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A PARAMETRIC MODEL FOR ESTIMATING COSTS FOR REMEDIATING CONTAMINATED SEDIMENT SITES USING A DREDGING METHOD - A BUDGETARY & PLANNING TOOL FOR DECISION-MAKERS

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ABSTRACT

Contaminated sediments, whether in freshwater or marine systems, pose a significant environmental challenge both within the United States and across the globe. When it comes to cost estimating for sediment-related cleanup projects, headline after headline seems to read something like “Cost Estimates Increased for XYZ Project” or “Cost Estimate Rises to $(fill in your own astronomical number way above original estimates).” Why do these calculations remain such a persistent challenge to financial professionals and planners charged with estimating such cleanup efforts? One predominant reason is that estimating the true costs of such projects is tremendously difficult and riddled with high degrees of uncertainty. Simply put, what professionals need is a “better mousetrap.”

To develop a better “mousetrap,” we assessed the current practices employed in developing such estimates. According to the U.S. Department of Defense and U.S. Department of the Army, there are three basic types of cost estimation techniques that are used either individually or in combination - Analogy, Build Up, and Parametric Modeling. Each approach has been used throughout industry with varying degrees of success. However, according to the DoD/DoA, there are currently no real-world examples of parametric models for estimation of sediment treatment project costs.

We have created a viable Parametric Model for assisting managers and decision-makers in developing appropriate cost estimates for the processing and

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disposal of dredged materials which can be used for planning and budgetary purposes, communicating with appropriate stakeholders, and providing guidance to senior management. This multi-variable financial model enables cost estimates for either a single site or a portfolio of sites [while still allowing for individual site specifications] by providing cumulative costs over the overall remediation time horizon. It allows for "what if" scenarios and provides both numerical and graphical depictions of these aforementioned cost estimates.

Keywords: dredging, parametric model, cost estimate, remediation, forecasting, planning

1. INTRODUCTION

Contaminated sediments, whether in freshwater or marine systems, pose a significant environmental challenge both within the United States and across the globe. Generally speaking, sediment remediation is complex and costly with numerous variables affecting the overall costs. While there are many approaches to sediment remediation, four methods are in general use:

Table 1. Sediment Remediation Methods

Remediation Method	**Description of Method**
Dredging	In lay terms, this is simply digging up the sediments which are then processed and disposed of accordingly.
Capping	This involves placing clean sand or gravel over the contaminated sediment in order to isolate the contaminants from the surrounding environment.*
Monitor / Natural Recovery	This involves the breakdown of contaminants due to physical, chemical and biological processes which occur in the environment, and the ability of the environment to rebound from the injuries caused by the contamination.*
In-Place (In-Situ) Treatment	This involves chemical, biological or thermal treatment of contaminated sediments where they lie, i.e. without excavation.

* Source: http://www.epa.gov/Region5/sites/foxriver/glossary.htm

This paper focuses exclusively on the dredging approach. Furthermore, costs contained in this paper are based on publicly accessible information from completed, real world dredging projects as well as decades of collective industry experience by the authors.

When it comes to cost estimating for sediment-related cleanup projects, headline after headline reads something like "Cost Estimates Increased for XYZ Project" or "Cost Estimate Rises to $(fill in your own astronomical number way above original estimates)." Why do these calculations remain such a persistent challenge to managers and decision-makers charged with estimating such cleanup efforts? One predominant reason is that estimating the true costs of such projects is tremendously difficult and riddled with high degrees of uncertainty. Simply put, what professionals need is a "better mousetrap."

So, if an entrepreneurial engineer was tasked with coming up with a "better mousetrap," they might methodically begin such an undertaking by (1) looking at the existing mousetrap, (2) understanding the needs that a new mousetrap must address, and (3) developing the new mousetrap. Our "mousetrap" is an improved cost estimating tool for financial professionals to use when estimating contaminated sediment project costs. One fortunate aspect of the challenge at hand is that while engineers require precise figures in the course of their work, managers and decision-makers can more readily accept a broader, yet appropriately narrow, range of numbers. For our purposes, we maintain this overarching assumption – that cost estimates, as used by these financial professionals, are intended to be used specifically for planning and budgetary purposes, to communicate with appropriate stakeholders, and to provide guidance to senior management.

2. CURRENT PRACTICE

In attempting to develop this better cost estimating "mousetrap" for decision-makers, we must first assess the current practices employed in developing such estimates. According to the U.S. Department of Defense (DoD, 1999) and U.S. Department of the Army (DoA, 2002), there are three basic types of cost estimation techniques that are used either individually or in combination when developing estimates for sediment work (table 2).

When thinking of the Analogy method, consider it the equivalent of a real estate agent or a home appraiser determining the value of your home. In order to do this, they will look at "comps" or comparables. Comps are data about properties recently sold, currently on the market, expired listings, and pending sales which are similar to the property whose value is being determined, your home in this example. Likewise, when planners need to estimate costs for a specific site/project, they draw appropriate comparisons to prior, completed projects of a similar nature. The biggest challenge of the Analogy method of estimating is that projects often have numerous unique, or site-specific, variables, making finding true comps rather difficult if not impossible.

When looking at the Build-Up method, consider the childhood riddle "how do you eat an elephant?...one bite at a time!" In this approach, an overall project is broken down into various, more manageable tasks which are subsequently estimated on their own and summed to reach a total project cost estimate. Continuing the real estate analogy, this would involve determining how much it would cost to excavate a home site, how much to build a proper foundation, how much to complete framing, roughing in electrical and plumbing, etc. and then adding all costs together to obtain a final cost to build a home. This method requires a detailed analysis of each task of the project and often involves cost categorization and tracking. This method, while having some advantages over Analogy estimates, is both time and labor intensive and often data is not available to support an estimate.

Table 2. Cost Estimation Methods

Technique	**Description**	**Advantages**	**Limitations**
Analogy	Compare project with past similar projects	Estimates are based on actual experience	Truly similar projects must exist
Build-Up	Each component is assessed and then component estimates are summed to calculate the total estimate	Accurate estimates are possible because of detailed basis of estimate; promotes cost tracking	Methods are time-consuming; detailed data may not be available; important costs are sometimes disregarded
Parametric Modeling	Perform overall estimate using design parameters and mathematical algorithms	Models are usually fast; they are also objective and repeatable	Models can be inaccurate if not properly calibrated and validated; relevant historical data required

Source: From U.S. Department of Defense (1999). Myers, T. E. (2005). "Cost estimating for contaminated sediment treatment – A summary of the state of the practice," DOER Technical Notes Collection (ERDC TN-DOER-R8), U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://el.erdc.usace.army.mil/dots/doer/.

Lastly, parametric modeling-based estimation is a computer-based technique utilizing complex statistical approaches, mathematical expressions, and/or historical cost databases to estimate the overall project costs. To once again compare this approach to the real estate market, the Parametric Model analogy would involve the use of square footage, lot size, site location, traffic patterns, features/quality of construction, etc., taking a very scientific approach to hit on target pricing. As might be intuitively expected, Parametric Models often utilize expanded Analogy methods and/or databases built with data from Analogy and

Build-Up estimates; when said data is available, Parametric Models offer a clear advantage to traditional estimation techniques. However, according to the DoD/DoA, there are currently no real-world examples of parametric models for estimation of sediment treatment project costs (Myers, 2005).

3. MULTI-VARIABLE PARAMETRIC MODEL DEVELOPMENT

Our goal was to create a viable Parametric Model for the specific purpose of assisting financial professionals and planners in developing appropriate sediment treatment cost estimates to be used for planning and budgetary purposes, to communicate with appropriate stakeholders, and to provide guidance to senior management. With this goal, we have developed a predictive financial model that incorporates numerous variables which impact the overall costs for the processing and disposal of dredged materials. Such factors that we considered and that can be specifically manipulated within the model to best reflect site specific considerations include:

- Sediment Physical Properties
- Chemical Concentrations
- Regulatory Classification (Hazardous vs. Non-Hazardous)
- Quantity & Type of Debris
- Volume of Material to be Dredged
- Rate of Dredging
- Work Schedule
- Funding Limitation(s)
- Type of Dredging
- Site Access & Upland Support Area
- Public Opinion

The model enables site owners to estimate costs for either a single site or a portfolio of sites [still allowing for individual site specifications] by providing annual and cumulative costs over the portfolio's overall remediation time horizon (by site). Users are able to manipulate variables to model "what if" scenarios such as "what if we delay the project commencement for X years?" or "what if the cleanup takes Y years instead of X years?" The model provides both numerical and graphical depictions of these aforementioned cost estimates.

To elaborate further on the aforementioned cost factors, table 3 gives a brief description of each and how they can financially impact a remediation project's overall costs.

Table 3. Cost Factor Descriptions and Range of Cost Impact

Cost Factors	**Description**	**Range of Cost Impact (per cubic yard)**
Sediment Physical Properties	The physical properties of sediment that will be dredged have significant impacts on material transport, dewatering, disposal and potential for beneficial use. The common properties that are most useful to evaluate impacts are particle size distribution, water content (or percent solids), organic content, Atterberg Limits and presence of separate-phase oil. These are all low-cost tests that should be performed on representative samples of sediment that may be dredged. Of particular importance is to properly classify sediment so as to best comprehend the cost impacts. For example, simply classifying sediment as “silt and clay,” “sand,” or “fine-grained” is not sufficient because there are wide ranges in types of silt and clay and sand which can have dramatically different effects on the chosen remediation approach.	\$5 - \$25
Chemical Concentrations	Chemical concentrations in dredged material impact all aspects of material processing; not just ex situ disposal. For example, if chemical concentrations are low, it may be permissible to allow overflow from hopper barges without treatment. However, if the material has high concentrations or is designated as hazardous waste, then regulatory agencies may prohibit any overflow without treatment and might even require secondary containment, air collection, monitoring and/or treatment to occur at special hazardous waste treatment facilities.	\$0 - \$50
Regulatory Classification (Hazardous vs. Non-Hazardous)	In the USA, all contaminated materials that are taken off site must be designated under various regulatory programs for transportation and disposal of materials that contain hazardous substances. However, sediment investigations often do not perform the tests that will be required to properly designate material, such as the Toxicity Characteristics Leaching Test Procedure (TCLP).	\$25 - \$1,500

Table 3. Cost Factor Descriptions and Range of Cost Impact (continued)

Cost Factors	**Description**	**Range of Cost Impact (per cubic yard)**
Quantity & Type of Debris	The quantity and type of debris in sediment to be dredged has a significant impact on treatment and disposal cost. Debris quantification, however, is difficult because the material that has the most impact on sediment processing and disposal is frequently too large for most subsurface sampling devices. Additionally, debris could include natural materials which are prone to causing damage to pumps, piping and treatment equipment, thereby adding to downtime and, thus, increasing costs. Finally, debris may also include items that could cause damage or injury to the dredging crew, especially at military installations (e.g. ordnance, containers with explosives or reactive chemicals).	$0 - $25
Volume of Material to be Dredged	The unit cost of disposal of dredged material depends on the volume of material processed, with the instinctive concept of “economy of scale” well understood. Furthermore, variations in volume impact dredging projects less than typical upland construction projects due to the relatively high cost of equipment mobilization and temporary site facilities.	$0 - $50
Rate of Dredging	The rates of dredging and project schedule have a significant impact on processing and disposal costs, as well as dredging and transport costs. The rates of dredging and disposal for work on the water are much different than are typical for upland work. This discrepancy has major impacts on the costs for contaminated sediment work.	$0 - $50
Work Schedule	Restrictions on work hours or work seasons also have a significant impact on costs. These types of restrictions are generally understood. If night or weekend work is restricted, then production will be lower and costs will likely be higher. Restrictions of work season (e.g. fish windows) have impacts on costs that are more difficult to understand.	$0 - $35
Funding Limitation(s)	Restriction on annual project funding can lead to increased cost due to stopping and re-starting work. Dredging and dredged material disposal requires specialized equipment and if work stops, then the equipment has to be transported to another project or placed on stand-by.	$0 - $100

Table 3. Cost Factor Descriptions and Range of Cost Impact (continued)

Cost Factors	**Description**	**Range of Cost Impact (per cubic yard)**
Type of Dredging	The impact of using mechanical or hydraulic dredges on processing and disposal costs is an important factor in overall costs. Hydraulic dredging is a popular and proven technology for navigation dredging projects and can move material at relatively low costs. However, when dredging contaminated materials, the costs for dewatering and water treatment must be carefully and realistically evaluated in selection of the dredge method. Any constraints that require faster dewatering or work in restricted space will increase costs.	\$10 - \$50
Site Access & Upland Support Area	Site access has a significant impact on costs. Unlike navigation projects, some contaminated sediment projects are done in lakes, rivers or inlets where access by the water is limited. In some cases, all dredging and processing equipment must be delivered to the site on truck and then assembled as part of mobilization. For those cases where upland processing and disposal is used, the availability of land area near the water and dock facilities are important factors. Lack of area or facilities can increase costs for items such as temporary docks and equipment maintenance sites. In some situations, multiple steps are required to transport dredged material from the dredging to the processing area, which increases costs. Lack of space and time may dictate the use of more expensive mechanical dewatering and water treatment systems. Although mechanical dewatering (i.e. belt press, plate and frame press or centrifuge) methods are effective for most sediment types, they are more expensive than passive dewatering methods.	\$0 - \$250
Public Opinion	Public opinions and concerns can impact costs when additional measures are required to address real or perceived environmental impacts from the work. In this sense, the public includes environmental groups, local business organizations and residential neighborhood groups. The best way to address such issues and avoid expensive delays is to involve and inform the public in every stage of contaminated sediment projects.	\$0 - \$50

Source: Otten, Mark (2004). "Factors Affecting Disposal and Reuse of Contaminated Dredged Material," World Dredging Congress XVII, Central Dredging Association, Hamburg, Germany.

As indicated in this chart, various components affect a contaminated sediment site's overall project costs. These costs and ranges were developed though extensive research of past, current, and proposed remediation efforts, as well as interviews with remediation project managers, industry experts, and key agency personnel. Despite the broad impacts that these variables can have on a project's costs, financial professionals and planners still must address the challenge of providing "best available" estimates of such projects' clean up costs for their own needs or when dealing with the various concerned stakeholders. As such, we have created a Parametric Model that incorporates to an appropriate level, the numerous factors described herein.

The model cost estimates are based on the assumption that the area of sediment contamination, dredge volume, and average cost per cubic yard are the key variables for determining the possible costs for a contaminated dredging project. The effects of the area of sediment contamination and dredge volume variables on the total project cost are intuitive; higher values for either variable will result in higher project costs. Assuming the average cost per cubic yard spans from a minimum of $10 per cubic yard to the maximum of $2,150 per cubic yard, the model is designed to narrow this range through a series of questions.

As the user answers questions about the project, the upper and lower bound of the range are adjusted depending on the answer provided. For example, if a user answers "Yes" to a question regarding offsite disposal, the lower bound of the range would be adjusted to a higher average cost per cubic yard. Conversely, if the user answers "No" to the same question, the upper bound of the range would be adjusted to a lower average cost per cubic yard. In other words, on average, offsite disposal of contaminated sediments will result in a higher possible project cost, while savings may be recognized if onsite disposal is available.

Each subsequent question builds upon the previous question, thereby affecting the final outcome through adjustments to the lower and upper boundaries of possible costs. All responses to the questions yield a more accurate range of costs as more information becomes available. As a final step, the greatly reduced range is multiplied by the total dredge volume and spread over the total years of each project phase previously identified by the user.

Within the current version of this model, users have the ability to:

- Complete an interactive questionnaire covering Removal, Process, Water Treatment, and Disposal matters
- Work on a portfolio of multiple sites simultaneously
- Address "what if" scenarios such as adjusting the starting time and/or duration of remediation
- Use intuitive toggle switches or slide bars to vary specific cost factors

- View automatically updated tables and graphical charts of the portfolio of sites included in the analysis
- See estimated annual remediation spend totals for each site and for the entire portfolio of sites
- See estimated annual remediation spend variance for each site and for the entire portfolio of sites
- Generate the net present value of the remediation spending over the portfolio's overall remediation time horizon

Sediment Sites

Volume (cy)	Site	Site 1	Unit Costs			
	Start Year	2008	Low	Mid	High	Average
	Duration	6	$25	$200	$500	$242
	Low	80,000	$2,000,000	$16,000,000	$40,000,000	$19,333,333
	Mid	125,000	$3,125,000	$25,000,000	$62,500,000	$30,208,333
	High	200,000	$5,000,000	$40,000,000	$100,000,000	$48,333,333
	Average	135,000	$3,375,000	$27,000,000	$67,500,000	$32,625,000

Average of Low Left to Up Right Diagonal $23,333,333
Average of Up Left to Low Right Diagonal $31,500,000

Volume (cy)	Site	Site 2	Unit Costs			
	Start Year	2009	Low	Mid	High	Average
	Duration	7	$25	$200	$500	$242
	Low	30,000	$750,000	$6,000,000	$15,000,000	$7,250,000
	Mid	50,000	$1,250,000	$10,000,000	$25,000,000	$12,083,333
	High	70,000	$1,750,000	$14,000,000	$35,000,000	$16,916,667
	Average	50,000	$1,250,000	$10,000,000	$25,000,000	$12,083,333

Average of Low Left to Up Right Diagonal $8,916,667
Average of Up Left to Low Right Diagonal $11,916,667

Upland Sites

Volume (cy)	Site	Site 3	Unit Costs			
	Start Year	2009	Low	Mid	High	Average
	Duration	6	$25	$150	$300	$158
	Low	75,000	$1,875,000	$11,250,000	$22,500,000	$11,875,000
	Mid	100,000	$2,500,000	$15,000,000	$30,000,000	$15,833,333
	High	125,000	$3,125,000	$18,750,000	$37,500,000	$19,791,667
	Average	100,000	$2,500,000	$15,000,000	$30,000,000	$15,833,333

Average of Low Left to Up Right Diagonal $13,541,667
Average of Up Left to Low Right Diagonal $15,625,000

Figure 1. Illustrative Input / Cost Form for Sediment and Upland Sites

In addition to these color-coded tables, as mentioned, the data is also portrayed graphically via auto-updating charts representing each individual site and the overall site portfolio as seen in the following chart:

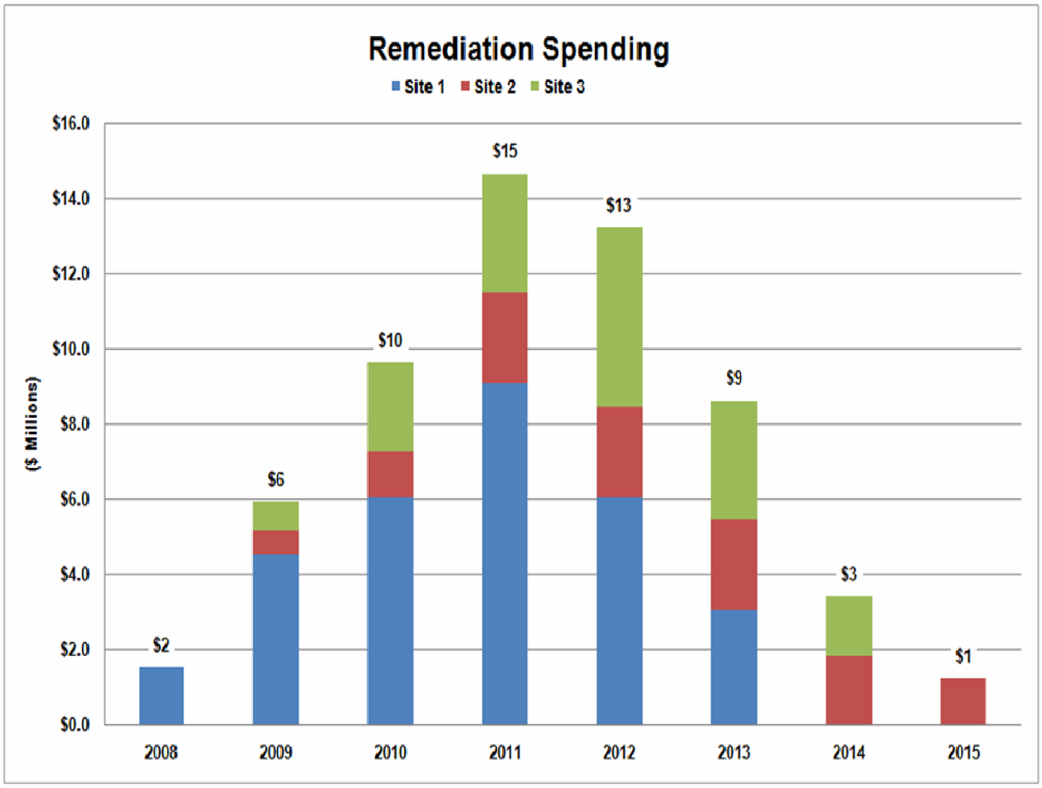

Figure 2. Illustrative Chart Showing Three (3) Sites over an 8-year Remediation Time Horizon

4. CONCLUSION

Dredging is one of the most frequently used methods of remediation for contaminated sediments. However, cost estimates for such projects are highly uncertain – often varying by 1,000% (i.e. 10x) or more – and as such are not of any great use to policy or decision-makers charged with estimating these efforts. With billions of cubic yards of contaminated sediments needing study and remediation, having an accurate method of estimating such undertakings is critically important. To date, no standardized tool has been accepted within the industry.

In nearly all circumstances, the cost estimates produced by this model will be unavoidably less accurate than costs produced in the more traditional preliminary engineering reports such as feasibility studies of alternatives. However, the primary purpose of the parametric cost model described herein is as a management tool for use in long-range cost forecasting conducted by managers and decision-makers for budgetary purposes versus more precise engineering estimates. It is intended to increase the accuracy of such estimates as well as to dramatically reduce the time required to generate estimates for projects of this nature. As more remediation data related to the dredging of contaminated sediments becomes available, we anticipate updates to the model. Additionally, we plan on incorporating input from additional remediation project managers, industry experts, and key agency personnel in an effort to further validate its process and outputs.

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