

**ESTIMATING PRODUCTION AND COST FOR CLAMSHELL  
MECHANICAL DREDGES**

A Thesis

by

ROBERT FLETCHER ADAIR

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2004

Major Subject: Ocean Engineering

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December 2004

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## **ABSTRACT**

Estimating Production and Cost for Clamshell Mechanical Dredges.

(December 2004)

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Clamshell dredges are used around the United States for both navigational and environmental dredging projects. Clamshell dredges are extremely mobile and can excavate sediment over a wide range of depths. The object of this thesis is to develop a methodology for production and cost estimation for clamshell dredge projects. There are current methods of predicting clamshell dredge production which rely on production curves and constant cycle times. This thesis calculates production estimation by predicting cycle time which is the time required to complete one dredge cycle. By varying the cycle time according to site characteristics production can be predicted. A second important component to predicting clamshell dredge production is bucket fill factor. This is the percent of the bucket that will fill with sediment depending on the type of soil being excavated.

Using cycle time as the basis for production calculation a spreadsheet has been created to simplify the calculation of production and project cost. The production calculation also factors in soil type and region of the United States. The spreadsheet is capable of operating with basic site characteristics, or with details about the dredge, bucket size,

and region. Once the production is calculated the project cost can be determined. First the project length is found by dividing the total amount of sediment that is to be excavated by the production rate. Once the project length is calculated the remainder of the project cost can be found.

The methods discussed in this thesis were used to calculate project cost for 5 different projects. The results were then compared to estimates by the government and the actual cost of the project. The government estimates were an average of 39% higher than the actual project cost. The method discussed in this thesis was only 6% higher than the actual cost.

## **ACKNOWLEDGEMENTS**

The author would like to thank his committee chair Dr. Robert Randall for all of his input and comments on this report and guidance throughout my graduate studies. He is also grateful for the recommendations and advice from his committee Dr. Billy Edge and Dr. Douglas Biggs.

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## INTRODUCTION

### **Purpose**

The overall purpose of this thesis is to develop a method to predict production for mechanical clamshell dredges using cycle time. There are currently methods to predict production for cutter suction and hopper dredges. The object of this thesis is to develop a working method for mechanical clamshell dredges. The emphasis is on using an adjustable cycle time factor and bucket fill factor to determine production. The cycle time is the period of time required to complete one dredging cycle. The method also allows for a variance in production due to the ability of the material being dredged to fill the total volume of the bucket (fill factor). Once the production is successfully estimated the output is used to predict the dredging total cost and duration.

### **Background**

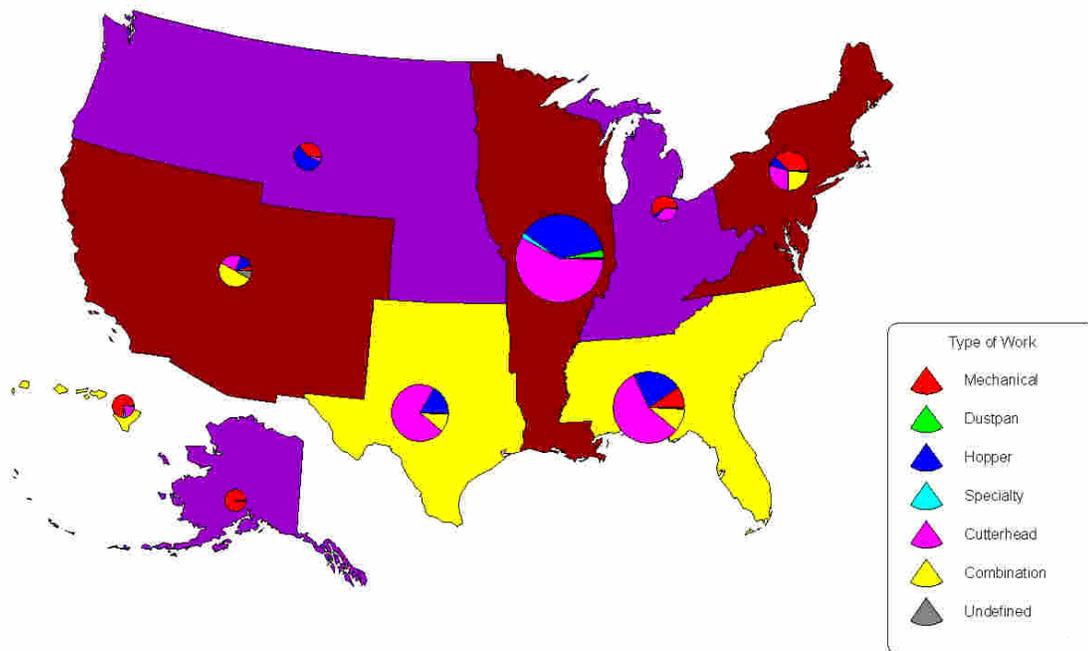
The earliest dredges were mechanical dredges. A few thousand years ago, people began using “Spoon and Bag Dredge” (Huston, 1970). This simple device consisted of a barge with at least one pole extending from the side of the vessel. This pole had a bucket on the end which was used to remove sediment or debris from the bottom. The sediment is then placed inside the barge. Once the barge was full, it was emptied at the shore and the process continued. Until the advent of the steam engine, dredges were powered by wind, animals or humans. An example of a wind powered dredge is the Krabbelaar

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This thesis follows the style of the *WEDA Journal of Dredging Engineering*.

scraper (Herbich, 2000). This was a wind powered, wooden hulled, scraper dredge. Once the steam engine and then the diesel engine were invented mechanical dredges began to resemble the ones used today.

There are several types of dredges used in the United States and around the world today. There are mechanical dustpan, hopper, cutter head, and other special types. Mechanical dredges are clamshell, backhoe, and bucket type dredges. A dustpan dredge uses a suction line to excavate sediment. Hopper dredges use a suction line and transport the excavated sediment on board the dredge. Cutter head dredges also called cutter suction or pipeline dredges use a rotating cutter head to loosen the sediment before it is excavated through a suction line. The breakdowns of the types of dredges in Figure 1 are from the Navigational Dredging Center (NDC, 2003). The pie graphs in Figure 1 show both the breakdown of types of dredges and the amount of dredging from the relative graph size. From Figure 1 the largest amount of dredging by volume is in the central United States, in the Mississippi river. The majority of the dredging in this region is done by hopper and cutter suction dredges. Mechanical dredging is prominent in North West, North East, Ohio River Valley, Alaska, and Hawaii. There is also noticeable mechanical dredge use in the South East and West Coast.



**Figure 1-Breakdown of Dredge Type Used Based on USACE District**

There are many classifications of mechanical dredges (Bray, 1997). A backhoe dredge is literally a backhoe used in a marine environment. It is either used off the shore, from a barge, or fixed to a vessel. A dipper dredge uses a rigid arm with a bucket on the end. It swings up as it cuts through the sediment. A bucket ladder dredge uses a chain of buckets on a belt to excavate sediment. The dragline dredge places its bucket away from the vessel in the sediment and then drags the bucket back towards the vessel. Finally the clamshell dredge or grabber dredge uses a bottom opening bucket at the end of a crane (Figure 2). The bucket is dropped or lowered directly down into the sediment, closed, and then raised to the surface. Mechanical dredges can be used for building new

channels, deepening existing waterways, removing contaminated sediment, or for harvesting clams (Gaspar et al., 2003).

An important characteristic of mechanical dredges is bucket size. Figure 2 shows the distribution of bucket sizes for mechanical dredges for the United States in 2003 (IDR, 2003). From Figure 2 it is apparent that the majority of buckets are smaller than 15 yd<sup>3</sup>. There are several buckets between 15 and 30 yd<sup>3</sup> (11 and 23 m<sup>3</sup>). After 30 yd<sup>3</sup> (23 m<sup>3</sup>) there are just a few buckets. The largest bucket found is 50 yd<sup>3</sup>. Hayes (2000) uses sizes from 1-100 m<sup>3</sup> (1-131 yd<sup>3</sup>) because these are the limits of crane capacity. This paper limits the range to 0-38 m<sup>3</sup> (0-50 yd<sup>3</sup>) due to the availability of buckets in the United States.

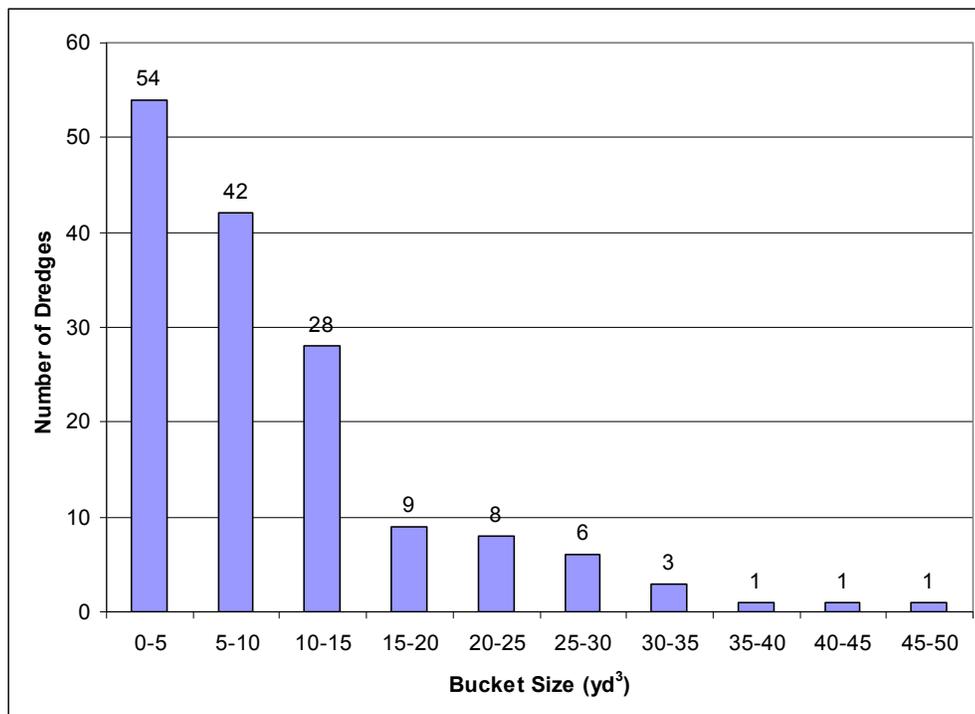


Figure 2-Distribution of Bucket Sizes in the United States (Multiply by 0.765 for m<sup>3</sup>)

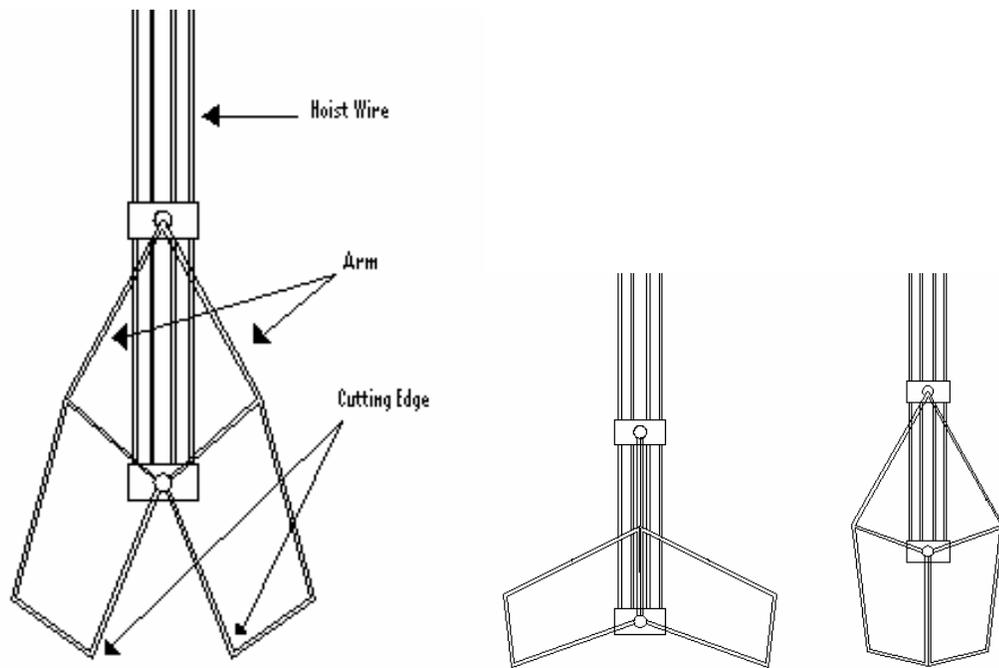
Figure 3 shows a mechanical clamshell dredge working just offshore on the west coast of Japan in the town of Sakata. The dredge is working near a public beach in late summer 2003. This picture shows the main components on a mechanical dredge. The dredge itself is the crane-like structure on the left side of the barge. The crane positions the bucket above a desired location and then lowers it to the bottom of the waterway. The bucket picks up the sediment as it closes. The closed bucket is raised out of the water and positioned over the barge. Finally the bucket is opened over the barge and the dredged material is placed in the barge. The cycle is then repeated for a new position until the desired depth is reached over the entire area. Figure 3 also shows a work boat and the barge which is supporting the dredge. The purpose of the barge is to support the weight of the dredging equipment and to position the clamshell bucket over the desired location.



**Figure 3-Mechanical Dredge in Sakata, Yamagata, Japan, 2003**

Figure 4 shows the different parts on a clamshell bucket. The hoist wire supports the weight of the clamshell and the sediment when it is full. The arm is what the actual bucket pivots around. During operation the bucket is dropped or lowered into the sediment and then closed. The cutting edge penetrates and cuts the sediment. The bucket then closes and is lifted to the surface. There are some differences in clamshell buckets. The middle clamshell in Figure 4 is a simple open bucket. Some buckets are closed with gaskets to prevent water from escaping. There are level cut clamshells such

as the ones described by Bergeron (2000). These buckets are more useful for environmental dredging. There are also other special buckets that are used for harvesting clams, these are made of a mesh that allows sediment to escape. Figure 4 displays the parts of a clamshell bucket as well as the bucket in the open and closed position. The bucket is lowered directly into the sediment in the open position. Once in the sediment, the clamshell is closed. Once the bucket is closed, the bucket is lifted out off the sea floor of the waterway, and the sediment is then transported and placed in a barge. The right side of Figure 4 shows the clamshell in the closed position. According to Tsinker (2004), clamshell dredges are best suited for soft sediments and difficult to access locations. Due to being on a barge the clamshell dredge is capable of being positioned in hard to reach locations. Also, since the dredge uses a mechanical cable to control the bucket, the clamshell is limited in depth of operation only by the length of its cable.



**Figure 4- Operation of a Clamshell Bucket (Key Components, Open Position, Closed Position)**

### **Literature Review of Clamshell Bucket Production and Cost Estimation**

Production for dredges is determined in various ways depending on the type of dredge.

There are currently publicly available methods for estimating production for both hopper and cutter suction dredges (Miertschin 1997; Miertschin and Randall, 1998; Belisimo,

2000). These methods use dredge pump and sediment characteristics to estimate

production. The specific gravity that can be carried is determined and used with other dredge specific properties to determine the time to dredge a given amount of material.

Both of these methods then use their output to estimate project cost and duration.

Currently the Center for Dredging Studies (CDS) at Texas A&M University does not have a method for estimating production and project cost for mechanical clamshell dredges using cycle time. Cycle time is the amount of time required for the dredge to complete one cycle. This is usually in units of time. Once cycle time is known, delay factors, such as the time to change hopper barges, can be applied and the total length of a project can be determined. Many cost estimation methods assume a constant value for cycle time. This constant value is usually about 60 seconds (Bergeron, 2000; Hayes, 2000). One of the foci of this thesis is to determine the sensitivity of production rate to cycle time.

Emmons (2001) used cycle time determined by depth and swing angle. This is an improvement over using a constant cycle time, but did not allow for factors such as the rate a bucket is raised or lowered, swing rate, as well as bucket opening and closing time. It is important to be able to vary the individual components of the dredge cycle in mechanical clamshell dredging. In these projects it is common to limit the velocity that the clamshell is allowed to travel through the water column. Slowing the bucket velocity reduces re-suspension, and reduces the sediment from re-suspension when the bucket strikes the bottom. Besides bucket velocity in the water column, the other parameters in cycle time are swing angle, swing velocity, time to open the bucket, time to close the bucket, and water depth. The combined time to complete all of these tasks is the cycle time, which is combined with bucket volume to define production ( $\text{m}^3/\text{h}$ ,  $\text{yd}^3/\text{h}$ ).

An additional factor to be considered in evaluating production is the bucket fill factor. The fill factor is the percentage of the bucket that is filled with sediment during a given dredge cycle. Depending on the sediment type, bucket velocity, and fall velocity, this value can vary considerably. Dense or hard sediments make it difficult for the clamshell to close, and the sediment may contain large voids. Clays are difficult for a bucket to cut. Due to the increased difficulty of excavating the dense clays, the bucket does not always reach its maximum possible depth into the sediment. If the bucket does not reach its maximum depth, it can not fill completely. Another reason a bucket may not be completely filled is due to voids between large particles such as rocks. A clamshell bucket uses its own weight and some mechanical advantage to cut the sediment and fill the bucket, so rocks can also keep the bucket from closing. A method of estimating the fill factor has been developed by Bray (1997). This method works well, but was developed for small buckets. It uses the bucket size and sediment type to provide a reduction factor. This reduction factor is multiplied by the size of the bucket and then is used to determine the estimated amount of sediment that is removed each cycle. However, it is necessary to determine the fill factor for buckets of any size. This is accomplished by fitting data from Bray (1997) and Emmons (2001) over the full range of bucket sizes.

Cycle time and fill factor are thus the dominant parameters in mechanical dredge production. The cycle time provides the time required for each dredge cycle and the fill

factor determines the amount of sediment removed each time. These factors are combined to estimate the maximum production rate for a clamshell dredge.

### **Clamshell Dredge Production Estimation Procedure**

The procedure for estimating mechanical dredge production is divided into 4 stages.

The first stage is developing a method of estimating cycle time. First, the parameters that determine cycle time must be determined. These parameters are water depth, bucket fall velocity, bucket close time, bucket open time, bucket lift velocity, swing angle, and swing velocity. Second, default or normal values for each of these parameters are determined. For example for most projects the average swing angle is 120 degrees (Emmons, 2001). The method must also allow the user to alter each parameter to match a specific dredge, or project requirements. This lets the method account for special cases such as environmental dredging, or special buckets. For an environmental project, a bucket may only be allowed to ascend at one third of its normal rate, and this increases the cycle time while decreasing the production rate. The goal is to obtain the average values from industry or the NDC (2003) for normal projects, and to have a method to vary these parameters for a specific project or dredge. This provides a cycle time that works for both normal and special cases.

The second stage for the mechanical dredge production estimation method is to determine the bucket fill factor. The fill factor is the percentage of the total volume of the bucket that is filled with sediment. For certain materials the bucket is not completely full. Bray (1997) provides limited data for fill factor for small dredges that are less than

8 m<sup>3</sup> (10 yd<sup>3</sup>). The fill factor for this method comes from curve fitting these data points with limited data points for larger dredges. This provides the method for estimating production for a large range of mechanical clamshell dredges.

The third stage is to develop a cost estimating method that uses the output from the production calculations to determine project cost. For this stage it is necessary to obtain contract information from the NDC (2003). Factors such as dredge cost, crew size, wage rates, mobilization costs, and disposal costs are considered. These data must be obtained from various regions to account for cost differences between the Pacific, Atlantic, and Gulf coasts. The U.S. Institute for Water Resources Navigational Data Center (NDC) provides information about the total cost of all dredging contracts awarded by the United States Army Corps of Engineers (USACE). This information is used to find the relationships between project costs around the United States.

The final stage of the mechanical clamshell dredge program is to verify its results against known projects and do a sensitivity analysis for the production estimation program. The sensitivity analysis is done to determine how production varies when either cycle time or fill factor are varied. The cost estimation is checked against actual projects from the NDC (2003). The projects used need to vary in both location and size to show the program is valid over a wide range of dredges. Once the production and cost estimation methods were verified, then the method was incorporated into an easy to

use spreadsheet form that allows the user to quickly estimate production and cost for a clamshell dredging project.

It is beneficial to have a method for predicting production of mechanical dredges based on cycle time. By basing the calculations on cycle time the production rates are accurate for a wide range of dredges and projects. The method is adjustable for the requirements of a specific project and still provides accurate results.

## CLAMSHELL BUCKET PRODUCTION THEORY

### Cycle Time ( $T_{cycle}$ )

The cycle time is the total time required for the dredge to empty, move to the desired location, fill the bucket and empty it. As the cycle time increases, so does the project length, and therefore cost. The terms are defined as swing angle ( $\theta_{sw}$ ), swing angular velocity ( $\omega_{sw}$ ), bucket fall velocity ( $u_f$ ), the time to close the bucket ( $t_g$ ), the bucket lift velocity ( $u_l$ ), the time to empty the bucket ( $t_e$ ), the water depth ( $d$ ), and the freeboard height of the barge ( $h_b$ ).

$$T_{cycle} = 2(\theta_{sw} \omega_{sw}) + t_g + t_e + u_f(d + h_b) + u_l(d + h_b) \quad (1)$$

### Swing Angle ( $\theta_{sw}$ )

The first parameter is swing angle ( $\theta_{sw}$ ). The swing angle is the difference between the location where sediment is dropped into the hopper barge and the location where the sediment is excavated. Swing angle is expressed in degrees for these calculations. An average value for swing angle is 120 degrees. This value is doubled when the total cycle time is calculated to account for swinging to and from the excavation site.

**Swing Speed ( $\omega_{sw}$ )**

Swing speed ( $\omega_{sw}$ ) is the rate that the mechanical clamshell dredge rotates to and from the excavation site and the barge. This is consistent with the swing speed of large cranes, and a default value is 21 degrees per second.

**Fall Velocity ( $u_f$ )**

The rate or speed at which the bucket is lowered to the bottom is the fall velocity ( $u_f$ ).

The bucket can be dropped in freefall, or lowered at a controlled rate.

**Grab Time ( $t_g$ )**

The grab time ( $t_g$ ) is the time required to close the clamshell on the sediment and is given in seconds. A common grab time value is 1 second, and it can be adjusted for buckets of various sizes.

**Lift Velocity ( $u_l$ )**

The velocity that the bucket is raised through the water column is the lift velocity ( $u_l$ ).

During environmental dredging the fall velocity is decreased to control re-suspension.

Re-suspension occurs when sediment leaves the bucket. This is when sediment enters the water column due to flow over the top of the bucket, sediment leaking out of the

bucket, the impact of the clamshell of the bottom. This is a problem in environmental dredging where contaminated sediments are being excavated. A common value for lift

velocity is about 0.3 m/s (1 ft/s) during environmental dredging or 1 m/s (3.3 ft/s) during normal dredging.

### **Empty Time ( $t_e$ )**

The empty time ( $t_e$ ) is the time required for the sediment to leave the bucket after opening. An average value is 2.6 seconds, which is the suggested default value.

### **Depth ( $d$ )**

For cycle time the average depth ( $d$ ) is used. This is the average excavation depth for the project. The depth is multiplied by the lift and fall velocity to determine the amount of time the bucket is in the water column.

### **Freeboard Height of the Barge ( $h_b$ )**

The barge freeboard height ( $h_b$ ) is the height above the free surface elevation that the bucket must be lifted. The freeboard height includes the height of the side of the barge plus any additional height necessary to clear the deck of the barge and any sediment.

This freeboard height is then added to the depth to find the total distance that the bucket must travel vertically.

### **Bucket Fill Factor**

The bucket fill factor is calculated by combining data from (Emmons, 2001) and (Bray, 1997). These data sets are then fit to an exponential curve and forced to stay below 1 for values up to 50 m<sup>3</sup> (65 yd<sup>3</sup>). If the fill factor value becomes greater than 1 the program calculates that the bucket is picking up a volume of sediment greater than its capacity.

For the remainder of the paper the dredged sediment is classified into 6 categories.

These categories are used to calculate bucket fill factor and bulking factor. The classifications are mud, loose sand, compact sand, sand and clay, stones, and broken rock. Mud consists of sediments such as loose silts, clays, and other fine grained sediment. Loose sand is sand that is not compacted. Compacted sand is dense sand that has been loaded or compacted. Sand and clay is a mixture of sands and clays. Stones consist of small rocks from gravel to cobbles. Broken rock is any sediment larger than cobbles.

Equation 2 is the bucket fill factor ( $f_m$ ) related to the bucket size (C) for mud:

$$f_m = 0.0474 \ln(C) + 0.7255 \quad (2)$$

With small buckets the fill factor is commonly between 75 and 85 percent. Once the bucket is 40 m<sup>3</sup> (52 yd<sup>3</sup>) or larger the fill factor is greater than 90 percent. The curve also fits the criteria that the fill factor is never greater than 1. It is also apparent from Figure 5 that it is important to be very accurate with bucket size below 10 m<sup>3</sup> (13 yd<sup>3</sup>).

The fill factor varies rapidly in this zone and can cause large errors in the production estimation program if an incorrect bucket size is used.

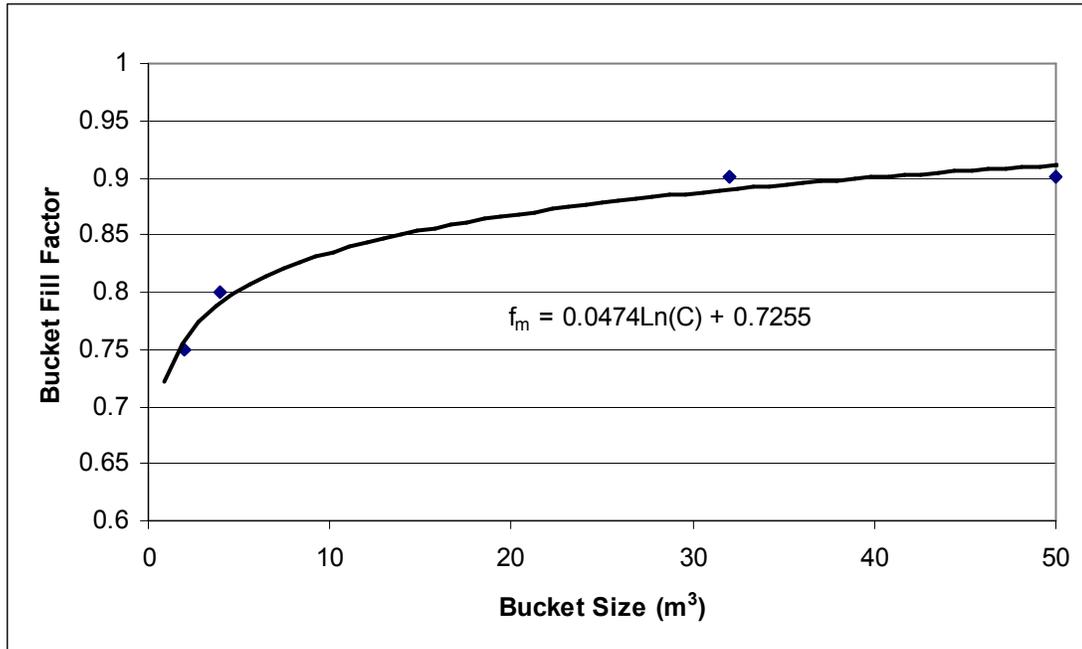


Figure 5-Fill Factor for Mud (Multiply by 1.3 to Convert to yd<sup>3</sup>)

Figure 6 is the fill factor curve for loose sand. Equation 3 is the bucket fill factor curve for loose sand:

$$f_m = 0.0614 \ln(C) + 0.6607 \quad (3)$$

The curve begins at 0.65 and reaches 0.9 for 50 m<sup>3</sup> (65yd<sup>3</sup>) buckets. One point is used at 50 m<sup>3</sup> (65 yd<sup>3</sup>) to keep the function below 1. It follows the same trend as the fill factor for mud with a very steep slope in the range with small buckets.

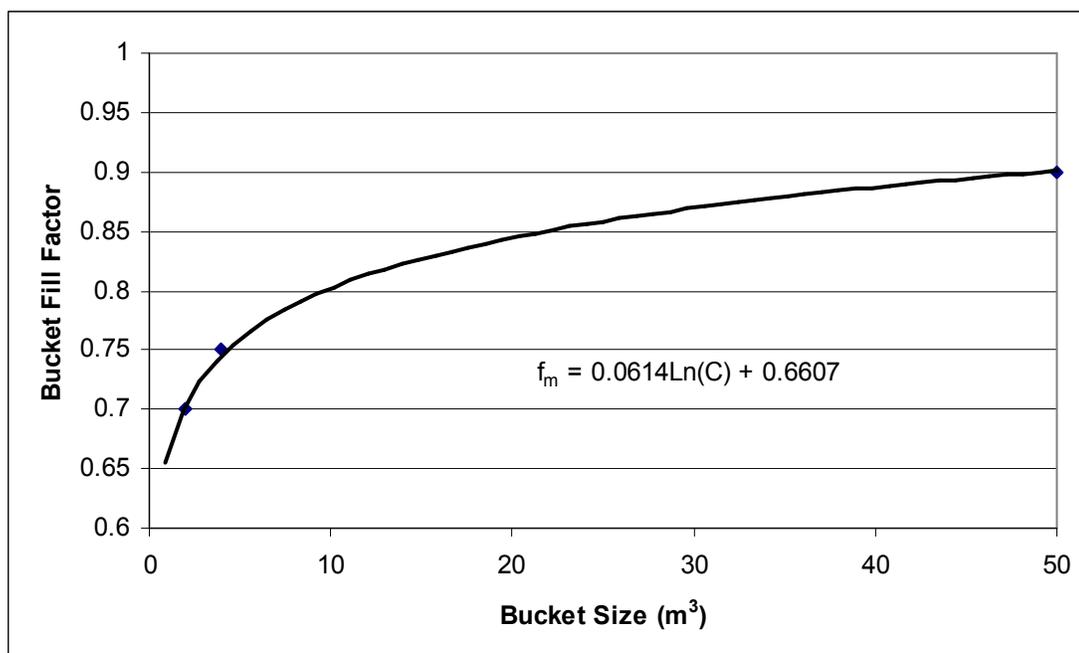
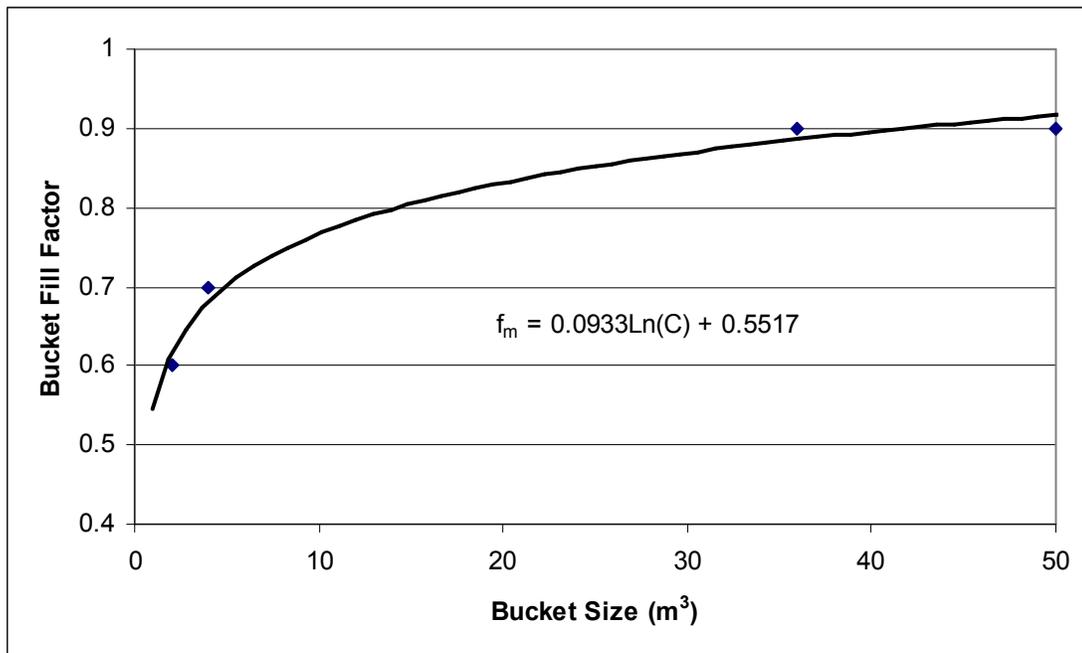


Figure 6-Fill Factor for Loose Sand (Multiply by 1.3 to Convert to yd<sup>3</sup>)

The fill factor curve for compact sand is displayed in Figure 7. Two additional points were used at 40 m<sup>3</sup> (52 yd<sup>3</sup>) and 50 m<sup>3</sup> (65 yd<sup>3</sup>) to keep the function below 1. The reason for this is that the initial slope is greater than the first two cases. With the two points the fill factor reaches 0.9 at 50 m<sup>3</sup> (65 yd<sup>3</sup>). The slope is relatively small once the bucket is larger than 20 m<sup>3</sup> (26 yd<sup>3</sup>). Equation 4 is the expression for compact sand:

$$f_m = 0.0933 \ln(C) + 0.5517 \quad (4)$$



**Figure 7-Fill Factor for Compact Sand (Multiply by 1.3 to Convert to yd³)**

For sand and clay the fill factor reaches 0.9 in Figure 8. There is one point placed at 50 m³ (65 yd³) to keep the curve below 1. The fill factor reaches 0.8 by 20 m³. Between 20 m³ (26 yd³) and 50 m³ (65 yd³) the slope is nearly linear. The sand/clay mixture continues the trend of rapid change between 0 and 20 m³ (26 yd³). Equation 5 is the curve for sand and clay.

$$f_m = 0.1228\text{Ln}(C) + 0.4214 \quad (5)$$

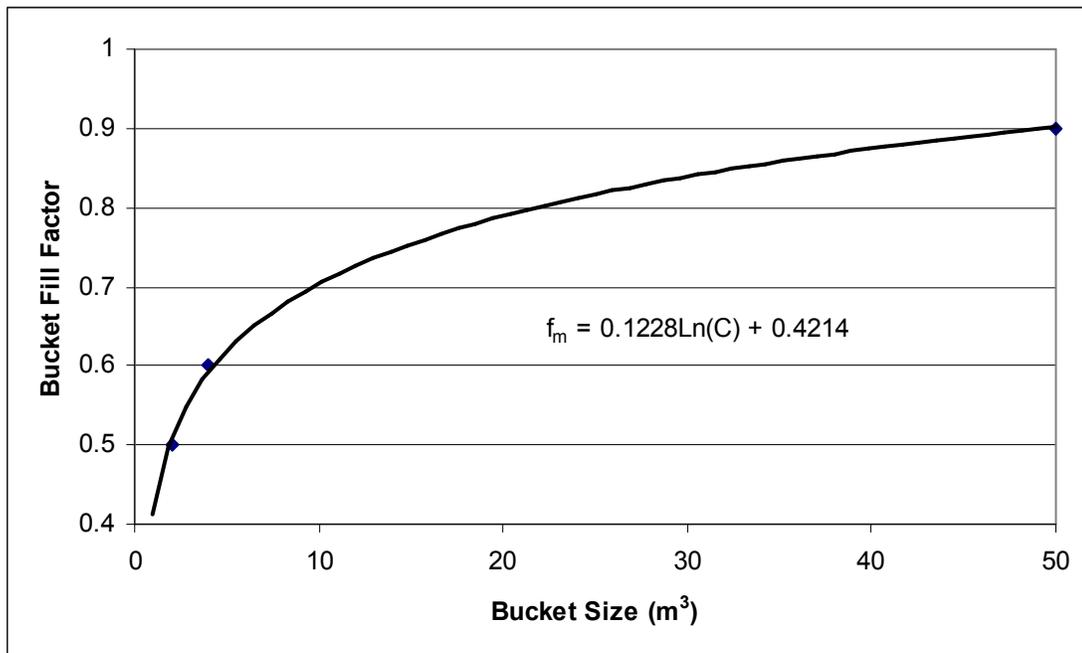


Figure 8-Fill Factor for Sand and Clay (Multiply by 1.3 to Convert to yd<sup>3</sup>)

The stone curve in Figure 9 is the first to not require an additional data point. When fitted to a natural log the fill factor stays below 1 from 0 to 50 m<sup>3</sup> (65 yd<sup>3</sup>) with the initial value as 0.25. Stones normally have a small fill factor for small buckets. The reason is that it is difficult for small light buckets to penetrate stones. The fill factor has a range from 0.25 at 0 to 0.81 at 50 m<sup>3</sup>(65 yd<sup>3</sup>) The expression for the stone fill factor curve is Equation 6:

$$f_m = 0.1443 \text{ Ln}(C) + 0.25 \quad (6)$$

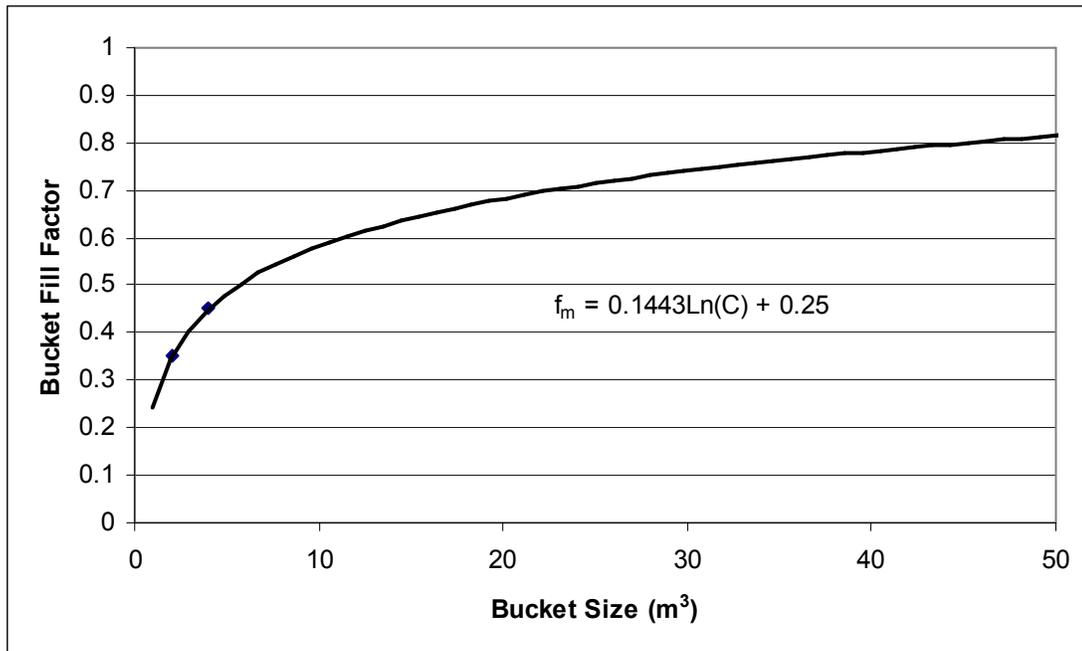
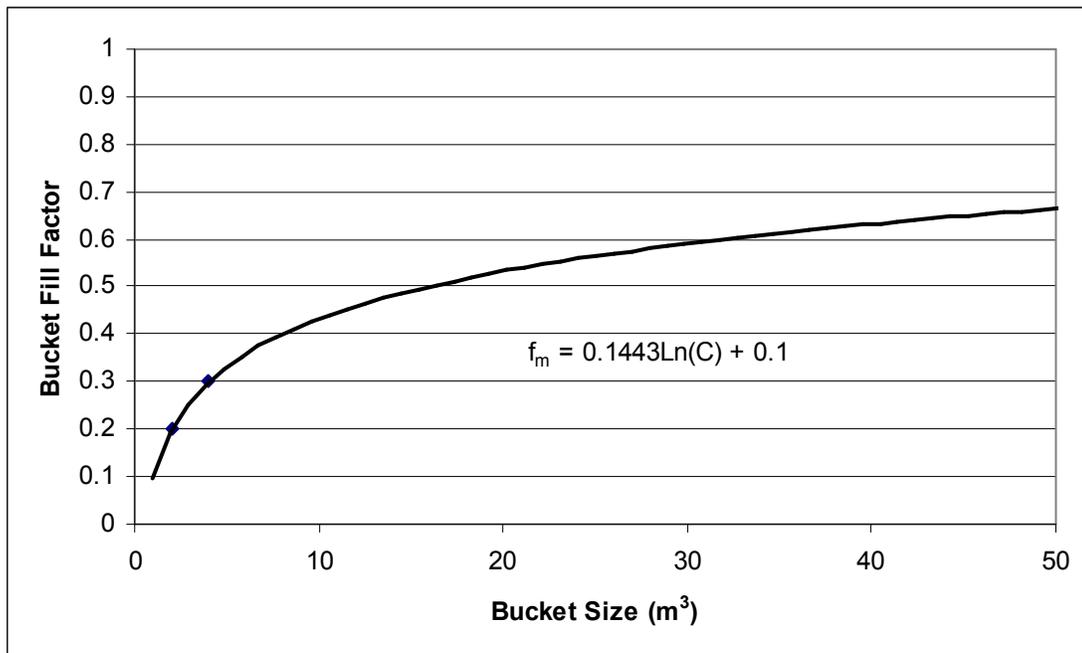


Figure 9-Fill Factor for Stones (Multiply by 1.3 to Convert to yd³)

Broken rock is the most difficult sediment type to excavate, and it is very irregularly shaped. This sediment type also contains the largest variation in sediment sizes. The third reason broken rock has a low fill factor is that large voids can form between rocks. Figure 10 shows the fill factor curve for broken rock. The initial value for broken rock is 0.1 and at 50 m³ (65 yd³) the fill factor approaches 0.7. Similar to the stone curve it is not necessary to force the curve below 1. The equation for the broken rock bucket factor is Equation 7.

$$f_m = 0.1443 \ln(C) + 0.1 \quad (7)$$



**Figure 10-Fill Factor for Broken Rock (Multiply by 1.3 to Convert to yd<sup>3</sup>)**

The bucket fill factors allow the amount of sediment removed each dredge cycle to be determined. These equations are integrated into the production and cost estimation spreadsheet and function in the background.

### **Comparison of Methods for Estimating Bucket Fill Factor**

For this thesis three methods of determining bucket fill factor are compared. Method 1 uses data provided by Bray (1997). These data provide two values for fill factor for each sediment type. These values are for relatively small buckets (<10 m<sup>3</sup>, <13 yd<sup>3</sup>). In the comparisons the fill factors are found by linearly interpolating between the two given values. Method 2 utilizes equations developed by Emmons (2001). Bucket size and

sediment type are input into the equation, and it provides a fill factor value. The third method (method 3) uses the equations discussed in the previous section to calculate fill factor. Though methods 1 and 3 use the same sediment classifications, method 2 uses slightly different classifications. All three methods included sand, and therefore the direct comparison is performed using sand.

Figure 11 is a direct comparison between bucket fill factor and bucket size. The range is from 0 to 50 m<sup>3</sup> (65 yd<sup>3</sup>). Method 2 begins above 1 and then drops below 1 at approximately 5 m<sup>3</sup> (7 yd<sup>3</sup>). The curve stays near 1 until 40 m<sup>3</sup> (52 yd<sup>3</sup>), and then at 40 m<sup>3</sup> (52 yd<sup>3</sup>) the curve begins to decrease. The curve for method 3 begins near 0.7 and gradually increases to 0.9 by 50 m<sup>3</sup> (65 yd<sup>3</sup>). Method 1 uses a linear curve fit to predict values past the provided data points (Method 1b). Method 1 is very effective for small buckets (<10 m<sup>3</sup>) (<13 yd<sup>3</sup>), but it is not designed to work past that point.

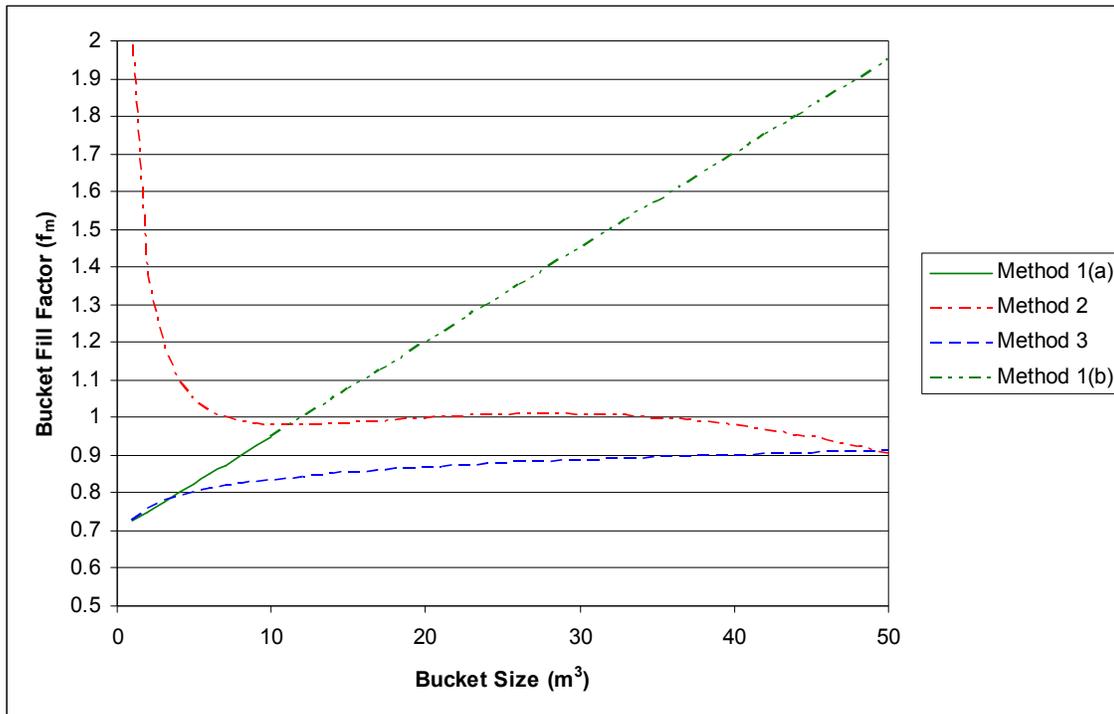
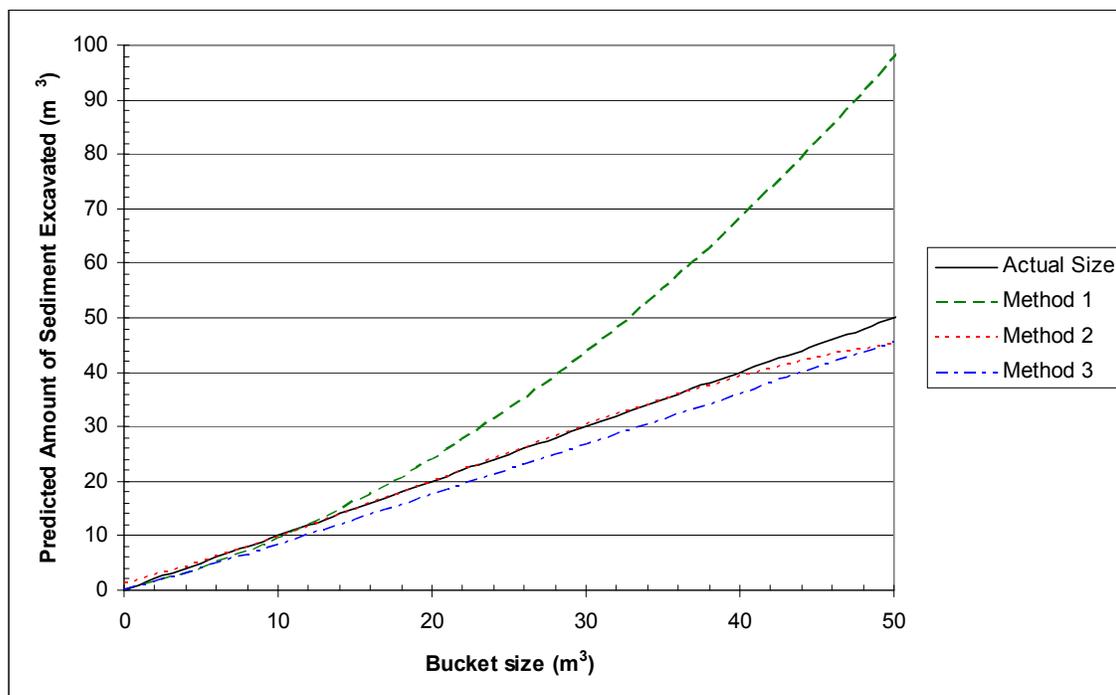


Figure 11-Comparison of Bucket Fill Factors (Multiply by 1.3 to Convert to yd<sup>3</sup>)

Figure 12 is the relationship between the three fill factor methods. The purpose of the graph is to display the relationship between the size of the bucket, and the predicted amount of sediment the methods predict is excavated. The graph is over a full range of bucket sizes from 0 to 50 m<sup>3</sup> (65 yd<sup>3</sup>). The predicted amount of sediment excavated ( $P_e$ ) is the fill factor ( $f_m$ ) for a specific method multiplied by the actual size ( $C$ ). Equation 8 is the relationship between the predicted amount of sediment excavated and the fill factor.

$$P_e = (C)(f_m) \quad (8)$$

Whenever the curve for a method is less than the actual size curve the fill factor is less than 1, and when the curve for a fill factor is greater than the actual size the fill factor is greater than 1. From 0 to 20 m<sup>3</sup> (26 yd<sup>3</sup>) all three methods appear to be collinear. At about 20 m<sup>3</sup> (26 yd<sup>3</sup>) method 1 begins to diverge from the actual bucket size, and it becomes unusable because the predicted amount of sediment excavated becomes larger than the actual size of the bucket. The other two methods function well to 50 m<sup>3</sup>.



**Figure 12-Comparison of Predicted Amount of Sediment Excavated as Predicted Using the Different Bucket Fill Factor Methods**

Figure 13 displays the relationships between the 3 methods and the actual size for buckets from 0 to 10 m<sup>3</sup> (13 yd<sup>3</sup>). Method 2 is nearly collinear with the actual size between 6 m<sup>3</sup> (8 yd<sup>3</sup>) and 10 m<sup>3</sup> (13 yd<sup>3</sup>). Between 0 and 6 m<sup>3</sup> (8 yd<sup>3</sup>) method 2 predicts

the factored size to be greater than the actual size. From 0 to 5 m<sup>3</sup> (7 yd<sup>3</sup>) method 1 and method 3 are similar. Both methods stay well below the actual size in this range. At 5 m<sup>3</sup> (7 yd<sup>3</sup>), method 1 begins to approach the actual size curve. Method 3 stays significantly less than the actual size curve until after 10 m<sup>3</sup>(13 yd<sup>3</sup>). Method 3, developed in this thesis, provides the best results for both large and small buckets.

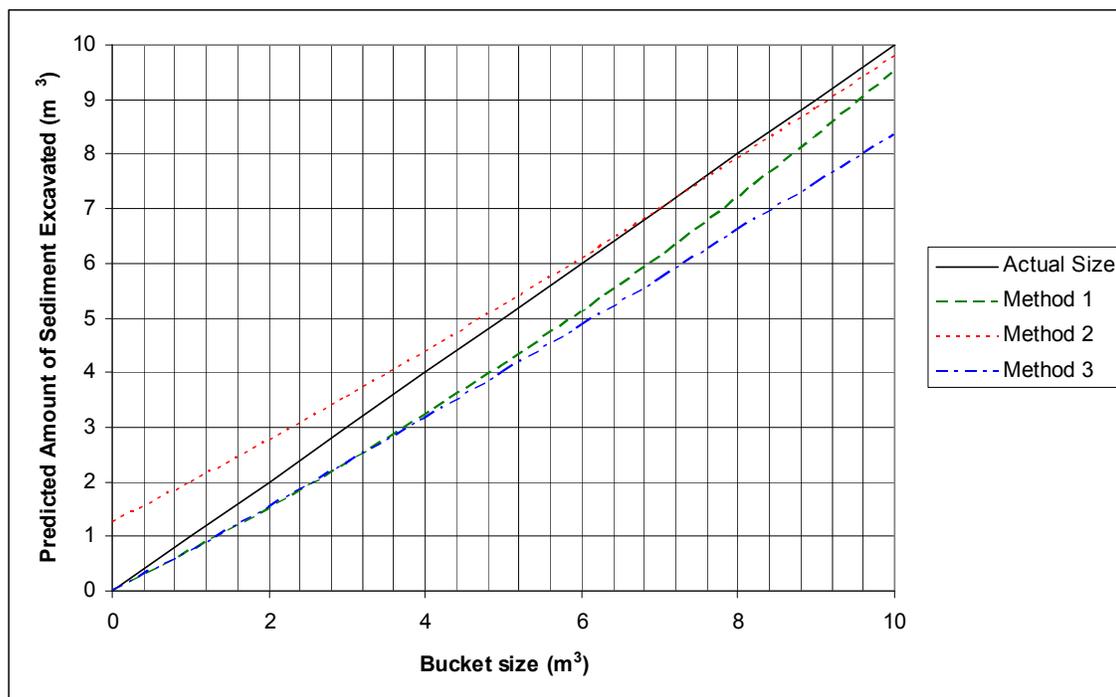


Figure 13-Fill Factor Comparison for Small Buckets (Multiply by 1.3 to Convert to yd<sup>3</sup>)

### Production Estimation and Delay Factors

Once cycle time ( $T_{cycle}$ ) and bucket fill factor ( $f_m$ ) are calculated, they are used to evaluate the nominal production ( $P_{nom}$ ). Bray (1997) defines nominal production as:

$$P_{nom} = \frac{3600}{T_{cycle}} C f_m \quad (9)$$

Equation 9 is the nominal production in either  $\text{yd}^3$  or  $\text{m}^3$  per hour. This depends on the units of the bucket size (C). Nominal production  $P_{nom}$  is one hour (3600 seconds) divided by the cycle time ( $T_{cycle}$ ) and then multiplied by the bucket capacity (C) and the bucket fill factor ( $f_m$ ). However, nominal production can be delayed for several reasons, for example the time required to change hoppers or advance the dredge. The first delay factor ( $f_a$ ) to consider is the time required to advance the dredge. Bray (1997) defines this as:

$$f_a = \frac{1}{\left(1 + \frac{t_a P_{nom} B}{Az}\right)} \quad (10)$$

In equation 10,  $t_a$  is the time required to advance the dredge, B is the bulking factor that is dependent on the sediment type and water content, A is the average area dredged, and z is the average thickness of the material. The second major delay is the time for changing hopper barge ( $f_h$ ).

$$f_h = \frac{1}{\left(1 + \frac{t_h f_a P_{nom} B}{H}\right)} \quad (11)$$

All of the variables in Equation 11 are the same as in Equation 10 with the addition of the hopper capacity H in meters, and  $t_h$  is the time required to change the hopper. Once

the delay factors are calculated, the actual production ( $P_{act}$ ) can be calculated using the nominal production ( $P_{nom}$ ) and the delay factors ( $f_a f_h$ ).

$$P_{act} = f_a f_h P_{nom} \quad (12)$$

$P_{act}$  is the actual production rate of the dredge ( $m^3/h$  or  $yd^3/h$ ), and all of the variables in Equation 12 have been defined previously in Equations 10 and 11. The actual production is the production rate at which the dredge can operate and is the value used to calculate project cost. The actual production rate does not include delays due to bad weather or equipment malfunction.

## CLAMSHELL COST ESTIMATION

### **Introduction to Clamshell Cost Estimation**

Once the production rate is determined the project cost can be estimated. Two things must be considered to determine the cost of the project. First, all of the individual costs must be calculated. Secondly, the length of the project must be calculated. The project length is determined by dividing the total sediment to be excavated by the maximum production rate. This value is then used to determine the length of time equipment is rented, and how long workers must be paid. The cost data has been taken from 3 sources. Means (2004) provides cost data on labor and some rental equipment and also provides methods to convert cost data from past years to current year values. The second source of cost data is the Institute of Water Resources Navigational Data Center's Report (NDC, 2003). NDC (2003) data provides overall project costs for around the country, and these data are used to create regional cost factors. These factors adjust project costs for various regions in the country. The final source of cost data is from previous work done by Emmons (2001). The method for estimating cost is discussed in more detail in the program architecture section.

### **Regional Cost Factors**

The estimated cost for the project comes from average cost data for the United States. There is a substantial difference between project costs in different regions of the country. This is due to labor rates, equipment costs, and other regional cost differences. For this reason it is necessary to adjust the total project cost depending on the area it takes place.

The cost estimation portion of the program is based on a national average. Therefore it is necessary to modify the results to find the project cost for the specific regions. The main regions in the United States are Alaska/Hawaii, Pacific Coast, Gulf Coast, Atlantic Coast, and the Great Lakes. The NDC provides the total cost of all contracts awarded. The first step in determining a cost factor is to sort all of the contracts by region. Then, all of the projects are plotted based on cost per  $m^3$  ( $yd^3$ ). Then the plots are visually inspected so that outliers can be removed. These outliers are projects that have a considerable larger average cost per volume than the rest of the data set. After all of the outliers have been removed, the average cost per volume for that region is calculated. The cost per volume for a specific region is then divided by the average cost per volume for the entire country. The ratio that results is the regional cost factor. This factor is then multiplied by the total cost of the project from the program. Figure 14 through Figure 23 display the range in project costs for specific regions. The data used came from the NDC (2003) and include all USACE mechanical clamshell dredging projects between 1990 and 2002. The data have been adjusted to 2004 dollars by using inflation factors from (Means, 2004). The cost per volume is determined from the actual total project cost divided by the total amount of sediment removed. The number of projects is on the x-axis, and the average cost per volume is on the y-axis.

Figure 14 is a graphical representation of all of the mechanical dredging projects in Alaska and Hawaii from 1990-2002. The projects range from \$6.50 per  $m^3$  (\$5 per  $yd^3$ ) to almost \$182  $m^3$  (\$140 per  $yd^3$ ). There are also only 11 projects in this region over the

12 year period. To determine the average cost per  $\text{yd}^3$  the two projects above  $\$52$  per  $\text{m}^3$  ( $\$40$  per  $\text{yd}^3$ ) were removed. The projects above  $\$52$  per  $\text{m}^3$  ( $\$40$  per  $\text{yd}^3$ ) do not represent normal projects and just increase the average cost.

Once the projects above  $\$52$  per  $\text{m}^3$  ( $\$40$  per  $\text{yd}^3$ ) are removed there are 9 projects for the Alaska Hawaii region. From Figure 15 it is shown that the projects range from a little less than  $\$6.50$  per  $\text{m}^3$  ( $\$5$  per  $\text{yd}^3$ ) to  $\$45.50$  per  $\text{m}^3$  ( $\$35$  per  $\text{yd}^3$ ). The average cost for the region is  $\$18$  per  $\text{m}^3$  ( $\$13.84$  per  $\text{yd}^3$ ). The Alaska and Hawaii region has the highest average cost because of increased transportation costs, labor rates, and large parts of the Alaskan coast freeze during the winter.

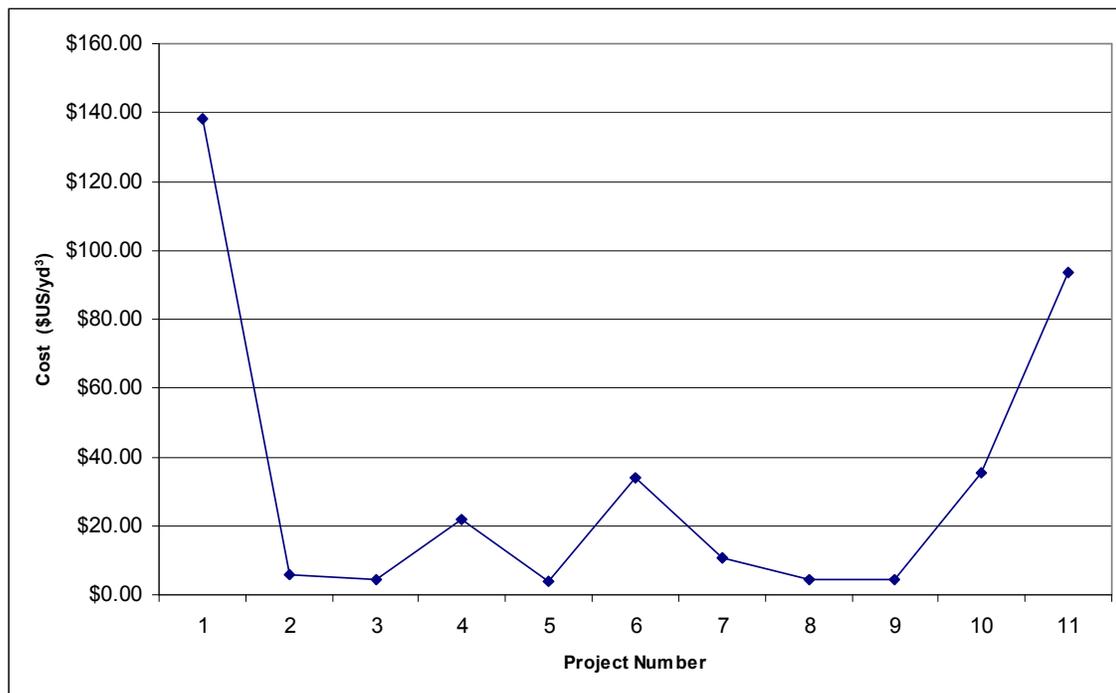
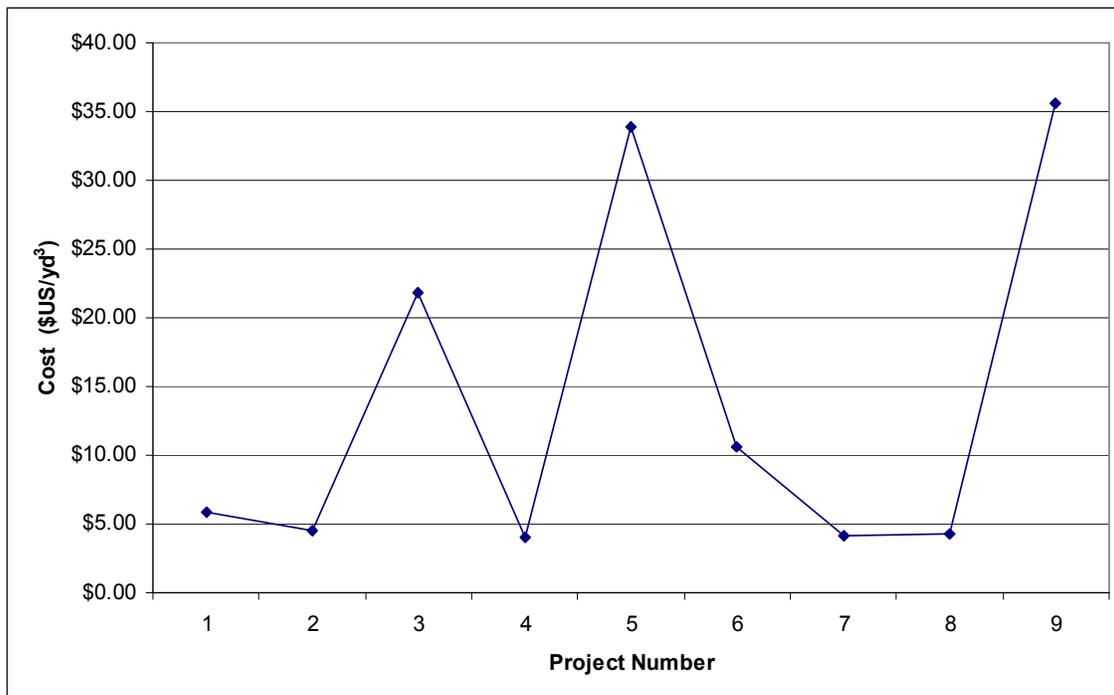


Figure 14-All Alaska and Hawaii Projects (1990-2002) (Multiply by 1.3 to Convert Cost to Dollars/ $\text{m}^3$ )

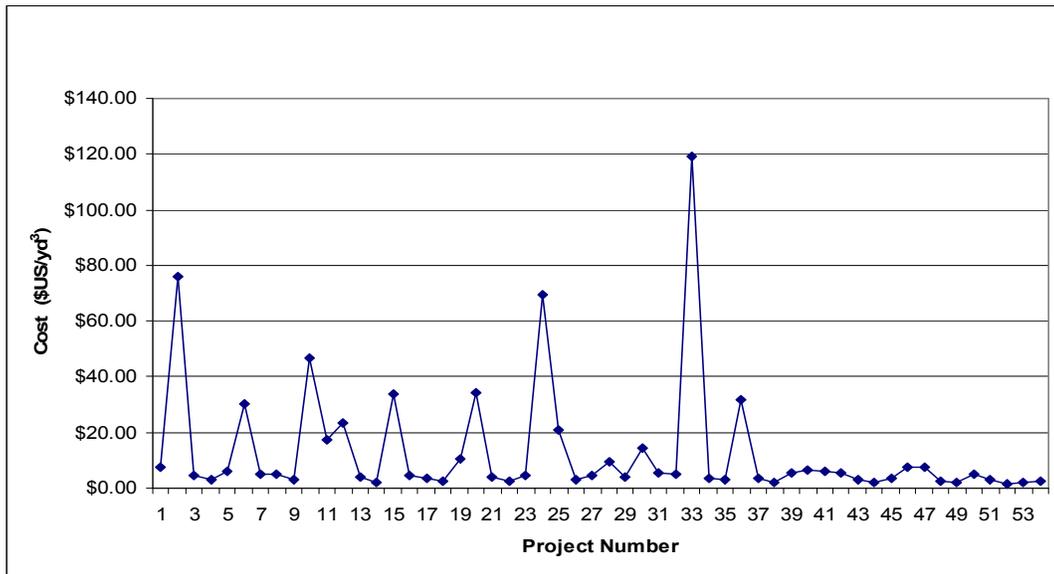


**Figure 15-Alaska and Hawaiian Projects without Outliers (1990-2002) (Multiply by 1.3 to Convert Cost to Dollars/m<sup>3</sup>)**

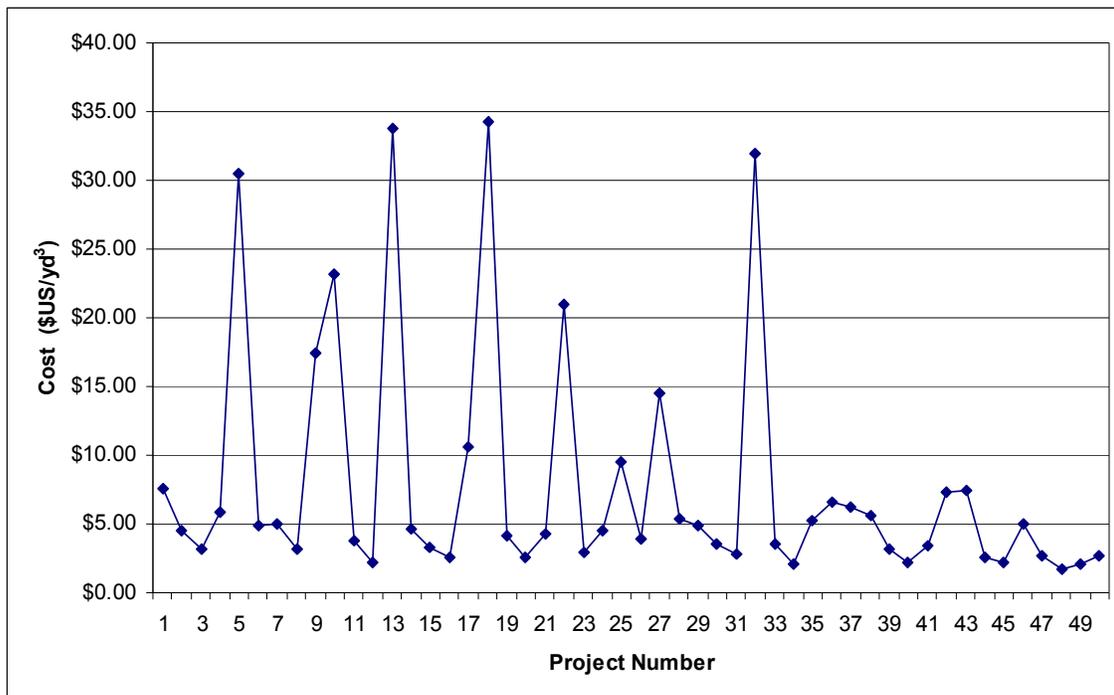
Figure 16 shows all the projects for the Pacific coast, and there were over 50 projects from 1990-2002. The range of cost per cubic yard is from less than \$3.90 per m<sup>3</sup> (\$3 per yd<sup>3</sup>) to almost \$156 per m<sup>3</sup> (\$120 per yd<sup>3</sup>). The majority of the projects are below \$26 per m<sup>3</sup> (\$20 per yd<sup>3</sup>). There are also several projects between \$26 per m<sup>3</sup> (\$20 per yd<sup>3</sup>) and \$52 per m<sup>3</sup> (\$40 per yd<sup>3</sup>). To find the average the four projects above \$52 per m<sup>3</sup> (\$40 per yd<sup>3</sup>) were removed.

With the 4 outliers removed there were 50 projects. This is a significant improvement in total number of projects from the Alaska/Hawaii region. The range is from less than \$3.90 per m<sup>3</sup> (\$3 per yd<sup>3</sup>) to almost \$45.50 per m<sup>3</sup> (\$35 per yd<sup>3</sup>). The average is \$10.09

per m<sup>3</sup> (\$7.76 per yd<sup>3</sup>) and is visually consistent with Figure 17 where the majority of the projects are between \$2.6 per m<sup>3</sup> (\$2 per yd<sup>3</sup>) to \$13 per m<sup>3</sup> (\$10 per yd<sup>3</sup>).



**Figure 16-All Pacific Clamshell Dredging Projects (1990-2002) (Multiply by 1.3 to Convert Cost to Dollars/m<sup>3</sup>)**

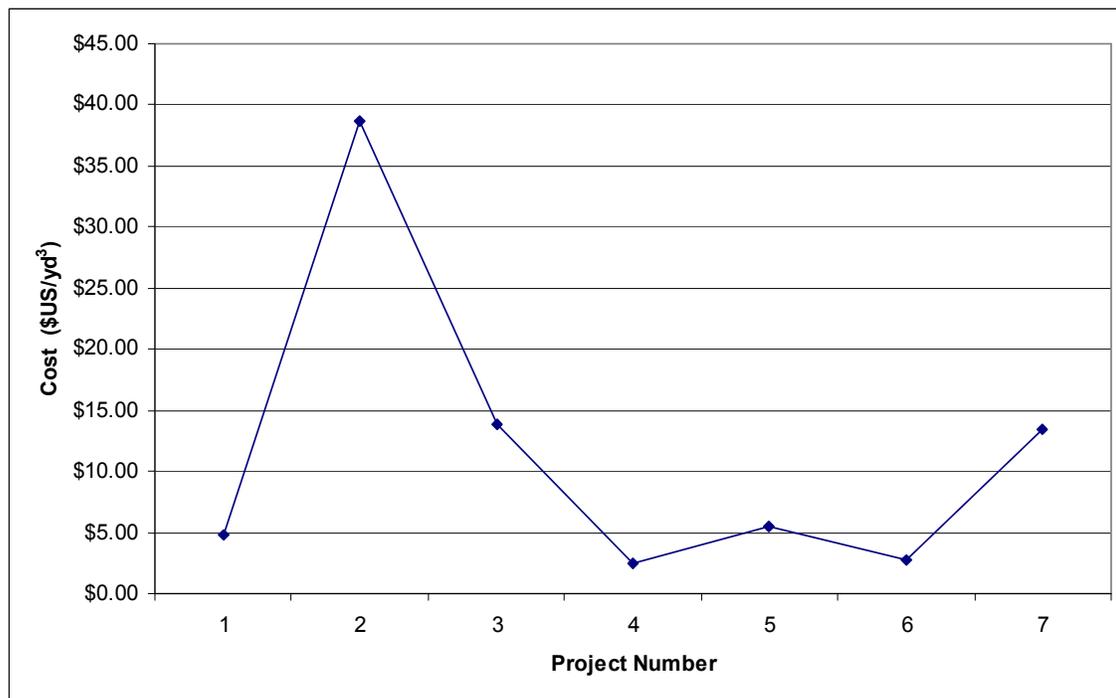


**Figure 17-Pacific Projects without Outliers (1990-2002) (Multiply by 1.3 to Convert Cost to Dollars/m<sup>3</sup>)**

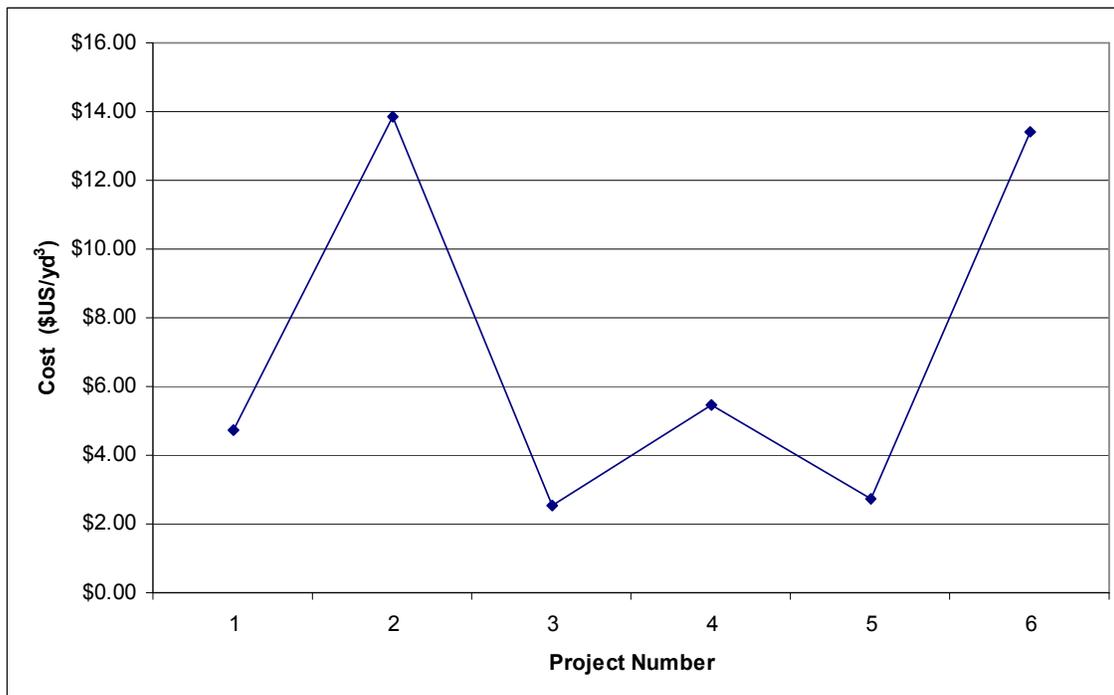
The Gulf coast presents a problem in predicting mechanical clamshell dredging projects because there are very few clamshell dredging projects completed in this region.

Between 1990 and 2002 there were only 7 mechanical dredging projects contracted by the USACE, and these projects are shown in Figure 18. The majority of dredging on the Gulf coast is accomplished with hopper or cutter suction dredges. In every region all projects above \$52 per m<sup>3</sup> (\$40 per yd<sup>3</sup>) were removed. An exception has been made for the Gulf coast. The project at \$49.40 per m<sup>3</sup> (\$38 per yd<sup>3</sup>) is removed. Since there were only 7 data points, then the \$49.40 per m<sup>3</sup> (\$38 per yd<sup>3</sup>) point skewed the results.

With the outlier removed Figure 19 shows the 6 projects on the Gulf Coast between 1990 and 2002. The projects all fall between \$2.60 per m<sup>3</sup> (\$2 per yd<sup>3</sup>) and \$18.20 per m<sup>3</sup> (\$14 per yd<sup>3</sup>). The Gulf Coast has the second lowest costs of any region in the country after the Atlantic coast with a regional average of \$9.26 per m<sup>3</sup> (\$7.12 per yd<sup>3</sup>).



**Figure 18-All Gulf Clamshell Dredging Projects (1990-2002) (Multiply by 1.3 to Convert Cost to Dollars/m<sup>3</sup>)**



**Figure 19-Gulf Projects without Outliers (1990-2002) (Multiply by 1.3 to Convert Cost to Dollars/m<sup>3</sup>)**

Figure 20 displays all clamshell dredging projects on the Atlantic coast between 1990 and 2002. The majority of the projects are below the \$26 per m<sup>3</sup> (\$20 per yd<sup>3</sup>) mark. The most expensive case had a cost of almost \$130 per m<sup>3</sup> (\$100 per yd<sup>3</sup>), but all projects above \$52 per m<sup>3</sup> (\$40 per yd<sup>3</sup>) were removed to find the average.

With the 2 outliers removed from Figure 21 there were 88 projects remaining. 18 of these projects have a cost of over \$13 per m<sup>3</sup> (\$10 per yd<sup>3</sup>). The average for the Atlantic coast is \$9.15 per m<sup>3</sup> (\$7.04 per yd<sup>3</sup>) which is the lowest in the United States. This is slightly less than the Pacific coast and \$0.10 per m<sup>3</sup> (\$0.08 per yd<sup>3</sup>) lower than the Gulf coasts cost.

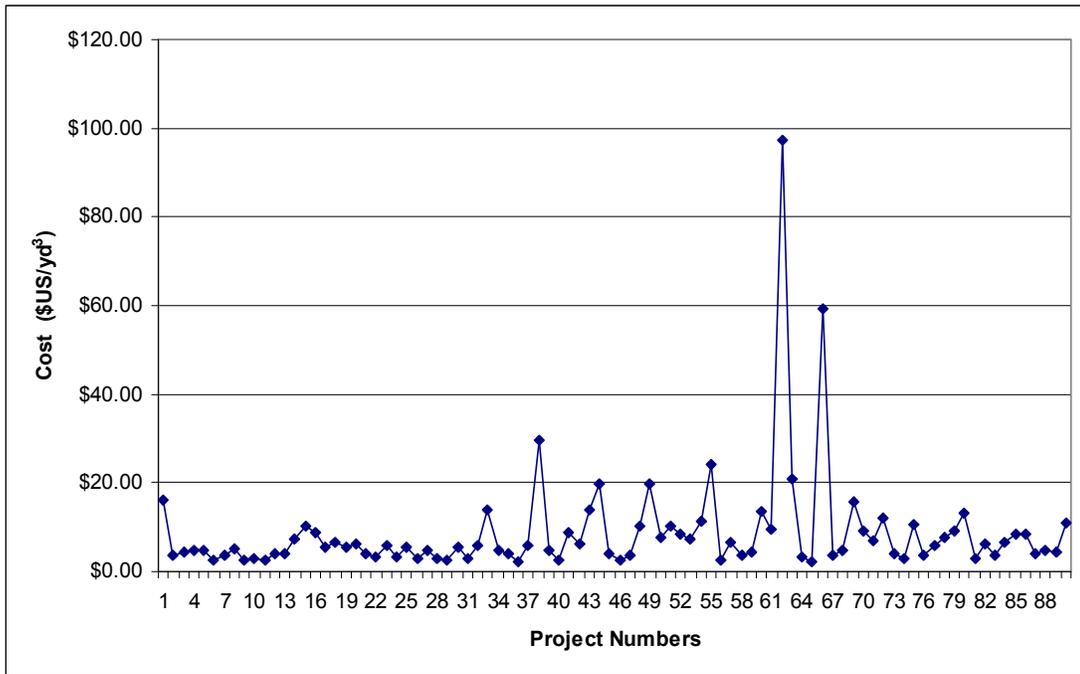


Figure 20-All Atlantic Coast Clamshell Dredging Projects (1990-2002) (Multiply by 1.3 to Convert Cost to Dollars/m<sup>3</sup>)

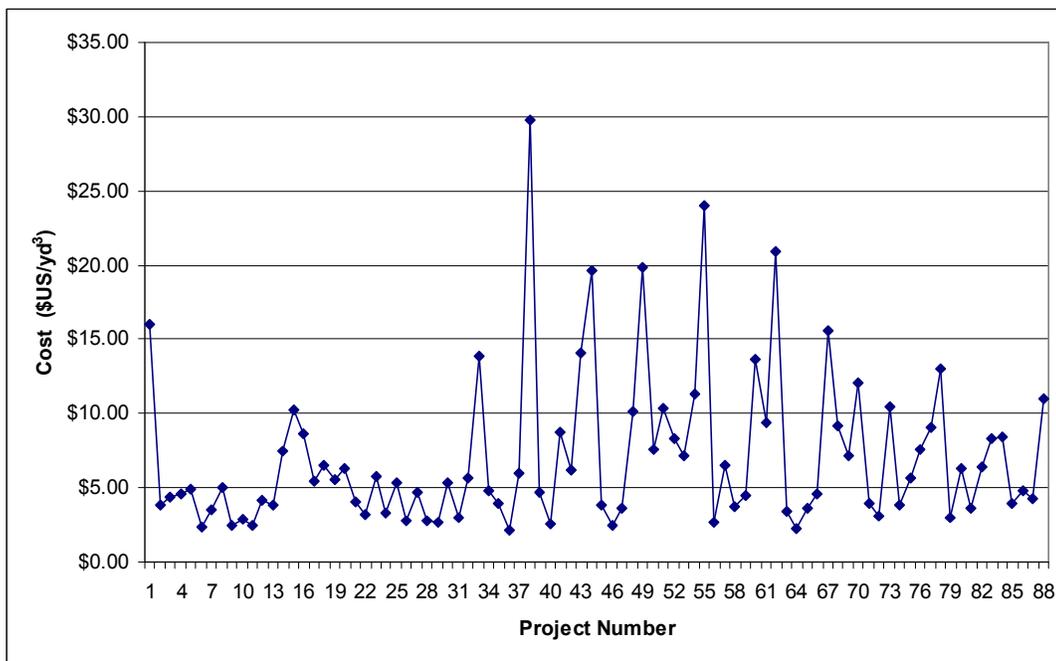
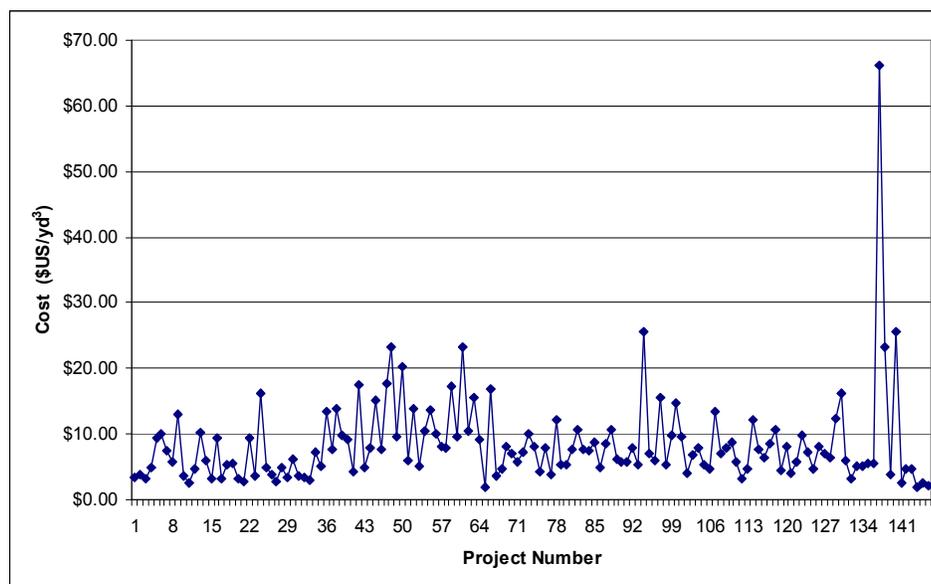


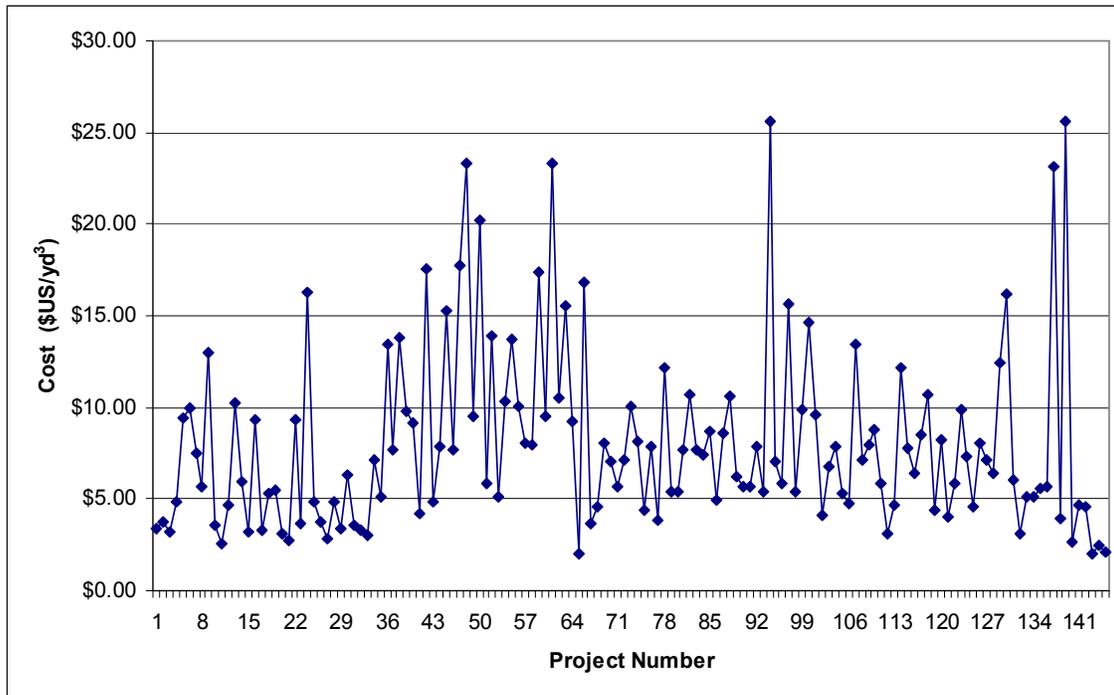
Figure 21-Atlantic Projects without Outliers (1990-2002) (Multiply by 1.3 to Convert Cost to Dollars/m<sup>3</sup>)

There were more mechanical clamshell dredging projects in the Great Lakes than any other region between 1990 and 2002. In Figure 22 it is apparent that all of the projects but one are under \$39 per  $m^3$  (\$30 per  $yd^3$ ). The remainder of the projects are between \$3.9 per  $m^3$  (\$3 per  $yd^3$ ) and \$35.10 per  $m^3$  (\$27 per  $yd^3$ ). Therefore the project with a cost of \$84.50 per  $m^3$  (\$65 per  $yd^3$ ) is removed and the remainder of the projects are used to calculate the average. This is consistent with removing all projects over \$52 per  $m^3$  (\$40 per  $yd^3$ ).

With the one outlier removed the Great Lakes projects range from \$0 to almost \$33.80 per  $m^3$  (\$26 per  $yd^3$ ). This can be seen in Figure 23. The average for this region is \$10.45 per  $m^3$  (\$8.04 per  $yd^3$ ). This is a full dollar more than the Pacific coast. The Great Lakes region is the second most expensive region after Alaska/Hawaii.



**Figure 22-All Great Lakes Clamshell Dredging Projects (1990-2002) (Multiply by 1.3 to Convert Cost to Dollars/ $m^3$ )**



**Figure 23-Great Lakes Projects without Outliers (1990-2002) (Multiply by 1.3 to Convert Cost to Dollars/m<sup>3</sup>)**

Table 1 shows the average cost per volume for each region. The average cost per volume at the bottom is the overall average. The regional cost factor is the ratio of the regional average divided by the overall average. The Alaska/Hawaii region has the largest average cost per volume and almost doubles the overall average cost per volume. The Atlantic Coast region has the lowest regional cost factor. The ratios between the national averages matches the expected values, with Alaska/Hawaii being the highest, and the Gulf and Atlantic Coasts being the lowest. Once the total cost of a project is calculated, it is multiplied by the regional cost factor to determine the total project cost. For example, a project with all of the same inputs costs is almost twice as much in Anchorage, Alaska, as it would in Boston Harbor.

**Table 1-Regional Cost Factor**

Region	Average Cost/yd <sup>3</sup>	Average Cost/m <sup>3</sup>	Regional Cost Factor
Alaska/Hawaii	\$13.84	\$18.10	1.71
Atlantic	\$7.04	\$9.21	0.87
Gulf	\$7.12	\$9.31	0.88
Great Lakes	\$8.04	\$10.52	0.99
Pacific	\$7.76	\$10.15	0.96
Average	\$8.11	\$13.28	

The regional cost factor is necessary to provide accurate cost estimation. Though production rates should be consistent anywhere in the United States given the same sediment and ocean conditions, project cost varies significantly between the Alaska/Hawaii region and the rest of the United States. The other four regions are within 10% of each other.

## SOFTWARE FOR CLAMSHELL DREDGE COST ESTIMATION

### Program Architecture

The cycle time, bucket fill factor, cost estimation, regional cost factor, and delay factors have been combined into an Excel spreadsheet to calculate production and total project cost. The main inputs for the spreadsheet are shown in Table 2, and all of the input units are in metric. The first column shows the variables for each term. The cells in the second column are the main inputs for the program. The cells in yellow are calculated by the spreadsheet and should not be changed. The third column contains recommended default values if the site specific value is not known. The fourth column shows the units for each variable, and the fifth column contains a brief definition of each variable.

**Table 2-Program Input**

Parameter	Value	Defaults	Units	Definition
Sediment type	2	2		See Table 3
R	3	3		Region
A	1142.7	1142.7	m <sup>2</sup>	Average area dredged
z	2	2	m	thickness of material dredged
H	3440	3440	m <sup>3</sup>	Hopper capacity
C	18.3	18.3	m <sup>3</sup>	Capacity of the bucket
V	1000000		m <sup>3</sup>	volume to be dredged
d	50		m	depth
h	2	2	m	freeboard height of the barge
ta	0.33	0.33	Hrs	Time to advance the dredge
sa	120	120	deg	Average swing angle
th	0.25	0.25	Hrs	Time to change hoppers
B	1.1			Bulking factor
fa	0.96			delay factor for dredge advance
fh	0.98			delay factor for barge change
fm	0.84			modification factor
Volume Dredged	15.36		m <sup>3</sup>	volume in-situ dredged
Pnom	232.19		m <sup>3</sup> /hr	Nominal Production
Pmax	184.61		m <sup>3</sup> /hr	Maximum Production
CT	238.11		seconds	Cycle time

Table 3 is the key for the various sediment types, and the appropriate sediment type. The sediment type effects the bucket fill factor calculation as well as the bulking factor. The bulking factor is used to calculate how long it takes for a hopper barge to fill.

The second input is the region, and Table 3 also shows the appropriate number to input for each region. The third input is A, the average area dredged. This is the area that the dredge can excavate before it has to move. The next inputs are the average thickness (z) of the material to be dredged, the capacity of the hopper barge in m<sup>3</sup> (H), the capacity of the bucket (C), and the total volume (V) of sediment to be removed in the project. The water depth at the site(d), and the freeboard height of the hopper barge (h), are needed to calculate the total vertical distance the bucket moves. The total distance the bucket moves is used in the cycle time calculation. The time to advance the dredge (ta), and the average swing angle of the dredge ( $\theta_{sa}$ ) denoted by “ta” in the spreadsheet. The swing angle ( $\theta_{sa}$ ) is multiplied by the swing rate ( $\omega_{sw}$ ) to determine a portion of the cycle time. The final input is the time required to change hopper barges (th).

**Table 3-Sediment Type Key and Region Key**

<b>Soil Type</b>	<b>Number</b>
Mud	1
Loose Sand	2
Compact Sand	3
Sand and Clay	4
Stones	5
Broken Rock	6

<b>Region</b>	<b>Number</b>
Alaska/Hawaii	1
East Coast	2
Gulf Coast	3
Great Lakes	4
West Coast	5

Table 4 is the second page of the spreadsheet, which contains calculations of the cycle time and the other factors that are used to sum all of components of the dredge cycle.

The first column is the different components of the dredge cycle. The second column is the values that the program is currently using. Each value can be adjusted for a specific dredge or location. The depth value and freeboard height of the barge come straight from the input phase and should not be manually adjusted on this page. The third column contains all of the default values. Components such as lift velocity can be adjusted to simulate environmental dredging projects.

**Table 4-Cycle Time Calculation**

Cycle time		
Factor	Time	Default
Average Swing Angle (degrees)	120	120
Swing speed (deg/sec)	21	21
Average Depth (m)	12.2	
Lift velocity (m/s)	0.30	0.3
Grab time (s)	1	1
Fall Velocity (m/s)	1	1
Time to empty clamshell (s)	2.6	2.6
Freeboard height of barge (m)	2	
Cycle time	75.9	seconds

The bulking factor is the amount the sediment is expected to swell (bulk) when it is excavated. This value is used to predict how often a hopper is filled, and therefore how often the hopper needs to be replaced. The program reads the sediment type from the input page and then picks the correct bulking factor from Table 5.

**Table 5-Bulking Factor (Bray, 1997)**

Bulking Factor Calculation	
Sediment Type	Bulking Factor (B)
Mud	1.15
Loose Sand	1.1
Compact Sand	1.3
Sand and Clay	1.25
Stones	1.3
Broken Rock	1.5

Table 6 displays the bucket fill factor calculation table. The spreadsheet uses the bucket size and calculates the fill factor for each type of sediment. Then the last cell checks the input page and uses the appropriate sediment type for the problem.

**Table 6-Bucket Fill Factor**

Fill Factor	
Sediment type	
Mud	0.86
Loose Sand	0.84
Compact Sand	0.82
Sand and Clay	0.78
Stones	0.67
Broken Rock	0.52

The average regional cost factors are tabulated in Table 7. The spreadsheet checks the input page and selects the appropriate regional cost factor. Then, the regional cost factor is multiplied by the total project cost to determine the project cost for that region.

**Table 7-Regional Cost Factor**

	average cost	factor
Alaska	\$13.84	1.71
East	\$7.04	0.87
Gulf	\$7.12	0.88
Great Lakes	\$8.04	0.99
West	\$7.76	0.96
Factor Used		0.87

Table 8 contains the factors used to adjust a projects cost for a specific past year (Means, 2004). The total project cost is multiplied by the index for 2004 and then divided by the index for the appropriate year.

**Table 8-Yearly Project Cost Transformation Factor**

Current Cost Index	
Year	Index
2004	100
2003	99.2
2002	96.8
2001	94.1
2000	90.9
1999	88.4
1998	86.5
1997	84.8
1996	82.9
1995	80.9
1994	78.5
1993	76.5
1992	74.8
1991	72.8
1990	70.9

The production calculations are located at the bottom of the input page. The first row is the bulking factor which comes from the bulking factor calculation chart. The next

calculation is the delay factor for advancing the dredge. The delay factor for changing the hopper (fh) is the third row. The fourth row is the modification factor which comes from Table 9. The next value is the volume dredged, which is (fm) multiplied by the bucket size.  $P_{nom}$  is the nominal production rate that comes from the cycle time and the modified bucket size.  $P_{act}$ , the actual production rate is  $P_{nom}$  multiplied by (fa) and (fh).  $P_{act}$  is used for calculating project length and for the other project cost calculations. The final row is the cycle time that the program calculated.

**Table 9-Production Calculation**

B	1.1		Bulking factor
fa	0.90		delay factor for advancing the dredge
fh	0.95		delay factor for changing hoppers
fm	0.84		modification factor
Volume Dredged	15.36	m <sup>3</sup>	volume of sediment actually dredged
Pnom	727.95	m <sup>3</sup> /hr	Nominal Production (Adair method)
Pmax	620.16	m <sup>3</sup> /hr	Maximum Production (Adair Method)
CT	75.95	seconds	Cycle time

Some of the cost data used for the program are based on costs from the year 2000. Table 10 is the chart used to find the difference in prices between 2000 and 2004. The ratio between the 2000 and 2004 cost factors is multiplied by all cost values that could not be found for 2004.

**Table 10-Cost Factor Transform from 2000 to 2004 (Means, 2004)**

2000 Cost Factor	120.9
2004 Cost Factor	133
Cost Factor Ratio	1.1

Table 11 contains several intermediate values used to calculate the project cost. The first column is the input values and the second column is the cost values converted from 2000 dollars to 2004 dollars. The third column is the description of each input. The size of the clamshell and hopper capacity are both from the input sheet. The third row is the dollar value of a hopper. The next two rows are the depth and cycle time from the production portion of the program, and the following three rows are used in fuel calculation where the fuel cost is for diesel fuel.

The subsequent five rows are cost values that have been transformed from 2000 to 2004 values. The final rows are the depreciation period, average number of working days, mobilization/demobilization cost, yearly insurance, and finally the bonding rate. All of these values are used to calculate the total project cost, and all of the cost transformations use the cost factor ratio in Table 10.

**Table 11-Cost Calculation Inputs**

<b>Input</b>	<b>2004</b>	<b>Description</b>
23.9355		Size of Clamshell (yd <sup>3</sup> )
4499.35		Hopper Capacity (yd <sup>3</sup> )
600000	\$660,049.63	Average Value per Hopper (dollars)
26		Dredging Depth (ft)
57.6		Cycle Time (seconds)
18		Hourly fuel usage for Dredge Engine (Gallon)
150		Daily fuel usage for House Power (Gallon)
100		Daily fuel usage for Winch House (Gallon)
1.3	1.65	Cost per Gallon for Fuel (Dollars)
150414		Required Dredging Volume (yd <sup>3</sup> )
5		Expected Overdredging (Percent)
4550000	\$5,005,376	Capital Cost of Dredge (Dollars)
		Average Daily Cost of Major Repairs and Overhauling for Dredge
1137.50	\$1,251.34	(Dollars)
		Average Daily Cost for Routine Repairs and Maintenance for Dredge
591.50	\$650.70	(Dollars)
		Average Daily Cost of Major Repairs and Overhauling for Hoppers
60	\$66.00	(Dollars)
		Average Daily Cost for Routine Repairs and Maintenance for Hoppers
30	\$33.00	(Dollars)
25		Depreciation Period (Years)
320		Average number of working days per year for dredge
250000	\$275,020.68	Mobilization/Demobilization Costs (Dollars)
113750	\$125,134.41	Yearly Insurance Cost (Dollars)
5		Bonding Rate (Percent)

The cost transformation between 2000 and 2004 costs for equipment and food is shown in Table 12. All of the values are then transferred into the equipment calculation portion of the program. The extra rows can be used to calculate cost for other equipment used and are automatically transferred into the equipment cost portion of the spreadsheet.

**Table 12-Equipment and Food Cost**

	<b>Units</b>	<b>Days</b>		
			<b>2000</b>	<b>2004</b>
<b>Crew Lodging</b>	1	6867	\$75	\$82.51
<b>Temporary Office Space</b>	1	359.7	\$150	\$165.01
<b>Tugboat contracted or in-house</b>	1	327	\$1000	\$1,100.08
<b>Crew boat</b>	1	327	\$750	\$825.06
<b>Barge</b>	3	327	\$1000	\$1,100.08
<b>Bulldozer</b>	0	327	\$400	\$440.03
<b>Marsh Buggy</b>	0	327	\$350	\$385.03
	0	327	0	\$0.00
	0	327	0	\$0.00
	0	327	0	\$0.00
	0	327	0	\$0.00
	0	327	0	\$0.00
	0	327	0	\$0.00
	0	327	0	\$0.00
	0	327	0	\$0.00
<b>Food Cost</b>			\$15	\$16.50

The crew cost calculation is shown in Table 13. Means (2004) is used to evaluate the crew size and labor rates. The daily food cost comes from Table 13. The crew cost calculation assumes three shifts working 8 hours in calculating daily totals. The final row in the table is the total daily crew cost which is the wage rate multiplied by 24 hours and the number of workers.

**Table 13-Crew Cost**

	Number	Rate	Daily Total
Labor Foreman	1	\$28.00	\$672.00
Laborer	2	\$26.00	\$1,248.00
Equipment Operator	2	\$33.65	\$1,615.20
Equipment Operator Oiler	1	\$29.20	\$700.80
8 hour shifts	3		
Total Crew	18		
Daily Food Cost/person	\$16.50	total	\$297.02
Total Daily Crew Cost			\$4,236.00

Table 14 is the overall cost summary and the first column is the label for each item. The first section is the production values. Next are the fuel and lubricant costs. The section after that is the individual cost totals. The second to last cell is the total project cost. The cost per volume is the total cost divided by the total volume of sediment excavated.

**Table 14-Cost Summary**

<b>Production Summary</b>		
Production Rate	yd <sup>3</sup> /hr	1021
Required Volume to be dredged	yd <sup>3</sup>	150414
Gross Volume (includes overdredging)	yd <sup>3</sup>	157935
Estimated Daily Run Time	hours	24
Required Dredging Time	hours	155
Required Dredging Days	days	23
<b>Fuel and Lubricant Cost</b>		
House Power		4,485
Dredge Engine Fuel (90% of total hours)		3,257
Winches		2,990
Lubricants (10% of Fuel Cost)		1,073
<b>Repair and Maintenance</b>		\$46,024
<b>Depreciation</b>		\$14,390
<b>Mobilization-Demobilization Cost</b>		\$275,020
<b>Insurance</b>		\$8,994
<b>Crew</b>		\$97,428
<b>Rentals</b>		\$110,442
<b>10% Overhead (Profit)</b>		\$56,410
<b>Total Job Cost</b>		\$614,909
<b>Price per Cubic Yard</b>		\$3.89

The bottom of the main page (Table 15) contains the overall output with the production is given in yd<sup>3</sup>/hr and m<sup>3</sup>/hr. The third row of Table 15 is the total cost of the project, and the final rows are the cost per cubic yard, and cost per cubic meter. These outputs are located on the first page so that they can be quickly checked as the inputs are changed.

**Table 15-Final Output**

<b>Output</b>		
Production	620	m <sup>3</sup> /hr
	811	yd <sup>3</sup> /hr
Total Cost	\$2,622,174	
Cost/m <sup>3</sup>	\$3.53	
Cost/yd <sup>3</sup>	\$2.57	

Table 16 is the calculations to compare current projects to past projects. The desired project is entered in the first cell. The cost transformation factor is then retrieved from Table 8. The factor is then used to calculate the project cost for any year between 1990 and 2004.

**Table 16-Final Output Adjusted for a Year Other Than 2004**

<b>Output for Historic Project</b>		
Project year	1994	2004
Factor used	78.5	
Total Cost	\$2,037,587	
Cost/m <sup>3</sup>	\$2.75	
Cost/yd <sup>3</sup>	\$2.00	

Use a Project year (1990-2004)

### **Sensitivity**

Once the production and cost estimating program is functioning it is necessary to determine if it is functioning properly, and to see if the results are accurate. The first step is to test the sensitivity. This is done by observing how the total project cost responds to varying inputs.

The initial conditions for the first sensitivity test on bucket size are shown in Table 17.

The sediment type used is loose sand, and the region is the Gulf Coast. All of the other defaults are left constant. The depth is set at 10 meters, and the volume to be removed is 1,000,000 m<sup>3</sup>. The spreadsheet is then run keeping everything constant except bucket size that is changed from 1, 5, 10, 15...50 m<sup>3</sup>.

**Table 17-Initial Conditions for Bucket Size Sensitivity Test**

Parameter	Value	Defaults	Units
Sediment type	2	2	
R	3	3	
A	1142.7	1142.7	m <sup>2</sup>
z	2	2	m
H	3440	3440	m <sup>3</sup>
C	18.3	18.3	m <sup>3</sup>
V	1000000		m <sup>3</sup>
d	10		m
h	2	2	m
ta	0.33	0.33	Hrs
sa	120	120	deg
th	0.25	0.25	Hrs
B	1.1		
fa	0.88		
fh	0.94		
fm	0.84		
Volume Dredged	15.36		m <sup>3</sup>
Pnom	831.25		m <sup>3</sup> /hr
Pmax	582.05		m <sup>3</sup> /hr
CT	66.51		seconds

The results from the first sensitivity test are shown in Figure 24. It is apparent from Figure 24 that overall project cost is very sensitive to bucket size. This is especially true in the range from 0 to 20 m<sup>3</sup>. Once the bucket size reaches 20 m<sup>3</sup>, variations in project cost are very small. This is consistent with the bucket modification factors. From the

region of 0 to 20 m<sup>3</sup> the bucket fill factors increase at a large rate. After 20 m<sup>3</sup> the slope flattens. From Figure 24 it is apparent that it is necessary to have accurate information on bucket size when dealing with buckets smaller than 20 m<sup>3</sup> (26.2 yd<sup>3</sup>). It is also apparent that increasing bucket size is a method of effectively reducing project cost.

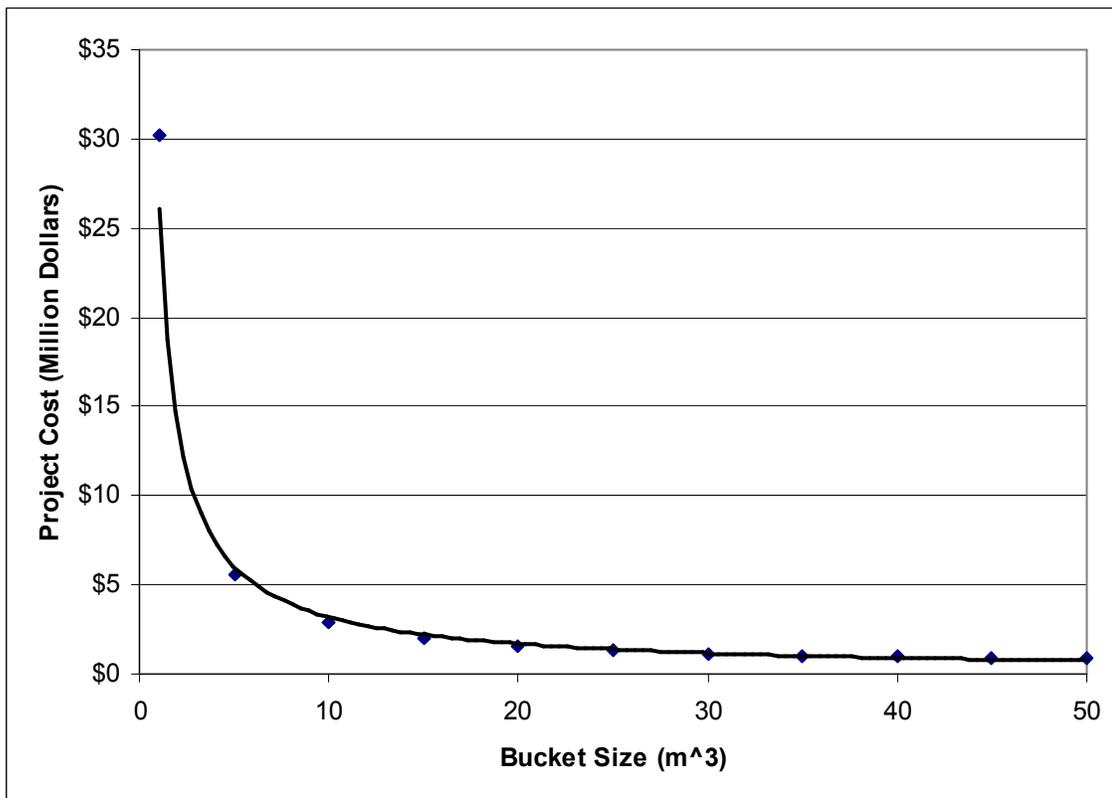


Figure 24-Project Cost Sensitivity from Bucket Size (Multiply by 1.3 for yd<sup>3</sup>)

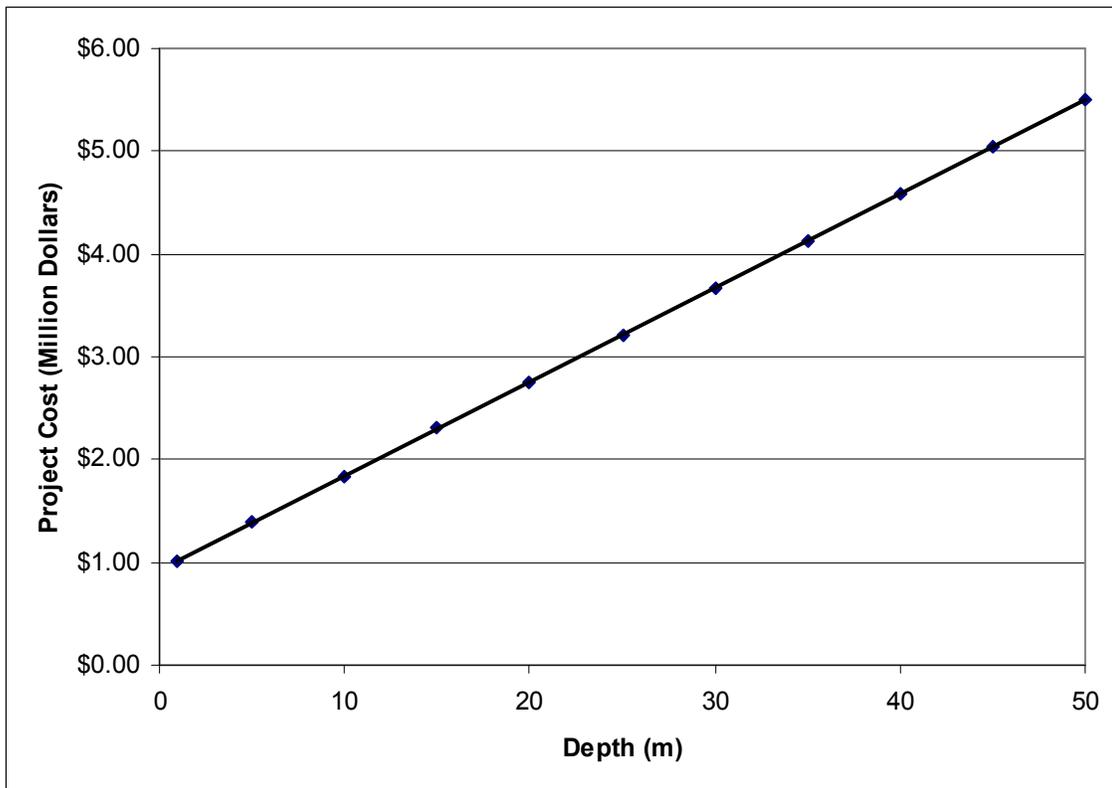
Table 18 contains the initial conditions for the sensitivity test for varying depth. All of the initial conditions are identical to the sensitivity test for varying bucket size. The test is conducted by holding all variables constant and changing the depth. The project cost is recorded at depths of 1, 5, 10, 15...50 meters. At each data point the project cost and

cycle time is recorded. Then the relationship between depth and project cost, or cycle time is plotted on two graphs.

**Table 18-Initial Conditions for Depth Sensitivity Test**

Parameter	Value	Defaults	Units
Sediment type	2	2	
R	3	3	
A	1142.7	1142.7	m <sup>2</sup>
z	2	2	m
H	3440	3440	m <sup>3</sup>
C	18.3	18.3	m <sup>3</sup>
V	1000000		m <sup>3</sup>
d	10		m
h	2	2	m
ta	0.33	0.33	Hrs
sa	120	120	deg
th	0.25	0.25	Hrs
B	1.1		
fa	0.88		
fh	0.94		
fm	0.84		
Volume Dredged	15.36		m <sup>3</sup>
Pnom	831.25		m <sup>3</sup> /hr
Pmax	582.05		m <sup>3</sup> /hr
CT	66.51		seconds

Figure 25 displays the relationship between project cost and depth. The projects range from \$1,000,000 at 1 m (1.1 yd) depth to \$5,500,000 at 50 m (55 yd) of depth. The relationship between project cost and depth is linear. This is the result that is expected. The depth is entered into a linear equation to calculate cycle time. Cycle time is proportional to project cost, and therefore, the project cost should be linearly related to depth.



**Figure 25-Sensitivity of Project Cost Due to Change of Depth (Multiply by 1.1 for yd)**

The relationship between change of depth and cycle time is shown in Figure 26. Cycle time changes linearly as depth is varied. This is expected since depth is a linear term in the cycle time equation. From this relationship and the relationship in Figure 26 it is apparent that cycle time is an important factor when determining project cost. While an estimate of 60 seconds may provide an accurate result in depths less than two meters, the cycle time doubles between 10 and 20 meters. This would in turn double a projects total time and greatly increase the project cost. Since a large number of ports and waterways in the United States are at a depth between 10 and 20 meters it is important to include cycle time in production estimates.

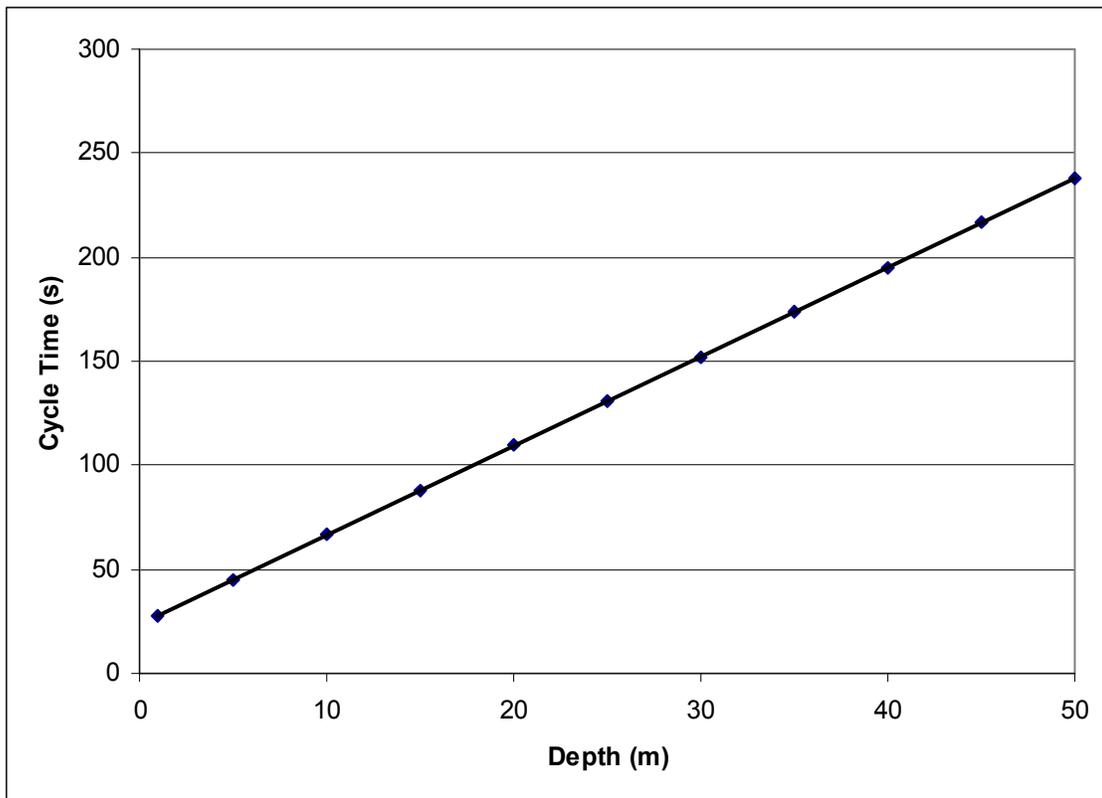


Figure 26-Sensitivity of Cycle Time from Depth Change

### Project Cost Comparison

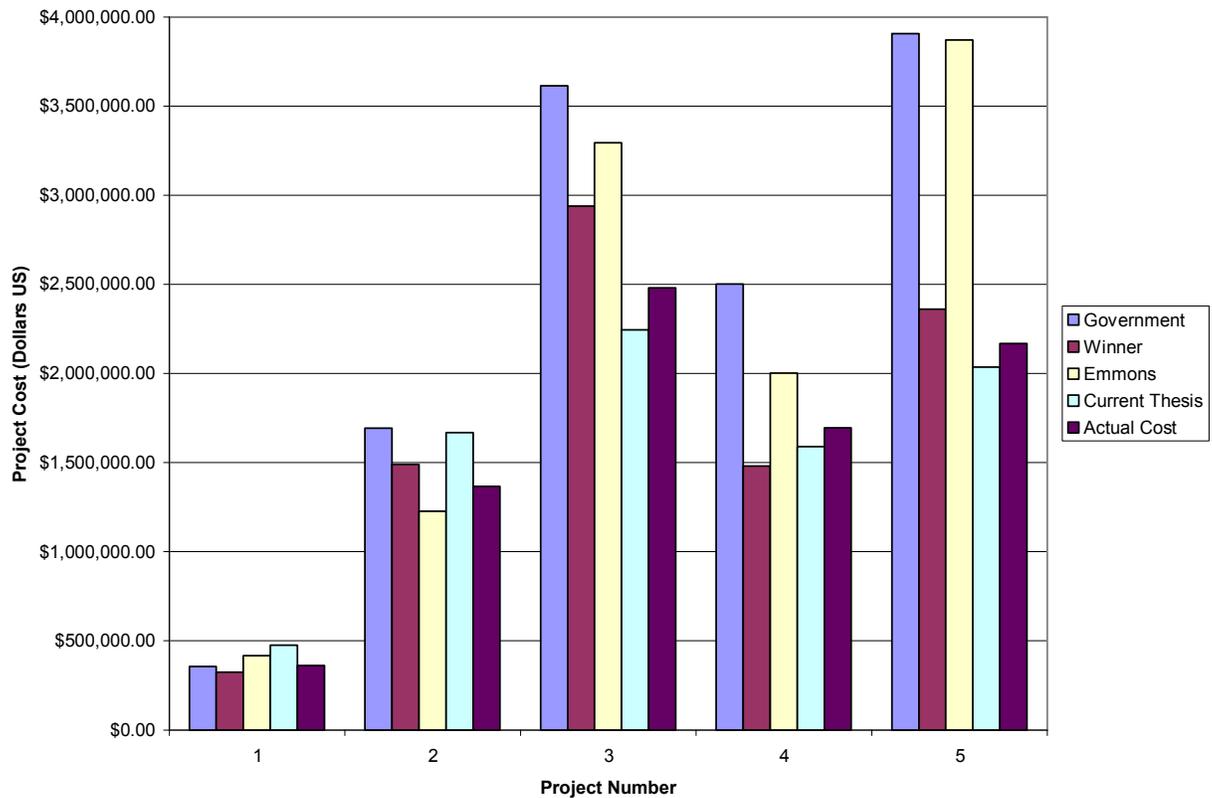
The second step in confirming the validity of the production and cost estimation program is to compare it to actual results. The cost estimation method developed in this thesis is compared with the government (NDC, 2003) estimate, the Emmons (2001) estimate, and the winning bid (NDC, 2003) and the actual project cost (NDC, 2003) for five different projects. The winning bid is the amount the winning contractor bid for the project, and the actual cost is the amount the project finally cost the sponsor.

The comparisons of project costs for the 5 projects are shown in Figure 27. Table 19 displays the relationship between the numbers on the graph and each project. It also shows the values for each bar in Figure 27.

The first project comparison is the Erie, PA project. The calculated project cost is 32% higher than the actual cost. Emmons (2001), predicts a project cost that is 15% above the actual cost while the government estimate (NDC, 2003) is 1% below the actual cost. The Erie project is also the smallest of the projects compared for this thesis. The second project in Figure 27 is from Coos Bay, OR in 1995. This thesis provided better results being only 22% above the actual project cost. The government estimate (NDC, 2003) is 24% above the actual cost.

The third comparison is Coos Bay, OR in 1997, which is the first project that this thesis predicted a cost under the actual cost. Also, with an actual cost of 2.5 million dollars US this is the largest project compared in this thesis. The Fernandina, FL project is the fourth project compared in Figure 27. In this comparison this thesis it 6% is below the actual cost and within \$110,000. The other estimates are within 20% of the actual cost with the exception of the government estimate that is 48% above actual cost. The fifth comparison is for Wando, NC harbor. In this comparison the estimates broke into two groups. The winning bid, this thesis and the actual cost were within \$400,000. The government and Emmons (2001) method were over \$1,600,000 above the actual cost. Figure 27 gives a graphical representation of the relationship between the different

estimation methods and the actual cost for each project. The data for Figure 27 is tabulated in Table 19.



**Figure 27-Project Cost Comparisons (1-Erie, 2-Coos 95, 3-Coos 97, 4-Fernandina, 5-Wando)**

**Table 19-Cost Comparison (Thousands of Dollars US)**

Region	Government	Winner	Emmons (2001)	Thesis	Actual
1-Erie	\$357	\$324	\$416	\$476	\$360
2-Coos 95	\$1,692	\$1,490	\$1,226	\$1,667	\$1,366
3-Coos 97	\$3,615	\$2,939	\$3,296	\$2,244	\$2,480
4-Fernandina	\$2,502	\$1,480	\$2,003	\$1,590	\$1,169
5-Wando	\$3,908	\$2,360	\$3,870	\$2,038	\$2,169

The project comparisons show that the method developed in this thesis is useful for estimating costs for mechanical dredge projects. It is more accurate in estimating large projects. There are some discrepancies in smaller projects. These are most likely due to assumptions being made in the cost calculation about crew size and other project costs. Also, the production rate is more sensitive for small projects using smaller buckets than it is for large projects. From Table 19 the mean difference and standard deviation between each method and the actual cost have been calculated for these 5 projects and tabulated in Table 20.

**Table 20- Percent Difference between Estimation Methods and Actual Project Cost**

Region	Thesis	Government	Emmons (2001)	Winning
1-Erie	32%	-1%	15%	-10%
2-Coos 95	22%	24%	-10%	9%
3-Coos 97	-10%	46%	33%	19%
4-Fernandina	-6%	48%	18%	-13%
5-Wando	-6%	80%	78%	9%
Mean	6%	39%	27%	3%
Standard Deviation	19%	30%	33%	14%

The government estimate (NDC, 2003) is an average of 39% higher than actual cost with a standard deviation of 30%. The results from Emmons (2001) are an average of 27% higher than actual cost with a standard deviation of 33%. The results from this thesis are 6% higher than the actual cost with a standard deviation of 19%. The only prediction method with better results for these 5 projects is the bid from the winning contractor. The winning bids were an average of 3% higher than the actual cost with a standard deviation of 14%.

## CONCLUSION AND RECOMMENDATIONS

It is possible to effectively estimate production and project cost for mechanical clamshell dredges. Two important components in estimating the production rate are the cycle time and the bucket fill factor. Traditionally the cycle time has been assumed to be about 60 seconds. In water depth greater than 10 m (11 yd) the cycle time is greater than 60 seconds. As the cycle time increases, the project cost increases as well. Therefore it is necessary to adjust the cycle time for specific projects.

The second important parameter in production rate and project cost is the bucket fill factor. It is necessary to determine how much of the bucket fills to estimate the production rate. The fill factor changes rapidly for bucket sizes between 0 to 20 m<sup>3</sup>. If the project uses a bucket smaller than 20 m<sup>3</sup> it is essential that the size and sediment characteristics are known. Once the predicted amount of sediment excavated is known production can be estimated.

There are several things that would be beneficial in predicting production for mechanical clamshell dredges. First the crew size is fixed unless the user knows details of a project. It would be beneficial to develop a way to automatically adjust the crew size depending on the size of the project. This would provide more accurate estimates of project costs. Since the labor rates are recurring costs, a small change over a long period is a major influence on project cost. If the program could be changed to vary crew size for the size of the project it would be beneficial.

A second area for improvement is the bucket fill factor. The factors used in the spreadsheet follows the expected trends and are extrapolated from actual data.

Experiments would help to verify the behavior of the large buckets. It could also explain the rapid change in fill factors for small buckets. Though the bucket fill factors behave as expected, it would help to refine them using experimental testing.

Finally, the delay factors for changing the hopper and advancing the dredge need to be improved. The actual delay factor for changing hopper barges does not include the number of hoppers, or the distance they have to travel between the disposal sites and the dredge. This assumes that there is always a hopper barge waiting which may not be true. The spreadsheet currently does a good job estimating production and project costs, but these improvements would allow for better estimates with less site specific information.

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## **APPENDIX 1**

### **MECHANICAL CLAMSHELL DREDGE PRODUCTION AND COST ESTIMATING SOFTWARE USERS MANUAL**

The cycle time method of production estimation has been incorporated into a spreadsheet so that calculations can be quickly made. This manual provides the user with a brief explanation of each page and how parameters can be modified for specific dredges, regions, and years. The first page of the spreadsheet contains the main input parameters, some calculated values, and the output from the program. Table 21 is a screen shot of the first page of the program. The values in green are input values. The grey values on the right are the recommended defaults if the specific value is not known. All of the yellow values are calculated by the spreadsheet. The outputs for the program are located at the bottom of the page.



the appropriate modification factor is chosen based on the sediment type. The bottom left is the regional cost modification factor. The spreadsheet picks the appropriate cost factor based on the region selected on the input screen. The cycle time section is the only part of this page that should be adjusted.

**Table 22-Internal Calculations**

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
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34													
35													
36													

The dredging job characteristics page (Table 23) contains inputs used for calculating the project cost. Inputs can be adjusted in the input column. If any of the cost values are adjusted, they should be entered in the column marked 2004. The description column contains details about each input, as well as any relevant units.

Table 23-Detailed Data Entry

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	<b>Dredging and Job Characteristics</b>													
2														
3	<b>Input</b>	<b>2004</b>	<b>Description</b>											
4	1		Utilize Predetermined Dredge Characteristics: Large Dredge (1); Medium Dredge (2); Small Dredge (3)											
5	23.9355		Size of Clamshell (yd <sup>3</sup> )											
6	4499.35		Hopper Capacity (yd <sup>3</sup> )											
7	600000	\$660,049.63	Average Value per Hopper (dollars)											
8	26.169		Dredging Depth (ft)											
9	120		Average Swing-Return Angle (degree) - 120 deg. is avg. value for clamshell with one scow along side											
10	57.62827		Cycle Time (seconds)											
11	18		Hourly fuel usage for Dredge Engine (Gallon)											
12	150		Daily fuel usage for House Power (Gallon)											
13	100		Daily fuel usage for Winch House (Gallon)											
14	1.3	1.65	Cost per Gallon for Fuel (Dollars)											
15	150414.3		Required Dredging Volume (yd <sup>3</sup> )											
16	5		Expected Overdredging (Percent)											
17	4550000	\$5,005,376.34	Capital Cost of Dredge (Dollars)											
18	1137.5	\$1,251.34	Average Daily Cost of Major Repairs and Overhauling for Dredge (Dollars)											
19	591.5	\$650.70	Average Daily Cost for Routine Repairs and Maintenance for Dredge (Dollars)											
20	60	\$66.00	Average Daily Cost of Major Repairs and Overhauling for Hoppers (Dollars)											
21	30	\$33.00	Average Daily Cost for Routine Repairs and Maintenance for Hoppers (Dollars)											
22	25		Depreciation Period (Years)											
23	320		Average # of working days per year for dredge											
24	250000	\$275,020.68	Mobilization/Demobilization Costs (Dollars)											
25	113750	\$125,134.41	Yearly Insurance Cost (Dollars)											
26	5		Bonding Rate (Percent)											
27														

Table 24 contains the adjustment of rental costs from 2000-2004 values. The top left contains the conversion from 2000 dollars to 2004 dollars. And for future years, the cost data can be updated by entering the new cost factor from Means (2004). The rest of the spreadsheet converts equipment costs from 2000 dollars to 2004 dollars. This data should not be adjusted unless costs are being changed to a new year.

**Table 24-Rental Cost Adjustment**

	A	B	C	D	E	F	G	H	I
1									
2	2000 Cost Factor	120.9							
3	2004 Cost Factor	133							
4	Cost Factor Ratio	1.100083							
5									
6									
7									
8									
9	<b>2000 Cost Values</b>								
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28	Food Cost						15	\$16.50	
29									

The project cost calculations are contained in Table 25. The top left is the rental cost calculation. The item costs come from the rental cost conversion page. The amount of equipment can be adjusted on this page. The top right is the crew cost calculation. The crew size used is the basic size from Means (2004). The bottom left of the page contains an itemized breakdown of the total project cost. At the bottom are the total project cost and the cost per yd<sup>3</sup>.

**Table 25-Project Cost Calculations**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	<b>Rental Cost Estimation</b>						<b>Crew Cost</b>									
2																
3																
4					<b>Units</b>	<b>Days</b>	<b>Input</b>	<b>Total</b>					<b>#</b>	<b>Rate</b>	<b>Daily Total</b>	
5							<b>Values</b>	<b>Cost (\$)</b>								
6					<b>Crew Lodging</b>	1	162	\$82.51	\$13,366.00				Labor Foreman	1	\$ 28.00	\$ 672.00
7					<b>Temporary Office Space</b>	1	297	\$165.01	\$4,900.87				Laborer	2	\$ 26.00	\$ 1,248.00
8					<b>Tugboat contracted or in-house</b>	1	27	\$1,100.08	\$29,702.23				Equipment Operator	2	\$ 33.65	\$ 1,615.20
9					<b>Crew boat</b>	1	27	\$825.08	\$22,276.67				Equipment Operator Oiler	1	\$ 29.20	\$ 700.80
10					<b>Barge</b>	2	27	\$1,100.08	\$59,404.47							
11					<b>Bulldozer</b>	0	27	\$440.03	\$0.00							
12					<b>Marsh Buggy</b>	0	27	\$385.03	\$0.00							
13						0	27	\$0.00	\$0.00							
14						0	27	\$0.00	\$0.00							
15						0	27	\$0.00	\$0.00							
16						0	27	\$0.00	\$0.00							
17						0	27	\$0.00	\$0.00							
18																
19					<b>Total Rental Cost (\$)</b>						\$129,650.25					
20																
21																
22																
23																
24																
25																
26																
27																
28																
29																
30					<b>COST SUMMARY</b>											
31																
32					<b>Production Summary</b>											
33					Production Rate	yd <sup>3</sup> /hr	857									
34					Required Volume	yd <sup>3</sup>	150414									
35					Gross Volume	yd <sup>3</sup>	157935									
36					Estimated Daily Run Time	hours	24									
37					Required Dredging Hours	hours	184									
38					Required Days	days	27									
39																
40					<b>Fuel and Lubricant Cost</b>											
41																
42					House Power		5,265.00									
43					Dredge Engine Fuel (90% of total hours)		3,882.30									
44					W/inches		3,510.00									
45					Lubricants (10% of Fuel Cost)		1,265.73									
46																
47					<b>Repair and Maintenance</b>		\$54,028.38									
48					<b>Depreciation</b>		\$16,893.15									
49					<b>Mob-Demob</b>		\$275,020.68									
50					<b>Insurance</b>		\$10,558.22									
51					<b>Crew</b>		\$114,372.00									
52					<b>Rentals</b>		\$129,650.25									
53					<b>10% Overhead</b>		\$61,444.57									
54																
55					<b>Total Job Cost</b>		\$669,782.27									
56					<b>Price per Cubic Yard</b>		\$4.24									
57																

For most projects the program can be run completely from the main page. The additional pages allow the user to adjust for site specific situations. The user can input costs that are specific to a location, adjust the cycle time calculation to a specific dredge, or change the cost information to the current year.

## APPENDIX 2

### NOMENCLATURE

A	Average area dredged at one location
B	Bulking factor
C	Capacity of the bucket
$d$	Water Depth
$f_a$	Delay factor to advance the dredge
$f_h$	Delay factor to change hopper barges
$f_m$	Bucket fill factor
H	Hopper capacity
$h_b$	Freeboard height of the barge
$P_{nom}$	Nominal production rate
$P_{act}$	Actual production rate
$T_{cycle}$	Cycle time
$t_a$	Time to advance the dredge
$t_e$	Time to empty bucket
$t_g$	Time to grab for bucket to fill
$t_h$	Time to change hoppers
$u_f$	Bucket Fall velocity

- $u_l$  Bucket Lift velocity
- $z$  Average thickness of material to be excavated
- $\theta_{sw}$  Bucket swing angle
- $\omega_{sw}$  Bucket swing rate

## APPENDIX 3

### EXAMPLE OF COST ESTIMATION PROGRAM FOR COOS BAY

**1997**

The purpose of this example is to allow the user to check if the spreadsheet is functioning properly. If all of the defaults in the spreadsheet are the original values these inputs will provide the output for Coos Bay 1997 in the thesis. Table 26 is the inputs used in the example. The simplest input to find is the volume to be dredged. This can be taken directly from the USACE (NDC, 2003). The capacity of the bucket and water depth comes from Emmons (2001). Region, depth, and bucket size can usually be found from the internet. The other values used are defaults for the spreadsheet. More site specific values must be obtained from the dredge contractor.

**Table 26-Inputs for Coos Bay 1997 Project**

Parameter	Value	Defaults	Units	Definition
Soil type	2	2	2	See chart to right for numbering system
R	5	3	3	Region
A	1142.7	1142.7	m <sup>3</sup>	Average area dredged
Z	2	2	m	thickness of material dredged
H	3440	3440	m <sup>3</sup>	Hopper capacity
C	18.3	18.3	m <sup>3</sup>	Capacity of the bucket
V	609000		m <sup>3</sup>	volume to be dredged
d	14.6		m	depth
h	2		2m	height of the barge
ta	0.33		0.33Hrs	Time to advance the dredge
sa	120		120deg	Average swing angle
th	0.25		0.25Hrs	Time to change hoppers

Once the inputs have been changed for the Coos Bay 1997 project the production and project cost are calculated. Table 27 displays the results for production, total cost, and cost per volume. These values are consistent with the values from the Table 19. The first set of values in Table 27 is the estimated production in 2004 dollars. The historic values are for 1997 which is the year the project took place.

**Table 27-Output for Coos Bay**

<b>Output for 2004</b>	
Total Cost	\$2,646,596
Cost/m <sup>3</sup>	\$4.35
Cost/yd <sup>3</sup>	\$3.16
<b>Output for Historic Project</b>	
Project year	1997
Factor used	84.8
Total Cost	\$2,244,314
Cost/m <sup>3</sup>	\$3.69
Cost/yd <sup>3</sup>	\$2.68

## VITA

Robert Fletcher Adair was born in Tyler, TX on October 15, 1979. After graduating from Robert E. Lee High School in 1998 he enrolled in Tyler Junior College for 1 year before transferring to Texas A&M University in College Station, TX. At Texas A&M Mr. Adair received a Bachelor of Science degree in ocean engineering in December of 2002. After graduating in 2002 Mr. Adair enrolled in graduate school in ocean engineering at Texas A&M. Mr. Adair graduated with a Master of Science degree in ocean engineering in December of 2004.

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