HEAD OF HYLEBOS–ADAPTIVE MANAGEMENT DURING SEDIMENT REMEDIATION

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ABSTRACT

Major sediment remediation projects can take place over a large area, over an extended period of time, and involve a wide range of variable site conditions. Successful completion of such complex projects can be enhanced by a flexible management framework that encourages ongoing adaptation of the remediation methods through continuous gathering and review of performance data, followed up by real time method adjustments to improve the effectiveness of the remedial action. The application of adaptive management to sediment remedial actions provides a mechanism to improve the effectiveness of the planned action by learning from the outcomes of ongoing actions and modifying the actions to achieve the desired outcome, as well as a means to respond quickly to unanticipated conditions.

One of the ways the Head of Hylebos Waterway sediment remediation project applied adaptive management was by the full-time observation of the dredging and subsequent sampling with concurrent adjustment of the dredging plan to improve the capture of impacted sediment and achieve a clean bottom throughout the dredging area. This approach resulted in 99% of the dredging area meeting the project chemical cleanup criteria, with 1% of the area requiring capping to control a groundwater related impacts that could not be resolved by sediment removal.

Keywords: Adaptive management, sediment remediation, environmental dredging, Hylebos, residual reduction.

INTRODUCTION

This report presents the dredge monitoring techniques used at the Head of the Hylebos Waterway sediment remediation project to adjust the dredging approach, along with a summary of the monitoring data showing the effectiveness of the program in achieving the cleanup criteria.

HEAD OF HYLEBOS MECHANICAL DREDGING PROJECT

The stated objective of the Head of Hylebos dredging was to remove the impacted sediment and a minimal volume of the underlying non-impacted native sediment to produce a final resulting surface comprised primarily of native sediment which when sampled in the upper 10 cm met the project chemical cleanup criteria. Those criteria were set forth as a list of dry-weight sediment chemistry concentrations known as the Sediment Quality Objectives (SQOs) for the Commencement Bay / Nearshore Tideflats Superfund Site in Tacoma, Washington. While the SQOs included 9 metals and over 40 organic compounds, the compounds and related SQOs that drove the cleanup at the Head of Hylebos were polychlorinated biphenyls (PCBs, 300 ug/kg), polycyclic aromatic hydrocarbons (PAHs, multiple), arsenic (57 mg/kg), copper (390 mg/kg), mercury (0.59 mg/kg), and zinc (410 mg/kg).

Mechanical dredging was selected for the Head of Hylebos Waterway to facilitate rail transportation and placement of dredged material into an offsite upland municipal-solid-waste disposal site, as well as to accommodate industrial debris which was expected in the sediment. The dredging plan incorporated components to reduce the potential for recontamination of remediated areas due to sloughing from adjacent impacted material, and to reduce residual layer formation.

The dredging plan typically involved two separate stages or passes of the dredge for each area to be dredged. In the first stage the thicker deposits of impacted material (five to fifteen feet thick) generally found outside the navigation channel, were removed using a mechanical dredge. During the second stage another dredging pass was completed using precision mechanical dredging equipment and methods to remove the remaining impacted material and expose non-impacted native sediment. The lower bank height of sediment during the second pass reduced the chance of recontamination of previously dredged areas from bank sloughing, and facilitated a more efficient and accurate

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second and final dredge pass. The thickness of material remaining for removal during the second pass was adjusted during the project in order to achieve the project objective in an efficient manner.

The project was initiated using a first dredging pass that was intended to leave on the order of two feet of impacted material overlying the native sediment. This approach was later revised such that the first pass dredging proceeded until native sediment was first observed in the dredge bucket, with the second pass then removing the remaining impacted material along with residual sediment resulting from the first pass. The second pass dredging design called for proceeded from top of slope down, to further reduce the potential impacts of sloughing.

The majority of the second pass dredging was performed using a barge mounted excavator with hydraulically operated clamshell bucket, with a small portion completed with a Cable Arm bucket deployed from a wire rope (Figure 1). The barge and excavator were fully instrumented and capable of providing +/- 10 cm accuracy (X, Y, and Z) of the cutting edge of the dredge bucket when properly operated. The project specifications called for individual bucket grabs to overlap and provide 100% coverage of the dredge area.

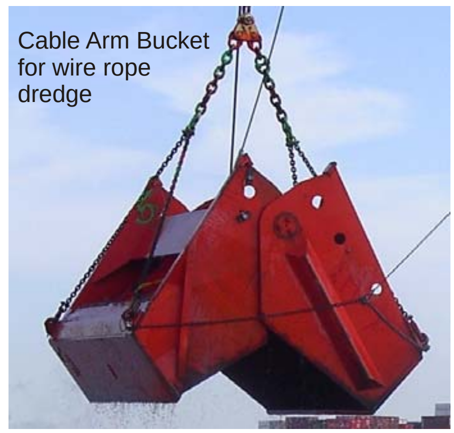

Figure 1. Enclosed mechanical dredging buckets.

The employment of precision dredging methods allowed the use of relatively small dredging management areas in the dredging plan. The management areas for dredging were based on the contractor's actual dredging plan, which generally consisted of parallel dredging lanes running the length of the waterway. Each dredging lane (~12 m, 40 ft. wide) was subdivided into approximate 465 m^2 (5,000 ft^2) areas designated as Construction Dredge Management Areas (CDMAs). The 16.8 ha (41.5 acre) dredging project was subdivided into about 400 CDMAs. The design depth of dredging varied from CDMA to CDMA in order to closely track the depth of impacted sediment in the waterway, reducing the volume to be removed to achieve the project objective.

Dredging of approximately 305,000 m^3 (400,000 cy) was completed over two in-water construction seasons (mid July to following mid-February), separated by an environmental resource window (mid February to mid July) to protect endangered fish species. The first construction season ran from July 2004 to February 2005 (2004CS) and the second season from July 2005 to January 2006 (2005 CS). The 2004CS dredging was performed by Bean Environmental of New Orleans, Louisiana. The 2005 CS dredging was performed by Envirocon, Inc. of Portland, Oregon working with Quigg Bros., Inc. of Aberdeen, Washington. The precision navigation system used during the second season was developed by eTrac Engineering, LLC of Sausalito, California.

The majority of the dredging during both construction seasons was completed with electronic/RTKGPS positioned articulated fixed-arm dredges. A smaller portion of the dredging was completed by conventional derrick barge (crane barge) using both a conventional rehandling clamshell bucket and a Cable Arm enclosed bucket. The dredged material was placed into barges for transport to an on-site dock for offloading. The dredged material was then removed from the barges using a hydraulic excavator (Komatsu 600 with custom stick) on the dock. The dredge material was trans-loaded into twenty foot open top containers on rail cars that passed along the back of the dock for delivery to the Regional Disposal Company landfill in eastern Washington.

ADAPTIVE MANAGEMENT THROUGH MONITORING OF RESIDUAL LAYER

Residual Contamination

In recent years the significance of residual contamination remaining after dredging has become an important component in the evaluation of the effectiveness of environmental dredging. Residual contamination as addressed in this paper consists of a post-dredging layer of disturbed sediment that remains on top of the dredged surface. It is composed of sediment that was disturbed by the dredging operation and then re-deposited on the surface of the dredged area. If the residual layer is composed of sediment that is chemically impacted above the project cleanup objectives, its presence can result in the failure of a project to meet the overall cleanup objectives. Consequently environmental dredging practices that limit the development of a residual layer can contribute to the overall success of remedial action.

For mechanical dredging, sources of the residual layer include:

- The erosion of sediment from around and within the bucket as it is placed on the bottom, closed, and raised through the water column. The sediment erosion from moving the bucket through the water column can be controlled with the use of enclosed buckets. However there can be resuspenion of contaminated sediment near the sediment-water interface by enclosed buckets if the bucket is improperly advanced into the sediment and then closed. This may explain the high levels of turbidity that have been measured near the mudline with the use of enclosed buckets. (Anchor Environmental, 1999)

- The overflow of turbid water from the sediment haul barge. This can be controlled with restrictions on barge overflow while at the same time capturing and treating the turbid water in the barge. During the 2005CS, roughly 3,000 m^3 (4,000 cy) of sediment was captured from 57,000 m^3 (75,000 cy) of turbid water pumped from the barges during the dredging of 50,000 m^3 (65,000 cy) of sediment. 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 7 to 10 cm (3 to 4 inch) thick layer of residual sediment on the bottom of the dredged area. (Fuglevand, Webb 2006)

- The sloughing of sediment from the sidewalls and headwall of the dredge cut face, back on to previously dredged areas, can generate a residual layer in previously dredged areas. This can be controlled through the use of relatively thin dredge lifts (few feet each) and by including a final cleanup pass of dredging once the bulk of sediment has first been removed ("two pass dredge approach"). (Dalton, Olmsted & Fuglevand, 2006)

- The remolding of soft fine-grained sediment by the dredging process can significantly reduce the strength of the material and generate a more liquid like flowable residual layer of sediment in the dredging area. This flowable material can be very difficult to capture with the dredge bucket and result in a residual layer that is difficult to manage and control once it is formed. The formation of this layer can be reduced (not eliminated) by a controlled and precise removal program using electronic/RTKGPS dredge positioning and mechanical dredging. Once formed, capture of the flowable layer can be accomplished with overdredging into underlying native substrate, provided that substrate is not hardpan or bedrock.

Monitoring of Dredged Areas

The Head of Hylebos dredge monitoring program was based on the project objective to achieve a bottom condition that met the sediment chemistry criteria, the SQOs at the completion of dredging. An adaptive management approach was developed and implemented to improve the likelihood of meeting that objective. It was based on gathering daily dredging performance data to measure post-dredging sediment quality, in combination with ongoing evaluation and adjustment of the dredging process in order to improve the quality of the post-dredging surface.

Sediment Characteristics

The sediment characterization for the project determined that the sediment that had accumulated since the industrial development along the waterway ("Recent" sediment) was chemically impacted, while the underlying and older sediment ("Native" sediment) was not chemically impacted. The Recent sediment was also physically and visually different from the Native sediment. The Recent/impacted sediments to be dredged were typically characterized as black, very soft, fine-grained clay (CH) or organic silty clay (OH). In the dredging industry, such material is typically characterized as soft black muck. The Native/clean sediments immediately below the Recent/impacted sediment are composed of consolidated granular and fine-grained sediment. These Native sediments consist predominantly of sand and silt with variable amounts of interbedded silt and clay layers.

Dredge Monitoring Approach

The dredge monitoring took advantage of the distinctly different visual characteristics of the Recent and Native sediment to guide the cleanup program, based on the strong correlation of Recent and Native sediment to impacted and non-impacted sediment. As detailed below, visual observations during dredging, in combination with the visual classification of several hundred post-dredging samples, was used to guide the removal of the Recent sediment in the cleanup areas and achieve the project objective.

Dredge monitoring was divided into two major activities, performance monitoring and compliance monitoring as follows:

> Performance monitoring: Daily monitoring of the dredging was completed to provide immediate feedback on the effectiveness of dredging and to provide a basis of making adjustments to the dredging methods in order to improve the outcome of the dredging. See Type 1, Type 2, and Type 3 monitoring described below. This monitoring was a key factor in adaptive management for the dredging.
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> Compliance monitoring: Multiple sediment samples were gathered and composited from within each compliance monitoring area (CO area) and tested for the project SQOs. The 42 acre dredging area was initially subdivided into 14 CO areas, with four to six sediment samples collected and composited from within each CO area for chemical analysis (see Type 4 monitoring, below). Since this testing was completed after dredging, it did not provide a good source of information on which to adapt the dredging process, but rather provided documentation that the action had achieved the overall cleanup objective. This type of compliance monitoring is what is typically required on a sediment remediation project, but unfortunately does not provide the necessary information in time to adjust the dredging process.

Performance Monitoring

Performance monitoring during the second pass dredging consisted of Type 1, Type 2, and Type 3 observations and testing as described below.

Type 1 – Visual Observations During Dredging: The Type 1 observations were completed by a member of the construction quality assurance staff (dredge observer) stationed in the cab of the dredge, sitting side-by-side with the dredge operator (Figure 2). The cab of the primary dredge used during the 2004 CS (Liebherr 984) was sufficiently large to house the dredge observer with the operator. The cab of one dredge used during the 2004 CS (Hitachi 800) and one used during the 2005 CS (Komatsu PC 750) required modification to expand the cab and provide sufficient room for both the operator and the observer.

Expanded Cab, 2005CS

View from cab, 2004CS

Figure 2. Expanded dredge cab for Type 1 observations.

When the precision dredging methods indicated the excavation level was approaching the estimated bottom of the Recent sediment, ongoing visual observations were made of the dredged material as it was placed in the haul barge, looking for the presence of Recent and Native sediment (see Figure 3 for example). The presence of only Native material in a dredge bucket, such as a stiff silt, was a positive indication that the dredging was sufficiently deep at that location to have removed the impacted sediment. On the other hand, the presence of only soft black muck (Recent) in a dredge bucket was an indication that the dredging had not advanced deep enough to remove the impacted sediment at that location. The presence of disturbed Recent sediment in the bucket indicted the presence of a residual layer of impacted sediment.

Figure 3. Type 1 visual observation of recent and native sediment in dredge bucket.

Adaptive Management: Based on the Type 1 observations of the material in the dredge bucket, the dredge observer adjusted the dredging depth in real time to target the removal of the impacted sediment with the goal of establishing a final dredged surface comprised primarily of Native sediment which when sampled in the upper 10 cm met the SQOs. This adaptive management technique allowed for real-time adjustment of the dredging plan when conditions varied from those based on interpolation between pre-dredging data points presented in the design. For example, the variations in the actual extent of Recent sediment over the distance between pre-dredging sample points, which can be a hundred to hundreds of feet apart, will generally not be exactly the same as a straight line interpolation between data points would indicate. In some cases variations between the interpolation and the actual conditions differed by several feet. Had the remediation been to simply dig to the design grades, which included limited overdredge, there would have been considerable areas where the impacted sediment would have not been completely removed. The full time observation of dredging accompanied by real-time adjustment in the dredging plan provided a means to remove all of the impacted material with only limited removal of Native material. While this approach is relatively new for environmental dredging, it is a standard practice for upland remediation, where oversight is often provided during excavation to assure removal of targeted material.

<u>Type 2 – Visual Classification of Post-Dredge Samples</u>: The effectiveness of the dredging was also monitored based on visual classification of surface samples collected immediately after dredging. Surface samples (approximately 20 cm to 30 cm deep, 8-12 in.) were collected with a custom fabricated hydraulically actuated enclosed mini-clamshell dredge (Power Grab) deployed from the project sampling boat (9.75 m (32 ft.) Kvichak). The Power Grab sampler (see Sediment Sampling Method below) was capable of penetrating up to 30 cm into the stiff Native sediment to assure a representative sample of the top 10 cm was collected. The Type 2 samples were typically collected within a day of dredging and visually classified into one of three conditions as follows:

> <u>Condition A</u>: A bucket of undisturbed soft black muck indicates that the Native sediment has not been reached. Condition A required additional dredging to remove the impacted sediment (soft black muck), followed by additional Type 2 sampling and visual classification until Condition B or C was achieved.
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> <u>Condition B</u>: Disturbed surface layer of residual material in the Power Grab bucket consisting of a blend of soft black muck and Native sediment overlying Native sediment. This residual layer is a typical condition

that results from dredging, and is a condition that is very difficult to completely avoid in dredging projects. The Head of Hylebos project was completed using methods specifically intended to reduce the thickness of this residual layer**.** If the residual layer was observed in the Power Grab bucket, then depending on the abundance of residual material either additional dredging was completed to remove additional residual material or Type 3 progress testing was conducted to establish the effectiveness of the cleanup.

Condition C: Native material at the surface. At this point Type 3 testing (laboratory analytical) was performed to establish the effectiveness of the removal.

Adaptive Management. The information from the Type 2 observations were conveyed to the dredge observers as it was generated. This information provided the dredge observer feedback on the effectiveness of the dredging operation in limiting the post-dredging residual layer. Using this information the sequencing of bucket placement during dredging and the depth of dredge cuts was adjusted to improve the overall performance of the program. For example, if the Type 2 observations showed the accumulation of a 10 cm residual layer, the bucket sequencing plan might be adapted to improve the capture and reduce the residual layer before stepping the dredge ahead. As adjustments in the dredging approach were implemented, additional Type 2 observations were again made immediately after dredging to determine if the adjustments were achieving the desired outcome.

Type 3 – Progress Indicator Chemical Analysis of Post-Dredge Samples: The top 10 cm of sediment from the grab samples collected for Type 2 observations were also used for Type 3 chemical analysis to verify the visual classification and to provide a direct indication of the chemical concentrations with respect to the SQOs. Type 3 chemistry results provided an in-progress indication of the effectiveness of the removal and were used to identify areas requiring additional remedial action. The sampling plan allowed for compositing up to five adjacent Type 2 samples for testing. However soon after starting dredging it was decided to submit each Type 2 sample for Type 3 testing in order to better define areas requiring additional remedial action. Each submitted sample was analyzed for a few of the primary indicator compounds for chemical analysis.

Adaptive Management. The information from the Type 3 testing provided an indication of the chemical concentration in the residual layer. A highly concentrated residual layer, even if only a few centimeters thick, could result in failure of the 10 cm surface sediment sample for compliance monitoring. As the Type 3 data was gathered and evaluated over the course of the project it came to be understood that even a residual layer of 5 cm would often result in failure of the compliance samples, with a resulting focus on modifying dredging methods to greatly reduce the post-dredging residual layer.

Compliance Monitoring

Type 4 confirmation sampling was completed to demonstrate achievement of the EPA mandated cleanup requirements for the waterway, expressed as the SQOs.

Type 4 – Confirmation Chemical Analysis of Post-Dredge Areas: Sediment composites were collected, following completion of dredging and Type 3 progress sampling, to demonstrate that the cleanup action had achieved the project objectives. A composite sample, typically consisting of the upper 10 cm of 4 to 6 discrete grab samples was generated for each Type 4 CO area and analyzed for the EPA specified chemical parameters. As discussed below, the dredging project resulted in 99% of the dredged area meeting the SQO cleanup criteria, with only a small area requiring capping due to the influence of groundwater that could not be corrected by sediment removal.

Sediment Sampling Methods

Discrete Type 2 sediment samples, a primary component of the performance monitoring, were collected on a daily basis immediately behind the operating dredge to provide immediate evaluation of the post-dredging residual layer for the Head of Hylebos project. Nearly 1000 discrete samples were collected over the two construction seasons using a $0.3m^2$ Power Grab (Power Grab) manufactured by Marine Sampling Systems of Burley, Washington (Figure-4).

Unlike typical surface grab samplers, the Power Grab is a hydraulically actuated clamshell bucket which is capable of collecting 1-foot thick samples in many sediment types ranging from soft fine-grained sediment to more dense and compact silts and sands (not hardpan or glacial till), as well as through some debris. The design of the Power

Grab allows it to reliably penetrate the sediment instead of scraping the loose sediment off the top of the sediment surface. All of the sample contact surfaces on the Power Grab are stainless steel while the frame of the sampler is aluminum. The Power Grab features include: 1) an electrically powered hydraulic power pack to close the clamshell jaws of the bucket; 2) wide adjustable feet on the frame that supports the bucket to control the depth of penetration of the frame into the sediment and to avoid over or under penetration of the sampler; 3) adjustable ballast (280-750 lbs) on the frame to provide additional reaction weight for sampling in stiff material, which is easily removed for sampling soft sediment; 4) a semi-circular cutting profile of the bucket to limit the disturbance of the sample; 5) and an enclosed bucket configuration to protect the sample from scour while being raised through the water column. These features allowed the sample team to consistently collect acceptable samples (without over- or under-penetration) in all sediment types found on the site.

Figure 4. Power grab sampling.

Once the Power Grab sample was brought on board the sampling vessel, the overlying bucket covers were removed and overlying water decanted. The 0.3m^2 sample footprint (roughly 1-3/4 ft. by 1-3/4 ft.) was sufficient to allow for sub-sampling to measure the thickness and characteristics of the residual layer, the characteristics of the underlying more compact native sediment, as well as the collection of sediment samples for chemical analysis. The Power Grab performed well throughout the two seasons of dredge confirmation sampling without any notable complications or problems.

Dredge Monitoring Results

The Type 2 and Type 3 performance monitoring provided measurement of post-dredging thickness of the residual layer as well as the chemical concentration of specific indicator compounds. Due to their widespread presence within the area to be remediated, PCBs were used as an indicator compound throughout the dredging area, while PAHs and various metals were added in specific sub-areas. The results of the Type 2 and Type 3 testing of the post-dredging samples gathered behind the dredge are summarized below:

Table 1. Summary of Type-2 and Type-3 (PCB) post-dredging monitoring data.

	Initial Post-Dredge Data (1)	Final Post-Dredge Data (2)
Samples Pass SQO, % (3)	72%	99%
Avg. PCB Concentration	234 ug/kg	76 ug/kg
Avg. Residual Thickness	6 cm	4 cm

(1) Samples collected following completion of the planned two-pass dredging program.
(2) Samples representing all CDMAs following completion of additional dredging in areas not initially passing SQO criteria
(3) Final post-dredging data includes SQO failing results from 4 CDMAs capped because of groundwater influence

The initial post-dredging data presented in Table 1 summarizes the Type 2 and Type 3 (PCBs) results of the first sample collected behind the dredge following completion of the planned two-pass dredging program. Of the roughly 400 CDMAs tested, 72% passed the SQO chemical performance criteria following the two-pass dredging program, leaving 28% of the CDMAs for further dredging. After that additional dredging all of the CDMAs passed the SQO criteria, except for 4 CDMAs that were capped because of groundwater driven impacts that could not be resolved by sediment removal.

The average PCB concentration in surface sediment (10 cm) following the planned two-pass dredging program was 234 ug/kg (parts per billion), as compared to the PCB SQO of 300 ug/kg. Following re-dredging of areas not initially passing the SQO criteria, the average PCB concentration in surface sediment (10 cm) remaining in the dredged area dropped to 76 ug/kg, which is about five percent of the average PCB concentration in the Residual sediment prior to dredging (1,575 ug/kg PCBs)..

The Type 2 monitoring included a measurement of the thickness of the residual layer in the Power Grab sampler. The average thickness of the residual layer following the completion of the two-pass dredging program was 6 cm Following re-dredging of areas not initially passing the SQO criteria, the average residual thickness for the entire project dropped to 4 cm with two-thirds of the residual thickness measurements below the measurement limit of 1 cm.

The cost of re-dredging those areas that did not pass the SQO criteria following the planned two-pass dredging program was specifically tracked during the 2005CS. The re-dredging costs accounted for about 10% of the 2005CS dredging costs, and did result in 100% of the 2005CS dredging area passing the SQO criteria. In addition to the benefit of getting a clean bottom, this re-dredging effort also reduced the need for long-term monitoring and reduced the risk of future recontamination from leaving impacted material in an active waterway.

CONCLUSIONS

The full time observation of dredging (Type 1 Monitoring) accompanied by real-time adjustment to the dredging plan provided a means to adapt to the unknown site conditions that exist between pre-dredging data points and achieve full removal of the target material. The information from the Power Grab samples collected immediately behind the dredge (Type 2 Monitoring) provided the dredge observer information on the thickness of the post-dredging residual layer which resulted in adjustments to the dredging program to further reduce the residual layer. The chemical concentrations measured in the top 10 cm of sediment following the planned two-pass dredging program (Type 3 Monitoring) provided an understanding that even a residual layer of 5 cm could result in failure of the compliance samples, which led to modifications to the dredging methods to reduce the post-dredging residual layer to less than 4 cm on average, and to less than 1 cm for two-thirds of the samples.

The adaptive management that resulted from the Type 1, Type 2, and Type 3 monitoring led to the successful completion of the Head of Hylebos Waterway sediment remediation. Of the 16.8 ha (41.5 acres) dredged, 16.6 ha (41 acres) (99%) achieved the project SQO cleanup criteria. Post-dredge capping was only required at a 0.2 ha (0.5 acre) area, and only because of groundwater associated impacts that could not be resolved by sediment removal.

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