# COMMENCEMENT BAY CASE STUDIES OF ENVIRONMENTAL DREDGING RESIDUALS

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## ABSTRACT

A critical issue in the initial evaluation, final design, and implementation of contaminated sediment dredging projects is assessment and management of residual contaminants that may remain after dredging is completed. Residuals can be composed of both "generated residuals" left by the dredging operation and "undisturbed residuals" remaining below the dredge prism or actual dredge cutline due to dredging inaccuracies, accuracy in defining the contaminated surface, or other factors. No removal technology can remove every particle of contaminated sediment, and field results to date suggest that post-dredging residual contamination levels often have not met desired cleanup action levels. Currently there is no commonly accepted method to predict the degree of generated residual sediment resulting from different dredges applied to different environmental settings.

This paper summarizes several Commencement Bay area and national case histories that have characterized the amount of generated residuals, and discusses key design and construction considerations relevant to the assessment and management of residuals. 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. Post-construction management strategies are also discussed.

**Keywords**: Dredging, residuals, contaminated sediment, Commencement Bay

## INTRODUCTION

Contaminated sediments pose potential human health and ecological risks and the problem has received growing attention in recent years. One of the primary advantages commonly attributed to removing contaminated sediments from the environment is that removal provides greater confidence in the long-term effectiveness of the cleanup, assuming that risk-based action levels can be achieved. Removal of contaminated sediments is primarily conducted using dredging technology, including both mechanical and hydraulic methods.

Initial reviews of dredge residual data have suggested that dredging achieves significant contaminant mass removal, but typically leaves a veneer of contaminated sediments over the post-dredge surface (Herrenkohl et al. 2003; Desrosiers et al. 2005). While additional dredging passes can remove some additional contaminants, the effectiveness in removing contaminants by repeatedly re-dredging decreases 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.

Dredging residuals concentrations have historically been underestimated at many cleanup sites, even when complicating factors such as debris were not present. Effective planning and design to effectively and efficiently address residuals requires realistic estimates of dredging residuals, as well as development of appropriate construction contingency plans.

This paper summarizes generally accepted definitions for residuals, discusses critical factors that affect residual generation, provides an overview of national case studies and discusses case studies from Commencement Bay in more detail, including planning and design considerations, and post-dredge management strategies.

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## RESIDUALS DEFINED

The 2006 "4Rs" workshop, sponsored by the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers' (USACE) Engineering Research and Development Center (ERDC) developed definitions of residuals in the context of environmental dredging (Bridges et al. in preparation). 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 cleanup action level) found at the post-dredge sediment surface that have been uncovered but not fully removed as a result of the dredging operation; and

- **Generated Residuals.** Contaminated post-dredge surface sediments (at concentrations above the cleanup 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 prism. While there are numerous potential causes, important documented sources of generated residuals include:
    - Sediments dislodged but left behind by the dredge head that fall to the bottom without being widely dispersed ("fall back"); and
    - Sediment moved by slope failures caused by the process of dredging.

Generated residuals typically accumulate above the dredging cutline as a thin layer of material 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 design, monitoring and management responses.

Generated residuals may be difficult to remove with additional dredging passes due to their physical characteristics, and may also be deposited in measurable quantities several hundred feet away from the point of dredging depending upon site hydrodynamic conditions (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.

## FACTORS AFFECTING RESIDUALS

Experience gained from environmental dredging projects performed over many years has revealed a number of factors that affect the degree to which a project will have residual contamination. The presence of undisturbed residuals can often be attributed to the level of confidence that the design dredge prism has accurately captured the full extent of where contaminants exist (horizontally and vertically). Because sampling-based investigations are unlikely to identify the extent of contamination everywhere within a site with 100 percent confidence, there will always be some uncertainty as to whether the dredge prism captures all of the in-situ contaminants, which can lead to undisturbed residuals.

Factors that affect the presence of generated residuals include: dredge material chemical and physical characteristics, contaminant distribution in the sediment profile, site conditions, equipment selection, and dredge operator skill. It is important to note that there are significant limitations associated with even the most modern dredging equipment, and the inherent distribution of contamination found at many sites – where higher concentrations typically occur in deeper sediments – can make the sediment removal process and achievement of risk-based action levels particularly difficult as well as costly. Most of these factors are self-evident, but a few are worth discussing in more detail.

- Contaminant distribution in the sediment profile: The action of dredging disturbs the in-situ material down to the extent of equipment penetration. Generated residuals may result from sediment resuspension from direct contact, loss of sediment from the bucket during ascent or descent through the water column, and/or through later sideslope sloughing. If the dredge cut thickness requires multiple passes to achieve the targeted dredge elevation, the chemical concentrations of the lower dredge pass will have significantly more effect on generated residuals than the upper layer of sediment removed in a prior dredge pass.

- Site conditions: In-situ site conditions have a significant influence on the occurrence of both generated and undisturbed residuals. The presence of significant amounts of debris, or the presence of a subsurface condition that prevents the dredge from completely removing the targeted sediment, increase the potential for higher quantities of residuals.

## NATIONAL 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 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.

Based on evaluating minimum data quality, Patmont and Palermo (2007) identified eleven (11) environmental dredging projects conducted throughout the United States that have quality data sets that can support reliable mass balance-based evaluations of undisturbed and/or generated residuals:

- **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)

The case studies span a range of physical settings (river, estuary, and variable slope/debris conditions), dredge volumes (2,000 to 400,000 cubic yards [cy]), dredge cut thicknesses (1 to 7 feet), dredge equipment type (mechanical and hydraulic), and chemical conditions. 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 measurements of post-dredge core sections, a thin layer of generated residuals ranging from 1 to 9 centimeters (average equals 5 cm) remained at all of the subject environmental dredging sites even after the final cleanup dredging pass (Patmont and Palermo 2007). 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/cm$^3$). Final post-dredge surface chemical concentrations of target chemicals, 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). Not surprisingly, projects with the greatest sediment concentrations 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 case studies environmental dredging projects, generated residuals were calculated by Patmont and Palermo (2007) 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 production dredging pass is a reasonable estimate of the generated residual sediment concentration resulting from that dredge pass.

For the eleven environmental dredging projects listed above, final generated residuals ranged from approximately 2 to 9 percent (average equals 4 percent) of the mass of contaminant dredged during the last production cut (Patmont and Palermo 2007). Similar generated residual percentages 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. The mass balance data indicate that the presence of hardpan/bedrock, debris, and relatively low dry density sediment are primary factors contributing to higher generated residuals.

## COMMENCEMENT BAY ENVIRONMENTAL DREDGING CASE STUDIES

The Commencement Bay-Nearshore/Tideflats (CB/NT) Superfund Site is located within and adjacent to the City of Tacoma at the southern end of Puget Sound in Washington State. It encompasses an active commercial seaport and includes 12 square miles of shallow water, shoreline, and adjacent land, most of which is highly developed and industrialized (Figure 1). EPA placed the CB/NT Site on the Superfund National Priorities List (NPL) in 1983, and attributed the contamination to a range of shipbuilding, oil refining, chemical manufacturing and storage, pulp and paper mills, and other industrial activities dating from the turn of the century.

**Figure 1. Aerial view of the Commencement Bay-nearshore/tideflats site.**

EPA's 1989 Record of Decision for the CB/NT Site set forth a cleanup plan that included control of upland sources, followed by sediment remediation either by dredging and upland/nearshore containment, or engineered capping. With more than 2 million cy of contaminated sediment removed as a result of a series of remedial actions between 1993 and 2006, the CB/NT Site is currently the largest completed environmental dredging site in the U.S., and was the first in the nation to complete a partial delisting of clean sediment areas from the NPL. Partial settlements for injuries to natural resources in the CB/NT Site have also been completed. Because of its relatively large size and complexity, EPA and the State of Washington divided the CB/NT Site into a number of separate priority project areas to effectively manage remedial actions (Figure 2). Approximate (rounded) contaminated sediment dredging volumes removed to date within each priority project area are summarized below:

- Hylebos Waterway Segment 5 (mouth) – 390,000 cy
- Hylebos Waterway Segment 3/4 (middle) – 200,000 cy
- Hylebos Waterway Segment 1/2 (head) – 400,000 cy
- Head of Hylebos Wood Debris – 80,000 cy
- Middle Waterway – 90,000 cy
- Olympic View Resource Area – 6,000 cy
- Sitcum Waterway – 400,000 cy
- Thea Foss Waterway Head – 4,000 cy
- Thea Foss Waterway – 500,000 cy


**Figure 2. Commencement Bay-nearshore/tideflats site priority project areas.**

In addition to the projects listed above, other contaminated sediment cleanup projects have also been completed to date within the CB/NT Site area. For example, although EPA did not identify the Blair Waterway as a priority problem area, the Port of Tacoma dredged 2.4 million cy of sediment from the Blair Waterway in 1993-1994 as part of an integrated navigation channel improvement, sediment cleanup, and habitat restoration project.

Lessons learned from the extensive environmental dredging experience within the CB/NT Site can be applied to other sediment cleanup sites with similar site conditions. As described in Patmont and Palermo (2007), in order to support reliable mass balance evaluations of generated and/or undisturbed residuals for these projects, data must be available for the following:

- 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; and
- 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 construction 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 of the CB/NT 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 four of the CB/NT projects listed above. Summaries of the available data are provided in Table 1. Data synthesis is ongoing for several other projects (e.g., Thea Foss Waterway dredging), and may be reported in future papers.

Due to the development and sediment deposition history of the CB/NT Site, the demarcation between overlying contaminated sediments (typically black sandy silt) and underlying clean native sediments (typically brown or grey silty sand) is easily discernable in the field based on visual examination of sediment color. During dredging operations, this visual distinction was used to verify remedial design predictions of the depth of the native contact. Particularly within the Hylebos Waterway, this visual marker proved extremely effective in verifying that the dredge prism had successfully removed undisturbed residuals. Following visual identification that the native contact had been achieved within individual sediment management areas (SMAs), and also following detailed bathymetric surveys verifying that "high spots" had been removed to the design grades, surface and near-surface sediment sampling was performed to verify that the cleanup standards had been achieved. Throughout the Hylebos Waterway, initial post-dredge verification sampling revealed that cleanup standards (including statistical provisions; see below) had been achieved in 75 to 95 percent of the SMAs, and no further remedial action was required in these areas. Within those SMAs that did not achieve cleanup standards (i.e., in 5 to 25 percent of the overall project area), additional cleanup pass dredging typically extended approximately 1 to 2 feet below existing grades. Following this additional cleanup pass dredging, verification sampling confirmed that cleanup standards had been achieved.

As described in EPA decision documents, confirmation that sediment cleanup standards had been achieved within the CB/NT Site was based on a statistical analysis of the post-dredge verification sampling data. The analysis involved calculating the 95th percentile upper confidence limit (95% UCL) of the mean concentration of samples collected within a given project area (e.g., the 60-acre Segment 5 dredging area), and comparing the 95% UCL with chemical-specific cleanup standards. Sediment remediation was considered successful if the 95% UCLs for all chemicals did not exceed the cleanup standards, and if no single sample exceeded the calculated location-specific 10-year natural recovery level. Details of this procedure are contained in the individual project documents (e.g., Anchor 2004a and 2004b).

**Table 1. Commencement Bay-nearshore/tideflats site residual characterization data.**

| | Middle Waterway Tacoma, WA | Hylebos Segment 5 Tacoma, WA | Hylebos Seg. 3 & 4 Tacoma, WA | Hylebos Seg. 1 & 2 Tacoma, WA |
|---|---|---|---|---|
| **Dredge Prism Sediment Characteristics:** | | | | |
| Avg. Total Solids (% wet) | 69% | 56% | 59% | 49% |
| Avg. Dry Density ($gms/cm^3$) | 1.17 | 0.85 | 0.90 | 0.69 |
| Geotechnical Description | Plastic Organic Silt/Sand | Plastic Organic Silt/Sand | Plastic Organic Silt/Sand | Plastic Organic Silt/Sand |
| Typical Slope | >8H:1V | >10H:1V | 4H:1V to flat | 7H:1V to flat |
| Relative Abundance of Debris | Low | Low | Moderate | Low |
| Primary Indicator Chemical | Mercury | HCBD | PCBs | PCBs |
| Cleanup Goal (ppm) | 0.59 | 0.011 | 0.30 | 0.30 |
| Avg. Chemical Concentrations (ppm): | | | | |
| Dredge Prism (incl. overdredge) | 3.0 | 0.19 | 2.9 | 1.6 |
| Exceedance Factor | **5** | **17** | **10** | **5** |
| Surface (0-10 cm) Samples: | | | | |
| Before Dredging | 2.2 | 0.071 | 0.63 | 0.69 |
| After Dredging | 2.3 | 0.004 | 0.22 | 0.23 |
| Final Post-Dredge Residual (cm) | | | | |
| Generated Residuals | 8 | 2 | 8 | 7 |
| **Dredging Characteristics:** | | | | |
| Dredge Volume (cy) | 90,000 | 390,000 | 200,000 | 400,000 |
| Avg. Dredge Depth (ft) | 7.1 | 4.1 | 4.9 | 5.9 |
| Bottom of Dredge Prism | Native Sand | Native Sand | Native Sand | Native Sand |
| Dredging Period | Jul '03 - Feb '04 | Jul '03 - Feb '04 | Jul '04 - Oct '04 | Aug '03 - Jan '06 |
| Primary Dredge Type | Clamshell | 20 cy Clamshell | 20 cy Clamshell | Clamshell and Bean |
| Typical # of Production Passes | 1 | 1 | 1 | 2 |
| Final Cleanup Action | Redredge & 0.5-ft Cover | 1 to 2 Redredge Passes | 1 to 2 Redredge Passes | 1 to 2 Redredge Passes |
| **Calculated Dredged Contaminant Remaining as Generated Residuals [a]:** | | | | |
| Mass Balance Calculation | **3.6%** | **1.7%** | **5.1%** | **3.4%** |

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.

The CB/NT dredging projects summarized in Table 1 used different design approaches to manage undisturbed residuals. For example, to minimize costs associated with upland transport and disposal, the Hylebos Segment 1/2 dredging project attempted to minimize the removal of clean material underlying the contaminated sediment layer by specifying equipment for the final production and cleanup passes that could achieve comparatively tight dredging allowable overdepth tolerances (DOF 2006). More conventional production dredging equipment was used for the initial, overlying cuts. For the final cuts, the Segment 1/2 project used a hydraulically activated bucket that could provide three-dimensional positioning control. This equipment was hydraulically controlled (unlike typical derrick clamshell equipment that controls the buckets using cables) and when closed was sealed to prevent loss of sediment and water. Use of this equipment substantially removed all targeted undisturbed residuals with minimal underlying clean sediments, and resulted in generated residuals equivalent to approximately 3.4 percent of the contaminant mass present in the last production cut.

The Hylebos Segments 3/4 and Segment 5 dredging projects used a different design approach (Anchor 2004a and 2004b). Sediment disposal for these projects was provided by a nearshore confined disposal facility located within the adjacent Blair Waterway, at a considerably lower transport and disposal cost compared to the upland facilities used for Segment 1/2. Thus, minimizing the removal of clean material underlying the contaminated sediment layer was less important in Segment 3/4/5 from a cost perspective, relative to Segment 1/2. Accordingly, a standard clamshell digging bucket was used for all phases of the Segment 3/4/5 project (i.e., for both production and cleanup pass dredging).

Use of the clamshell equipment for the Segment 3/4/5 project substantially removed all targeted undisturbed residuals with minimal underlying clean sediments, and resulted in generated residuals ranging from 1.7 percent (Segment 5) to 5.1 percent (Segment 3/4) of the contaminant mass present in the last production cut. Though chemical concentrations (and corresponding exceedance factors relative to cleanup standards) were highest in Segment 5 (see Table 1), the total dredge volume of the second cleanup pass in this project area (approximately 30,000 cy, or 8 percent of the first production and cleanup pass volume) was less than in the other project areas. These results are consistent with the relatively low amounts of debris and comparatively high sediment dry density in Segment 5. Based on a review of environmental dredging projects completed across the U.S., the presence of hardpan/bedrock, debris, and relatively low dry density sediment are primary factors contributing to higher generated residuals (Patmont and Palermo 2007).

The CB/NT Site data suggest that generated residuals are difficult to capture, regardless of the dredging equipment used. Final generated residuals achieved on the CB/NT Site projects were consistent with the national range of 2 to 9 percent (average equals 4 percent) of the mass of contaminant dredged during the last production cut (Patmont and Palermo 2007). While the data set is limited, the CB/NT Site case studies suggest that while specialized dredge equipment may facilitate removal of undisturbed residuals with a minimum of underlying clean material, such equipment may not provide substantive benefits for generated residuals management.

## RECOMMENDED DREDGE PLAN DESIGN PROCESS

Dealing with undisturbed and generated residuals 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.

Because selecting dredging equipment does not appear to be an effective means of controlling residuals by itself, the dredge plan design becomes even more critical. Traditionally, dredge plan design was based only on ensuring that the dredge prism fully encompassed the estimated extent of contaminants. However, it is becoming more apparent that dredge plan design should also take into account residuals management. The following general steps outline a process in which residuals can be incorporated into an overall design process.

1. Identify the confidence in the horizontal and vertical extent of contamination through the use of available statistical tools such as geostatistical modeling
2. Establish a level of confidence for removal, and design the dredge prism to appropriately optimize and balance removal of undisturbed residuals and removal of underlying clean sediments
3. Develop a post-dredge verification sampling plan from which to base decisions on whether or not cleanup levels will be achieved, and develop a decision tree for appropriate contingency response actions
4. Estimate undisturbed and generated residuals anticipated on the post-dredge surface at the completion of the initial production and cleanup dredging pass
5. Optimize the dredge prism based on project-specific cost considerations
6. Finalize verification sampling and contingency plans for residuals management (both generated and undisturbed)

The dredge plan optimization step should consider the following issues:

- Focus on mass removal
- Limit removal of clean sediment (typical) to minimize volumes
- Establish realistic expectations of generated residuals
- Balance environmental risk of generated versus undisturbed residuals
- Consider other project non-environmental requirements (e.g., need for fill in disposal facilities)
- Weigh cost-benefit for dredge plan scenarios to select preferred scenario that best meets environmental cleanup goals and other project needs

## POST-DREDGING MANAGEMENT ACTIONS FOR RESIDUALS

As discussed below, there are several possible post-dredging management actions for residuals, considering the corresponding residuals characteristics that would be determined by monitoring, and the site conditions amenable to the action as would be determined by an engineering/ operational evaluation. The selection of a residuals management approach would depend on the nature and extent of the residuals (presence of generated residuals vs. undisturbed residuals, residual thickness, residual density, and chemical of concern concentrations) as well as an engineering/operational assessment of site conditions as related to potential management actions. Depending on the specific management option selected, additional sediment verification sampling may need to be performed to verify the effectiveness of the action.

### Monitored Natural Recovery (MNR)

MNR is a remedial approach in which natural processes such as sedimentation, sediment mixing, and degradation reduce contaminant concentrations over time. MNR is a potential management approach for post-dredging residuals if the layer thickness and concentrations of the residuals would allow for MNR within acceptable time frames. Essentially, the same considerations that apply to selection of MNR as primary remedial approach (e.g., as opposed to dredging) would apply in selection of MNR as a post-dredging management approach for residuals.

### Residual Sand Cover

Residual caps or sand covers are terms used to describe a thin layer of clean material (usually a few inches up to one feet) placed over residuals to provide short-term isolation and long term mixing. Sand covers have been successfully used at a range of environmental dredging projects, including within the CB/NT Site (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

An engineered isolation cap can be considered as a residuals management action in cases where substantial layers of residuals, especially undisturbed residuals, cannot be effectively removed. The considerations for evaluating engineered caps as a residuals management option are identical to those for design of engineered caps as a primary remedial option, and EPA guidance for design of engineered caps is generally followed.

### Cleanup Dredging Pass

At some of the CB/NT Site 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 that my not have been successfully removed during the initial production and/or cleanup pass. Additional production pass dredging was not required for the CB/NT Site case studies summarized in Table 1.

The basis for selecting one or more of the above residuals management approaches should be defined in the monitoring and management plan for the project. In some cases a project-specific "decision tree" may be developed with specific rules for selecting the management option based on the nature of the residual layers as defined by post-dredging verification sampling.

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