AUTOMATED MANAGEMENT OF AGITATION DREDGING BY HOPPER DREDGES

Gary L. Howell, James Rosati III[1], K.C. Clark[2], and Thomas W. Richardson[3]

ABSTRACT

A method of optimizing the environmental and economic benefits of agitation dredging by hopper dredge is described. The method is based on a Sustainability Cost Benefit Ratio that includes terms for maximizing dredging performance as well as maximizing the environmental benefits of the total project. A planning model creates an operational model that can run on an on-board dredge monitoring computer, such as the Silent Inspector. The computer output provides direct advice to the dredger on the duration of agitation for each cycle time.

Keywords: Silent Inspector, sustainable, on-board, optimization

INTRODUCTION

The paper examines the economic and environmental benefits of managing hopper dredge contracts with an optimum combination of agitation dredging and economic load strategy. Agitation dredging with a hopper dredge is a well known and widely practiced technique. Richardson (1984) documented several Corps of Engineers projects and examined the economic benefits of agitation dredging on total navigation maintenance costs.

For hopper dredges, agitation dredging means to extend the dredging cycle by allowing more material to overflow the hopper. For projects where tidal currents are favorable, the material will move out of the channel and into the ebb tidal shoal or littoral system. Economic benefits accrue by reducing the cumulative time spent on disposal and reducing the quantity of material placed in the disposal area. Environmental benefits accrue by returning sediment to the natural system, and minimizing the resident time, fuel consumption, and air particulate release of the dredge.

Agitation may not be beneficial during all phases of excavation. There can be economic and environmental reasons to minimize overflow. Agitation during the flood tide allows suspended material to move back into the upper channel and estuary and can contribute to higher long-term maintenance costs. Controlling this case was common practice prior to the wide spread adoption of pay-by-survey contract dredging. Barring constraints for environmental concerns, there is no economic incentive for a dredger to limit agitation during periods of high potential re-deposition up-channel of the project area. The most common environmental constraint is minimizing turbidity around the hopper dredge during excavation. This concern is based on hypothetical fish impacts.

Figure 1 shows an example of hopper dredge data from the Silent Inspector during agitation dredging. The constant hopper volume is achieved early in the cycle. As dredging continues, the hopper density slowly increases. The time to the disposal site is short relative to these dredging cycles. In this case dredging continues throughout a 24 hr tidal cycle. Project engineers would like to know if this is the most economic way to operate the dredge, considering both near term and long term maintenance costs. Another question is the effect of long cycles on disposal site management and environmental impacts and benefits.

We propose unified planning that considers environmental impacts simultaneously with economic benefits. We define *sustainability* as the optimum combination of minimal long-term maintenance costs, minimal adverse environmental impacts, and maximum beneficial environmental enhancement. The best plan provides the greatest sustainability within the available project budget.

[1] Research Engineers, Coastal and Hydraulics Laboratory, U.S. Army Corps of Engineers, Engineering Research and Development Center, Mobile, Al.

[2] Chief, Dredging Function, New Orleans District, U.S. Army Corps of Engineers, New Orleans, La.

[3] Director, Coastal and Hydraulics Laboratory, U.S. Army Corps of Engineers, Engineering Research and Development Center, Vicksburg, Ms.

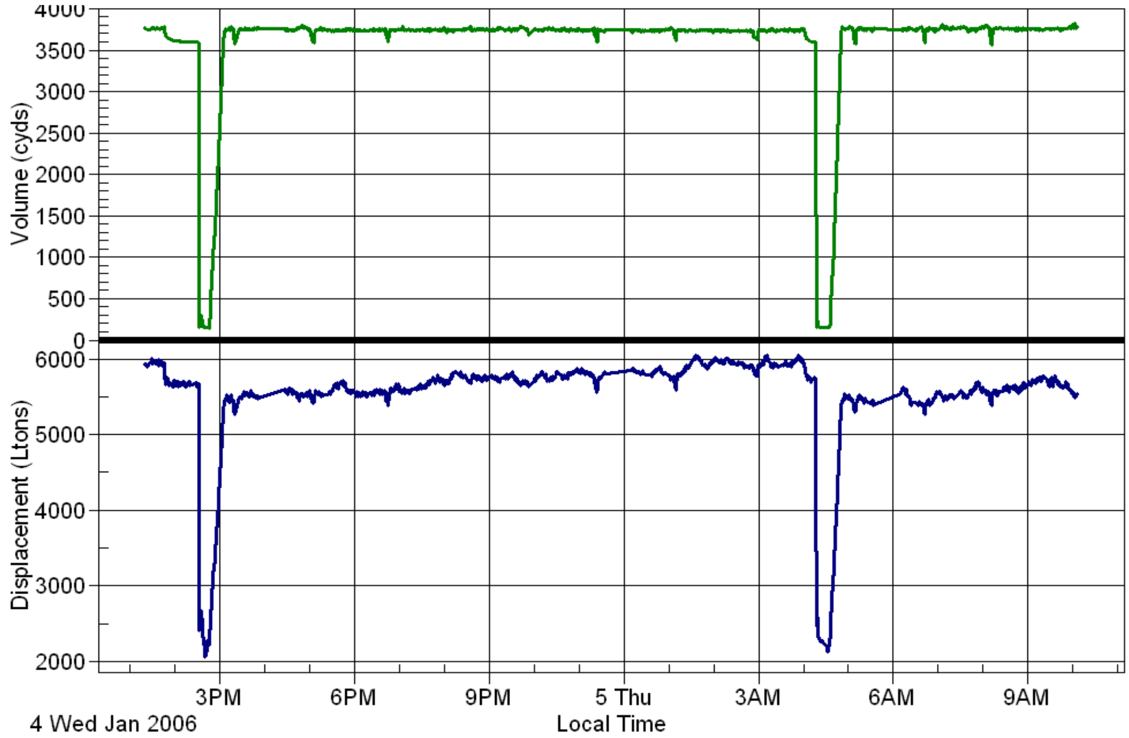

Figure 1. Example of constant volume agitation dredging monitored by the SI.

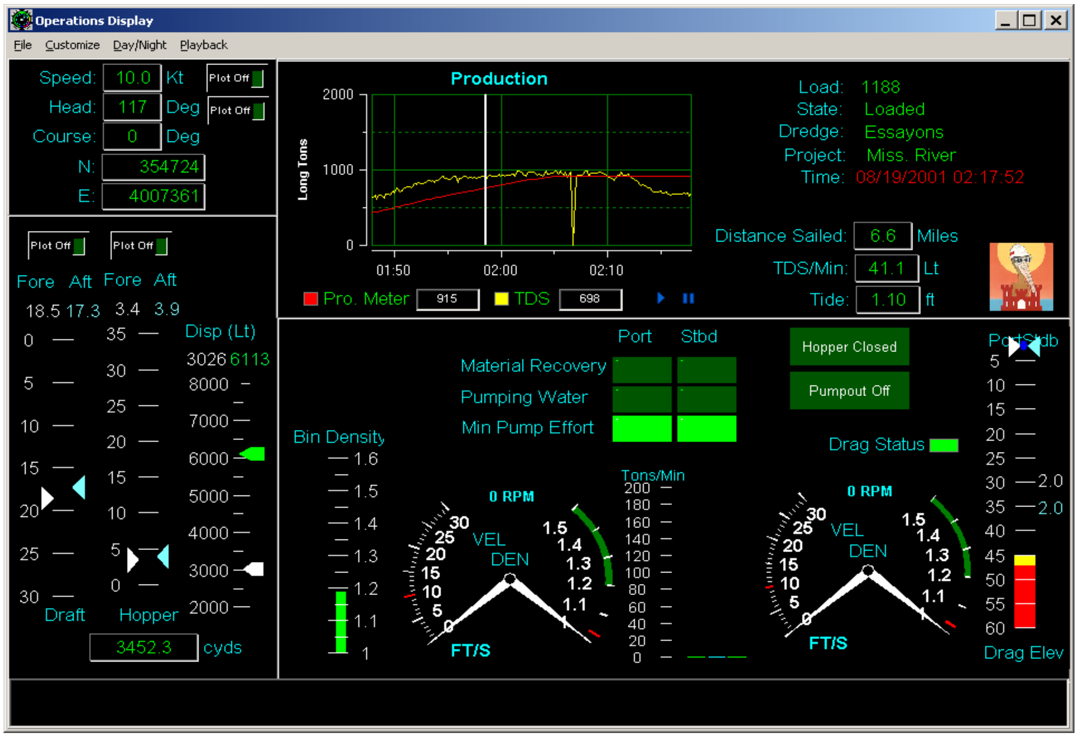

Figure 2. Example of the economic load plot from the SI display. The white line in the production graph shows the computed economic load time.

The widespread availability of automated monitoring computers on hopper dredges provides the opportunity to apply optimal management techniques during dredging operations. Rather than static constraints and performance specifications, the dredger's specified operation can be based on preplanned rules applied to current conditions. Howell and Clark (2002) showed how the economic load concept could be automatically computed to optimize the cycle time of hopper dredges using measurements of existing conditions. Economic load optimization is applicable in the case where a hopper dredge is operating in overflow mode and the travel time to the disposal area is short to moderate. In these cases there is an optimal hopper load that maximizes the total production and disposal over a sequence of loads.

For projects with the required current velocity and sediment suspension characteristics, agitation dredging will be more economic than disposal using economic load cycle times. This economy accrues to the specific maintenance job, but at potential cost to long-term maintenance costs. A best-of-both approach would employ agitation during ebb tides and periods where transport contributes little to future costs. During unfavorable periods disposal based on dredge and haul economic load cycle times would be required.

Implementation would use the on-board monitoring computer such as the Silent Inspector (SI) (Howell, Rosati, & Russo, 2006) which has economic load computing capability. Figure 2 shows the on-dredge display of the Silent Inspector with the economic load window open. The display shows loading continuing past the economic load implying that the dredge is operated for agitation. Building on this foundation, a moving frame tidal current prediction using the real-time water level and astronomical tide prediction would be added to the onboard software. Data from sediment fall-velocity would be used to predict deposition and turbidity. Dredge production measurements, weights, and volumes will be used to predict quantities. These data would provide input to a real-time value-engineering model that optimizes sustainability.

The paper presents a conceptual outline of how such a system would operate. Future research and development is required to complete the model and implement it with software. A period of test and evaluation for real-world dredging projects will be required to evaluate its efficacy and practicality.

OUTLINE OF THE METHOD

First we develop a framework for a rational analysis of dredging efficiency and environmental sustainability. The familiar Cost-Benefit ratio formulation is used as an objective function for minimization by optimization methods. The terms of the ratio correspond to the benefits and costs during project execution and those residual cost-benefits that accrue during the project lifetime. The terms are interdependent. For example lower execution cost plans may result in lower sustainability benefits or higher subsequent costs during project lifetime. Economic factors such as the present value of future benefits are not included at this stage of development. We name the ratio the *Sustainability Cost-Benefit Ratio* (SCBR).

We propose a *Planning Model* that can estimate SCBR during the planning of a maintenance project. The analysis will find the minimum SCBR for varying dredging requirements. The model captures the project specific requirements as well as generic knowledge of hopper dredging techniques. The analysis is performed once and then reused for multiple maintenance scenarios.

The relationship between estimated execution monetary costs and the SCBR can help select the lowest SCBR achievable with available funds. The execution plan that corresponds to this SCBR is the candidate optimal plan that minimizes immediate and long-term costs, while maximizing the sustainability of the project.

During execution of the dredging the accrual of the actual costs and benefits can be monitored by an on-dredge computer system that can automatically determine dredging activity from sensor data. Such a system in the Corps of Engineers is known as the Silent Inspector (SI).

Based on the optimum plan, an *Operational Model* is created that can execute on the SI computer. The model contains a set of rules and goals that are derived from the plan. The model compares these with the measured parameters during dredge operation. For example information on tidal currents, suspension, re-suspension, and deposition rates can be coupled with the data on the hopper load (weight and volume), overflow, and weir configuration to advise when to proceed to the disposal area.

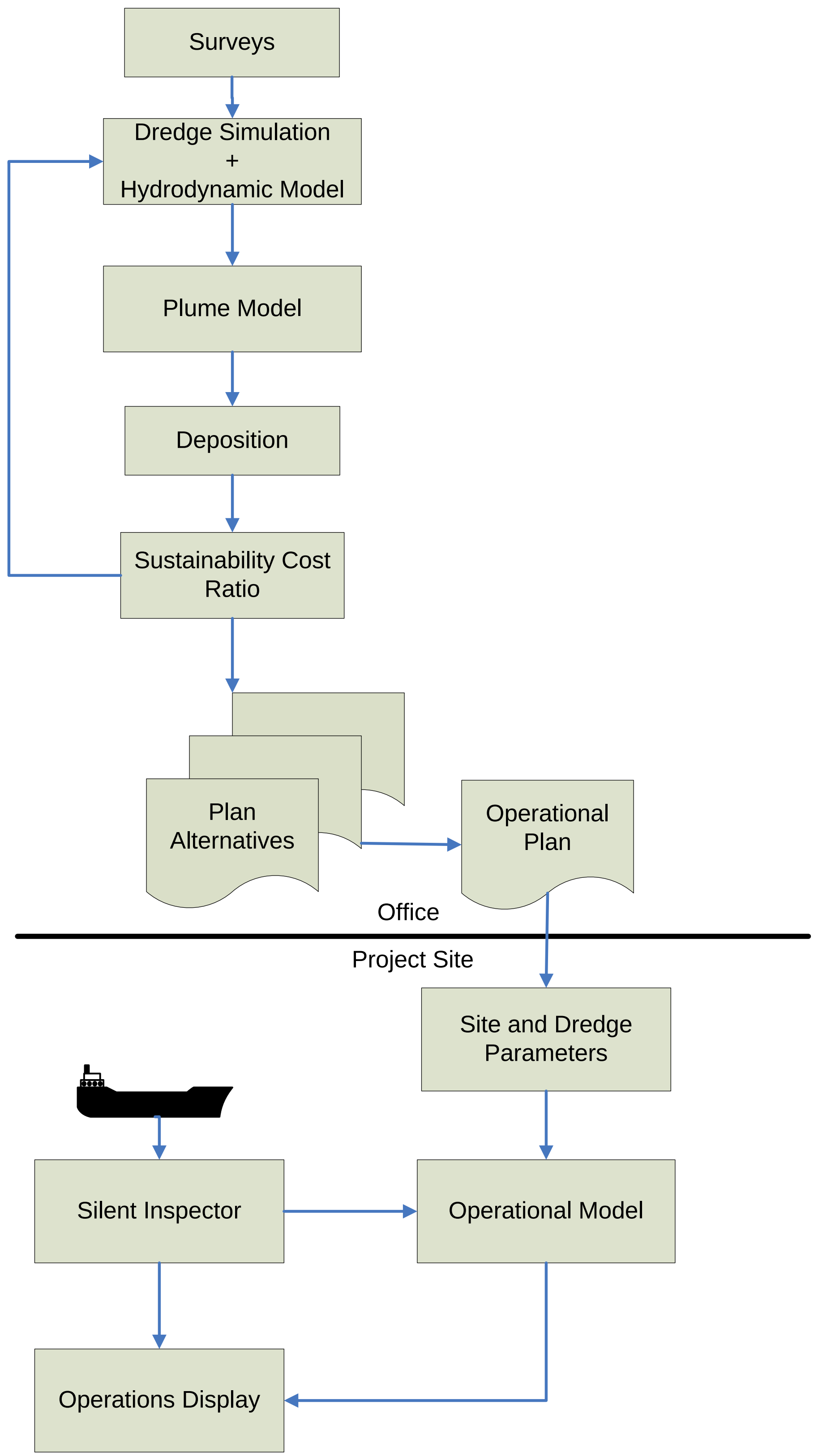

Figure 3. Block diagram of the system.

Figure 3 shows a system diagram of the Planning and Operational models. The Planning model is a set of standard modules that estimate the various terms of the SCBR. Each model instance contains site specific data that includes historical information, local heuristics, and the most recent surveys and weather information. The framework is a feedback model that seeks plans with the lowest SCBR and that meet operational and environmental constraints. The Operations manager selects the operations plan from the candidates based on his knowledge of financial budgets, stakeholder issues, and other intangibles.

The selected plan is processed to provide a set of parameters that direct the on-dredge operational plan. The operational model assimilates data from the Silent Inspector and continuously monitors past performance and projects the near future performance of the plan. The projections are displayed to the dredge operator to time the termination of dredging and the beginning of disposal transit.

The important parameters for a typical coastal channel maintenance project are summarized in the following table. Operational parameters will be estimated for the planning model and measured during operation.

Table 1. Model parameters.

Parameter	***Description***
Hopper dredge position and heading	Simulated for planning and measured for operations
Hopper dredge velocity	Dredge speed over ground and course over ground are measured for operations
Dragarm(s) velocity and density	Simulated or measured from the production meters. Measured mass flux input to the hopper.
Hopper Entrainment ratio	The ratio of the amount of material retained aboard versus the total amount pumped. Also referred to as the settlement ratio.
Re-deposition ratios	The percentage of overflow material that redeposits into an area such as the channel, ebb shoal, or adjacent beach.
Dredging Efficiency	The ratio of dredging time versus the total cycle time.
Total Mass moved	Hopper mass + overflow mass + re-suspended mass
Hopper mass	Production rate (mass) * time * dredge efficiency * entrainment ratio
Overflow mass	Production rate* time * (1- entrainment ratio)
Channel mass	Overflow mass * channel re-deposition ratio
Total effective mass	Hopper mass + (overflow mass – channel mass)
Total effective effort	Total effective mass * Sustainability factor
Sustainability factor	Project specific weighting of the Total effective mass
Grain size and specific gravity	Sediment characteristics of the channel
Dredge plant agitation limitations	The limit on material quantity that can be safely loaded and disposed in the hopper.
Hopper cycle times	Summary of dredge cycle times and distance to the disposal site.
Velocity field	The water velocity through out the project area as a function of time in the tidal cycle and prevailing river flows (if any).

THE PLANNING MODEL

The planning model attempts to minimize the SCBR where the SCBR is defined as:

$$\frac{\sum \text{Operation Costs} + \sum \text{Residual Costs}}{\sum \text{Operation Benefits} + \sum \text{Residual Benefits}} \tag{1}$$

The Operation and Residual refer to the time period of dredging (Operation) and the future period during the project lifetime (Residual).

Each term in the cost-benefit summations is:

$$\mathrm{W_i}\, P_{\mathrm{i}}\, N\, T_c\, Phi \tag{2}$$

Where *P* is the process parameter; *W* is the weighting factor; *N* is the number of cycle times the parameter is active, *Tc* is the average cycle time when the parameter is active, and *Phi* is the tidal current weighting factor. In general each *P* requires a separate relationship to compute using any of the other parameters as inputs.

THE OPERATIONAL MODEL

The goal of the operational model is to advise on the optimal dredge time and therefore the cycle time on a load-by-load basis. The economic load will establish the minimum cycle time. The limit on the maximum cycle time will be determined by the minimum of the updated SBCR recomputed using all the terms available to the on-dredge computer. An absolute maximum is the safe navigation capacity of the hopper. Depending on the dredge plant characteristics, it can be configured for agitation dredging, such as overflowing from the surface versus the bottom of the hull, and depending on the type of material) the weir height. Figure 5 displays the conceptual output of the model. The model computes the total effective mass transported by the dredge. The SI gives the total hopper mass and input mass flux to the operational model. The operational model computes the channel mass and therefore the total effective mass for a load. The progress towards an effective load (greatest total effective mass * sustainability factor) is displayed on the loading progress bar. The dredge crew can get a visual indication of the amount of material that can be potentially re-deposited in the channel via the arcs showing the predicted distance from the dredge of the sediment overflowed from the hopper. The positions of the arcs change with the orientation and position of the dredge and the computed flow field.

The cost-benefit parameters include contribution from dredging, transport, and disposal.

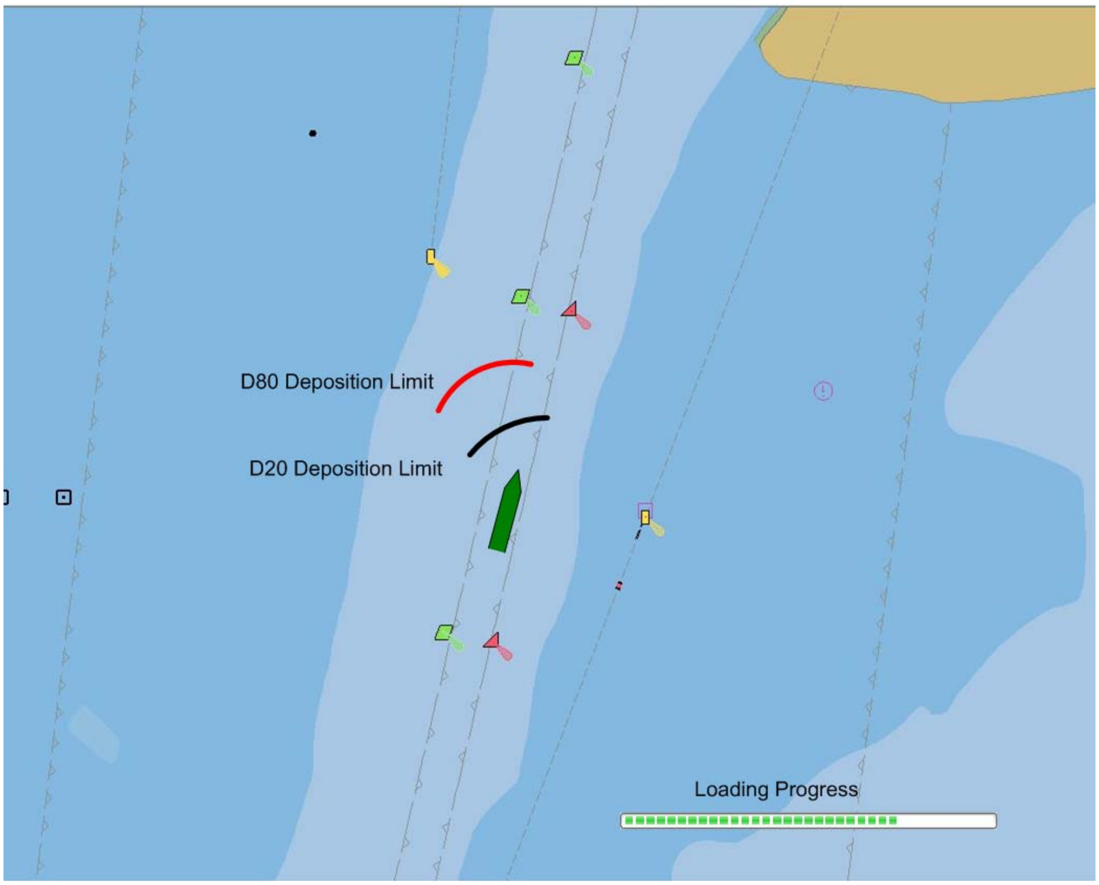

Figure 5. Example of conceptual operational model output for dredge crew.

FUTURE WORK

Future work will develop prototype versions of the SCBR model and optimization analysis. These will be tested against SI records of previous projects. Another area of interest is providing more detailed guidance in dredging contract specifications on the operational execution of the project. The goal here is to assure residual benefits, while allowing the contractor the maximum flexibility to plan his work. The use of automated guidance from SI during operation will impact the contractor's production. Means to provide guidance on these impacts in the solicitation information must be developed.

CONCLUSION

We examined the potential for using the on-board monitoring and automated analysis system to optimize dredge operation during agitation dredging. An optimization objective function called the Sustainability Cost Benefit Ratio is proposed. The potential of such an analysis can enhance the planning phase of contract specifications and give the contractor additional operational guidance that will maximize efficiency and the long-term environmental sustainability of the project. Availability of on-board sensor data and analysis capability can be used to provide in-progress operational guidance that maximizes efficiency and benefits.

ACKNOWLEDGEMENTS

The work and opinions presented here are those of the authors and do not represent current policy or guidance of the U. S. Government and the Army Corps of Engineers. Permission to publish this work was granted by the Office, Chief of Engineers, Army Corps of Engineers.

REFERENCES

Baird, W.F. and Associates, (2004). "Development of the MMS Dredge Plume Model", *Technical Report* prepared for Department of Interior, Minerals Management Service, under Contract # 01-02-CT-85139.

Howell, Gary L. and Clark, K.C., (2002). "Real-time computation of economic load for hopper dredges", *Proceedings Dredging 02, Orlando, Fl.*

Howell, Gary L., Rosati James, and Russo, Edmond (2006). "Plan for National Implementation of Silent Inspector",*Proceedings of the Western Dredging Association Technical Conference XXVI*, San Diego, Ca.

Richardson, T.R., (1984). "Agitation Dredging: Lessons and Guidelines from Past Projects", *Technical Report HL-84-6*, Waterways Experiment Station. Vicksburg, MS 39180.

Soulsby (1997). *Dynamics of Marine Sands,* Thomas Telford, London.

Vlasblom and Miedema (1995). "A theory of determining sedimentation and overflow losses in hoppers", *Proceedings of the XIV World Dredging Congress,* Amsterdam.