AN EVALUATION OF OVERDEPTH DREDGING AND ITS ENGINEERING AND ENVIRONMENTAL IMPLICATIONS: CASE STUDIES FROM THE NORTHEAST

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ABSTRACT

In a typical navigation dredging project under construction a required depth, and an allowable (paid) overdepth will be specified. The required depth must be achieved for successful completion of the project, and it may include safety and underkeel clearance elements. The allowable overdepth dredging is permitted to allow for the inaccuracies of the dredging process and it is generally 61 cm (2 ft.) deeper than the required depth. However it has always been recognized that there are also varying amounts of non-paid dredging that usually occurs, which is dredging outside the horizontal and/or vertical limits (allowable overdepth) of the project. In recent months this non-paid overdepth dredging has been the subject of controversy primarily with regulatory agencies, who in some cases has viewed dredging outside the project limits to be a potential environmental regulatory violation. In this paper we will evaluate overdepth dredging (paid and non-paid) for a variety of dredging projects from the New York Harbor / Long Island area to determine the degree of overdepth dredging that occurs given the requirements of the particular dredging projects/contracts, and to identify trends and differences. A variety of dredge types and dredged material characteristics will be examined, for both new work (consolidated) and maintenance (unconsolidated) dredged material. Implications to environmental regulations and enforcement will be discussed. Engineering considerations will also discussed in light of future project designs. It is hoped that an evaluation of specific dredging data from past projects will give all parties greater insight in what we can expect a final product from a dredging project will be, given the specifics of the individual project (type of dredge, type of dredged material, design requirements, etc.). This insight will help engineers to create better designs for future projects, and help environmental regulatory agencies ensure that environmental clearances are inclusive of all possible impacts.

KEYWORDS: Navigation, project operations, project management, bathymetry, surveys

INTRODUCTION

Dredging is the method by which thousands of miles of navigation channels in the U.S. are maintained each year, and the means by which most channel improvements are made. Dredging is not an exact science. There is an inherent imprecision in the dredging process which varies depending on the physical nature of the dredged material, the channel design and the type of dredging plant being used. In order to obtain a desired depth uniformly throughout a navigation channel some quantity of additional material below this desired depth will need to be removed. This fact is recognized in all U.S. Army Corps of Engineers technical guidance documents and regulations relating to channel design and dredging operations, and also in construction contracting documents. It is a well known and accepted industry practice as well. The dredged material that is removed as a result of this practice is known as overdepth dredging.

Although overdepth dredging has been an accepted practice as long as dredging has been done, it has recently gained some new attention due to a few noteworthy incidents at a few East and West Coast major ports. Some of these cases are the subject of regulatory enforcement actions so we will not discuss specifics here. The importance of these cases is that they instigated a new awareness of overdepth dredging with environmental compliance agencies, the U.S. Army Corps of Engineers and dredging contractors. It required us all to re-look at the means by which we characterize our dredging projects for the purposes of environmental compliance. In many cases there are questions about whether the dredged material generated by overdepth dredging has been adequately characterized for environmental compliance during the project planning phase. The magnitude of overdepth dredging has also

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been questioned – does it constitute a significant portion of the dredging project or is it incidental in quantity? Also, how much overdepth dredging should be allowed? This ties directly into the accuracy of the dredging operation – is 30.5 cm (1 ft.) of overdepth adequate? 61 cm (2 ft.)? More? These and other questions have been raised, and many opinions have been offered to answer them. But to these authors' knowledge, there has been little objective data presented to date which might be used to validate any of the opinions.

In order to bring some objectivity to the discussion of overdepth dredging we decided to take a look at it from an engineering perspective, by analyzing before and after dredging bathymetric surveys of several actual dredging projects from the Port of New York and New Jersey. By "forensically" analyzing the results of normal navigational dredging operations we hope to provide an insight into the magnitude of overdepth dredging that actually occurs, the predictability of overdepth dredging that will occur relative to the project design features, and its relative significance in the overall scheme of things (both from an engineering and environmental perspective). In performing this analysis we tried to utilize a variety of types of dredging projects, both new work construction and channel maintenance, so that some of the variables that affect dredging accuracy (physical nature of the material, type of dredging plant, etc.) will be captured. It is hoped that an evaluation of specific dredging data from these projects will provide greater insight in what we can expect a final product from a dredging project will be, given the specifics of the individual project. This insight will help engineers to create better designs for future projects, and help environmental regulatory agencies ensure that environmental clearances are inclusive of all possible impacts.

OVERVIEW OF DREDGING PROCESS

Broadly speaking there are two families of dredges, mechanical and hydraulic. Mechanical dredges typically used in New York District are the clamshell and the backhoe excavator. Clamshell dredges are cranes mounted to a spud barge. Clamshell dredges can be equipped with a variety of buckets, such as "environmental buckets", which are optimized to dig unconsolidated material with a minimum of resuspension, to "rock buckets" that are designed to penetrate and dig very hard material. Backhoe dredges are a hydraulic powered excavator mounted on a spud barge. These dredges are typically used in highly consolidated material (such as consolidated rock and glacial till) where their superior breakout force gives them an edge over clamshells.

There are a wide variety of hydraulic dredges. Due to environmental considerations and the nature of typical dredging projects here, they are not used in New York District as often as mechanical dredges. When a hydraulic dredge is used in New York District it is typically a hopper dredge. A hopper dredge is a self-propelled vessel that scrapes relatively shallow layers off the bottom using trailing drag arms and pumps the dredged material into the hold of the ship. Hopper dredges are well suited to dredging unconsolidated material such as silt or sand.

In a typical dredging project the plans and specification are generally written so that there is a required depth to be achieved throughout the dredging area (also called the dredging prism). Any areas within the dredging prism that are not at the required depth would require the contractor to re-mobilize equipment and remove the material. Typically the means by which we determine whether the contractor has achieved the required depth is by performing before and after dredging bathymetric surveys.

As discussed above, there is an inherent imprecision in the dredging process which needs to be addressed in the plans and specifications for a projects. Typically this has been captured by adding an "allowable overdepth" to the project design. This is typically 61 cm (2 ft.) deeper than the required depth, but on occasion more or less additional depth may be specified based on the specifics of the dredging operation. For example in some coastal projects, where wave action can significantly affect dredging operations, 91.5 cm (3 ft.) of allowable overdepth may be specified. In softer materials 30.5 cm (1 ft.) or 45.8 cm (1.5 ft.) of additional depth may be appropriate. Zero overdepth is not typical, and is rarely used. Allowable overdepth is not required to be removed but the contractor will be paid for any quantities of allowable overdepth that are removed based on before and after dredging bathymetric surveys.

Beyond the required depth and allowable overdepth there will always be some quantity of material dredged that is deeper than the allowable overdepth. This may be attributable to the imprecision of dredging or to a variety of physical factors such as sea state, type of material to be dredged, etc. Corps of Engineers regulations concerning design of dredging projects and cost estimating recognize that all projects will have some non-pay overdepth material that is dredged from outside the dredging prism and require that this material is accounted for in the design and cost estimate. Corps guidance also requires that this quantity of dredged material needs to be considered for its impacts to the environment, and factored into required environmental compliance documentation.

The reason why overdepth dredging may be an environmental issue is because characterization of both the quantity and chemical quality of the dredged material is very important in evaluating the impacts of the disposal of the dredged material and the quality of the environment in the channel after dredging is completed. If overdepth dredging is not properly described and characterized possible environmental impacts will not be properly addressed. If environmental testing does not sample deep enough into the sediment, and miss sampling the overdepth dredged material, there is a risk that chemically uncharacterized dredged material may be improperly disposed. Also, the quality of the sediment that is exposed after the dredging is completed may not be properly characterized if testing does not go deep enough. This could lead to possibly erroneous conclusions concerning the effects to aquatic biota from dredging the channel. Finally the quantity of dredged material directly correlates to physical impacts to the environment at the disposal site – the more sediment you have the greater the possible impact. If the quantity of overdepth dredging is not properly estimated it could lead to misleading conclusions concerning the environmental impacts that may occur at the disposal site. For all these reasons the issue of overdepth dredging has become of concern to environmental review and regulatory agencies, and to this point there has not been much objective data to review to try to answer some of these questions.

The questions that need to be addressed are how much overdepth dredging is to be expected, given the specifics of a particular project design, and when does the non-pay overdepth dredging become significant from and environmental perspective? Is overdepth dredging predictable and consistent or random and highly variable? Do physical factors such as the type of dredging equipment or the physical nature of the dredged material have a major influence on the amount of overdepth dredging that occurs? It is hoped that this paper will provide more insight into these questions and help us to better understand the issue of overdepth dredging.

DESCRIPTION OF STUDY PLAN AND METHODS

To execute this study we considered what projects would make good study subjects, what data from the projects would be illuminating and how to analyze the data.

There are a wide variety of dredges, geologies and project types that could be considered. Fortunately with the wide variety of dredging performed in New York District there was a wealth of data we could use. The first step then was to choose a handful of projects that would be representative. The projects chosen for this paper will include clamshells using environmental buckets, backhoe dredges and hopper dredges.

The geology of New York Harbor is extremely varied due to the fact that it is an area where four distinct geologic provenances intersect, representing igneous and metamorphic bedrock overlain by Mesozoic sedimentary formations, coastal plain sediments and glacial terrains. A brief discussion of the material types encountered while dredging New York Harbor is necessary to understand why the projects analyzed in this paper were chosen. Different materials have different particle sizes. As material becomes coarser the maximum theoretical accuracy of dredging decreases. In other words, if one has a 3 meter diameter boulder that sticks 61 cm into the required dredging prism, the entire boulder will need to be removed, leaving a hole that extends 1.5 meters below the required depth.

The types of material dredged in New York Harbor include Holocene silt and sand, Pleistocene clay and till and Jurassic rock. Silt consists of organic fine-grained unconsolidated particles. Silt can adsorb contaminants fairly easily so the use of environmental clamshell is often required. Sand is coarser than silt and tends not to adsorb contaminants. Clay is a fine grained but cohesive material. The clay encountered in New York Harbor is typically reddish brown in color. It can vary from very soft to as stiff as modeling clay. The stiffer clay can break into fairly large chunks when dredged. Glacial Till is a cohesive material that varies in size from grains of sand to large boulders. These boulders have been described as “being as large as a small school bus”. Rock in New York Harbor, from easiest to hardest to dig, consists of shale, serpentine, sandstone and diabase. Backhoes can often dig shale and serpentine, while sandstone and diabase typically need some sort of pre-treatment (such as blasting) in order to be dredgeable. The projects chosen for this paper will include at least one example of each type of geology.

The two types of projects we can consider are "maintenance" and "new work" dredging. Maintenance dredging is performed in recently deposited material. This material tends to be silt or sand. If the original channel was constructed through rock, clay or till then there will be a very hard horizon several feet below the maintenance depth. This horizon would put a limit on how far the dredge can penetrate. In other channels, particularly coastal inlets, the material is sand even well below the authorized channel. New work dredging is typically in hard material such as rock, clay or till. Typically below the authorized channel is the same type of material as was in the authorized channel.

As discussed earlier Contractors are commonly paid for up to 61 cm (2 ft.) of material beyond the required project depth. Different allowable overdepth limits have been tried in New York. A common supposition is that Contractors will try to take all the paid overdepth. It is therefore worthwhile to consider this as a variable in the analysis.

A variety of maintenance and new work projects will be considered. Table 1 summaries the projects selected for further study.

Table 1 – Dredging projects chosen for this analysis (1 ft. = 30.5 cm)

Project Title	Maintenance or New Work	Predominant Material	Typical Dredge	Allowable Overdepth (ft.)
Kill van Kull Area 3	New Work	till	backhoe	1.5
Kill van Kull Area 4a	New Work	rock	clamshell	0.0
Kill van Kull Area 5	New Work	rock	backhoe	1.5
Kill van Kull Area 6	New Work	clay	backhoe	1.5
Kill van Kull Area 7	New Work	clay	clamshell	0.0
Kill van Kull Area 8	New Work	clay	backhoe	1.5
Port Jersey Area 1	New Work	till	clamshell	1.5
Arthur Kill 2005	Maintenance	silt	clamshell	2.0
Seguine Point 2004	Maintenance	silt	clamshell	2.0
Jamaica Bay 2004	Maintenance	sand	hopper	2.0
East Rockaway 2005	Maintenance	sand	hopper	2.0

The most obvious source of data for analyzing overdepth dredging is the post-dredging bathymetric survey. Less obvious than the post-dredging survey, but nearly as important, is the survey that was used create the Plans and Specifications (P&S). It is common for areas deeper than project depth to exist within a project. If these natural deep areas aren't excluded from the analysis then these naturally deep areas would skew the results. It is the P&S survey that defines the limit of the shoal, which in turn is the limit of dredging. Data from outside the shoal are excluded when the post-dredging survey is analyzed.

A complete discussion of bathymetric surveying is beyond the scope of this paper but a brief discussion of the type of survey used is in order. Typically the New York District uses what is known as a "multi-beam" survey. Multibeam sonar is used for bathymetric surveys in areas requiring total bottom coverage. The multibeam sonar system has a transducer that continually transmits numerous sonar beams in a swath or fan-shaped signal pattern. This makes the systems ideal for mapping large areas rapidly, with essentially 100 percent bottom coverage. This type of survey produces a very detailed map of the seafloor.

Just having a post-dredge survey is not in itself particularly informative. A post-dredge survey will have tens of thousands of data point. Given the large amount of data, one must find a way to remove that which is extraneous and present the information in a relevant way. Having selected the projects to study the next decision is how best look at the data from these projects. Often we would produce a contour map of the data, but with small elevation changes over a large area they would be hard to read. Another approach was to answer the question "what is the deepest point", but is that one point significant in light of the entire data set? We suggest a better approach is to look at the data statistically. If a patterns can be found on how the post dredge depths are distributed we may be better able to predict non-paid overdepth for future projects, which hopefully will allow more fruitful dialogue with regulatory agencies.

Theoretically one could print out the post dredge survey, overlay the P&S survey and manually select data points. Given the volume of data this would be an inefficient process. A better method would be to take advantage of CAD technology to automate the process. New York District uses MicroStation V8. MicroStation has tools that greatly simplify the data filtering process. The channel and shoal limits from the P&S were brought into MicroStation as a layer. The channel and shoal limits were used to create what MicroStation refers to as a "region". The post-dredge survey was then brought in as another layer. MicroStation could then be used to process the data in several ways. First, it was used to export the portions of the post-dredge survey that were inside the "region" as an XYZ text file. This file could then be easily imported into Excel for further analysis. Second, MicroStation was used to calculate volume of material removed, both within and without the pay prism. The XYZ data from MicroStation is readily brought into Excel using the "Import Text File" function. In Excel graphing the data as a standard distribution curve and calculating statistics such as mean, median, mode and standard deviation was accomplished using Excel's standard suite of built in functions. It should be noted that post-dredging bathymetric and volumetric data from the side slopes of the channels were not included in this analysis. We felt that this would have been extremely complicated due to the varying slope depths and including it would not necessarily add significant value to the overall analysis.

RESULTS

Figures 1 through 11 are the distribution curves of the depths recorded on the after dredge surveys for all projects evaluated. Table 2 is a summary of all statistical data and project-specific information for each distribution curve. We also have included gross quantity dredged (required depth + allowable overdepth + non-pay overdepth) and non-pay overdepth for selected projects, showing the percentage of the gross quantity dredged (pay plus non-pay) that constitutes the non-pay overdepth for each project. Time and resource constraints prohibited us from analyzing quantities from all projects so we selected a few representative ones for this paper. We will discuss the new work deepening projects separately from the maintenance dredging.

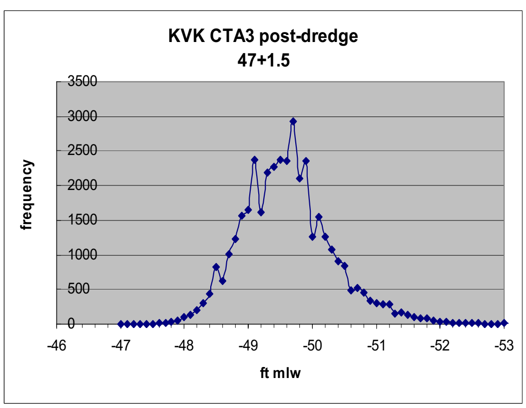

Figure 1 – Distribution Curve of after-dredge depths for KvK Area 3 (1 ft. = 30.5 cm)

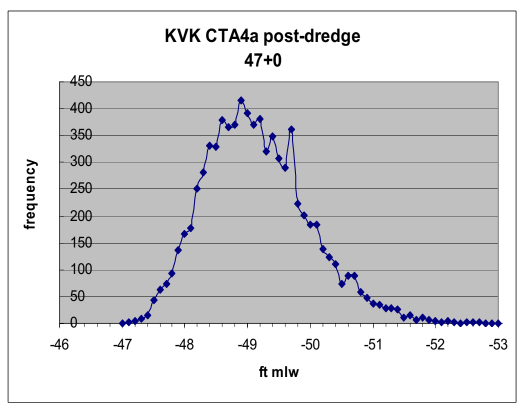

Figure 2 – Distribution Curve of after-dredge depths for KvK Area 4(a) (1 ft. = 30.5 cm)

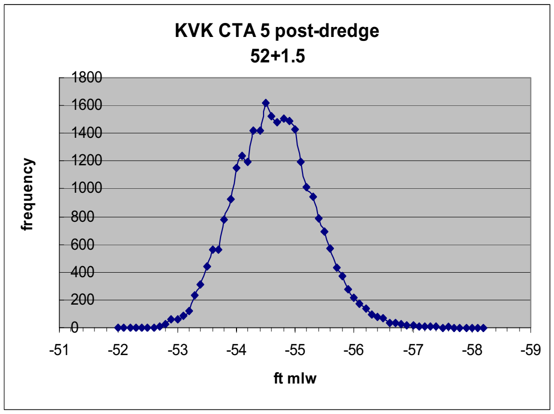

Figure 3 – Distribution Curve of after-dredge depths for KvK Area 5 (1 ft. = 30.5 cm)

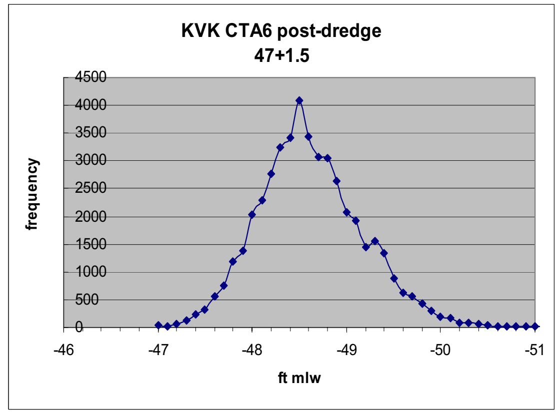

Figure 4 – Distribution Curve of after-dredge depths for KvK Area 6 (1 ft. = 30.5 cm)

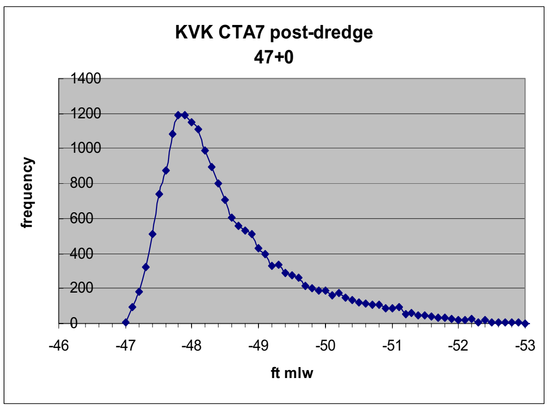

Figure 5 – Distribution Curve of after-dredge depths for KvK Area 7 (1 ft. = 30.5 cm)

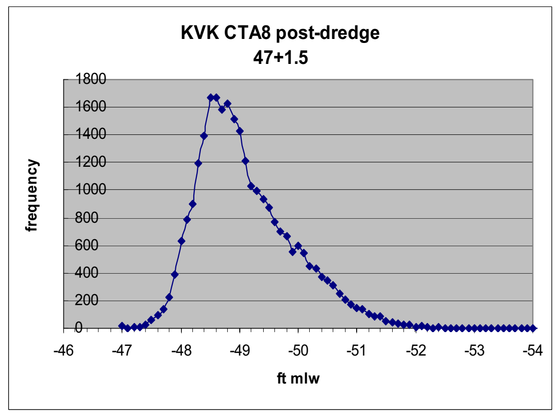

Figure 6 – Distribution Curve of after-dredge depths for KvK Area 8 (1 ft. = 30.5 cm)

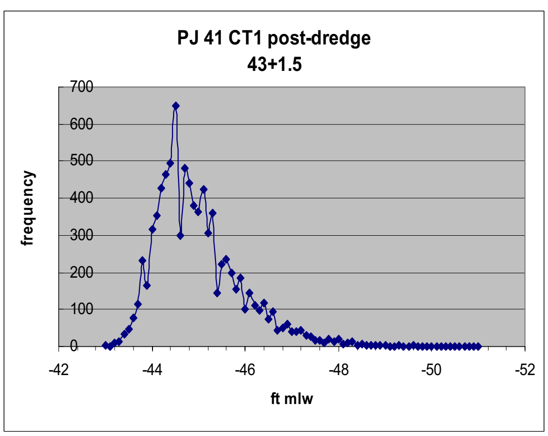

Figure 7 – Distribution Curve of after-dredge depths for Port Jersey Area 1 (1 ft. = 30.5 cm)

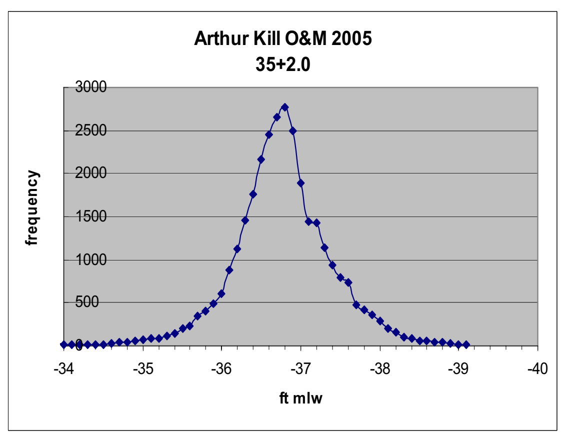

Figure 8 – Distribution Curve of after-dredge depths for Arthur Kill 2005 (1 ft. = 30.5 cm)

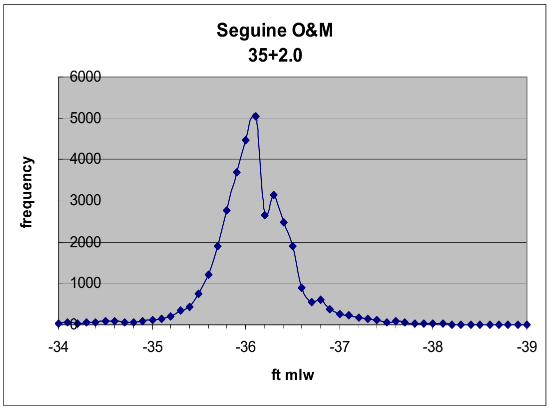

Figure 9 – Distribution Curve of after-dredge depths for Seguine Point 2004 (1 ft. = 30.5 cm)

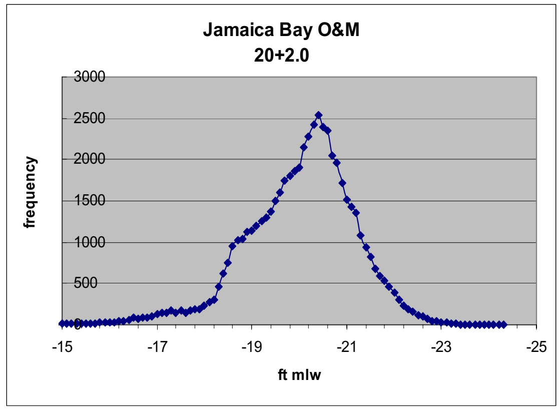

Figure 10 – Distribution Curve of after-dredge depths for Jamaica Bay 2004 (1 ft. = 30.5 cm)

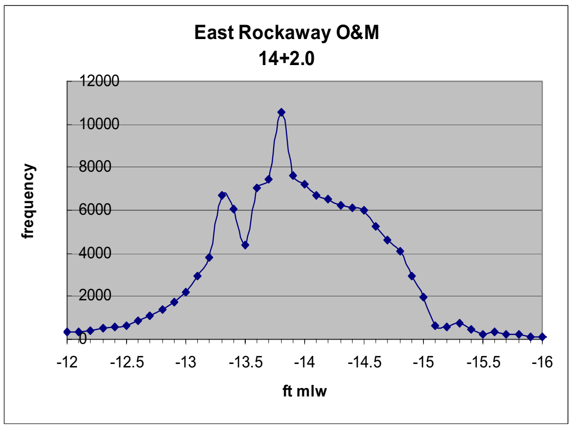

Figure 11 – Distribution Curve of after-dredge depths for East Rockaway 2005 (1 ft. = 30.5 cm)

A review of all the graphs for new work harbor deepening projects shows several similarities between the projects. First, all the graphs show a normal distribution around a mean, generally with single modal dominance. Almost all the soundings in every case are deeper than the required depth. The mean, median and mode also show a very tight distribution, within a few centimeters (tenths of a foot) of each other in most cases. Only KvK Contracts 7 & 8 and Port Jersey Contract 1 show more than a few centimeters of variation between mean median and modal depths, at 21.3 cm (0.7 ft.), 18.3 cm (0.6 ft.) and 15.3 cm (0.5 ft.) respectively. The standard deviation is also very small, ranging from approximately 15.3 – 30.5 cm (0.5 ft. to 1.0 ft.). The primary modal depth is usually either the same as the maximum pay depth (depth of allowable overdepth) or approximately 30.5 cm (1 ft.) deeper than the maximum pay depth. Even in the cases where there was zero allowable overdepth (KvK Contracts 4(a) and 7) the primary modal depth was approximately 30.5 - 61 cm (1 - 2 ft.) below the maximum pay depth. Although some soundings are as much as 3.0 – 3.3 meters (10 - 11 ft.) deeper than the required depth, very few soundings are more than two standard deviations from the mean. In the case of these very deep after-dredge soundings there may have been rock, hard clay or glacial till material that came up in big pieces, thereby leaving a large depression in the bottom.

This small variance between the mean median and mode, and the strong single modal dominance indicates a relatively good degree of dredging accuracy and reveals the purposeful efforts of the dredge operations. It appears that dredge operators, knowing that the inherent variability of dredging is between one and two feet on average, are taking this into account when setting their dredging depth. Knowing that half the soundings will be shallower and half will be deeper, they are setting their dredging depth approximately at 45.8 – 62 cm (1.5 - 2 ft) deeper than the required depth. This way they are assured that most of the dredging area will be at least at the required depth when completed. This maximizes their efficiency as it minimizes any returns to areas already dredged because of high spots that need to be removed to achieve the required depth.

Table 2 –Project specific information and statistical data for each project analyzed. Gross Quantity dredged is the sum of all pay and non-pay dredged material (1 ft. = 30.5 cm; 1 CY = 0.76 meters^3).

Project	Required Depth (FT)	Allowable Overdepth (FT)	Mean Depth (FT)	Median Depth (FT)	Modal Depth (FT)	SD (FT)	Max. Depth (FT)	Gross Quantity Dredged (CY)	Non-Pay Overdepth Quantity Dredged (CY)	Overdepth % of Total
KvK Area 3	47.0	1.5	49.6	49.5	49.4	0.75	58.7			
KvK Area 4(a)	47.0	0.0	49.1	49.1	48.8	0.83	53.5			
KvK Area 5	52.0	1.5	54.6	54.6	54.5	0.69	58.2	2,408,010	272,670	11.32
KvK Area 6	47.0	1.5	48.6	48.6	48.6	0.57	53.8	2,216,010	321,895	14.53
KvK Area 7	47.0	0.0	48.5	48.2	47.8	1.01	54.3			
KvK Area 8	47.0	1.5	49.1	48.9	48.5	0.82	55.9			
Port Jersey Area 1	43.0	1.5	45	44.8	44.5	0.93	53.7			
Arthur Kill 2005	35.0	2.0	36.7	36.8	36.8	0.75	39.8	78,975	5,310	6.72
Seguine Point 2004	35.0	2.0	35.9	36.1	36.1	1.09	38.9	80,690	-11,520	-14.28
Jamaica Bay 2004	20.0	2.0	20.0	20.2	20.1	1.25	27.5	179,140	12,085	6.75
East Rockaway 2005	14.0	2.0	13.9	13.9	13.8	1.10	18.0	142,500	-5,170	-3.63

If we examine the amount of non-pay overdepth material dredged compared to the gross quantity dredged (Table 2) we see that the non-pay overdepth is generally between 10% and 15% of the gross quantity. It is interesting to note that the standard Government contract for dredging contains the "variation in estimated quantity" clause, which states that variations in dredging quantities at +/- 15% are not subject to negotiations for price changes. It implies that variations less than 15% are not significant enough to re-visit existing contingencies in the contract price. If we use this as a measure of "significance" in our analysis, it appears that the amount of non-pay overdepth dredged material from new work deepening projects are not very significant on the whole. Granted, there are many factors that may come into play when determining environmental significance, such as quality of the sediment with depth. The variation in estimated quantity clause was not designed to assess environmental significance, but it was designed to address contingencies in planning and estimating costs and effort based on natural variability in dredging quantities. It none the less gives us a rough guide as to the relative magnitude of the non-pay overdepth dredging issue for the deepening projects, which turns out to be within what one would expect.

A review of all the graphs for the maintenance dredging projects shows several similarities with the deepening projects, and with each other. As with the deepening projects, all the graphs show a normal distribution around a mean, generally with single modal dominance. The mean, median and mode also show a very tight distribution, within a few centimeters (tenths of a foot) of each other. Standard deviations are slightly higher than the deepening projects, ranging from 22.9 – 38.1 cm (0.75 - 1.25 ft.) but they are still not very significant overall. Although some soundings are as much as 1.2 – 2.1 meters (4 - 7 ft.) deeper than the required depth, very few soundings are more than two standard deviations from the mean. This is where the similarities end.

For the harbor maintenance dredging projects (Arthur Kill 2005 and Seguine Point 2004), strong single modal dominance is seen. Almost all the soundings in every case are deeper than the required depth. But the primary modal depth is 30.5 – 61 cm (1 - 2 ft.) deeper than the required depth, rather than the maximum pay depth as was the case for the deepening projects. The small variance between mean, median and mode and single modal dominance indicates a similar level of dredging accuracy and purposeful efforts as for the deepening projects. However in the case of harbor maintenance dredging it appears that the dredge operators are setting their dredging depth 30.5 – 61 cm (1 - 2 ft.) below the required depth rather than the maximum pay depth, but are still achieving the required depth. This may be due to the nature of the dredged material typical of harbor maintenance projects. This material is generally low density fine-grained organic silts, easy to dig and easily moved around by the motion of the bucket on the bottom. In these types of projects dredge operators may be setting their dredging depths to the shallower depth than for the deepening projects because they know that the material is easier to manipulate with the dredge, and they therefore do not need to dig as deep. If we examine the amount of non-pay overdepth material dredged compared to the gross quantity dredged (Table 2) we see that for the Arthur Kill 2005 non-pay overdepth made up only 6.8% of the total amount dredged which is approximately half the percentage of non-pay overdepth for the deepening projects. For Seguine Point 2004 we actually saw a gain of material in areas that were already below the maximum pay depth (-14.3%). This tends to reinforce speculation that the softer, more easily movable fine grained dredged material is being re-contoured to some degree during the dredging process, resulting in less overdepth dredging in general, both pay and non-pay.

For the coastal maintenance dredging projects (Jamaica Bay 2004 and East Rockaway 2005), single modality is evident, but there appears to be a secondary mode present at shallower depths than the dominant mode. Approximately half the soundings on these graphs are not as deep as the required depth. The primary mode appears to be at the required depth rather than some deeper depth as was the case for the deepening and harbor maintenance projects. Although the variance between mean and mode is small, at a few centimeters (tenths of a foot) in both cases, the standard deviation is higher than for most of the other projects. This is apparent by the broader bell shaped curve than for all the other projects. In both these cases a hopper dredge was used for the dredging. Hopper dredges operate differently than clamshell or backhoe dredges and do not "set" their dredging depths in the same way. They remove relatively shallow layers of dredged material with each pass and make multiple passes over an area, rather than set a dredging depth and remain over the area until they have achieved that depth. Based on these graphs it appears that the dredge operator did not try to dredge much deeper than the required depth, which is rational because the inherent variability of the dredging process for these dredges are probably not as great as for mechanical dredges given the same physical condition of the dredging project. However, the fact that half the soundings are shallower than the required depth, plus the presence of a secondary modal depth shallower than the primary modal depth is interesting. It appears that channel infilling was occurring in areas already dredged at the same time the dredging was still taking place. This would make sense given the dynamic nature of dredging an open ocean coastal inlet in the Fall and early Winter. . If we examine the amount of non-pay overdepth material dredged compared to the gross quantity dredged (Table 2) this further reinforces this idea. The amount of non-pay overdepth for Jamaica Bay 2004 is very low at 6.8%, and for East Rockaway 2005 we see a gain of material in areas already dredged (-3.6%). It appears that the nature of how hopper dredges work coupled with the dynamic nature of the coastal projects give us a very different picture of overdepth dredging than harbor maintenance or deepening projects.

CONCLUSIONS AND RECOMMENDATIONS

For the deepening projects it appears that the degree of overdepth dredging is fairly predictable and consistent, regardless of whether a clamshell or excavator dredge was used. Because of the relatively hard nature of the dredged material (rock, till and clay) it appears that the dredge operator takes into account that dredging is less precise than in softer materials. Dredge buckets designed to dig hard materials such as rock and till have large-toothed lips, which are geared to penetrate and rip up large chunks of the bottom. So to increase his efficiency, minimizing the possibility of having to re-dredge areas that have not achieved the required depth, the dredge operator is setting the dredge depth to 30.5 – 61 cm (1 - 2 ft.) below the maximum pay depth. The quantity of non-pay overdepth that this generates does not appear to be very significant, generally less than 15% of the total quantity dredged. This is consistent with existing contracting guidance that allows for variability in dredging quantity of up to 15% before either party can re-visit contingencies.

The implications for project design are that engineers should factor in approximately 30.5 – 61 cm (1 - 2 ft.) of additional depth below the maximum pay depth for deepening projects in hard materials and a 10-15 % contingency for estimating project costs. This is consistent with existing Corps of Engineers regulations and technical guidance concerning design of new projects. The environmental implications are that sediment characterization and environmental documentation must consider that an additional 30.5 – 61 cm (1 - 2 ft.) of non-pay overdepth may be dredged below the maximum pay depth, and that additional non-pay dredged material quantity of 10-15% may occur as a result of the overdepth dredging. It is important to note that ensuring adequate sediment characterization of the overdepth dredging does not necessarily imply that additional testing needs to be done. In most cases harbor deepening projects are dredging pre-industrial ancient sediments or rock with depth, which are usually not contaminated. A decision whether to test this sediment depends on the project specifics, and a balancing of environmental risk. Sometimes just knowing what the geology of the dredged material is enough to give environmental review agencies the confidence they need to complete a negative finding of environmental impacts. Sometimes testing of a relatively homogeneous clean sediment layer at shallower depths is enough to give that same level of confidence. The operative goal is to have enough environmental information to adequately and appropriately characterize the sediments with depth to ensure that environmental documentation, such as NEPA analyses, can take the required "hard look" at potential environmental impacts and come to meaningful and complete conclusions. The level of information necessary to achieve this goal will vary from project to project, but the evaluations must take into account the overdepth dredging or they will be incomplete.

For harbor maintenance dredging projects using a clamshell dredge it also appears that the degree of overdepth dredging is fairly predictable and consistent. Because of the relatively soft nature of the fine grained silts being dredged it does not appear that dredge operators need as much depth to account for dredging variability. It appears that setting their dredging depth to the maximum pay depth is adequate to ensure that they efficiently achieve the required depth. The soft nature of the dredged material appears to minimizes the amount of non-pay overdepth dredging that occurs to less than approximately 7% of the total quantity dredged at maximum, and in some cases may actually facilitate moving the dredged material around on the bottom so that there is a net "gain "of non-pay overdepth dredged material as deeper areas within the dredging prism are filled.

The implications for project design are that engineers need not factor in more than 61 cm (2 ft.) of allowable overdepth in their designs for mechanical maintenance dredging in soft materials, and need not look at quantity contingencies of greater than approximately 6-7%. In this case existing Corps of Engineers regulations and technical guidance do not seem to differentiate between project design for deepening projects and maintenance projects, and appear to be more conservative in approach than what is needed for maintenance dredging. The guidance appears to be most appropriate for deepening projects. The environmental implications are that sediment characterization may not need to consider more than the 30.5 – 61 cm (1 - 2 ft.) of allowable overdepth already contained in most project designs, and that any additional non-pay overdepth quantity will not be significant, generally less than 7% of the total. However it is still important to appropriately characterize all overdepth quantities, pay and non-pay, in required environmental reviews in order to fully comply with existing laws and regulations. Similar considerations outlined above for deepening projects apply here as well. Also, environmental reviews also must recognize that some degree of sediment re-contouring of the bottom may occur due to the soft nature of the material and the action of the clamshell. The degree to which this occurs will vary based on project specifics and should be evaluated on a case-by-case basis.

For coastal maintenance dredging projects, overdepth dredging appears to be the least predictable of the cases we observed due to the dynamic nature of the dredging environment and the nature of hopper dredging. Because hopper dredging in easily removable sediment, such as sand, is more accurate than mechanical dredging, dredgers can target the required depth as their goal. This will minimize the amount of non-pay dredged material to be less than approximately 7% as was the case for harbor maintenance dredging projects. However due to the dynamic nature of coastal inlets there is evidence that channel infilling may be taking place as dredging is occurring, based on the secondary modality seen in the graphs. This could cause a net gain in non-pay material to be observed but due to natural processes, not due to the action of the dredge as appears to be the case with harbor maintenance projects.

The implications for project design are similar as for harbor maintenance dredging, i.e. that engineers need not factor in more than 61 cm (2 ft.) of allowable overdepth in their designs for hopper dredging in sand, and need not look at quantity contingencies of greater than approximately 6-7%. As for harbor maintenance dredging projects, Corps regulations and technical guidance on overdepth considerations may be more conservative than is necessary for these types of coastal maintenance projects. The environmental implications are the same as for harbor maintenance projects, i.e. consideration of the 30.5 – 61 cm (1 - 2 ft.) of allowable overdepth already contained in most project designs appear to be adequate, and that any additional non-pay overdepth quantity will not be significant, generally less than 7% of the total quantity. Environmental reviews should recognize that channel infilling may occur during the dredging process, and that since sand does not generally accumulate chemical contaminants due to their chemically inert nature, adequate sediment characterization may merely involve confirming that the sediment with depth is truly sand.

In summary it appears that the magnitude overdepth dredging is most predictable for harbor deepening, somewhat predictable for harbor maintenance and least predictable for coastal maintenance projects due to a variety of factors, i.e. nature of the dredged material, accuracy of the dredging equipment and physical nature of the dredging environment. However, the degree to which non-pay overdepth needs to be considered in environmental reviews is inversely proportional to the predictability of the magnitude of overdepth dredging. Harbor deepening projects seem to generate the largest amount of non-pay overdepth, harbor maintenance projects produce some non-pay overdepth, and coastal maintenance projects seem to produce the least. But in every case the degree of non-pay overdepth does not appear to be very high, and within the expectations as contained in Corps dredging project design regulations and guidance. However it should be recognized that existing design guidance appears to be overly conservative for maintenance dredging projects. In all cases the magnitude of overdepth dredging needs to be considered in the environmental compliance reviews or these reviews will not be complete. In the case of harbor deepening projects the degree of significance of overdepth dredging is greatest, requiring the most thought and consideration when documenting and evaluating possible environmental impacts resulting from the dredging and disposal of the dredged material. Harbor and coastal maintenance projects appear to be less significant in overdepth dredging, so the review of its impacts should be simpler. But other environmental considerations, such as sediment smoothing on the bottom and rapid shoaling, may need to be considered as well.

It should be noted that the conclusions reached as a result of this study are based on a fairly limited number of cases. As mentioned earlier there are many variables that could affect the degree of overdepth dredging and this paper could not possibly take all those factors into account. We suggest that more detailed analyses that accounts for each variable would provide greater insight as to their relative influence on overdepth dredging. However, even with the limited number of examples covered in this paper, it is interesting to note that certain patterns can be discerned and these results do lead to reasonable conclusions about the nature of overdepth dredging. We hope that this paper has provided useful insight into overdepth dredging and how it should be evaluated and represents not the final word, but leads to further inquiries and more refined insight on the subject.

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