CERCLA SEDIMENT REMEDIATION – ANALYSIS OF PROJECT COST FROM COMPLETED AND PLANNED PROJECTS

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ABSTRACT

At this moment, there are several relatively large cleanups planned in the rivers and harbors of the United States. Costs for some of these projects are projected to exceed $1 billion. It is an appropriate time to reflect on how the cost of sediment remediation has changed over the decades. The first sediment remediation projects conducted under CERCLA occurred in the 1980s. These projects generally involved the application of a single technology, such as dredging, with relatively few ancillary technologies or management practices. As a result, these projects generally had relatively lower overall costs compared to more recent projects which involve multiple technologies and extensive ancillary technologies and management practices. We analyze the costs of several projects from each decade since the 1980s and compare this to the projected costs for projects that have not yet been bid or constructed. The results indicate that, on average, the unit cost of sediment managed has risen from under $100 per cubic yard to over $1,000 per cubic yard. Interestingly, the costs of the underlying technologies have not risen proportionally to overall unit cost. More recent projects have involved large multiyear cleanups and a movement towards selection of larger more complex remedies. The effect of the application of the more complex approach has been, among other things, to generally increase the overall cost of the work based on the amount of sediment managed. Given that these complex projects can take years (or even decades) to move from the feasibility study to implementation, net present value calculations, and associated discount rate, need to be considered and can have a major impact on the total calculated cost of the remedy. We have evaluated a probabilistic modeling approach to evaluate cost drivers, risk of cost increase, and to better inform contingencies. Questions for practitioners to address include whether the increases in overall unit cost reflect improvements in risk reduction or other aspects of project performance.

Keywords: Sediment Management, Alternative Selection, Cost Estimates, Cost-effectiveness, Net Present Value

INTRODUCTION

In the next decade or so, it is proposed that various entities spend several billion dollars to cleanup contaminated sediments in rivers around the country. The idea of cleaning up contaminated sediments is not a new one, and in fact has been of ongoing interest since the 1980s when it was realized that in spite of significant advances in water quality derived from the Clean Water Act the contaminated sediments at the bottom of our rivers and harbors held an enormous inventory of toxic chemicals that could still cause harm to human health and the environment.

Early efforts to address these contaminated sediments most predominantly included dredging to remove the contamination from the water body. Disposal was often at an on-site facility built for the purpose, but sometimes included processing of the contaminated sediment and transport far from its origin for ultimate disposal. The scale of these projects varied from relatively small sites in rivers, harbors, and lakes to some considerably larger sites encompassing segments of rivers or multiple areas within a larger harbor.

By contrast, projects proposed today encompass larger lengths of river and anticipate much more complex remedies including more complex technologies and greater off-site disposal. As a result, the anticipated cost of the cleanups proposed today are considerably greater than those of the past, in terms of both absolute total dollars, and all-

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inclusive unit cost (the total cleanup cost per unit volume of sediment). The reasons for this trend are many. Remarkably, though, the fundamental unit cost of the core marine construction aspects of the work have not changed that much. Rather we have added numerous features to the typical project that radically alter its cost profile. In this work we seek to illuminate the changes that have occurred so our community can have a more enlightened debate on the efficacy and potential benefit of current practices. Additionally, we seek to stir a debate on the way in which the cost of these large projects is estimated at various stages in the feasibility and design stages of the work.

HISTORY AND TRENDS IN THE COST OF SEDIMENT REMEDIATION

In the 1980s and 1990s sediment remediation projects generally consisted of the removal of less than one million cubic yards with total costs of often lower than $100 million. Now we are facing a generation of projects that involve multiple millions of cubic yards with costs in the billions of dollars and durations on the order of decades [1]. Sediment remediation projects have become larger in terms of geographic extent, volume, complexity, expense, and duration. This is in part due to a more sophisticated approach to sediment projects because of advanced site investigation techniques and more detailed analysis of source control, recontamination, and bioavailability, amongst other things. Remediation technologies have also made advances, although removal (dredging) is still the overwhelmingly preferred technology. There is greater acceptance of monitored natural attenuation and enhanced monitored attenuation; an increased understanding of specific reagents for in-situ treatment technologies although full-scale implementation is not widespread; and increased efficiencies for ex-situ treatment but no new ex-situ technologies. In addition, many new requirements have been incorporated into sediment remedial alternatives beyond the removal itself, including residual controls, underwater sound, fauna exclusion, and air quality controls.

Although the cost of technologies has not risen significantly since the 1980s and 1990s, the total project unit cost seems to be steadily increasing. This particular unit cost is defined as:

$$\textbf{all in unit cost} = \frac{\textit{total post–study cost of action}}{\textit{total value of sediment managed in action}} \quad (1)$$

Available cost information for sediment remediation projects from 1995 to 2013 was compiled where sediment removal (dredging) was the primary remedial action. This cost information was gathered based on personal communications with those knowledgeable in the costs. Cost information for sediment remediation projects has and continues to be difficult to ascertain. A summary of the data is provided in Table 1.

Table 1 Summary of cost information for sediment remediation (dredging) projects from 1995 to 2013.

Project	Year[1]	Total Cost (million $)	Total Removal Volume (cubic yards)	All-In Cost ($ / cubic yard)	Dredge Unit Cost ($ / cubic yards)
Sitcum Waterway[2]	1994	18.1	2,830,000	6.41	1.25 to 25
Foss[3]	2006	53.8	1,060,000	50.8	3 to 7
Hudson River[4]	2007			1,900	
Passaic River Phase I Removal Action[5]	2012	61	41,434	1,460	

[1]Year indicates year construction was initiated.
[2]Total cost includes construction costs only and excludes design and other costs. Range of dredge unit costs based on dredge and placement of material from waterway and side slopes/under piers. Only 30% of 425,000 cubic yards of sediments from Sitcum Waterway contaminated; combined with navigational dredging project.
[3]Total cost includes construction costs only and excludes design and other costs.
[4]Only all-in unit cost available.
[5]Total costs include all pre- construction, site preparation, construction, transport and disposal, and engineering and monitoring costs.

This information shows the increase of total remediation costs as well as all-in unit costs from the 1990s to present day. Comparatively, dredge costs in 1994 and 2006 were remarkably similar. Although this is not a full analysis of all significant sediment remediation projects that have occurred throughout the decades it serves as an example of the trends that have been observed throughout the industry.

This begs the question: what is driving costs so high? The addition of various features to the remedy, including but not limited to, rigid barriers for turbidity control, increased monitoring and best management practices, and requirements for more precise construction controls are all contributing to this cost increase. However, the most significant contributor to the increase is the preference for off-site disposal of moderately contaminated sediments.

FACTORS IMPACTING THE COSTS OF ALTERNATIVE AND THE ESTIMATION OF COSTS

Costs play a significant role in evaluating sediment remediation alternatives. In fact, it is one of EPA's (U.S. Environmental Protection Agency) nine criteria used in assessing the merits of proposed options. Unfortunately, the inherent nature of sediment projects (i.e., conducted underwater) makes them extremely difficult to cost, especially during the early stages of a Remedial Investigation/Feasibility Study (RI/FS) process where relatively little information is available. The recent trend towards the development of larger and more complex projects only exacerbates this dynamic. If not accounted for properly, it is likely that inaccurate cost estimates will lead to inappropriate remedial decisions, allowing for significant cash outlays that may be both unnecessary and ineffective. Moreover, early allocation efforts are requiring more and more accurate understandings of cost.

As indicated, regulatory agencies appear to be drawn towards the "mega" scale project. The reason for this is not completely clear, although community input and political pressures most certainly have an effect. Some recent examples of these larger projects include the Hudson River (2.75 M cubic yard dredged over 6 years), Fox River (3.8 M cubic yard dredged and 446 acres capped over 6 years), and Passaic River (proposed 4.3 M cubic yard to be dredged and 650 acres to be capped). In effect, these programs represent a series of smaller (yet significant) construction projects conducted over multiple seasons/years, which can lead to a dramatic reduction in efficiencies and an associated increase in overall transaction costs.

In addition to extensive project durations, regulatory requirements also affect bottom line costs. Generally speaking, such mandates tend to constrain production, and interfere with the natural flow of work. They can also add costs in the form of intensive monitoring activities and associated analytical needs. For example, as part of the Hudson River Phase I dredging project, EPA established performance criteria relating to three variables: production rate, sediment resuspension and residual concentration. Because these three factors are so closely linked to one another, it was ultimately shown to be extremely difficult, if not impossible, to meet all three criteria at the same time. Likewise, the constraints were relieved. In the meantime however, GE was forced to spend a great deal of time and money during the initial design phase in an attempt to meet the mandated requirements.

Lately, underwater sound (UWS) has become a topic of interest in the regulatory community. The concern centers on the potential impact that underwater noise (generated during dredging operations) could have on the natural movement and migration of native fish species. Consequently, agencies have been requiring UWS monitoring as part of these larger dredging programs. During the Passaic River Phase I Removal Action, National Marine Fisheries Service (NMFS) requested that UWS data be collected during dredging (including associated sheetpile installation process). While the data were not to be used for compliance purposes, the cost to plan and implement was not inconsequential. This is merely one example of how regulatory mandates can confine and restrict dredging projects, adding to both the inefficiency and cost of the overall program.

So what does all of this mean in terms of developing accurate estimates for purposes of decision-making? Under the current RI/FS paradigm, more advanced and precise estimates are generated during the latter stages of a given project, usually in the design phase. As shown in [2], the allowable cost range early in the process varies between -30% and +50%, and subsequently narrows later in the project's life. When projects were considered "smaller", this approach was generally acceptable. However, when these mega projects (some valued in the billions of dollars) are viewed through this older RI/FS prism, it is easy to understand why interested parties value more accurate estimates much earlier in the process.

Not only that, but EPA generally espouses a deterministic approach to a situation with numerous and significant variables. In essence they tend to advance the use of hard numbers, along with contingency percentages (scope and bid). While these contingencies may allow for some flexibility, they do not encapsulate the many potential obstacles and challenges faced during a typical sediment cleanup, let alone one that is to occur over many years, and in some cases, decades. The overarching message is that there are far too many unknowns associated with a given sediment remediation project in its early life stage (means, methods, access, etc), and as we progress towards bigger and more complex projects, regulators need to reassess their decision-making strategies, especially as it relates to cost.

This suggests that a more robust and accurate costing process is needed. As such, a few concepts should be considered:

- Technical analyses of critical operational elements should not be deferred until the design stage, but instead should be completed during the earlier evaluation stages.
- While cost guides/databases can be useful, contractor quotes are much more precise and, overall, much more valuable.
- Sensitivity analysis is another critical aspect of evaluation that is needed, but typically not performed. This is especially true of these larger projects where multiple variables of great significance can often conflict. Understanding how costs vary as a result of such unknowns is extremely important.
- Likewise, probabilistic costs should be developed, providing a much more realistic estimate of overall costs. This idea is discussed further below.

MANAGING COST RISK AND UNCERTAINTY

As described above, the allowable cost range early in the RI/FS process varies between -30% and +50%, and subsequently narrows later in the project's life. Probabilistic cost analysis is one tool for managing cost risk and uncertainty by answering the "what if question" (e.g., what if the time scale of the remediation increases; what if the volume of dredge material increases, etc.). The "what-if" costs are not typically included in cost analysis. Probabilistic cost modeling is useful for remedial approach decision making because it allows uncertainty to be incorporated into the cost estimate. By incorporating uncertainty into the cost estimate, the user can see a range between the low-end cost, if everything goes as planned and the high-end cost or the worst case scenario cost. In addition to a range of costs, the model also informs the user of cost drivers and risks of cost increase and helps inform contingencies. By knowing which factors influence costs the greatest, the user can then focus on investigating the high impact factors which will allow for a better refinement of overall costs and allow for managing sources of cost creep throughout the project. Finally and perhaps most importantly, probabilistic cost modeling allows for a transparent evaluation of what the actual costs may be which in turn can be used by regulators and other groups when deciding upon a selected remedy.

The first step in developing a probabilistic cost model is to assign probabilities or ranges to address uncertainty for critical decision values. The next step is to input the range or probabilities of the critical values into predictive modeling software. For purposes of this paper, we used Crystal Ball to run a Monte Carlo Simulation. Crystal Ball is an add-in for Microsoft Excel. Monte Carlo Simulation is a computational algorithm designed to evaluate a large number of unknown or uncertain parameters. In the case of this paper we used a Monte Carlo Simulation to evaluate the uncertainty of capital costs associated with a sediment remediation site. The modeling software randomly samples the specified numbers within a range of assumptions over a specified distribution. A uniform distribution was selected to model each decision variable. In the uniform distribution, the range between the minimum and maximum values is specified and it is assumed that all values in the range are equally likely to occur. The model output provides a probability distribution for the total cost of the remediation along with the expected, or most likely, total cost of remediation based on the variability associated with the input parameters (e.g., changes in the volume or cost of dredging and/or capping).

The software also provides a sensitivity analysis which informs which variable has the greatest influence on cost in the model. In the case of our example, we conducted a parameter sensitivity analysis to evaluate which input variable had the greatest effect on the cost of the sediment cleanup. The sensitivity analysis for our example is calculated as a percentage, so the greater the percentage the greatest effect on total cost.

To illustrate the use of a probabilistic cost modeling we chose to evaluate Alternatives E, F, and G of the Portland Harbor Feasibility Study [3]. For each Alternative evaluated (E, F, and G), a detailed cost estimate associated with capital costs was prepared by using the capital costs presented in Appendix G of the Portland Harbor Feasibility Study [3] and a lower and higher cost estimate based on professional judgement and experience at other large scale sediment sites. For example, the capital costs for the lower end estimate were based on assumptions that the total volume of sediment that would require remediation would be lower than estimated in the Feasibility Study, and that associated the time period would be shorter. Conversely, the capital costs associated with the higher end cost estimate were assumed to be greater due to the likelihood that the Feasibility Study is underestimating the remediation time period and the volume of dredge material actually removed. A similar approach was used for both Alternatives F and G. The cost estimates for each alternative were then used in the probabilistic cost model.

The model results are displayed as cumulative probability distributions on Figure 1 for each of the three Alternatives E, F, and G. The cumulative probability distribution shows the predicted range of remediation costs associated with each alternative and also the likelihood that the remediation costs will be above or below a certain dollar amount. For example, the median predicted costs shown on Figure 1 for Alternative E ($2.1 billion), Alternative F ($3.6 billion), and Alternative G ($6.6 billion) are greater than the EPA's estimated cost for Alternative E ($1.4 billion), Alternative F ($2.4 billion), and Alternative G ($3.3 billion). The "worst-case" scenario costs for Alternative E ($3.5 billion), Alternative F ($6.5 billion), and Alternative G ($9.8 billion) are almost three times greater than the Feasibility cost estimate.

A sensitivity analysis was also performed to determine which factor in the capital costs had the greatest overall influence on costs. Under each alternative, disposal costs have the greatest influence on the cost estimates (the sensitivity analysis output for Alternative E is shown in Figure 2 as an example). The other two alternatives followed a similar pattern with disposal driving costs, followed by dredging of contaminated sediments.

There are two key points from this example using Alternatives E, F, and G from the Portland Harbor Feasibility Study. The first is that the actual range of costs associated with each alternative is far greater and more expensive than estimated in the Feasibility Study. The second key point is that much of the uncertainty associated with the cost could be refined by better defining the actual removal volume via open water dredging. The volume of material dredged is directly correlated to the volume of material that will be transported and disposed at an off-site facility, which also has the greatest impact on overall remedy costs.

In summary, the benefit of using a probabilistic cost modeling approach is that the range of potential costs associated with each alternative can be evaluated to determine the most cost-effective and appropriate remedial options. The user is also able to apply "what-if" scenarios (e.g., changes to the time period or volume of material) to evaluate various options. The model results provide a clear visual representation of the range of costs that can be used in project discussions and in reports. Additional investigation/work can focus on items with a higher uncertainty to tighten up cost estimation.

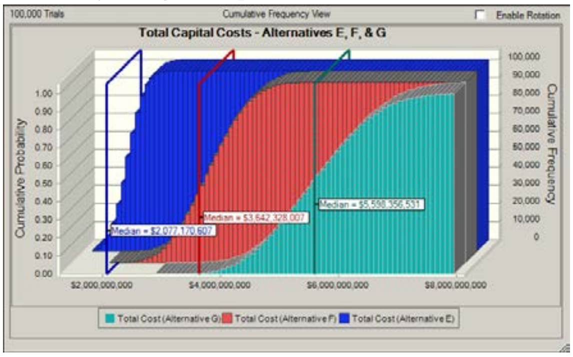

Figure 1Cumulative Probability for Alternative E, F, and G's Capital Costs

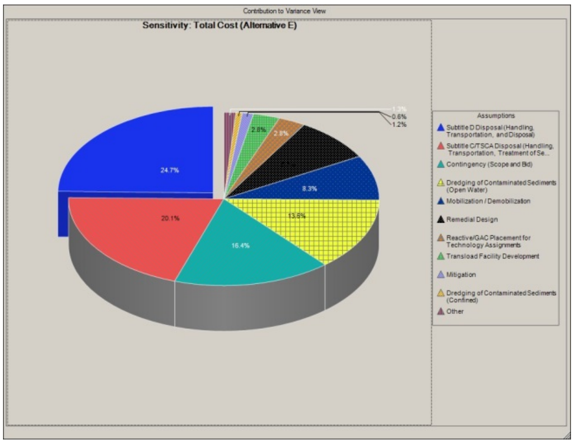

Figure 2 Alternative E – Sensitivity Analysis for Capital Costs

CONCLUSIONS

The scale and complexity of sediment remediation projects has dramatically increased over the last several decades. There are now large cleanups planned in the rivers and harbors of the United States that are projected to exceed $1 billion and span over decades. The all-in unit cost of sediment remediation has risen dramatically despite that the cost of the technologies has not risen by much since the 1980s and 1990s. The increase in unit cost is being driven by larger lengths of river and also more complex remedies, including complex technologies and off-site disposal. The cost of such cleanups plays an important role in evaluating sediment remediation alternatives. Unfortunately, the inherent nature of complex large scale “mega” sediment remediation projects makes them extremely difficult to cost, resulting in inaccurate cost estimates. This will result in inappropriate remedial decisions which may result in significant cash outlays that may be both unnecessary and ineffective. One tool for managing the cost risk and uncertainty is to develop a probabilistic cost analysis. A probabilistic approach can inform decision makers on the most likely cost associated with an alternative, provide a range of cost estimates, and also provide the variable which has the most influence on the overall cost. All of these attributes allow for a more transparent evaluation of what the actual costs may be which in turn can be used for choosing a preferred alternative.

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