) focused in part on dredging residuals. Building on that workshop, Patmont and Palermo provide a summary of the sources, nature and extent, monitoring, and management of dredging residuals as part of these proceedings (Patmont and Palermo 2007 and Palermo and Patmont 2007). Based on this work, undisturbed and generated residuals can be generally defined as follows:

- **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 re-deposited on the bottom either within or adjacent to the dredging footprint.

As discussed above, data from numerous completed remedial dredging projects has shown that it is unreasonable to expect that typical removal technologies can remove every particle of contaminated sediment and that even a well-designed and implemented remedial dredging project will likely result in some amount of residual sediment within the footprint of or adjacent to the post-dredge surface. Moreover, it is important to distinguish between generated and undisturbed residuals since each may require different methods for prediction, may pose different levels of risk, and may requirement different monitoring and management options.

Currently, there is no commonly accepted method for estimating the amount of generated or undisturbed residuals. However, Anchor Environmental has analyzed data available for eleven environmental dredging projects to estimate the range of generated residuals for varying site conditions, COCs, and dredge equipment (Patmont and Palermo 2007). Based on a mass balance approach, final generated residuals for the projects reviewed ranged from approximately 2 to 9 percent (with an average of 4 percent) of the mass of contaminant dredged during the last production cut. Similar generated residual percentages were observed for both mechanical and hydraulic dredges. Methods to evaluate the probability of encountering undisturbed residuals are currently under development.

DREDGE PLAN OPTIMIZATION

As discussed above, an initial dredge plan can be developed based on the extent of contamination identified during remedial investigations. However, recent project experience has shown that dredge plan design should also take into account residuals management. Therefore, during the design process it is important to realistically estimate the likely residual contamination that will remain within the biologically active surficial sediment layer, based on the range of generated residuals developed from previously completed projects, as well as site-specific factors.

One approach to dealing with anticipated dredging residuals is to optimize the required dredge plan during the remedial design phase to balance the environmental risk of generated and undisturbed residuals. This type of approach can be used to focus remedial efforts on increasing the confidence of meeting the project cleanup level by concentrating on COC mass removal, while concurrently reducing the volume of clean sediment (below the action level) captured in the dredge plan. Furthermore, dredge plan optimization during the design phase can be used to limit the potential for re-dredging, or "cleanup pass" dredging (i.e., additional dredging following completion of the production dredging to the limits and grades required by the design), which is often costly and ineffective in removing generated residuals due to their physical characteristics.

The following general steps outline a process in which residuals management can be incorporated into an overall design process:

1. Utilize available statistical tools (e.g., geostatistical modeling) to identify the horizontal and vertical extent of contamination at various levels of confidence.
2. Design the dredge plan to encompass the extent of the targeted contaminated sediment at an appropriate level of confidence in order to ensure a balance between reducing the potential for undisturbed residuals, while concurrently minimizing dredging of sediment below the action level.
3. Estimate undisturbed and generated residuals anticipated on the post-dredge surface following the completion of dredging to the limits of the initial dredge plan, based on the available case histories.
4. Optimize the dredge plan to balance the risk of relatively high concentrations of undisturbed or generated residuals and the removal of underlying sediments below the action level.
5. Identify areas where alternative remedial response actions (e.g., combined dredging and engineered capping) may be more effective at removing contaminant mass and managing residuals than dredging alone.
6. Develop a plan for assessing the success of the remedial dredging at achieving the project cleanup goals. Typically, a post-dredge verification sampling plan involves measuring post-dredge surface sediment concentrations, which will form the basis for appropriate contingency response actions if project cleanup goals are not achieved with the initial dredging.

RESIDUALS MANAGEMENT OPTIONS

It is important to realize that even with appropriate planning and dredge plan optimization residuals are still likely to remain following the final dredge design production pass. Therefore, it is critical to develop residual management options (RMO) that can be effectively and efficiently implemented to achieve the project cleanup goals. These RMOs should be developed during remedial design so that field decisions can be made in a timely manner to prevent extended down-time during construction. A well structured decision framework can be developed prior to construction and utilized in the field for identifying appropriate RMO approaches based on the results of post-dredge confirmation sample results.

Such a decision framework should include consideration of the following:

- thickness of residual layer
- residual density
- COC concentrations of the residuals
- mass ratio of generated residuals to undisturbed residuals
- site conditions (e.g., characteristics of underlying sediments or presence of hardpan)
- engineering considerations (e.g., proximity to utilities and sensitive structures)
- cost-benefit considerations

Evaluation of the above variables will lead to the selection of an appropriate RMO to effectively address post-dredge conditions. RMOs implemented on other projects generally include monitored natural recovery (MNR), additional dredging passes with varying required cut thicknesses, and placement of sand covers and engineered caps (Palermo and Patmont 2007). Depending on the specific RMO selected, additional sediment verification sampling may need to be performed to verify the effectiveness of the action and to determine whether or not subsequent work is required to meet remedial goals. The conditions for which these RMOs should be implemented, as well as the pros and cons of these options, are discussed below.

Monitored Natural Recovery. MNR is an appropriate RMO to consider at sites where future sedimentation and/or COC degradation rates can be reasonably forecasted; therefore, allowing a reasonable estimate of residual COC concentration decay within an acceptable time frame. MNR generally applies to sites where residuals concentrations are marginally above the action level.

Additional Dredging Passes. At some sites, additional dredging is necessary to address residual sediment above the action level. The additional dredging passes may be designed to address a thin veneer of generated residuals that exceeds the action level by several orders of magnitude or to remove a deeper deposit of undisturbed residuals that may have been missed by the initial site characterization. Accordingly, one of two dredging RMOs may be implemented:

- Cleanup pass: a cleanup dredge pass set at an elevation in such a way as to attempt to remove only a thin surficial layer of material, with the intent of removing a layer of generated residuals and a minimal thickness of underlying clean material

- Additional production pass: one or more production passes targeting thicker layers of residuals, especially undisturbed residuals. This action would only be needed for cases in which the initial site characterization was incomplete and setting of the initial production dredge cut elevation left a considerable thickness of contaminated sediment.

RMOs that include additional dredging can be effective at some sites, but are often inefficient and costly. In cases where additional dredging was required, subsequent RMOs such as a residual cap or cover of clean material have often been necessary to deal with persistent generated residuals that could not be captured by re-dredging (Patmont and Palermo 2007).

Sand Covers and Engineered Caps. For sites where post-dredge conditions do not warrant re-dredging, sand covers and engineered caps can be cost-effective and protective alternatives. Depending upon the nature and extent of the residuals, a sand cover may be used to enhance natural recovery processes and meet secondary project goals, such as habitat enhancement. Where higher levels of residuals contamination are identified within impracticable dredge areas (e.g., underlying hardpan or adjacent sensitive structures), engineered isolation caps may be design and constructed to provide a protective solution to residual contamination.

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Conference on Remediation of Contaminated Sediments (Savannah, Georgia)

Presented by:
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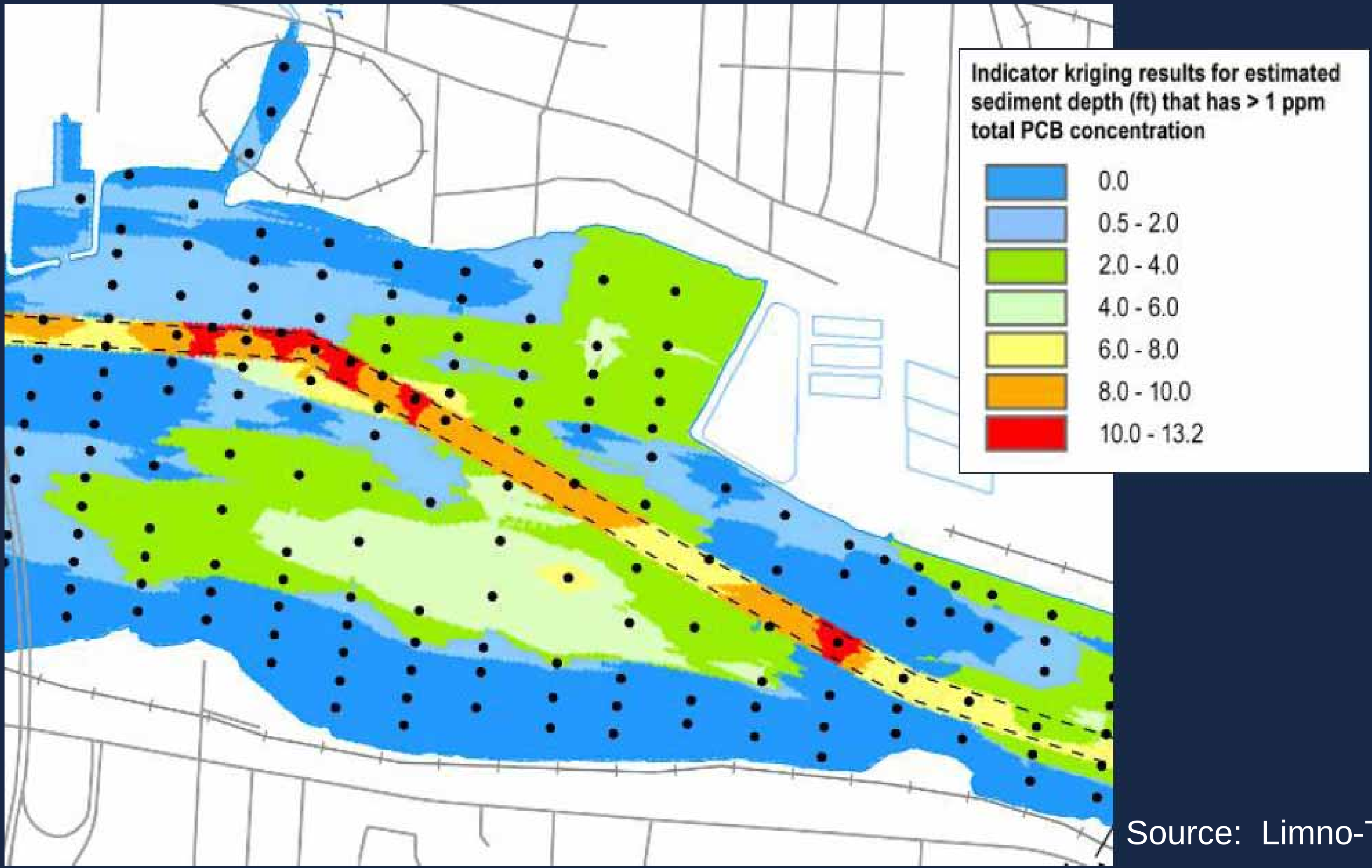
January 24, 2007

Dredge Plan Design Process

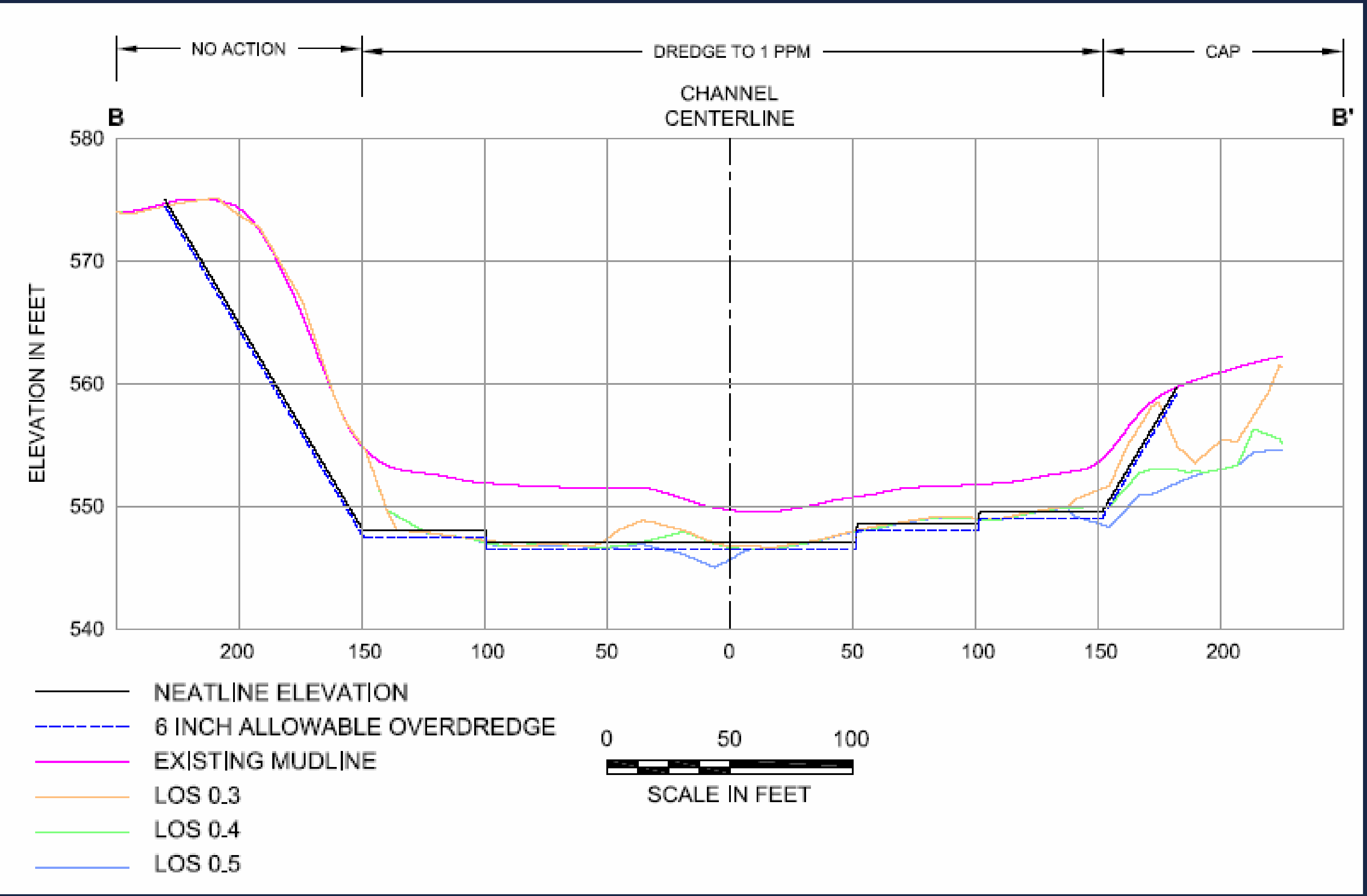
1. Identify depth of contamination through geostatistical modeling
2. Design dredge plan to achieve action level with given level of confidence
3. Estimate anticipated residuals
4. Optimize dredge plan
5. Plan for residuals management

Geostatistical Modeling of Depth of Contamination



Source: Limno-Tech Inc.

Design Dredge Plan



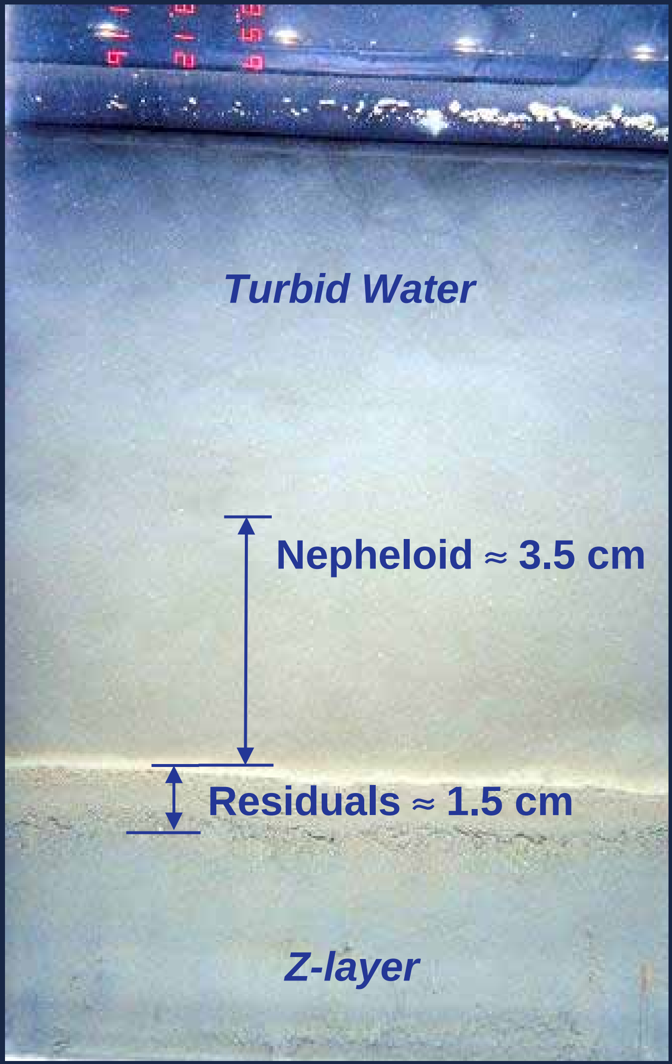
Estimating Residuals

What are Residuals? (In case you missed the last 2 presentations)

1. Undisturbed Residuals: Contaminated sediment that remains after dredging below the design interface (i.e. the "neat line")
2. Generated Residuals: Contaminated sediment dislodged but not removed by dredging

Estimating Residuals

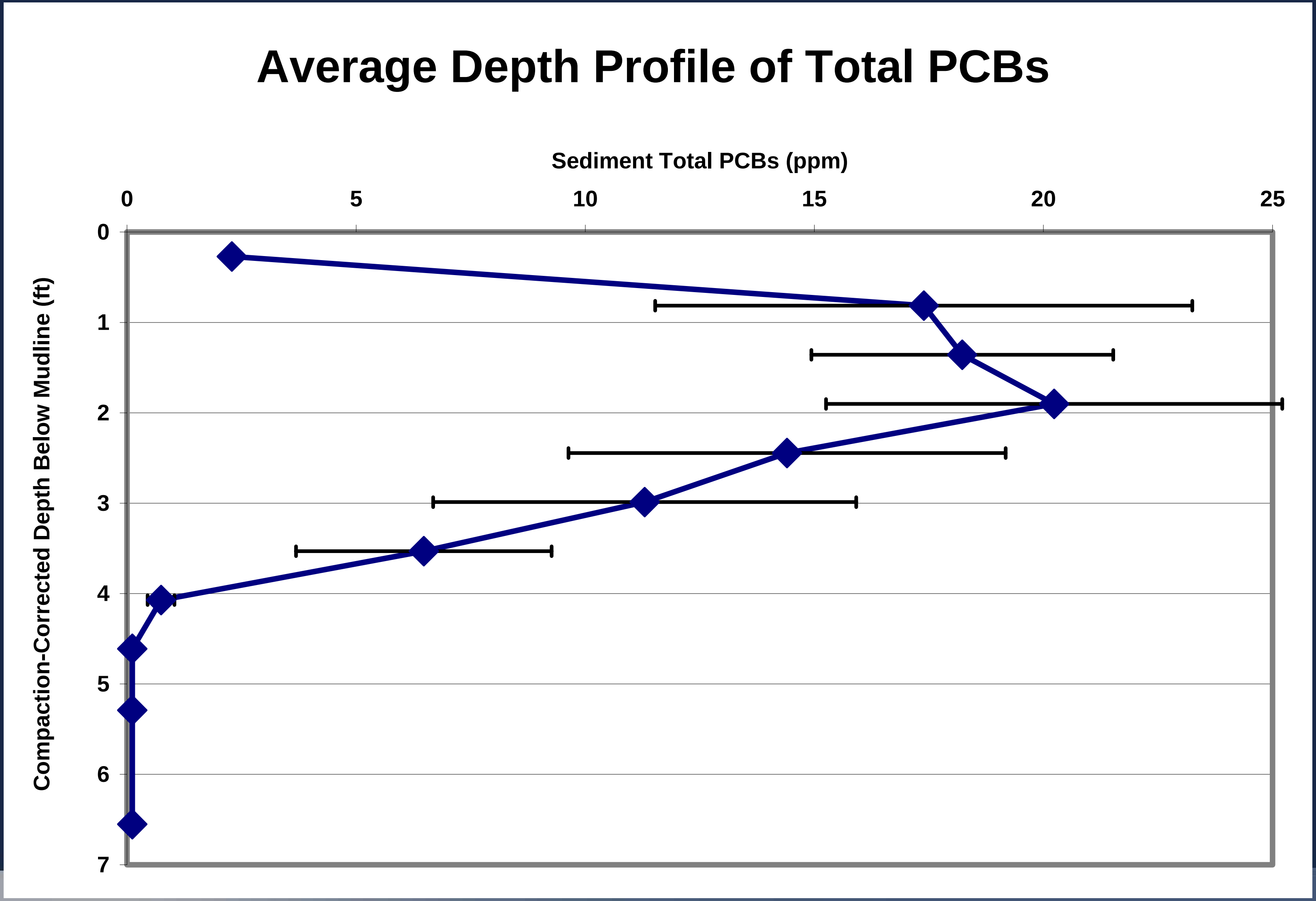
- Residual mass balance using database of completed projects
  - Range of 2 to 9% by mass (Avg. 5%)
  - Residual conc. equal to average of sediment dredged



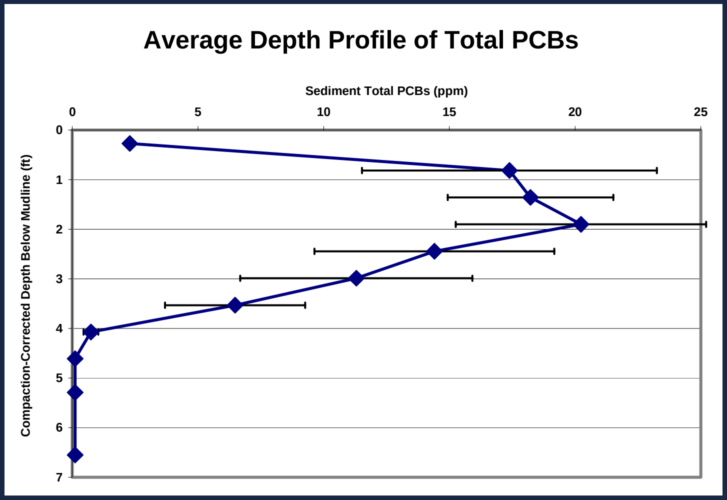
Dredge Plan Optimization

- Focus on mass removal
- Limit removal of “clean” sediment
- Realistic expectations for generated residuals
- Balance environmental risk of generated vs. undisturbed residuals

Example PCB Profile



Comparison of Undisturbed and Generated Residuals (5% mass release)



DREDGE PLAN

Average Cut = 4.0 feet

$MPA_{(O.D.)}$ ~ 5 g/m²

CONFIRMATION SAMPLE

5.6 ppm Avg.

UNDISTURBED RESIDUALS

PCBs = 0.4 ppm

$MPA_{(Ru)}$ ~ 0.03 g/m^2

GENERATED RESIDUALS*

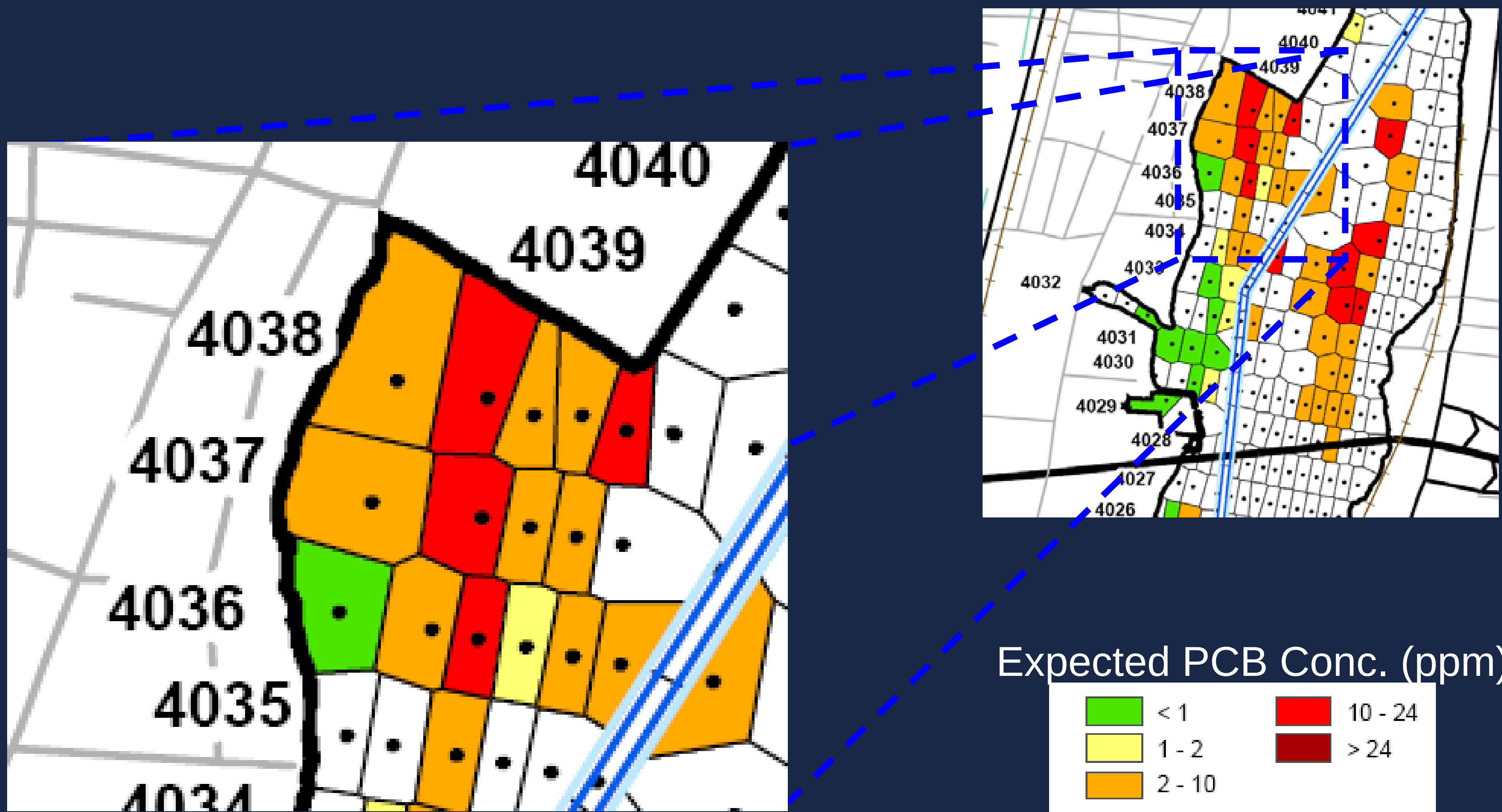
Anticipated Thickness ~ 2.1 inches

PCBs = 10.6 ppm

MPA ~ 0.26 g/m^2

* Assuming one production pass

Expected Post-Dredge Surface Conc.



Residual Management Options

- Monitored Natural Recovery
- Residuals Cap or Sand Cover
- Engineered Isolation Cap
- Additional Dredging (Production or Cleanup)

→ Decision Tree

Decision Tree Considerations

- Nature of residuals (undisturbed vs. generated)
- Characteristics of residuals (thickness, density, concentration)
- Site conditions
- Environmental benefit and effectiveness of additional dredging


Questions?