BOEING PLANT 2 SEDIMENT REMEDIATION: REMEDIAL DREDGING METHODS TO MANAGE THE RISKS OF RESIDUALS, RESUSPENSION AND RELEASE; THE BENEFITS AND COSTS

Robert S. Webb, P.E.[1], Brian Anderson[2], Steven Tochko[3], Paul Fuglevand, P.E.[4], Teal Dreher, P.E.[5]

ABSTRACT

Background/Objectives: The recently completed Boeing Plant 2 site restoration project on the Lower Duwamish Waterway (LDW) in Seattle Washington proved successful in implementing multiple advanced technologies in sediment remediation intended to effectively manage risks associated with residuals, resuspension and release of impacted sediment. The Remedial Dredging Methods (RDMs) used during the project demonstrated that residuals and releases from mechanical dredging can be significantly reduced or eliminated from that predicted by much of the literature and previous projects. In addition, state-agency required dredge-water quality limits resulted in the development and first-time use of electrocoagulation for dredge water processing on a large scale. Use of these advanced technologies, integrated with other site ecosystem enhancements, resulted in the project being awarded the World Organization of Dredging Associations 2016 Environmental Excellence Award for Environmental Dredging.

Approach/Activities: As one of four Early Action Areas within the LDW Superfund Site, the Boeing Plant 2 Early Action Area presented multiple challenges and implementation risks. Located at the upstream end of the Superfund site, the Plant 2 Early Action Area contained some of the more broadly elevated concentrations of PCBs (polychlorinated biphenyls) within the LDW. This presented risks associated with potential downstream losses of PCBs due to resuspension and release during dredging. Stakeholders initially pressed regulators for in-water containment (sheet pile wall) during performance of the remedial action to mitigate the release risk. Instead a series of RDMs were implemented to increase certainty of remedial action success while reducing risks associated with re-suspension, releases and residuals.

To meet the strict chemical and physical criteria for the dredge return water, electrocoagulation was used as the primary form of treatment. The system was designed to meet the highly variable site conditions, including tidal fluctuations, changes in water salinity, widely ranging suspended solids concentrations, accommodating both mechanical and hydraulic dredging, and footprint limitations.

Addressing stakeholder concerns and meeting dynamic agency requirements for this dredge project proved to add capital and operating cost to the project implementation.

Results/Lessons Learned: This talk will present the RDMs that were developed and implemented for the project, the associated surface water quality and dredge residuals monitoring results, and resulting costs associated with each of the major components of the work.

Keywords: Sediment Remediation, Costs, Dredging, Duwamish Waterway, Electrocoagulation

[1] Principal Engineer, DOF - Dalton, Olmsted & Fuglevand, Inc., 1236 Finn Hill Road, Poulsbo, WA, USA, 360-394-7917, rwebb@dofnw.com

[2] The Boeing Company, Seattle, WA, USA, (425) 373-8825

[3] The Boeing Company, Seattle, WA, USA

[4] Principal Engineer, DOF - Dalton, Olmsted & Fuglevand, Inc., 10827 NE 68th Street, Kirkland, WA, USA, 425-827-4588, pfuglevand@dofnw.com

[5] Project Engineer, DOF - Dalton, Olmsted & Fuglevand, Inc., 1236 Finn Hill Road, Poulsbo, WA, USA, 360-394-7917, tdreher@dofnw.com

INTRODUCTION

This paper will discuss the Remedial Dredging Methods (RDMs) used for the Boeing Plant 2 site restoration project, along with related project costs. Also presented are various elements that affect costs that often are not considered during early planning.

The RDM's used on the project resulted in essentially no measurable post dredging residuals, significantly reducing risks for the project owner. The RDM's were developed in response to U.S. Environmental Protection Agency (EPA) and other stakeholders initially requiring that a very expensive sheet pile wall be constructed around the site. There are many factors, not always obvious or considered that can have significant impacts on project costs. These cost drivers can vary regionally and are often driven by regulatory compliance and risk mitigation desired by the owner.

PROJECT OVERVIEW

The Boeing Duwamish Sediment Other Area (DSOA) Corrective Measure and Habitat Project took place on the Lower Duwamish Waterway in Seattle, Washington, between 2013 and 2015. This project was an EPA Early Action Area (EAA), which contained about one mile of the five mile long segment listed for the EPA Superfund site. The work included removal of 125,000 cubic meters (163,000 cubic yards) of contaminated sediments and placement of 145,000 cubic meters (190,000 cubic yards) of imported backfill material. The primary contaminants of concern for the project were PCBs, arsenic, dioxin, and cPAHs. To comply with in-water work restrictions related to salmon migration and local tribal fishing, the work was performed over three in-water work seasons.

The site is an urban river, with residential neighborhoods and industrial areas abutting the waterfront and project area. The river is used for commercial vessel traffic and recreational vessels as well as kayaks and canoes. Tribal fishing using nets is generally performed each fall.

REMEDIAL DREDGING METHODS

The EPA and other stakeholders initially wanted Boeing to construct a sheet pile wall around the area to be dredged in order to avoid potential contaminant releases to the waterway (See Figure 1). Such a wall would have cut off half of the river, creating significant adverse consequences including obstructing navigation, constricting river flow, resulting bed scour outside the wall spreading contaminants downstream, and its hindrance to efficient dredging operations and barge movement, as well as a prolonged project duration. As an alternative solution, Boeing proposed using 10 specific remediation dredging methods (RDMs) that were developed in order to reduce or eliminate potential contaminant risk (release, resuspension, and residuals; the 3Rs), while also avoiding the negative consequences associated with building the sheet pile wall. After review from the EPA, US Army Corps of Engineers, and the local citizen technical advisory group, the RDMs were approved in place of the sheet pile wall.

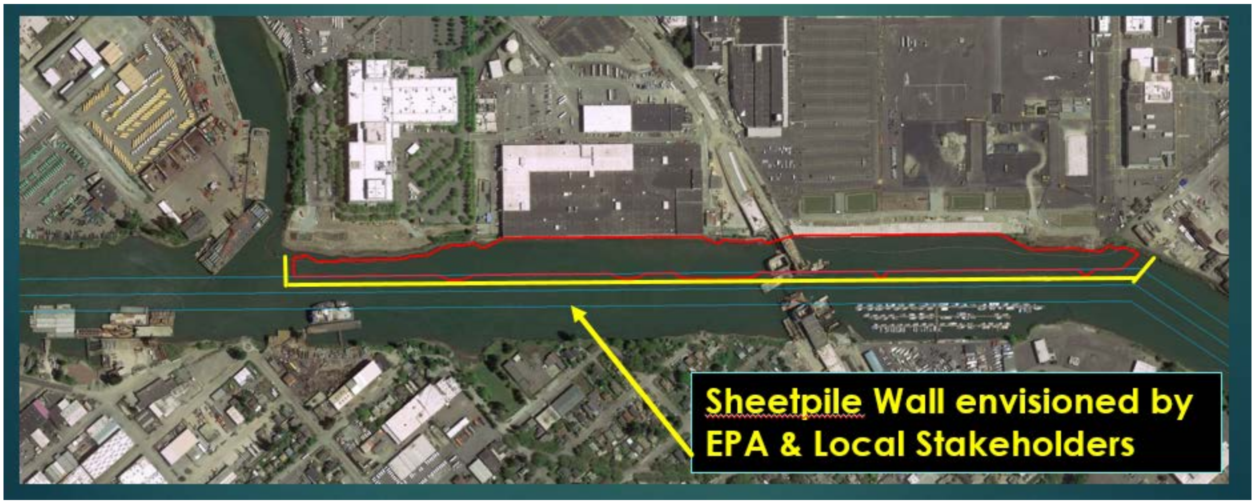

Figure 1. Potential sheet pile wall around site.

The RDMs were developed specifically to allow accurate removal of the targeted contaminated sediment, while reducing the risk of the 3Rs and eliminating the need and associated cost and complications for a wall around the perimeter of the project. Using these RDMs, dredging was conducted in an efficient and cost effective manner that resulted in essentially no measurable downstream releases of polychlorinated biphenyls (PCBs) and generally no observable residuals (one sample location showed a disturbed residual layer but multibeam bathymetric survey taken post dredge and before sampling showed a slope failure within this area and sloughage of material from outside the remedial footprint.).

The RDMs used on the project included the following:

Accurate Delineation of Elevation of Contamination (EOC): A complete and detailed delineation of the target sediment as a three-dimensional geospatial digital terrain model (DTM) was created prior to dredging. This reduced the risk of removing more unimpacted sediment than necessary to meet project objectives. Reducing overdredging reduces disposal costs, which are often two to three times the cost of dredging itself.

Precision Dredge Plan: Prior to the start of dredging, a precision dredge plan was created based on the DTM and the size and volume of the environmental bucket to be used for dredging. This essentially gave the contractor a roadmap to the required dredging work. This plan provided a final cut elevation for each bucket, which allowed the contractor to efficiently remove sediment to near the believed non-impacted sediment surface and then remove the final material with appropriate care.

Dredge with Excavator: Using a hydraulic excavator versus a cable supported clamshell or crane for the dredging work allowed for much more control, precision, and accuracy with bucket placements, which reduces the amount overdredging and related disposal costs for disposal of non-impacted material. The fixed arm of the excavator (Figure 2) provides greater control and ability to instrument compared to a cable supported clamshell.

Figure 2. Instrumented excavator with clamshell bucket.

RTK-GPS Based Bucket Positioning: In order to accurately achieve the lines and grades within the precision dredge plan, equipment of suitable accuracy and precision is required. The dredge was able to target sediment using an electronically instrumented precision excavator (+/- 10 centimeter [4-inch] accuracy) with DTM electronic display of target sediment. This was achieved using real time kinematic global positioning system (RTK GPS) with inclinometer on the excavator boom and stick, along with instrumentation on the bucket (Figure 3) to show orientation and open-close position.

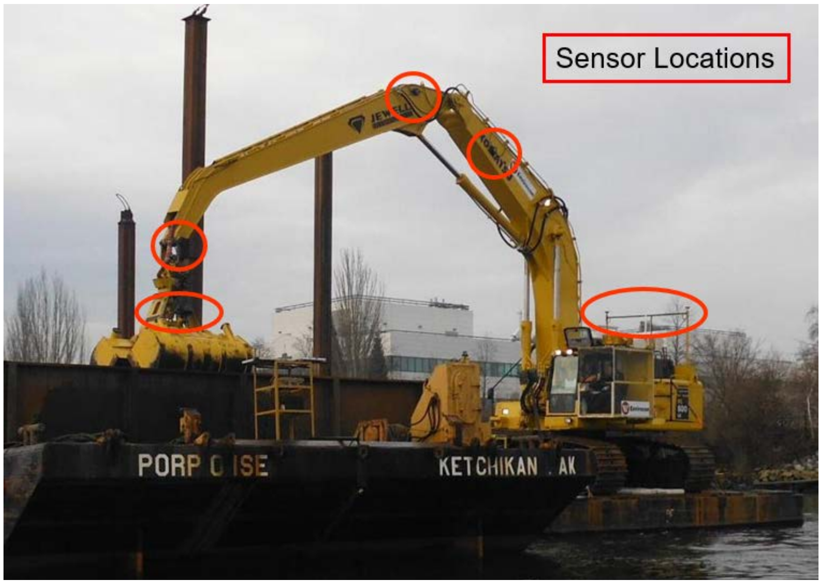

Figure 3. Instrumented excavator with clamshell bucket.

Stair-Step Cuts on Slope: The dredge targeted the sediment in layers in order to avoid over-steepened slopes and bank failures, which can be a source of contaminant release and resuspension. All slopes were dredged in a stair step fashion consistent with material stability to reduce sloughage and generation of loose residuals which are then difficult to remove. Slopes were dredged with excavator to avoid the difficulty of accurately removing sediment with a cable supported clamshell bucket on a slope as shown on Figure 4.

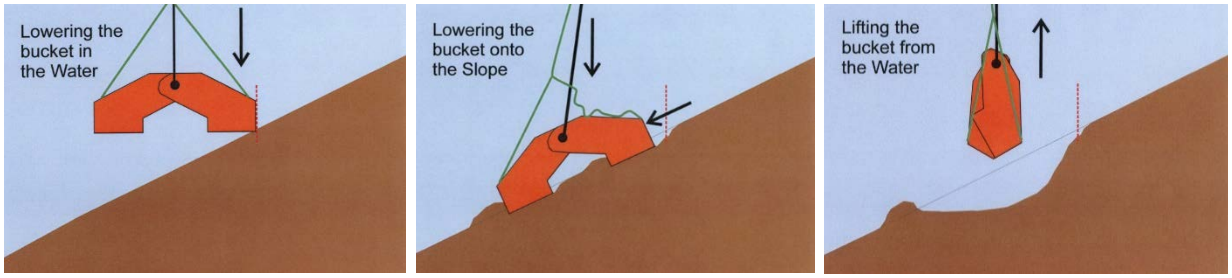

Figure 4. Cable support clamshell difficult to position on slopes.

Enclosed Environmental Bucket: Dredging was conducted using an enclosed double-arc closing environmental bucket to limit sediment remolding and also reduce the risk of the 3Rs. The bucket used has a relatively flat footprint that does not use a plowing type action to collect material during closing, but rather uses more of a slicing action to remove a block of sediment. This results in less water entrainment within the dredge material.

No Overfilled-Buckets: In order to reduce the risk of contaminant release, the contractor was instructed to carefully avoid overfilling the dredge bucket at all times. This was made possible by the instrumented dredge equipment. When the bucket is overfilled, significant quantities of sediment can be suspended up into the water column thru the bucket vents during bucket filling and closing and from excess material being washed off the top of the bucket during ascent thru the water column (Figure 5).

Figure 5. Example of overfilled bucket.

Remove Water from Sediment Barges and Process – No Barge Overflow Allowed: The free-water from the dredging process was collected from the barge (Figure 6) and pumped to an on-shore treatment facility to remove contaminants before being discharged back to the waterway. This greatly reduces the risk of releasing contaminants.

Figure 6. Pumping water from sediment barge during dredging.

Place Initial Backfill: As a precaution, fifteen centimeters (six inches) of backfill material was placed over completed dredge areas as soon as practicable behind the dredge in order to reduce or eliminate potential mobilization of any residuals.

On-Board Dredge Engineer: A two-person team consisting of dredge engineer and operator was in the dredge cab (Figure 7) to implement the RDMs, improve environmental outcomes, and increase dredge productivity. Teaming a full-time, on-board dredge engineer with the dredge operator resulted in a cleaner, faster, and lower-cost project when compared to more conventional methods that would have resulted in greater residuals, releases, dredge volumes and disposal costs. Having the engineer monitor implementation of the RDMs, the dredge plan, stair-step dredge cuts, and barge loading and status—as well as coordinate upcoming stepping and moving of the dredge—allowed the dredge operator to focus solely on optimizing dredge operation. As a result, the precision of the dredging improved; overdredging below the target elevation was reduced or eliminated; and cycle time, bucket fill factor, and effective working time all improved. The dredge engineer collected valuable operating data that was used daily to improve project efficiency and effective time.

Figure 7. Expanded cab with operator and dredge engineer.

PROJECT RESULTS

Water Quality Monitoring

Turbidity monitoring was conducted 89 meters (150 feet) downstream of dredging operations. The criteria was 5 nephelometric turbidity unit (NTU) maximum over background. 108 monitoring events were conducted, and of those 96 of the events showed no exceedances and only 12 events exceeded the criteria with results between 5.2 to 13.4 NTU over background. For these exceedances, some issues were identified which could have contributed to the elevated turbidity including debris, backfill, and other projects working nearby.

PCB monitoring was also conducted at 89 meters (150 feet) downstream of the dredging operations. The criteria for this was not to exceed 0.03 ug/L PCBs. 53 monitoring events were done, and of these, only one event exceeded the criteria with a result of 0.067 ug/L PCBs. This exceedance could also have been contributed to by encountering debris and other projects working nearby.

Post Construction Sampling

After completion of the remediation in the waterway, post-construction cores were taken in order to document the results of the project. 19 sediment cores were taken throughout the DSOA area, and of those samples, only one core showed a residual layer (Figure 8), while all others showed that there was no residual layer, showing that the RDMs that were implemented were very successful in eliminating residuals.

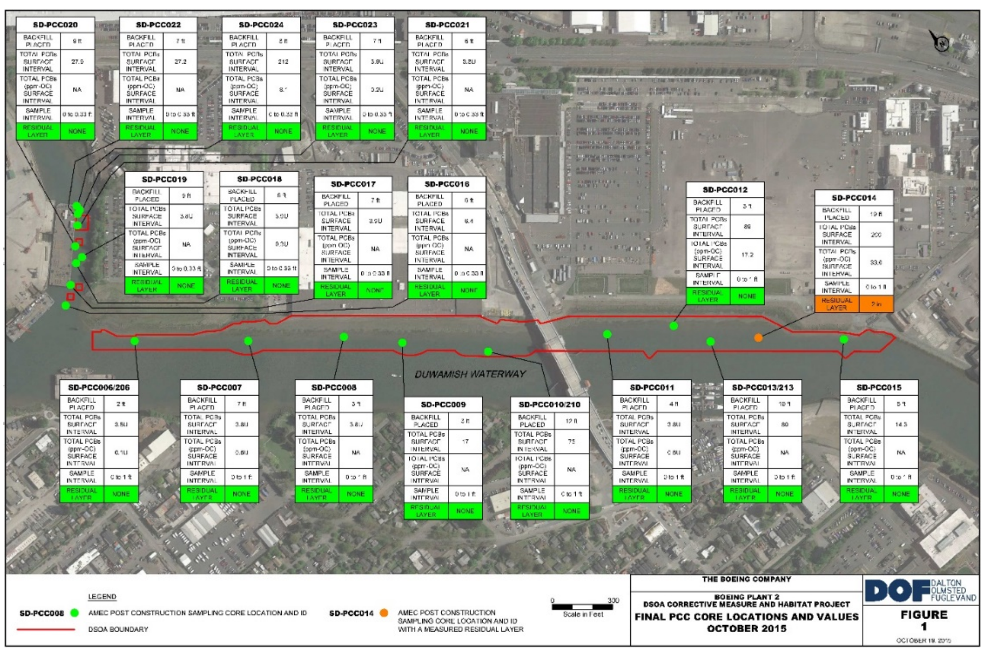

Figure 8. Post dredging results.

COST DRIVERS

Addressing stakeholder concerns and meeting dynamic agency requirements for this sediment remediation project added to the capital and operating cost for the project. Boeing needed their dredging contractor to strictly adhere to the RDMs in order to reduce risk by reducing or eliminating residuals and to protect downstream areas from contaminant resuspension and release. The project was a Resource Conservation and Recovery Act (RCRA) site, which required additional permits including a state-implemented Clean Water Act (CWA) 401 permit. Some of the main cost-drivers for the project are discussed below.

Dredge Return Water: During the planning and contracting stages, including within the EPA approved project plans and project bid documents, dredge water was to be processed onshore using chemical flocculants and Geotubes, with discharge of resulting water back to the waterway as dredge return water. As a RCRA project, discharge of the dredge return water back into the Duwamish required a state issued Water Quality Certificate which resulted in the discharge being regulated by the state as a National Pollution Discharge Elimination System (NPDES) outfall, with no short term water quality variances allowed. Marine chronic water quality criteria were required to be met at point of discharge. Additionally, the use of chemical flocculants would not be allowed without significant toxicity testing, which would have created significant project delays and added cost. Because of this no chemicals could be used for water processing. In order to meet the strict regulatory criteria for the dredge return water, a Dredge Return Water System (DRWS) was constructed using electrocoagulation instead of chemical flocculation. Electrocoagulation is a proven technology that had been applied to mining, stormwater and industrial applications but had not previously been used for a dredging project. The use of electrocoagulation required a much larger, more complex and more costly system than necessary for the use of chemical flocculants and geotubes. This included construction of a large settling basing prior to electrocoagulation and use of a large clarifier post electrocoagulation. The relative magnitude of the two systems for the same dredge production rate can be seen in Figures 9 and 10.

Figure 9. Geotube and chemical flocculent dredge water system (Head of Hylebos).

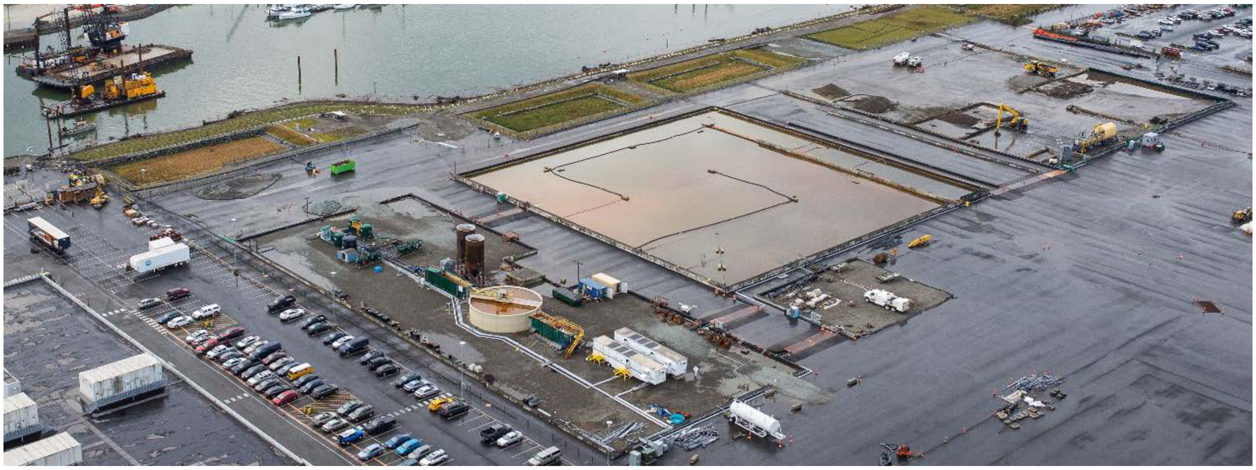

Figure 10. Electro coagulation dredge return water system (Boeing Plant 2 Sediment Remediation).

Compared to the originally planned geotube and chemical flocculent system the electrocoagulation system increased project costs by approximately $7 Million.

In-Water Work Seasons and Active Tribal Fishery: Another cost driver for this project was the allowable in-water work window in order to protect salmon and tribal fishing. In many areas of the Puget Sound and other Washington state waters, the in-water work season is restricted to six months or less of the year. For this project, in water work was suspended each year from March-August in order to protect out-migrating juvenile salmon. Due to this, dredging was conducted over three construction seasons, requiring multiple mobilizations and demobilizations and equipment costs to be incurred during the off season to assure its availability during the following construction season.

Additionally, the Duwamish Waterway is an active fishery for the Muckleshoot Indian Tribe, with Tribal fishing generally occurring from August thru early December. During that time period, large numbers of Tribal fishing vessels, fisherman and nets are present in the waterway. Tribal fishing activities and proximity to project equipment is shown in Figure 11. Boeing worked with the Muckleshoot Indian Tribe to support their fishing during the project by coordinating the daily movement of barges with their activities.

Costs associated with performing the work over three separate in-water seasons and working to avoid interference with Tribal fishing increased project costs by an estimated $7 Million.

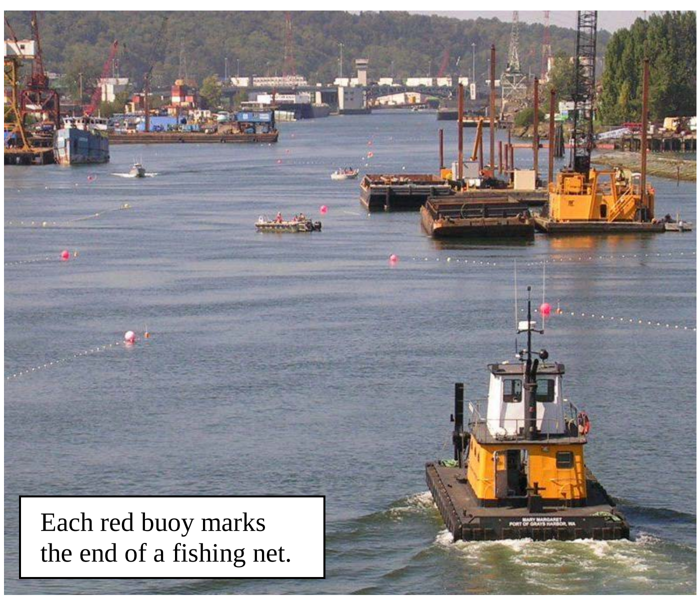

Figure 11. Tribal fishing boats and nets in waterway during remedial action.

Other Construction Projects: Other projects in the vicinity impeded or complicated project activities and increased project costs. Additional project coordination and navigational challenges occurred due to neighboring sites conducting other Early Action Area (EAA) remediation projects concurrently (Figure 12) and the construction of a new bridge (Figure 13), which bisected the project site requiring dredging to be performed under the new bridge. Dredging under the bridge was a slow and carful process and required use of diver hydraulic dredging immediately adjacent to the new bridge structures. Although successfully performed, dredging under the new bridge, coordinating with bridge construction and construction of adjacent EAA’s added project complexity and costs.

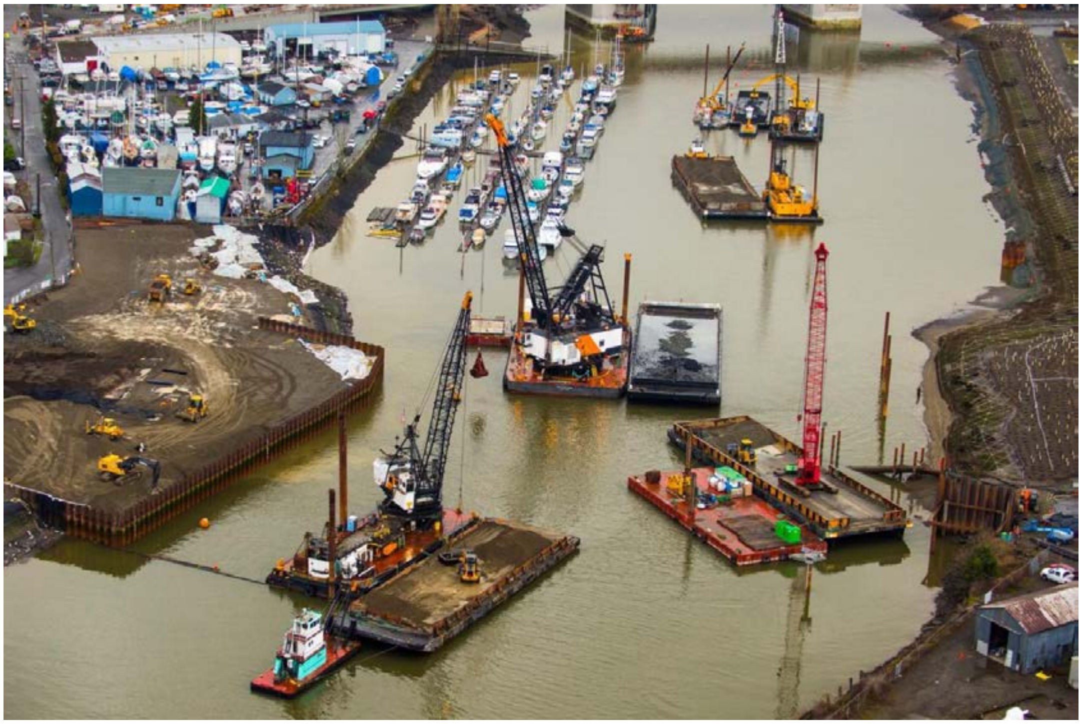

Figure 12. Other neighboring projects can create impediments.

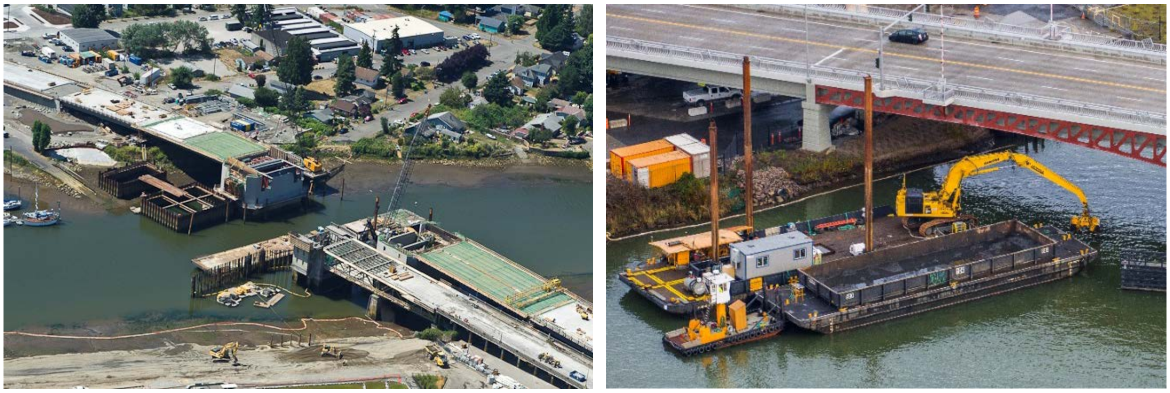

Figure 13. County bridge construction and resulting dredging under new bridge.

Working Hours Per Day: In order to reduce the project impact to the residents located on the waterway’s west bank, the EPA initially restricted in-water work to daylight hours. This would have made a significant impact on the cost of the project due to the high daily equipment rates and a prolonged project duration, so Boeing proposed a pilot 24 hour per day, 7 day per week work schedule in combination with strict best-management practices for noise and light control. The pilot was successful and the EPA and neighbors agreed to allow day and night work (see Figure 14) to continue for the three seasons. If two shifts per day had not been allowed, project duration would have doubled increasing costs.

Figure 14. Working multiple shifts reduces project duration and costs.

Backfill: Part of the project requirements was to backfill dredged areas back to original grade, including restoration of the subtidal elevations for habitat concerns. This required the placement of over 240,000 metric tons (265,000 tons) of backfill material. In order to meet water quality guidelines, the backfill material had to be washed and the turbidity during placement couldn’t exceed 5 NTU over background (see Figure 15), which required slower placement of backfill material than could otherwise be achieved. Backfilling increased project costs by $13 Million.

Figure 15. Example of 5 NTU water and backfill placement with turbidity.

Transload Capacity: One of the big sources of downtime for the dredge was the transload facility being unable to unload sediment barges due to full capacity of their sediment vault; an approximate 7200 metric ton (8000 ton) capacity storage area. The transload facility relied on rail cars to unload their vault, so there were times when delay from the rail cars caused a delay to the dredge due to all the sediment barges being full. There are many factors that can interrupt the consistent flow of rail cars needed to support a project. With limited storage capacity, rail cars must be delivered, loaded and removed from project site at a rate roughly consistent with project production. Factors at the landfill and along the transportation corridor can affect rail car availability as can the availability of crews to move the rail cars. Downtime on the dredge, which can bring the entire project to a standstill, can have significant cost impacts to a project. These cost increases can be very large if such delays create the need for an additional dredging season. Such factors are difficult to anticipate and factor into project cost estimates but must be considered to develop realistic production and cost estimates.

COST SUMMARY

Table 1 shows a summary of the project costs, including a price per cubic yard of sediment dredged. As described above, many factors related to compliance increased the cost of the project including water treatment per the state CWA 401 permit and project coordination and in-water work windows.

Mobilization costs were increased due to performing work over multiple seasons.

Dredging costs for the bulk of the dredging were $89 per cubic meter ($68 per CY), but were roughly 20 times higher for specialty dredging and offloading of Toxic Substance Control Act (TSCA) level sediments and from under the newly constructed bridge requiring diver dredging.

Disposal costs are roughly three times the cost of open water dredging itself. If disposal costs could be reduced by means of project or regional Confined Disposal facilities (CDFs), the total cost of remediation by dredging could be significantly reduced.

The accuracy provided by the precision excavator can significantly reduce disposal quantity and costs. A precision excavator can reduce overdredge volume across the project area by 10 to 15 cm (4 to 6 inches). For the Boeing project, this reduces the project volume by 6880 to 9940 cubic meters (9,000 to 13,000 CY). This results in a savings of $2 to $3 million based on dredging and landfilling costs. This savings from volume reduction alone more than paid for the onboard dredge engineer.

Backfilling to grade added $13 Million in project costs in order to restore the area.

Table 1. Construction costs for Boeing Plant 2 Remediation.

Activity	Units	Quantity	Cost	Unit Cost
Mobilization/Demobilization			**$3.7 M**	
DREDGING AND LANDFILLING				
Dredging				
Open Water	m^3 (CY)	*123,500 (161,500)*	*$11.0 M*	***$89/m^3 ($68/CY)***
Under Bridge	m^3 (CY)	*765 (1000)*	*$1.2 M*	*$1600/m^3 ($1200/CY)*
TSCA	m^3 (CY)	*380 (500)*	*$0.6 M*	*$1600/m^3 ($1200/CY)*
Survey/Controls			*$2.0 M*	*$16/m^3 ($12/CY)*
Dredging Total	m^3 (CY)	**125,000 (163,000)**	**$14.7 M**	**$118/m^3 ($90/CY)**
Landfill (1) 209,000 Metric Tons (230,000 Tons)			**$29.7 M**	**$240/m^3 ($182/CY)**
TOTAL Dredging + Landfilling			**$44.4 M**	**$360/m^3 ($272/CY)**
BACKFILL, DERRICK SUPPORT / OUTFALLS				
Backfilling				
Purchase & Deliver			$6.1 M	
Place w/ Derrick			$7.0 M	
Backfill Total	**Metric Tons (Tons)**	**240,000 (265,000)**	**$13.1 M**	**$55/Metric Ton ($49/Ton)**
Derrick Support / Outfalls			**$4.8 M**	
TOTAL Backfill & Derrick Support			**$17.9 M**	
CONSTRUCTION MANAGEMENT / OVERSIGHT				
Sampling & Monitoring			$2.9 M	
Construction Oversight			$1.9 M	
Construction Management			$2.5 M	
CM/Oversight Total			**$7.3 M**	10% of Construction Cost
Total Construction Cost			**$73.3 M**	

(1) Landfill includes water treatment (4.4 M gallons), sediment offload, stabilization, transport & disposal

CONCLUSIONS

The implementation of these RDMs can be a very effective strategy for significantly reducing or eliminating the risk of contaminant residuals, release, and resuspension. From the results of Boeing Plant 2 site restoration project, it was shown the dredging residuals don't have to be a given for a dredging project, as previous literature about dredging has suggested. The RDM's do add project costs, but those costs can be offset by reduction in overdredge quantities and improved efficiency while achieving risk reduction for the owner.

This project also encountered several factors that drove the cost of the project up, including compliance issues, in-water work windows, and downtime due to sediment offload at the transload facility. Factors such as reduced in-water work periods increase the costs for all projects by increasing the cost for equipment. Equipment that must be paid for and maintained 12 months per year may only be able to be used for less than 6 months per year, so ownership costs must be spread over less working time and scarcity of equipment during reduced work windows can further increase project costs.

Water quality criteria that requires the placement of clean backfill material at less than optimal rates in order to prevent increase of 5 or more NTU's above background, even when such value is well below the range of natural variation within the waterway, increase costs.

These factors should be taken into account, as applicable, when cost estimating for a project. If project equipment can physically place 4500 metric tons (5000 tons) per day but only 900 metric tons (1000 tons) can actually be placed in order to avoid exceedances of the 5 NTU criteria, both project schedule and costs will be significantly impacted. Projects in different areas may not encounter these exact issues, but will have unexpected issues that increase project complexity and costs.

Citation

Webb, Robert S.; Fuglevand, Paul; Anderson, Brian; Tochko, Steven; and Dreher, Teal. "Boeing Plant 2 Sediment Remediation: Remedial Dredging Methods to Manage the Risks of Residuals, Resuspension and Release; the Benefits and Costs," *Proceedings of the Western Dredging Association "Dredging Summit and Expo 2017"*, Vancouver, British Columbia, Canada. June 26-29, 2017.