WATER MANAGEMENT DURING MECHANICAL DREDGING OF CONTAMINATED SEDIMENT

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ABSTRACT

This paper addresses the contribution of barge overflow water generated during mechanical dredging of contaminated sediment to the formation of a residual sediment layer in the work area. First it presents a method to estimate the amount of water generated by mechanical dredging and then presents a case study of a water management system at an environmental dredging project that captured suspended solids from barge water prior to discharge back to the water body. The findings of the case study document that barge overflow can be a significant contribution to the formation of a residual layer of sediment at a mechanical dredging project.

Key Words: Barge overflow, residual layer, fill factor, captured water ratio, geotubes.

INTRODUCTION

Environmental dredging is one of three primary options for the remediation of contaminated sediment, in addition to capping and monitored natural recovery. In recent years the significance of sediment resuspension during dredging, contaminant release because of dredging, residual contamination remaining after dredging, and environmental risk associated with dredging (the "4Rs") have become important considerations in the evaluation of the effectiveness of environmental dredging. Reduction of the 4R's improves the environmental effectiveness of sediment remediation. This paper presents information on water management techniques for mechanical dredging of contaminated sediment that result in the reduction of contaminant release and residual layer formation due to dredging.

Conventional mechanical dredging techniques developed for navigation projects can and will suspend and release sediment into the water column, which can result in the accumulation of residual sediment in the work area. Two significant mechanisms of sediment release during mechanical dredging are 1) the erosion of sediment from the bucket as it is raised through the water column, and 2) the overflow of turbid water from the sediment haul barge (the topic of this paper).

From a navigation dredging perspective, the accumulation of a relatively thin layer of residual sediment on the bottom does not adversely impact the objective of the work, which is to lower the bottom to an acceptable elevation for ship traffic. From an environmental remediation perspective, the accumulation of a relatively thin layer of contaminated residual sediment can significantly impact the success of the action. This is because the surface layer of sediment is a primary zone of biological activity in an aquatic environment. Sediment quality criteria are often focused on the top few inches of material in a waterway, and the accumulation of a few-inch thick residual layer of contaminated sediment following dredging can be adverse to aquatic animals and the ultimate success of the project.

WATER CAPTURED IN A CLOSED MECHANICAL BUCKET

The analysis in this paper assumes the use of closed dredging buckets, which are becoming widely used and often required for sediment remediation. The two halves of a closed bucket are designed such that when brought together fully they form a closed container that isolates the material in the bucket from the water column. This isolation generally eliminates erosion of sediment from within the bucket while the bucket is being lifted through the water column. Because the bucket is closed, it also retains the water captured in the bucket until the contents are placed into the barge. Consequently a closed bucket will normally deliver a fixed volume of material into the barge, which can be at various proportions of water and sediment. For example, a 4.6 cubic meters - cu m (6 cubic yard - cy) closed bucket that is half full of sediment will contain 2.3 cu m (3 cy) of sediment and 2.3 cu m (3 cy of water. That same bucket only 1/3 full of sediment will deliver 1.5 cu m (2 cy of sediment and 3.1 cu m (4 cy) of water into

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the barge. Closed buckets used for dredging have some type of vent at the top of the bucket that allows water and air to escape as the bucket is lowered thru the water column. These vents are typically closed by a rubber flap or similar device during bucket ascent thru the water column.

Overfilling the bucket is normally avoided during environmental dredging to limit the suspension of sediment in the water column from the dredging process. This requires individual bucket cuts that generate less than a full bucket of sediment. This results in more water being generated during environmental dredging as compared to navigation dredging, where fuller buckets are typically desired.

The degree to which a dredging bucket is filled by sediment is called the bucket Fill Factor (F_f). It is expressed as the volume of sediment captured in the bucket (V_{cs}) divided by the capacity of the bucket (V_b).

Fill Factor $$F_f = V_{cs}/V_b \quad (1)$$

A 4.6 cu m (6 cy) bucket filled half full of sediment would have a fill factor of 0.5 (3 cy sediment / 6 cy capacity). The same bucket 1/3 full of sediment would have a fill factor of 0.33 (2 cy / 6 cy). The fill factor can be used to estimate production rates for mechanical dredging. The parameter will vary project to project and site to site dependent on many parameters including thickness of cut, bucket size & type, material type, and operator skills.

Higher fill factors are possible with easily dug material. For example, the fill factor for a digging bucket in a full bank of loose sand might be on the order of 1, while the fill factor for the same bucket and operator digging hard sand or stiff clay might be only 0.4. This would generally be due to the inability of the bucket to penetrate the harder material. The fill factor also drops as the thickness of dredge cut becomes less than is needed to fill the bucket. For example, the fill factor for digging a 0.3 m (1 ft) thick layer of sand might be only 0.3 as compared to 0.8 for digging a 1.2 m (4 ft) thick layer of sand with the same operator and bucket. This is because in the first case, the operator would attempt to limit penetration to prevent over-dredging beyond the desired depth whereas in the second case, there may be sufficient bank thickness that the operator can let the bucket dig to its full depth.

Because environmental dredging often involves the removal of relatively thin layers of sediment, the associated bucket fill factors are typically less than associated with navigation dredging. Consequently sediment remediation dredging can generate considerably more water in the bucket and hence in the haul barge than is associated with navigation dredging.

While the fill factor describes how much sediment is captured in a mechanical bucket, another term can be used to describe the amount of water captured in a mechanical bucket, the Captured Water Ratio (R_{cw}). It is the ratio of the volume of captured water in a bucket (V_{cw}) to the volume of captured sediment (V_{cs}) in a bucket.

Captured Water Ratio: $$R_{cw} = V_{cw} / V_{cs} \quad (2)$$

This paper assumes the use of closed buckets, which means the volume of captured water (V_{cw}) plus the volume of captured sediment (V_{cs}) equals the volume of the bucket (V_b).

Closed Bucket Volume: $$V_b = V_{cw} + V_{cs} \quad (3)$$

For example, a 4.6 cu m (6 cy) bucket filled half full of sediment would hold an equal volume of water and would have a captured water ratio of 1 (3 cy water / 3 cy sediment). Based on the relationship between V_{cw} and V_{cs} (3), and the definition of bucket fill factor (1), the captured water ratio can be re-written as a function of the fill factor.

Captured Water Ratio: $$R_{cw} = (1-F_f) / F_f \quad (4)$$

Given the average fill factor for a project, the total volume of water captured by the bucket and placed in the barge (V_{dw}) from dredging the in-situ volume of project sediment (V_{ds}) can be estimated as V_{ds} times the average captured water ratio.

Volume of Dredged Water: $$V_{dw} = R_{cw}*V_{ds} \quad (5)$$

Assuming that all of the material captured in the bucket goes into the barge, the volume of dredged material (V_{dm}) in the barge is the sum of the in-situ volume of sediment dredged (V_{ds}) plus the volume of dredged water (V_{dw}).

Volume of Dredged Material:

$$V_{dm} = V_{ds} + V_{dw} \quad (6)$$

$$V_{dm} = V_{ds} + R_{cw} * V_{ds} \quad (7)$$

$$V_{dm} = V_{ds} (1 + R_{cw}) \quad (8)$$

Based on the above, the captured water ratio can be used as a basis to estimate the total volume of water that will be captured by the bucket and then managed during a mechanical dredging project. For example, if the anticipate fill factor for a 4.6 cu m (6 cy) bucket is 0.66 for the site conditions at a 76,000 cu m (100,000 cy) (in-situ) dredging project, then the captured water ratio would be 0.5, the volume of dredged water would be 38,000 cu m (50,000 cy), and the volume of dredged material (as loaded into the barge) would be 114,000 cu m (150,000 cy), as shown below.

GIVEN
V_b = 6 cy (4.6 cu m) closed bucket
$F_f = V_{cs} / V_b = 4/6 = 0.66$

CALCULATE
$V_{cs} = F_f * V_b = 0.66*6$ cy = 4 cy sediment
$V_{cw} = V_b - V_{cs} =$ 6 cy – 4 cy = 2 cy water
$R_{cw} = V_{cw} / V_{cs} = 2/4 = 0.5$ or
$R_{cw} = (1-F_f) / F_f = (1-0.66)/0.66 = 0.33/0.66 = 0.5$

APPLY
V_{ds} = 100,000 cy (76,000 cu m) in-situ sediment
$V_{dw} = V_{ds} * R_{cw}$ = 100,000 cy * 0.5 = 50,000 cy (38,000 cu m) dredged water
$V_{dm} = V_{ds} + V_{dw}$ = 100,000 cy + 50,000 cy = 150,000 cy (114,000 cu m) dredged material, or
$V_{dm} = V_{ds} (1+ R_{cw})$ = 100,000 cy (1+0.50) = 150,000 cy dredged material

Table 1 presents this calculation for bucket fill factors ranging from 0.2 to 1.0. While the in-situ volume of dredged sediment remains constant at 76,000 cu m (100,000 cy), the volume of dredged water increases from 0 at a fill factor of 1, to 305,000 cu m (400,000 cy) at a fill factor of 0.2. At the same time the total volume of dredged material placed in the barges goes from 76,000 cu m (100,000 cy) at a fill factor of 1 to 380,000 cu m (500,000 cy) at a fill factor of 0.2. While a project average fill factor of 0.2 is not likely, there may be portions of a project where the fill factor can be as low as 0.2, such as when thin lifts of sediment are being removed in the final stage of cleanup. These estimates of captured water can be used to plan water management facilities.

Table 1. Dredged volumes as a function of bucket fill factor.

F_f	R_{cw}	Sediment V_{ds} (cy)	Water V_{dw} (cy)	Total V_{dm} (cy)
1	0	100,000	0	100,000
0.8	0.25	100,000	25,000	125,000
0.7	0.43	100,000	43,000	143,000
0.6	0.67	100,000	67,000	167,000
0.5	1	100,000	100,000	200,000
0.4	1.5	100,000	150,000	250,000
0.3	2.3	100,000	233,000	333,000
0.2	4	100,000	400,000	500,000

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CASE STUDY - WATER MANAGEMENT DURING ENVIRONMENTAL MECHANICAL DREDGING AT HEAD OF HYLEBOS WATERWAY

Table 1 indicates the magnitude of water that can be generated by a mechanical dredging project. However little data is available on the average fill factor associated with sediment remediation by mechanical dredging. The following discussion presents a description of the water management system utilized during late 2005 and early 2006 for the mechanical dredging at the head of Hylebos Waterway, part of the Commencement Bay / Nearshore Tideflates Superfund Site at Tacoma, Washington.

Dredging Project

Dredging of approximately 65,000 cy (50,000 cu m) of impacted sediment was performed using two dredges. The majority of the dredging was completed by Envirocon, Inc. of Portland, Oregon using an articulated fixed-arm dredge (Komatsu 750 excavator on a barge) with a 2.3 cu m (3.0 cy) closed hydraulic clamshell bucket (Figure 1). The clamshell was manufactured by Young Corporation of Seattle, Washington. A smaller portion of the dredging was completed by Quigg Bros., Inc. of Aberdeen, Washington from a crane barge using both a conventional rehandling clamshell bucket (2 ½ cy, 1.9 cu m) and a Cable Arm closed bucket (4 cy, 3 cu m). In all cases the dredged material was placed into flat-deck barges with water tight four-foot side walls (250 cy, 190 cu m capacity) for transport to an on-site dock for offloading. The dredged material was removed from the barges using a hydraulic excavator (Komatsu 600) on the dock equipped with a Young hydraulic clamshell bucket. The dredge material was trans-loaded into containers on rail cars that passed along the edge of the dock for delivery to the Regional Disposal Company landfill in eastern Washington.

Figure 1. Young's closed hydraulic clamshell bucket for articulated fixed-arm dredge.

Water Management

The water management system consisted of a barge dewatering system, sediment capture system, and discharge system back to the waterway as dredging return water. The barge dewatering system consisted of a Godwin 4-inch (0.1 m) diameter discharge submerged centrifugal pump deployed from a 20-ton crane located on a small work barge (Figure 2). The work barge was normally positioned alongside the sediment barge while it was being loaded by the dredge. The pump was submerged into the accumulated water in the sediment barge and turbid water was pumped through a 0.1 m (4 inch) diameter HDPE floating line to the upland sediment capture system. The operation focused on removing as much water as practical from the barge, without removing the underlying sediment in the barge. This was done to prevent barge overflow and increase barge capacity for sediment as well as reduce the volume of water that became entrained in the sediment.

At the upland sediment capture system the turbid water that was pumped from the barges entered a settling chamber to separate sand sized and larger particles. The overflow from the settling chamber was pumped into one of four 70 cu m (18,000 gallon) mixing tanks supplied by Rain for Rent (Figure 3). Each mix tank of turbid water was managed on a batch basis. A grab sample of the turbid water was collected from each tank and tested with polymer

(Nalco # 7768) to determine proper dosing. The required amount of polymer/water blend was then added to the tank and gently mixed for a few minutes as the fine grained sediment formed sand sized floc. The flocculated material was then pumped to one of three Mirafi Geotubes (18 m (60-ft) circumference by 30 m (100 ft) long) for separation of the sediment and the water (Figure 4). The flocked sediment was retained in the Geotube, while the clarified water passed through the non-woven geotextile wall of the tubes.

Figure 2. Barge dewatering system.

Figure 3. Mixing tanks, upland sediment capture system.

Figure 4. Geotubes with mixing tanks in background.

The water passing the Geotube was then pumped into a holding lagoon, from which it was pumped through sand filters and bag filters (Rain For Rent) prior to discharge back to the waterway (Figure 5).

Figure 5. Sand filters (center) and bag filters (right) prior to discharge to waterway.

Dredged Water

The volume of dredged water (V_{dw}) generated by the dredge is estimated as the sum of the volume of the water pumped from the barge (V_{pw}) and the volume of water entrained in the sediment in the barge (V_{ew}).

Volume of Dredged Water: $V_{dw} = V_{pw}+V_{ew}$ (9)

The entrained water was offloaded with the sediment and shipped to the landfill for disposal. The degree to which water is entrained into the sediment is dependent on several factors, including sediment type, the type of bucket used for dredging, the method of operating the equipment, the manner in which sediment is placed into the barge, as well as the water capture methods. Preliminary analysis of project data indicates that the volume of entrained water was on the order of 15% to 20% of the in-situ volume of dredged material.

Estimated Quantities

The estimated quantities of dredged sediment, captured water, and captured sediment for the Head of Hylebos sediment remediation project for the 2005-2006 construction season are summarized below.

Table 2. Dredging and water management approximate quantities, head of Hylebos sediment remediation. 2005-2006 Construction Season.

Parameter	Value	
#1. In-situ volume of dredged sediment (V_{ds})	65,000 cy	50,000 cu m
#2. Volume of water pumped from barges (V_{pw})	75,000 cy	57,000 cu m
#3. Volume of entrained water (V_{ew})	10,000 cy	8,000 cu m
#4. Volume of dredged water (V_{dw}), (= #2 + #3)	85,000 cy	65,000 cu m
#5. Volume of dredged material (V_{dm}) (= #1 + #4)	150,000 cy	115,000 cu m
#6. Volume of sediment captured in Geotubes	4,000 cy	3,000 cu m
#7. Captured water ratio (R_{cw}), (= #4/#1)	1.3	
#8. Average fill factor (F_f), (= #1/#5)	0.4	

The water management system processed an estimated 57,000 cu m (75,000 cy) of turbid water pumped from the sediment barges (V_{pw}) that came from the dredge buckets. When processed, the57,000 cu m (75,000 cy) of turbid water produced on the order of 3,000 cu m (4,000 cy) of sediment in the Geotubes. The 3,000 cu m (4,000 cy) of solids represents approximately 2.5% solids by weight in the 57,000 cu m (75,000 cy) of captured turbid water. The 3,000 cu m (4,000 cy) of sediment collected in the Geotubes represents approximately 6% of the in-situ volume of dredged sediment. It also represents a potential 0.07 – 0.1 m (3 to 4 inch) thick layer of very fine grained residual sediment, had the turbid water been allowed to overflow the barge and the suspended solids settle back to the bottom in the dredge area rather than be captured and processed.

CONCLUSIONS

The volume of material placed in a barge by a mechanical dredge using a closed bucket will consist of both sediment and water, with the potential for water volumes to equal or exceed the in-situ volume of sediment dredged. Discharging the captured water back to the waterway as barge overflow water will often result in the release of sediment back to the dredged area and the formation of a residual layer of sediment over the dredged surface. There is also potential for offsite migration of the sediment, producing a residual layer outside the original project area.

The average bucket fill factor for a given project is a function of several conditions, including the size and configuration of the bucket, the nature and thickness of the dredge cuts and sediment, and the attributes of the dredge operator. The average bucket fill factor can be used to estimate the amount of water that will produced by a mechanical dredging project, expressed as a function of the in-situ volume of sediment to be dredged.

Recent data collected during mechanical dredging with a closed bucket at the Head of Hylebos Waterway in Tacoma, Washington documented that more water than sediment was delivered to the barge by the closed bucket (an estimated 65,000 cu m (85,000 cy) water and 50,000 cu m (65,000 cy) of sediment). Of the 65,000 cu m (85,000 cy) of dredged water, an estimated 8,000 cu m (10,000 cy) was entrained in the dredged material and shipped to a regional landfill for disposal. Processing of the 57,000 cu m (75,000 cy) of water pumped from the sediment barge resulted in the capture of a volume of sediment (4,000 cy, 3,000 cu m) roughly equal to 6% of the in-situ dredged volume. If the turbid water in the sediment barge had been allowed to overflow back into the waterway, it would have released enough sediment to form a 0.07 – 0.1 m (3 to 4 inch) thick layer of residual sediment on the bottom of the entire dredged area.

With proper management of barge overflow a significant quantity of contaminated sediment can be captured that would otherwise be released and accumulate in a residual layer (several inches thick) on the bottom of the water body. Failure to captured and manage barge overflow water will add to the environmental risk associated with dredging and potentially result in failure to achieve the project cleanup objectives.