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Sediment Remediation: A Case Study of Residual-Driven Volume Expansion and Project Risk

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Abstract

- **Background/Objectives.** This paper presents information related to sediment volume expansion associated with environmental dredging. It is based on published and unpublished work conducted during 2004-2007 as part of the remediation of the Head of the Hylebos sediment remediation project. Sediment volume expansion results from several factors including bulking, under characterization of the dredge volume, and recontamination associated with contaminated residual materials. Volume expansion increases both project risk and cost.
- **Approach/Activities.** The analyses and evaluations presented in this paper are derived from the Head of the Hylebos Site. This sediment remediation site represents a nearly ideal case to evaluate the effect of residuals on volume expansion because bulking was not a significant factor based on site mineralogy and issues associated with under characterization of the site were not present.
- **Results/Conclusions.** Residuals represent a significant problem during the implementation of environmental dredging projects. The effect is an increase in project risk and cost. Residual recontamination was principally responsible for more than doubling the design sediment volume in the Head of the Hylebos. Methods to reduce the project level risks associated with the effect of residuals are presented.

Introduction

This case study addresses sediment volume expansion during an environmental remediation project located in the Hylebos Waterway which is part of the Commencement Bay CERCLA site in Tacoma, Washington. Sediment volume expansion generally occurs as the result of three variables: a) inadequate characterization of the spatial extent of substances the remediation is intended to address; b) the problems associated with the removal and redistribution of contaminated residuals during dredging operations. In the Hylebos Waterway, despite excellent spatial characterization, residuals caused a significant expansion in dredge volumes, and c) sediment bulking due to mineralogy. These factors will be discussed and several suggested project risk management tools and approaches will be presented. Commencement Bay was included in the National Priorities List in 1983. EPA performed the Remedial Investigation (RI) between 1983 and 1985 and developed the site's Feasibility Study (FS) during the period 1986 to 1989. By the early 1990s, the EPA recognized additional environmental studies were required in order to develop remedial designs for the various operable units, including the Hylebos Waterway. These studies, called Pre-Remedial Design Engineering (PRDE) Studies began in 1993 and were completed by early 2000. A major effort was made to fully characterize sediments in the Waterway. This characterization involved extensive vertical sampling and characterization throughout the site. The physical conditions present in the Hylebos Waterway included relatively shallow depths (35-40 feet) in the broad navigational turning basin and in the channel. The site is estuarine with a thin freshwater lens that varied seasonally. In addition, the entire waterway is subject to 14-16 ft tidal variations in depth.

The geology of the sediments present at the site included sandy silts above tighter native material. Sampling conducted during the PRDE Studies indicated that the primary substances of concern (PCBs, PAHs and metals) were present in the upper deposits consisting of sandy silts. The lower tight silts represented clean native material.

Technical Approach to Remediation

The Hylebos Waterway was divided into two operable units for the purpose of sediment remediation in the early 2000s: the Head of the Waterway and the Mouth of the Waterway. The upper turning basin (a portion of the Head operable unit), was remediated separately under a state-led consent decree. This paper focuses on the EPA-led portion of the Head of the Waterway cleanup.

The objective of the EPA-led sediment remediation in the Head of the Hylebos Waterway was to achieve a bedded surface weighted average sediment total PCB concentration of 300 ug/kg. The initial surface weighted average concentration of total PCBs was 685.9ug/kg. Additional site specific Sediment Quality Objectives (SQOs) are presented in Table 1. The PRDE Studies indicated that 41.5 acres of sediment in the Head of the Waterway would require remediation by dredging. During the course of the PRDE Studies, over 100 sediment core samples and more than 500 surface sediment samples were used to characterize the spatial distribution of the site specific SQOs across and beneath the 41.5 acres of sediment.

Post dredge sediment bulking is typical of cohesive sediments containing clay particles. Because the Head of the Hylebos project involved dredging sediments that could be classified as greywacke, while clay sized particles were present, there was virtually no mineralogical clay materials associated with the clay sized fraction. This is a common condition involving recent sediments in the Pacific Northwest. As a result, post dredge bulking was not a significant factor associated with volume expansion involving the Head of the Hylebos environmental dredging project.

INSERT TABLE 1 HERE

As the primary remedy, EPA selected state of the art precision dredging methods to remove the 190,000 cubic yards of in situ contaminated sediments. This decision was based on three key factors: (1) a data set that provided excellent vertical control related to the depth of contamination for the 41.5 acre area; (2) relatively shallow water depth; and (3) a clear delineation in color and density between the contaminated sand layer and the underlying clean silt layer. EPA estimated that the project could be completed in one in-water season (i.e." fish window") that began in July 2004 and ended in late January 2005. The dredging would be completed in two passes. The first pass would remove all but about two feet of silty sand above the clean silt layer. The second pass would remove remaining silty sand residuals. EPA estimated that the desired level of remediation could be achieved with the removal of 220-250,000 cubic yards of sediment.

The contractor conducted precision dredging using barge mounted excavators equipped with hydraulically operated clamshell buckets. The excavators were equipped with electronically positioned

articulated fixed arms. The equipment achieved bucket placement accuracy of plus or minus 10 cm within the three dimensions (x, y, and z). This technology was essential to achieving an overlapping bucket placement pattern during dredging.

The project goal was to dredge to a clean surface. EPA expected to achieve this clean, remediated surface after the second pass. EPA approved a confirmation sampling program to determine if the second pass achieved the desired objectives. The program was based on 14 Compliance Monitoring (CO) areas. These CO areas were further divided into 400 Construction Dredge Management Areas (CDMAs) which were 5000 square feet each. Each CDMA was tested, following the second dredge pass, for the SQOs listed in Table 1. The testing consisted of randomizing the surface grid and then discrete sampling at 4 to 6 nodes within the CDMA. The discrete samples were composited and analyzed. Thus, a surface weighting criteria was applied to verify whether the dredging had achieved a clean remediated surface. In the case of the Head of the Hylebos, the difference between the pre-remedial concentration and the remedial objective was within the same order of magnitude: a reduction from 685.9 ug/kg to 300 ug/kg. This represents a 44 % reduction in surface weighted average total PCB concentration. It was anticipated, mistakenly as set forth below, that this small difference in magnitude between the current sediment concentration and the sediment quality objective would reduce the likelihood that residuals would interfere with the attainment of the remedial objective.

Difficulties with Volume

By October 2004, it was obvious that this project was proceeding much slower than anticipated. The primary reasons were: (1) more than two dredge passes was often required to achieve an acceptably remediated surface, and therefore (2) the volume of sediment being dredged to achieve a clean, remediated surface was significantly greater than the engineering analysis had indicated. Dredging continued through late January 2005. At the end of the first season of remedial activity, about 75% of the site had been successful remediated. A second season of dredging began in July 2005 and work was completed by February 2006.

The dredging project in the Hylebos Waterway during the period 2004-6 provides some very useful insight into the problems associated with volume estimation and expansion during environmental dredging projects. The fact that Total PCBs were an important SQO in the Hylebos provides a common objective that makes the insights from the Hylebos generalizable to other sediment remediation projects in Region 10 and elsewhere.

During the Hylebos remediation, approximately 72 % of the CDMAs achieved a surface weighted average concentration of 234 ug/kg total PCBs after two dredging passes; while 99% of the CDMAs achieved a surface weighted average concentration of 76 ug/kg after three (3) or more passes. The project generated 410,000 cubic yards of sediment given a very accurately identified in situ volume of 190,000 cubic yards of sediment that exceeded SQOs. Because of the significant problem associated

with residuals when remediating to 300ug/kg total PCBs, an additional 220,000 cubic yards of material had to be removed from the site and the project took twice as long as was originally planned.

Contaminated residuals plague sediment remediation projects. As a general rule, the higher the initial concentration and the lower the SQO, the greater the problem with attainment of the remedial objectives as a consequence of residuals will be. This results in a higher volume inflation factor associated with achieving a clean surface. Residuals are difficult to control, even with a precision bucket, for a number of reasons including:

- Surface disturbances caused by the dredge bucket at the sediment water interface. This has been observed as high levels of turbidity at the mud-line even when using environmental buckets
- Uneven bucket placement resulting in poor overlap and rills and ridges of contaminated sediment remaining after dredging is completed. This is particularly problematic when cable dredges are used in deeper water systems. Mechanical excavators with accurate locating systems were specifically used to avoid this problem during the Hylebos dredging program. However, such equipment may not be capable of dredging to depths greater than 40 feet because of structural limitations associated with articulated fixed arm excavators.
- Overflow of turbid water from the dredge bucket during the lift to the surface.
- Overflow of turbid water from the sediment holding/transfer barge
- Sloughing of contaminated sediment from side and headwalls of the dredge cut face

Effect of Volume Expansion on Sediment Remediation Project Risk

In several important ways, the Head of the Hylebos project represented an ideal situation for environmental dredging. The system was extremely well defined based on very extensive testing and there was a well indentified clean surface that allowed the dredge prism to be accurately estimated. The Head of the Hylebos was also well suited for the application of precision environmental dredging equipment because of its relative shallow and quiescent nature. Based on its sediment mineralogy, post excavation bulking was not a significant factor in volume expansion. Despite these attributes, residuals contributed to major issues with project implementation and volume inflation.

Organizations (including EPA, other governmental entities and agencies, potentially responsible parties, stakeholders, etc) are strongly cautioned to avoid making irreversible decisions based on volume estimation until sufficient vertical sampling and control has been completed as a result of PRDE Studies. Because cost estimates for sediment remediation projects are very sensitive to volume estimates, such estimates should not be considered to be accurate “30%” costs until such time as the vertical distribution of the SQOs is well understood throughout the Sediment Management Area (SMA). This will not be the case in most SMAs until after PRDE Studies have been completed. Unless a complete vertical characterization has been completed, accurate 30% design level volume estimates are not possible.

Before settlements based on Feasibility Study (FS) level volume and cost estimates can be achieved, this significant level of uncertainty must be addressed. In order to predict the level of effort and costs associated with a project, the sediments must be adequately characterized in three dimensions. This can be a significant challenge for several reasons:

First, the configuration of the dredge prism must be adequately determined to establish an accurate volume estimate. Because the configuration of the prism is determined by the distribution of SQOs, the extent of spatial characterization is critical. Geospatial tools, including Kriging, can be used to assess the effect of uncertainties related to the extent of spatial data on the volume of the contaminated sediments present in the dredge prism. The process of Kriging spatial data allows the identification of the actual standard deviation of an interpolated parameter. The standard deviation of the inferred value allows for the objective evaluation of the accuracy of the spatial configuration and in situ characterization of the contaminated sediment.

Second, contaminated sediment sites are frequently associated with dynamic fluvial or estuarine systems where natural recovery mechanisms can result in significant changes to sediment concentrations during the life span of the project. In the case of the Head of the Hylebos, ten years elapsed from the Record of Decision until the completion of the PRDE Studies. Another seven years passed before the dredging project was completed. Significant change in sediment chemistry is not only possible during periods of a decade or more, it is likely.

Once the in situ volume estimates are established, the effect of residuals must be taken into account. This is particularly important if the EPA requires a “dredge to clean” approach to remediation. In the case of the Hylebos, where state of the art environmental dredging technologies were used specifically to control residuals, the actual volume that was required to be removed to achieve a 300 ug/kg total PCB SQO (on an area weighted basis) was 2.15 times the well established in situ volume. The actual volume was 410,000 cubic yards which is significantly greater than the in situ volume of 190,000 cubic yards plus 30% or 247,000 cubic yards.

Had the SQO for total PCBs been less than 100 ug/kg (based on a surface weighted average), the total volume of sediments would have been much greater than 410,000 cubic yards simply due to the effects of low level surface recontamination by residuals.

As the number of dredge passes required to achieve a “clean surface” increases, the duration of the project increases as well. In the case of the Head of the Hylebos, what was planned to be accomplished in one dredging (or in water) season actually took two seasons to complete using the best available technology and residuals management practices throughout the project.

The Head of the Hylebos sediment remediation project provides important lessons to others faced with managing the project risks associated with environmental dredging projects. Although the site was well characterized prior to dredging, significant volume expansion occurred. The primary cause was

residuals preventing attainment of the cleanup objective, despite the fact that the cleanup objective was within the same order of magnitude as the pre-remedial concentration.

Volume inflation and project risk are closely tied: as volume increases so does project cost and duration. In the case of the Head of the Hylebos, the cost of the actual sediment remediation was $58,800,000. The project costs by category are presented in Table 2:

Insert Table 2 Here

Sediment volume was responsible for 66% of the total cost of the remedy implementation at the Head of the Hylebos or about $38,800,000. It is obvious uncertainty in sediment volume has a significant effect on project risk and therefore cost.

Recommendations for Managing the Risk of Volume Expansion

Obviously, there is a significant project risk associated with volume expansion in dredging based sediment remediation projects. In situ volume estimates should never be used as the final dredging volume required to achieve a clean surface. In the case of the Head of the Hylebos, a volume expansion factor of 2.1 times the actual in situ volume is noteworthy because it is due entirely to residuals and not errors in site characterization. For most sites, it would be prudent to assume at least 2.5 to 3 times the in situ volume will have to removed to "get to a clean surface". This volume expansion factor should be included in project cost estimates from the FS through Remedial Design.

Dredge volume is the basis of approximately 66% of the total project costs. During the Remedial Action, the project should track progress using a metric based on surface area "dredged to clean" divided by volume removed. Tracking project progress by volume alone is a certain path to failure. Project contingency should not be released by the project until all areas have been dredged, sampled and passed appropriate criteria. The reason for this is simple, as demonstrated in the Head of the Hylebos. While many of the CDMAs will achieve the clean up objective after two passes (70% in the Hylebos), a significant portion will not (30% in the Hylebos) and these CDMAs could require many more additional dredge passes before being classified as "clean". There is no way to know if this ratio will be the case at different site. The only pragmatic way to manage this risk is to retain sufficient contingency as an available reserve through completion. The formula for releasing contingency should be created on a site specific basis based on the combined effects of a) volume expansion due to risk associated with site characterization, b) sediment bulking based on sediment mineralogy and c) the effect of contaminant residues on achieving an adequately clean surface.

Addressing the Residual Issue in Cleanups and Settlements

Most environmental dredging projects are done by a performing party (or parties) under a Remedial Design/Remedial Action (RD/RA) Consent Decree with EPA. The performing party then obtains cash out settlements or judgments against other parties associated with the contaminated sediment. The key factor in a smooth RD/RA and cash out process is the degree of cost certainty regarding the RA work.

In a typical scenario, the performing party will take the cost estimates from the RD, and apply a premium to cover administrative costs and potential cost overruns. The residual issue identified above will potentially undermine this cleanup paradigm at sites where residuals pose a significant threat of exponential expansion of dredge volumes. Too much uncertainty makes parties unwilling to enter RD/RA decrees with potentially open-ended financial consequences, and the cash out premium becomes too great to facilitate settlement.

As set forth in this case study, the key factors that can drive up residuals, and thereby undermine cleanup agreements, are:

(1) A large differential between the current concentrations of the COC and the cleanup level for the COC (e.g., if the cleanup level is currently orders of magnitude below the current level, the residual issue will be substantial);

(2) Whether there is a clear delineation between the impacted layer and an underlying clean layer, and whether it is possible to dredge into the clean interface. This condition was present in the Hylebos, but was not sufficient alone to overcome the residuals issue;

(3) The depth and quiescence of the water body; at greater depths, and higher current, it becomes more difficult to precision dredge. Water currents increases scalloping and increase the difficulty of achieving a clean surface by the spreading of residuals.

Clearly, it is not in the interest of EPA, potentially performing parties, potential cash out parties, or the community to have dredging projects bog down because of massive uncertainty associated with residuals.

Where these factors are significant, regulators should look at tools other than dredging to manage residuals. One approach is for a dredging phase that focuses on mass removal, followed by a capping phase that traps residuals below a clean layer. This allows for accurate volume measures for the dredging, as long as there is good delineation between the impacted sediment and the underlying clean layer. This procedure addresses the need to reduce environmental risks by obtaining a cleaner post remediation surface sediment layer and by achieving an approach to better control project risk. Similarly, capping costs can be accurately estimates based on the surface area to be capped and an agreed upon path to address the engineering required to determine the composition of the cap.

Tables

Table 1: Head of the Hylebos Sediment Quality Objectives (SQOs)

Substance	SQO	Basis for the SQO
Total PCBs	300 ug/kg	Human Health: Consumption of resident flatfish
PAHs	Varied	Human Health: Consumption of resident flatfish
Arsenic	57 mg/kg	ARAR: AET
Copper	390 mg/kg	ARAR: AET
Mercury	0.59 mg/kg	ARAR: AET
Zinc	410 mg/kg	ARAR: AET

Table 2 Head of the Hylebos Project Cost Breakdown

Cost	Type	Percent of Total Cost (%)
Project Management, Monitoring, Fees	Fixed	15
Misc. Other Costs	Fixed	4
Mobilization & Demobilization	Fixed (Unless the project extends over multiple dredging windows)	15
Dredging	Variable Based on Volume	17
Sediment Handling	Variable Based on Volume	12
Transportation & Disposal	Variable Based on Volume	31
Water Management	Variable Based on Volume	6

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