ASSESSING REMOVAL APPROACHES FOR VARIABLE SEDIMENTS IN HIGHLY URBANIZED AREAS

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ABSTRACT

Channel deepening and beach replenishment projects get a great deal of press; however, these types of projects do not represent all of the types of dredging necessary to maintain our waterways. Small urban waterways such as canals, bays, ponds, and lagoons affect our lifestyles as well. Besides recreational and aesthetic benefits, their natural function is as part of the urban water cycle. These waterways may also convey treated wastewater, CSO and storm water that result from development within their watershed. . The result is a mixture of natural marine materials, as well as a variety of solids that result from long-standing discharges of treated wastewater, CSO, storm water and their associated contaminants. Urban development creates confined, highly visible work sites where this accumulated material limits water depth making waterbodies nearly unusable for navigation or recreational uses.

Urban areas present a unique set of factors that make design and execution of dredging projects challenging. This paper presents potential factors to consider when designing a dredging project where variable sediments occur in urban settings. The factors are demonstrated in a case study of two similar waterbodies within the New York City area. These waterbodies share similar surroundings, discharges, and physical constraints.

Keywords: dredging, contaminated sediment, design, shallow waterbodies, cost assessment

INTRODUCTION

Dredging can be an inherently difficult undertaking. The presence of water complicates even the most straight-forward sediment removal project and unknowns are almost unavoidable. It is critical to thoroughly consider the information relevant to a site in order to overcome the inevitable issues that threaten budgets and on-time project completion. Highly urbanized areas can be one of the more challenging site types that an engineer must design for and a dredger must work within. Prior to the advent of the Clean Water Act, developing cities had historically capitalized on their proximity to water as a means to dispose of various types of wastes. Storm and sanitary sewers, had historically conveyed waste and storm water from developed areas into these receiving waters. Solids from these systems easily collect at the point of discharge, as do a plethora of items that are dumped along the shoreline of a waterbody. The accumulated material is physically heterogeneous, ranging from typical marine sediments to organic, degrading muck, and often contains any variety of debris. Development also often results in limited work areas that can make equipment access an issue. These issues include the requirement to navigate through narrow channels and negotiate low clearance bridges, bulkheads, docks, and other structures.

This paper will review factors that may be part of a dredging design process in developed, highly urbanized areas and demonstrate how the interaction of these factors guide the selection of dredge equipment and other project components. Factors to consider include the chemical and physical variability of the target materials, the physical size and configuration of the site, applicable regulations, and the influence of these factors on project cost. This paper will illustrate how these factors may drive engineering decisions through the presentation of case studies. Two similar and geographically proximate waterbodies in New York City will be reviewed as a case study of comparison and contrast.

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DESIGN DECISION PROCESS

Designing for dredging presents the engineer with a variety of factors to consider. These constraints can be grouped generally into three major categories, as shown in Figure 1. Each of these categories, "Site Characteristics", "Regulatory Constraints" and "Differences in Cost", contain factors that independently may influence designs, but must also be considered cumulatively to arrive at a preferred design approach. At the very core of a dredging design is the selection of the type of equipment to be used for removal of the intended material. Both hydraulic and mechanical dredging methodologies should be considered appropriate for use in urban areas until each are assessed considering the unique project site constraints.

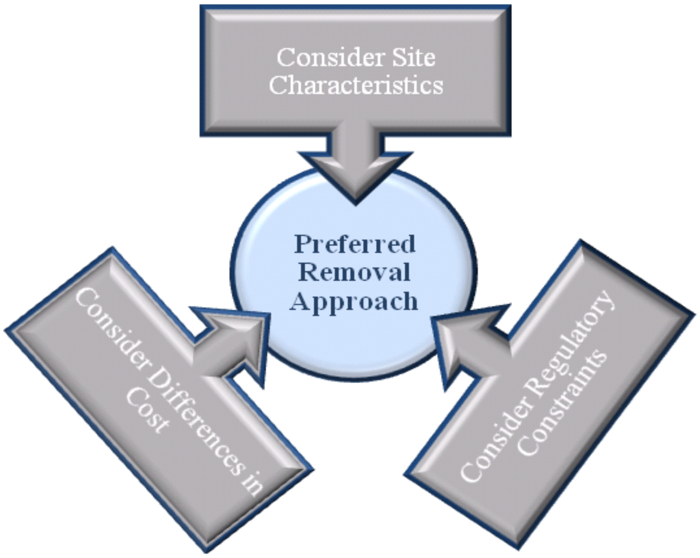

Figure 1. Factors influencing the engineering assessment.

Site Characteristics

The physical nature of the target material and overall layout of the site directly impact what dredge technologies are viable for construction. Material properties and site layout may certainly affect whether a specific piece of equipment can effectively access and remove the desired material. Typical sediments within an urban environment will be a heterogeneous mix that can range from clean silts and sands that accumulated naturally, to organic material and debris that have accumulated in the sediment as a result of human influence. Setting aside the metric of efficient production, the basic question "can a specific type of equipment dig the target material" should be answered. The answer is generally that with some exceptions, it can generally be assumed that conventional hydraulic or mechanical equipment is designed to remove the bulk of material that exists within urban tributaries.

However, efficient removal is important and the nature of the target sediments may favor one type of dredge over another. Though material may be comprised mainly of granular material such as silts and sands, heterogeneity with organic matter and debris may expose limitations to particular types of dredge equipment. For instance, debris is not uncommon in urban waterways, as illustrated in Figure 2. Items such as timbers, concrete, wire and plastic in all forms and sizes can find their way into the waterbody through combined and storm sewers as well as from the shoreline dumping. Cutterheads and slurry pipelines of hydraulic dredges are particularly sensitive to clogging when encountering debris causing work to stop for lengthy repair. Where clogging does not occur, the debris may be pushed aside by the cutterhead and not removed which may not achieve the objectives of the project. Mechanical equipment is more capable of dealing with issues regarding debris compared to hydraulic dredging. However, the debris may prevent proper bucket closure which could result in the loss of material to the waterbody although the debris itself might be recovered.

Figure 2. Debris typical of urban waterways.

Similarly, degraded, organic-rich sediments such as those shown in Figure 3 may be little more than flowing muck. This "ooze" may pose issues for efficient removal by mechanical means and be more readily removed by hydraulic systems. The generation of pressure waves generated by a lowering or raising bucket (particularly open bucket-type excavators) is a common cause of spillage. Flowing muck also tends to adhere to the sides of the dredging equipment. Subsequently sloughing causes material to be "rinsed" from equipment and lost as suspended solids to the surrounding water column as the bucket is raised through the water column, resulting in increased turbidity Dredging mechanically, even with its associated issues, will deliver muck at near *in situ* densities, avoiding dewatering issues on difficult materials. "Ooze" may be more easily entrained hydraulically, but the ease with which it subsequently dewaters will affect its cost-effectiveness as the water entrained by hydraulic equipment must be removed from the sediment slurry before its transportation and ultimate disposal

Figure 3. Organic muck collected from dead-end tributary.

Anticipating the digging environment should also include assessing those areas adjacent to the proposed dredge site. Shorelines are often lined with sensitive wetland habitats or degraded structures such as bulkheads, retaining walls, bridge abutments and docks. The engineer must consider the precision with which equipment can operate, and the effect of dredging on the stability of these structures. Therefore, efficiency of removal may actually be maximized by combining dredging techniques, or planning the dredge profile specifically to avoid the area. The critical question to be answered is whether the proposed equipment can access the dredge area. Shoreline development may limit width of waterways, and structures surrounding the shore may interfere with land-side access.

Figure 4. Undermining vegetation and structures should usually be prevented in near-shore dredging.

Point source discharges of storm or combined sewers deposit suspended material in the water immediately near the outfall as water velocity is reduced. The result is often small areas that quickly fill with sediments. If this material is allowed to accumulate, water depths can disappear as sediment collects, which ultimately results in a two-fold problem of tight working conditions and a lack of water in which to work. The dredging objectives may not alleviate the problem of limited depth for navigational purposes. In the case studies to be discussed, dredging is proposed to provide a final water depth of as little as two to three feet.

Narrow conditions may slow production while dredge units and work vessels are moved carefully, but rarely will it pose dramatic interference. For instance, a small float-mounted mechanical excavator may have a working width of about 6.1-m (20-ft), while a material barge may be 9.15-m (30-ft) in width. Working side by side requires greater than 15.2-m (50-ft) when providing an allowance for smaller work boats; working in series (one behind the other) will minimize the operable width even further. When a point is reached that small dredge units and construction vessels cannot feasibly navigate a work site, the waterway is likely narrow enough to consider land-side excavation as a method of dredging. Existing long reach excavators can reach 15.2-m (50-ft) or more.. Access from shore may pose its own constraints and infeasibility, but there are potential benefits to be had, not the least of which is avoiding depth-limited areas.

Shallow conditions have a larger impact on assessing appropriate dredging methods. When selecting a viable dredge technology, one must consider the size of the dredge itself and any other associated vessels in relation to the site area. The dredge itself is not necessarily the most critical piece of equipment to consider in terms of water depth for site access. Lagoon and pond oriented hydraulic dredges routinely draft approximately 61-cm (24-inches), similar to small mechanical excavators on modular marine construction platforms and dredge-specific excavators. Mechanical methods have some disadvantage at depth-limited sites, because a haul barge is necessary to remove the material from the work area. Haul barges may draft up to 4.9-m (16-ft) when fully loaded and shallow draft-specific barges may still require between six and eight feet of water to navigate the waterbody. For purposes of this discussion, “draft-limited” is considered any depth that prevents unimpeded access of construction vessels; effectively, where water depths do not exceed 4.9-m (16-ft).

Draft-limits do not automatically preclude use of mechanical methods. Certainly specialized plants have been purposefully developed to minimize handling issues; however, these are not necessarily numerous and the availability of such equipment is a consideration. “Access” dredging can be considered (and often is) to make water for the equipment with conventional drafts. This technique produces additional dredged material which must be handled and properly disposed impacting construction time and cost. On projects where hydraulic technologies are completely infeasible, access dredging may be unavoidable. Additionally, on projects where hydraulic technologies are feasible, the cost of access dredging to allow for mechanical dredging should be assessed versus the cost of the dewatering slurry.

Regulatory Constraints

Often, dredging of urban waterbodies is performed as part of an established remedial program for an adjacent upland site. . However, this is not always the case. For dredging projects performed in New York State (NYS) that are not a part of a formal remedial program, the NYS Department of Environmental Conservation developed a guidance document titled *Technical and Operational Guidance Series 5.1.9 (TOGS)*. This document provides direction for "navigational dredging projects, dredging of channels and berths, dredging of ponds, trenching for pipelines and cables, and dredging in both marine and fresh waters..."

The TOGS provides a screening list of compounds typical of contaminated sediment, and provides a tiered classification system related to the magnitude of contaminants observed. Based on overall classification, the TOGS provide acceptable dredging technologies and disposal options. These range from "Class A: No Appreciable Contamination (No Toxicity to aquatic life)" to "Class C: High Contamination (Acute Toxicity to aquatic life)". Class A material may be removed and disposed of in any generally accepted manner. Class C material; however, must be dredged by a closed, environmental bucket or hydraulic dredge, with the dredged sediments disposed of at a contained upland facility. . Using the appropriate guidance documents can reduce the options that may be considered, but it is important to understand the limits set forth by the guidance, and work within these imposed limits.

Regulators can impose additional restrictions to those explicitly stated within guidance documents. Permit stipulations and access permission are two examples of regulatory restrictions. For instance, permits routinely limit the acceptable levels of down-field turbidity. The dredging process itself may not necessarily be the source of turbidity. Wheel wash from moving vessels can suspend fine muck, as shown in Figure 5, creating thick plumes of turbid water. Production rates from mechanical dredges may be slowed significantly if downtime is required to allow suspended solids to resettle sufficiently before opening silt curtains to move vessels from the dredge area. Hydraulic dredge plants may require additional filtration steps for the dewatering process to control discharge of residual suspended solids from the dewatering step. In a manner similar to site characteristics, mitigating regulatory constraints may impact overall project cost.

Figure 5. Visual turbidity may be enough to exceed permit stipulations.

Cost Considerations

Cost considerations are both independent and dependent on other factors. Market factors define current costs for operators, equipment, and fuel, and contractors seek to maximize profit while remaining competitive. However, assessing sediment characteristics and the impacts of applicable guidance requirements can result in a planned approach that maximizes the efficiency of available equipment. For purposes of this paper, it has been assumed that hydraulic dredging is more costly than mechanical means on a unit cost basis because dewatering of dredged material slurry is a necessary step in handling. The factors for this generalization should be assessed for each job. The benefit of hydraulic equipment at sites with limited water depths is that the shallow draft dredge plant is the only vessel that needs to access the work area continually, as the dredged material can be pumped via pipeline out of the work area for handling. Conversely, mechanical dredge plants require immediate access to a barge to unload during each bucket cycle, and the draft requirements of these material barges might require access dredging, which would increase the overall quantity of material to be handled. From a strict cost perspective, the cost balance becomes one of cost per unit to the overall quantity of material to be removed. Hydraulic dredging may carry a greater overall cost for each cubic yard of dredged material, but minimizing the overall quantity of material to be removed may yield a lower total project cost.

Where disposal options are expensive, as in cases where elevated contaminants are present, the cost of sediment disposal is a large cost consideration. Upland disposal costs may equal the per unit cost of actual dredging, and range up to several times more if the material to be disposed of is deemed “hazardous material”. The potential for sediment contamination in urban areas is very real as waterways co-exist with legacy sources of contamination such as indirect historical industrial discharges (intended or otherwise) and other point source discharges when regulation of such indirect discharges may not have existed. Silts, clays, and organic materials tend to bind contaminants and require disposal options that need to be controlled. Minimizing overall disposal quantity may be the driving force more due to the cost of disposal than the incremental cost of dredging.

CASE STUDIES

Site Background

Jamaica Bay is part of the Gateway National Wildlife Refuge, designated by the United States National Parks Service, situated generally between Sandy Hook, New Jersey and Brooklyn, New York. The Bay is also a designated New York State Significant Fish and Wildlife Habitat (EEA, 2008). Jamaica Bay is bordered by the New York City boroughs of Brooklyn and Queens. Accordingly, the area surrounding the Bay is highly urbanized. This development has resulted in the numerous waterways tributary to the Bay being used as discharge points for treated wastewater and storm water run-off. The wastewater collection system proximate to the dredging sites was constructed as “combined sewers” by original design. At times, and as a result of precipitation events of certain durations and intensity, the volume of storm water and waste water within the combined sewer is too high to be handled by the existing water pollution control plant. During these limited occurrences, that combined sewage which cannot be handled by the plant is directly discharged to the Bay via combined sewer overflows (CSO). These overflows result in discharge of not only the water component but also the suspended solids component which might include debris, organic matter, oils and greases, etc. The US Army Corps of Engineers recognizes that “industrial history”, including CSO and storm water discharges, have resulted in contaminated sediments within existing sediments and remaining tidal marshes (USACE 2004). Hendrix Street Canal (Hendrix) and Paerdegat Basin (Paerdegat) are two such tributaries that receive CSO discharges.

Both Hendrix and Paerdegat are approximately 2134.1 linear meters (7,000 linear feet) long from their head-end to their confluence with Jamaica Bay and each have considerable bulkheading at their shorelines. Hendrix ranges from 45.7 to 76.2 meters (150 to 250 feet) in width and from zero to 4.6 meters (15 feet) in depth at mean low water (MLW), although greater depths are generally observed near the mouth of the Bay. A CSO discharge is located at the head-end of the Canal. Paerdegat is wider (152.4 meter (500 foot) width) and deeper (6.1 meter (20 feet) at MLW) than Hendrix and has three separate CSO discharges at its head-end. These waterbodies are tidally influenced; however, their closed configuration makes them depositional sinks for solids and fines, as is evidenced by the CSO sediment mounds which are exposed at low tidal conditions. Additionally, Hendrix also receives treated effluent from a water pollution control plant serving the boroughs of Brooklyn and Queens, NY

There are three individual target dredge areas within the two waterbodies, as shown in Figure 6. The head-ends of both Hendrix and Paerdegat have CSO discharge locations and are heavily shoaled with CSO-related sediments that have accumulated since the time of initial dredging. The mouth of Paerdegat is less impacted by CSO-related material; however, the mouth is occluded by shoaled sands. This creates navigational challenges for the numerous private boaters traveling between marinas within the Basin and the Bay. Both waterbodies are bisected near the Bay by the Belt Parkway.

Figure 6. Proposed dredging areas within Brooklyn, New York.

Project Objectives and Rationale

The accumulated CSO material is believed to be a source of nuisance odor to the surrounding community when exposed at low tide and dredging is being undertaken by the City to mitigate the occurrence of these odors. Figure 7 shows the degree of sediment exposure at low tide. Each target area has its own target dredging depth. The uppermost 442.1 linear meters (1,450 linear feet) of Hendrix is to be dredged to 0.76 meter (2.5 feet) below MLW. This dredge area ranges in depth from zero MLW to minus six feet MLW. The uppermost 198.2 linear meters (650 linear feet) (head-end) of Paerdegat is to be dredged to 0.91-meter (3-feet) below mean lower low water. This area ranges in depth from zero MLW to minus 2.4 meters (8 feet) MLW. After dredging, the sediments within both of these waterbodies will be continually submerged at low tide levels.

Figure 7. Mean low water condition exposes collected CSO sediments within Hendrix Street Canal.

The dredging at the mouth of Paerdegat is being performed as part of an agreement between the City and private stakeholders to improve navigational access to marinas located within the Basin. An approximately 243.9-meter

Table of Contents

(800-foot) long, 12.2-meter (40-foot) wide section at the mouth of Paerdegat is to be dredged to 3.7 meter (12 feet) below MLW to restore reasonable water depth for navigation by private boat owners to the Bay. This dredge area is bisected by the Belt Parkway bridge and the bulk of material to be removed is immediately adjacent to the bridge supports.

Nature of Target Materials

The material currently collected at the head-end of both Hendrix and Paerdegat has been collecting since the early to mid 1900s when each was last dredged. It is high in organic material ranging up to more than 20% Total Organic Carbon (TOC), and low in overall solids content which ranges between 20% to 40% solids. It resembles a black muck with little grain structure, although larger grained sands accumulate at shorelines and depositional areas. The CSO material has a D_{50} of approximately 0.025 mm exhibiting the overall characteristics of organic silt to clay with some sand.

Much of the material was deposited decades prior to implementation of environmental regulations. Given that the combined sewers historically received unregulated discharges prior to promulgation of the Clean Water Act, anything that was discharged or washed into the combined sewers could be deposited within these tributaries via CSO discharges. The chemical nature of the CSO material is therefore unsurprising. Figure 8 shows the predominant contaminants within the tributaries and the range of contamination observed. These include the metals of cadmium, lead, and mercury, and persistent pesticides including Chlordane and DTT as well as poly-chlorinated biphenyls (PCBs). Compounds characteristic of fuels and oils were also found (poly-aromatic hydrocarbons and BTEX) at lower relative concentration levels. Observed concentrations through the dredging depth well exceed state screening limits for protection of waters and established levels for acute affects to biota. The concentrations of these constituents significantly increase with the depth of the sediment. The lowest concentrations are observed at the present day sediment surface corresponding to the most recently deposited sediments, suggesting that control programs such as the City’s Industrial Pre-Treatment Program have had a positive impact on these waterways.

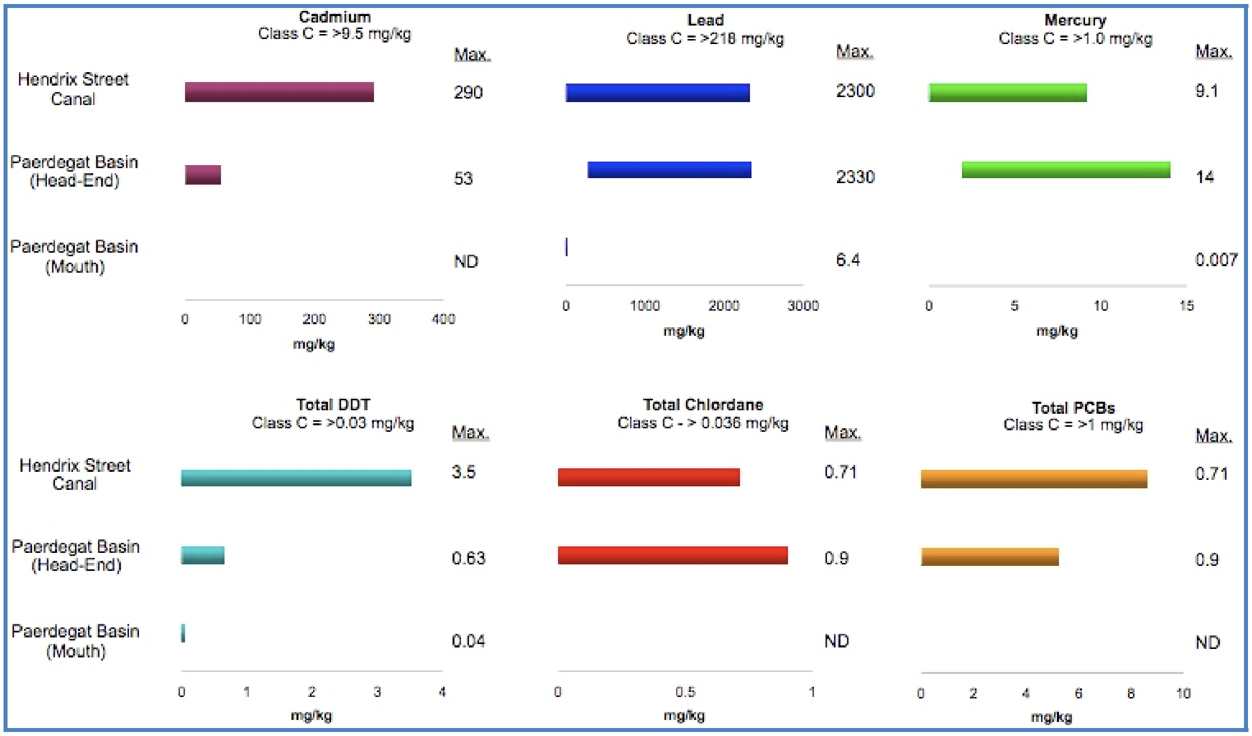

Figure 8. Primary chemicals of concern within the target dredge areas.

The material at the mouth of Paerdegat exhibits very different characteristics. Shoaling of larger grained sands has occurred, while collection of fines and organic material has not occurred. The material in this area is predominantly graded sand (D_{50} 0.35 mm) at 70% to 90% solids with virtually no organic matter (less than 1%). As evidenced in Figure 8, appreciable levels of contamination are absent from the mouth sediments. The difference in grain size and organic content is significant, as fine silts, clays and organic matter typically bind contaminants. Figure 9 provides a visual comparison between collected CSO core samples (left) and mouth core samples (right).

Figure 9. Visual comparison of CSO sediment (left) to shoaled marine sand (right).

Assessing Design Factors for CSO Sediments

As shown in Figure 8, the target material in the head-end of Hendrix and Paerdegat exceeds the limit for "Class C" contaminants per NYSDEC guidance. Simply by inspection of the TOGS, Class C material must be dredged by environmental means, explicitly precluding the use of an open bucket excavator. "Environmental" closed buckets and hydraulic methods are deemed potentially acceptable. Dredged material disposal is also limited to upland facilities only.

Figure 10. Belt Parkway bridge over Paerdegat Basin.

The Belt Parkway bridge imposes an additional regulatory constraint. A recent barge strike on the bridge supports over Paerdegat (shown in Figure 10) has left the pier system damaged. As a result, the New York City Department of Transportation (DOT) advised that construction vessels such as barges should not travel beneath the Belt Parkway until the bridge is reconstructed. The NYCDEP is in discussion with both the DOT and the United States Army Corps of Engineers to assess if changes to construction techniques, such as using only small material barges to travel beneath the bridge, might minimize the risk of further damage and be an acceptable compromise to allow dredging to occur mechanically. Such a compromise would necessitate an additional rehandling step on the Bay side of the

Table of Contents

bridge to a larger barge suitable for open water travel through the Bay. A DOT restriction could preclude use of mechanical equipment, since removal by barge directly to a processing facility is the only feasible means of handling material. Hydraulic dredging would continue to be feasible with slurry pumped to dewatering facilities either on land or on barges in the Bay beyond the bridge.

Hendrix has no such access restriction, although the bridge's support piers within the Canal are particularly narrow and would require material rehandling from smaller to larger barges. Hendrix also appears to be largely free of debris that would impede the progress of a hydraulic dredge or cause disruption to production by an environmental bucket mechanical dredge. Therefore the preferred removal approach ultimately will be refined by assessing construction cost.

Site access to the head-end is limited by depth with both the work area and most of the downstream area being less than 3.05-meter (10-feet) deep, with much of the work area less than 0.61-meters (2-feet) deep at MLW. Small mechanical and hydraulic dredge plants were deemed appropriate for work within the confines of the dredge area, with the realization that work production would be partially reliant on tidal cycles to provide suitable water. A conceptual design was developed to assess relative construction costs. Based on this design, it was estimated that a channel approximately 18.3 meter (60 feet) wide and 1219.5 meter (4,000 feet) long would have to be dug to provide water for construction vessels to access the dredge area if a mechanical dredge were employed. This access channel would deepen the Canal an average of four feet beyond existing grade for the areas outside the proposed dredge area, and also require a channel four feet deeper than the proposed cut elevation within the dredge area. Conceptually, this equates to an additional dredging volume of 24,697 cubic meters (32,300 cubic yards). The target material volume is approximately 15,292 cubic meters (20,000 cubic yards); access dredging would more than double the total volume removed and costs would scale in-kind because much of that material is Class C and would require appropriate disposal.

While additional dredging for barge access increases overall project volumes, in this case the dewatering process necessary for hydraulic methods actually decreases the volume for disposal. Bench-scale dewatering testing demonstrated an increase in solids content resulting in approximately 58% reduction in volume. Increased solids content yields a decrease in sediment volume requiring disposal. It would be reasonable to assume disposal volumes for material dredged mechanically would be greater than *in situ* due to bulking; however, the degree of bulking was not assessed directly and therefore *in situ* volumes were used for a cost analysis.

Table 1 includes a summary of the quantity and cost comparison of hydraulic and mechanical dredging used to assess dredge methodology within Hendrix. This information demonstrates that for this site, hydraulic dredge methods are more costly on a per unit basis, but can result in a lower overall project cost because less material is dredged. Conversely, if the mechanical method is used, the total quantity dredged increases significantly and the overall project cost can be higher, even though the method is less expensive per unit. Dredging for the Hendrix project was ultimately designed and permitted for hydraulic methodology.

Table 1. Cost comparison of hydraulic vs. mechanical dredging in Hendrix Street Canal.

	In situ Solids (cy)	Disposal Solids (cy)	Unit Cost ($/cy)*	Dredging Cost (2007 $)*
Hydraulic	20,000	10,000	$365	$7,300,000
Mechanical	52,300	52,300	$250	$12,800,000
Target volume	*20,000*	*20,000*	---	---
Access volume	*32,300*	*32,300*	---	---

**Costs noted are based on the dredging component of the proposed design only; the total project costs and overall unit costs are higher and include other components.*

Assessing Design Factors for Shoaled Sands

In contrast to CSO sediments, the sand material at the mouth of Paerdegat is uniform, well sorted, and does not exceed Class A standard contaminant screening values. Chemical concentration and physical characteristics of the target material do not immediately eliminate the use of any dredge technology or disposal option. In fact, the sand characteristics are potentially suitable for reuse within the Basin or Bay, and practically negate the costs of disposal; however, a more thorough assessment of suitability would be necessary before reuse at a particular location can genuinely be considered feasible. For the purposes of demonstrating a contrasting assessment, it will be assumed that barge travel beneath the Belt Parkway bridge is allowable.

Depths of the proposed material extend to just below MLW elevation; however, the embankment is sharply sloped providing up to 6.1 meters (20 feet) of water depth immediately adjacent to the target material. The need to remove additional material for vessel access is not anticipated. Further, the target material is sand and no reduction in disposal volumes would be anticipated. Appropriate dredging methodologies can therefore be assessed on the basis of equivalent volume, and as such would indicate that mechanical dredging (including open bucket types) could be effective at a lower cost than hydraulic dredging.

In addition to the need for dredging the 4205.3 cubic meters (5,500 cubic yards) of shoaled sands within the mouth area of Paerdegat, the 11,621.9 cubic meters (15,200 cubic yards) of CSO sediments also must be addressed; making CSO sediment removal the bulk of the target material. The head-end of Paerdegat is similar to Hendrix, and hydraulic dredging would likely be more cost-effective. Should this project be awarded as a single contract for removal of the head-end and mouth material, the overall cost would be influenced by available equipment and efficiencies of mobilization costs. As part of the detailed design, a cost assessment will be performed to assess if the project should be split into two contracts, which may yield lower overall costs. Ultimately, the most suitable dredge methodology may be the one that yields the lowest project costs based on competitive bidding.

CONCLUSIONS

Dredging within urban waterways presents obvious challenges of access and sediment variability. Developing a complete engineering design also requires assessment of less obvious factors. Assuming dredge selection is chosen appropriately for the material type, and considers the applicable regulations, then cost factors become the drivers for selecting the appropriate methods on a project-specific basis. Most often it is balancing all these factors that generate a solid, cost-effective dredge project approach.

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