WESTERN DREDGING ASSOCIATION
(A Non-Profit Professional Organization)

Journal of Dredging Engineering

Volume 5, No. 2, June 2003
Official Journal of the Western Dredging Association

WEDA XXIII Technical Session on Safety

IN THIS ISSUE

JOURNAL EDITORIAL BOARD

WEDA BOARD OF DIRECTORS

AIMS & SCOPE OF THE JOURNAL

The *Journal of Dredging* is published by the Western Dredging Association (WEDA) to provide dissemination of technical and project information on dredging engineering topics. The peer-reviewed papers in this practice-oriented journal will present engineering solutions to dredging and placement problems, which are not normally available from traditional journals. Topics of interest include, but are not limited to, dredging techniques, hydrographic surveys, dredge automation, dredge safety, instrumentation, design aspects of dredging projects, dredged material placement, environmental and beneficial uses, contaminated sediments, litigation, economic aspects and case studies.

ECONOMIC ANALYSIS OF DREDGING WINDOWS: FRAMEWORK, MODEL, AND EXAMPLES

Thomas Grigalunas[1], Meifeng Luo[2] and James Opaluch[3]

ABSTRACT

Dredging windows -- periods when dredging will be permitted – are increasingly used as a policy for protecting fish and wildlife (seabirds, marine mammal) habitat in estuaries, rivers, and harbors. Windows avoid harmful effects on species targeted for protection but may give rise to several costs. This paper provides an economic analysis of dredging windows. We examine the issues involved, present an economic framework for assessing the benefits and costs of windows, and provide illustrative estimates of some of the issues involved. We show that, for the case considered, windows can come at a high cost in terms of benefits lost due to delayed recovery at a disposal site and foregone dredging benefits.

INTRODUCTION

International trade is a major component of the United States economy, and much of this trade moves on vessels – container ships, tankers, and bulk cargo carriers. There is a major ongoing movement to maintain, improve, and develop ports, driven by the rapid growth in oceangoing trade, advances in vessel design, increased efficiency of dockside operations and competition among ports. As a result of these factors, enormous economic and political pressures exist throughout the United States to dredge channels, berths, and turnaround basins to accommodate larger vessels.

Port development can create substantial benefits in the form of reduced transportation costs and may have environmental and social benefits as well, if use of vessels and feeder ports reduces truck traffic, for example. At the same time, port development in general, and dredging proposals in particular, raise environmental issues and invariably generate resistance from environmental organizations, the fishing industry and other stakeholder groups. These conflicts may lead to modification in plans, substantial delays, additional management or mitigation requirements – and often, all three.

Port development raises a number of economic issues concerning the definition, physical quantification, and valuation of the incremental effects of individual benefits and costs. This paper focuses on a subset of port issues: the use of dredging windows to avoid losses that dredging can cause for commercial and recreational users of fishery resources. Dredging and

[1] Professor, Department Environmental & Natural Resource Economics, University of Rhode Island
[2] Ph.D. Candidate, Department Environmental & Natural Resource Economics, University of Rhode Island
[3] Professor, Department Environmental & Natural Resource Economics, University of Rhode Island

marine dredge disposal can cause mortality to fish, shellfish and crustaceans. As a result, short- and long-run losses in commercial and recreational catch may occur, and these costs are an appropriate part of any benefit-cost analysis of port development. Other species may be affected by dredging and, if so, should also be considered.

The use of dredging windows to avoid harming certain, vulnerable species is being increasingly pursued as a management tool. However, the benefits and costs of windows are unclear and any assessment of the net benefits of windows requires consideration of several effects. First, dredging windows can reduce impacts to critical ('target") fisheries by suspending dredging operations in an area during a critical period for the fishery (e.g., during spawning). However, use of a window may also affect other "incidental" species at the dredge site. For example, some incidental species may be afforded protection from dredging if their critical period coincides with that for the target species. But the use of dredging windows will prolong the overall period within which dredging operations occur, which may exacerbate impacts to other species that are not protected by the window. Prolonging the dredging period may also extend operations at marine disposal sites, leading to a delay in recovery. Additionally, windows delay completion of port projects, and hence cause a loss in the potential benefits associated with dredging. Also, the present value of dredging costs may increase if sedimentation occurs during delays. Finally, dredging within multiple windows may increase dredging costs, due to the need to re-mobilize equipment at the beginning of each window. All of these factors affect the overall efficacy of windows as a marine resource management policy.

The relative importance of these effects differ by site and season, and any assessment of the benefits and costs of dredging windows requires considerable engineering, biological, and economic data. Some of these data are difficult to obtain, and rarely, if ever, is there the luxury to base decisions on perfect data. However, even imperfect data can prove useful for informing the decision making process. In the sections that follow, we draw together some recent work that examines the benefits and costs of dredging and dredge disposal. Our framework uses concepts and methods from environmental and natural resource economics, but requires substantial information from, and close cooperation with, engineers, biologists, ecologists, and others.

ECONOMIC FRAMEWORK FOR ASSESSING DREDGING WINDOWS

Dredging for port maintenance, expansion, and development creates a variety of benefits and costs that involve important engineering, economic, biological and other issues. In this paper, we focus on the relatively narrow issue of dredging windows. We take the overall scale of the port, the dredging technology used, and other dredging strategies (e.g., sequencing) as givens, and we put aside other important issues, such as the benefits and costs of alternative disposal options, e.g., beneficial uses of dredged sediments such as for beach re-nourishment, as fill for port expansion, or for construction material. We also focus only on the impact of dredging to fisheries; other possible species affected (e.g., marine mammals and seabirds) are not considered. Finally, we assume dredging projects are designed so that harmful effects (e.g., mortality, other impairment, bioaccumulation and bio-concentration) from contaminated sediments are avoided.

Separate analyses of these issues of course should be considered in cases where they are important concerns.

To assess the consequences of using dredging windows, all of the potential incremental benefits and costs must be considered. Use of windows raises at least four issues:

- Windows are designed to reduce impacts to vulnerable target species at the dredging site by eliminating exposure to dredging impacts. There may also be a reduced impact to other species that are present at the same time.
- Dredging windows by definition extend the length of the overall dredging period, which may increase impacts to species whose critical period does not coincide with the dredging window.
- Dredging windows also extend the length of the disposal period, and delay recovery of fishery resources at the marine *disposal* site, imposing additional impacts.
- Dredging equipment must be re-mobilized (perhaps multiple times) at the dredge site once the critical period passes, resulting in additional costs.
- Delay in the project due to windows comes at a cost—the foregone benefits that the public would have received from the port project, such as reduced transportation costs. This can be a substantial cost, as the example below makes clear.

An appropriate assessment of dredging windows requires consideration of all of these factors. This in turn requires that both biological and economic elements of the problem be considered. Below we discuss a framework that addresses each of these issues.

Impacts of Windows to Species at the Dredging Site

The cessation of dredging activities between windows reduces impacts to species that would otherwise be impacted from dredging activities. Simultaneously, dredging windows extend the overall dredging period, potentially increasing impacts to species whose critical period does not coincide with the dredging window. Here we discuss a framework that can be used to model these two effects of dredging windows. Below we assume that adults are mobile, and can avoid impact areas, so that impacts are to larvae of the various species that are exposed to the sediment plume. However, it is conceptually straightforward to include adults in the analysis, where appropriate.

In general, assessing population impacts due to loss of larvae is a difficult task, and depends upon knowledge of key biological factors for the species of concern. The beneficial impact of dredging windows is calculated by determining the change in adult populations due to the reduced larval impact from dredging. If the population of a particular species is limited by habitat for juveniles or adults, then larvae may not be a limiting factor, and loss of larvae due to dredging may have little or no impact on subsequent adult populations. In cases where larvae are a limiting factor, accurate forecasting of the effect on adults is complicated by a host of factors that influence population dynamics and that are difficult to predict before hand (e.g., environmental factors, such as water temperature, etc.). Nevertheless, for management purposes, we can get a rough indication of the potential importance of the impact using estimates of average values for key parameters, such as survival rates.

Age classes prior to legal size are subject to natural mortality, after which they are subject to both natural and fishing mortality by commercial and recreational users for harvested species. Assume there are *I* target species in a dredging window, and the window lasts for *m* months a year. Assume the dredging would take T years with no window; a longer period will be involved with windows. An illustration of dredging activity, with and without a dredging window, is given in Figure 1. The upper part stands for nonstop dredging; the lower part illustrates use of a dredging window that lasts *m* months each year.

The number of years required to finish the dredging with windows depends on the timing of the period of dredging and cessation of dredging, as shown in Figure 1. In the best case scenario, the beginning of the allowable dredging window coincides with the beginning of actual dredging activity. In this case, the total dredging period with dredging window can be calculated as:

$$X = (1-W/12)*Int((12*X-1)/W) + T \qquad (1)$$

where X is the total period of dredging in years, W is the length of the dredging window in months, Int is the integer function which rounds the argument down to the closest integer, T is the time of the dredging activity in months. So for the example in Figure 1a, a 6-month dredging window and 12 months of dredging activity, the total dredging period is 18 months. Representative delays in completing a dredging project due to windows are indicated in Table 1.

A cohort-type model (e.g., Ricker, 1975) can be used to model the effect of windows on the affected populations, and to calculate the associated changes in the recreational and commercial catch. Below we focus primarily on incremental economic values associated with changes in commercial and recreational catch due to dredging windows.

If for i^{th} species ($i \in (1, 2, \ldots, I)$), let there be N(0) larvae produced each year in the area impacted by dredging. For simplicity we assume that for species protected by windows, the entire larvae period is outside the dredging window, and for species whose impact is exacerbated by widows, the entire larval period is *within* the dredging widow. It is conceptually straightforward to extend this analysis to cases where the larval period is partly within and partly outside of the window.

Below we estimate the economic value of commercial and recreational catch from a loss of a given population of larvae. This represents a benefit for species that are protected by the widow, as this is a reduction in dredging impact associated with protection of those species. In contrast, this represents a cost for species whose impact is exacerbated by the prolonged overall dredging period.

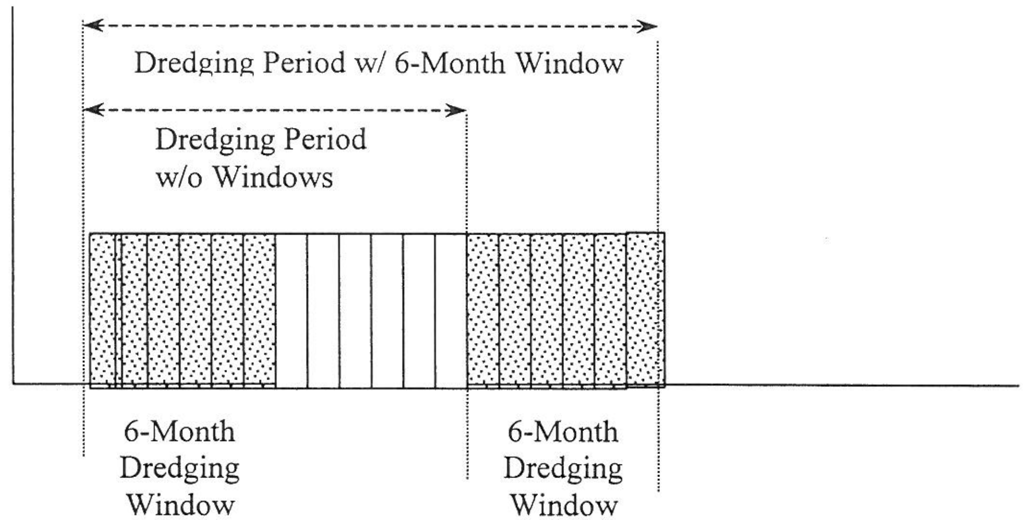


Figure 1a. **Dredging Period With Versus Without Window: Best Case Scenario**

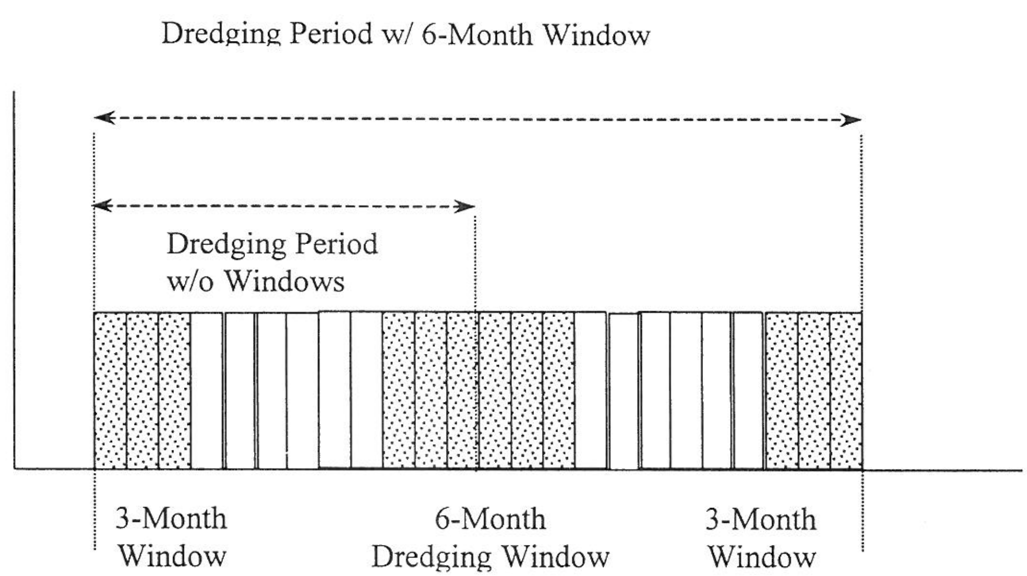


Figure 1b. **Dredging Period With Versus Without Window: Worse Case Scenario**

Table 1. Total Dredging Period as a Function of Months of Dredging Activity and Length of Dredging Window

Dredging Activity- (T) (Years)	2	2	2	3	3	3	4	4	4	5	5	5
Window (m) (Months)	9	8	6	9	8	6	9	8	6	9	8	6
Total Dredging Period - w/ Window (X) (Years)	2.5	2.67	3.5	3.75	4.33	5.5	5.25	5.67	7.5	6.5	7.33	9.5

Assume the recruitment age for the ith species is k^i_r, the life span is K^i, natural mortality rate for age class k is $M^i(k)$, and fishing mortality is F^i for age classes $\geq k^i$, the weight for the ith species at age class k is W^i_k, and the fish value is p^i. Then the present value of the catch from N(0) larvae is:

$$PV_t = \sum_{i=1}^{I} \sum_{k=k_r^i}^{k_{cu}^i} \frac{D^i p^i W_k^i F^i N^i(0) \prod_{k=1}^{k_r^i - 1} (1 - M^i(k)) \prod_{k=k_r^i}^{K^i} (1 - M^i(k) - F^i)}{(1+r)^k} \qquad (2)$$

Where D^i is an indicator variable, equal to +1 for species that are protected by the dredging window and −1 for all species that are adversely affected extending dredging outside the dredging period. The indictor variable would be an appropriate fraction for cases where the critical larval period extends across the dredging window. So if ½ of the larvae of a particular species are protected by a dredging window, D^i would equal ½.

For a multi-year dredging project, there may be more than one window, as noted. Consider all the dredging windows during T years' period, the net effect with the dredging window for all species is:

$$B_{w,dre} = \sum_{t=0}^{T-1} \frac{PV_t}{(1+r)^t} \qquad (3)$$

where PV_t is positive for species protected by dredging windows and PV_t is negative for species adversely affected by dredging windows.

Costs due to adverse biological effects at disposal site

Dredging windows lead to a prolonged total dredging period, and hence a delay in recovery of species at marine disposal sites. Marine disposal of dredged materials can impact species at the disposal site, and the associated losses included short-term, long-term, and ecological (food web) losses. Short-term losses include population impacts and associated losses in catch during the disposal period. Long-term impacts include losses starting at the end of the disposal period and extending through the time of full recovery of the impacted populations. Ecological impacts include indirect impacts to species in higher trophic levels due to dredging-related impacts to prey species.

To estimate these losses, a cohort model (e.g., Riker, 1975) is used to model impacts to species affected at the disposal site. Using this model and estimates of commercial and recreational fishing mortality, the value of foregone commercial and recreational catch can be estimated through the period of recovery for several hypothetical disposal sites. The calculations below are meant to be illustrative of the kind of analysis that can be done, and the sensitivity of impacts at the disposal site to the total dredging period that would be associated with dredging windows.

We assume a 500-acre disposal site in Narragansett Bay and in Block Island Sound. A key assumption in the analysis outlined here was that disposal causes 100% mortality at the disposal site, and that biological recovery begins immediately at the end of the disposal period. We also assume that disposal only of non-toxic sand and that the disposal site has a sand bottom prior to disposal. Thus, the physical environment at the disposal site is largely unchanged following disposal, and subsequently the biological populations recover over time, eventually returning to initial conditions, as depicted in Figure 2. Disposal begins at time d_0, and the population of the species in question drops from P^0 to P^1. Disposal continues until d_1 without dredging windows, when natural recovery commences. Complete biological recovery occurs at time r_1.

The incremental impact at the disposal site of employing a dredging window is to extend the disposal period, thus extending the period of short-term damages, and delaying the recovery period. This is illustrated in Figure 2. With dredging windows, disposal continues through time $d_2 > d_1$, and complete recovery is delayed until time $r_2 > r_1$. The shaded area in the diagram indicates the incremental delay in recovery at the disposal site over time due to dredging windows. We calculate the economic value of lost commercial and recreational catch due to this delay in recovery.

The model described above was applied using data from Rhode Island fisheries. The value of lost catch resulting from a two-year disposal period at a 500-acre disposal site in Narragansett Bay is $2.5 million. If a 6-month dredging widow is used with two years of dredging activity, the total dredging period is 3.5 years. The value of lost catch resulting from a 3.5-year disposal period in a 500-acre disposal site in Narragansett Bay is $3.0 million. Thus, the dredging window results in an incremental cost of roughly $0.5 million, or approximately 20%.

Table 2 contains estimates for different lengths of dredging activity and dredging windows, with disposal at a 500-acre site in Narragansett Bay and a similar site in Rhode Island Sound. These numbers provide an indication of the incremental costs of dredge windows to recreational and commercial fishing due to population impacts at a marine disposal site.

For the cases we explore in Narragansett Bay, dredging windows result in an incremental costs for delayed recovery that range from $96.4 thousand for an 8 month dredging window and one year period of dredging activity, to $744.3 thousand for a 6 month dredging window and three year dredging activity. These estimates range from 4% to 27% of the total lost catch due to disposal. For the cases we explored in Rhode Island Sound, dredging windows result in an incremental cost that ranges from $14.9 thousand to $114.4 thousand, and the percentage increase in cost ranges from 5% to 31%.

Costs of Equipment Re-mobilization Due to Dredging Windows

With no window, equipment would be brought to the site, and dredging would proceed until the task is finished. With dredging windows, equipment is mobilized at the dredging site at the start of the window and is removed at the end of the window. Therefore, there is a cost to re-mobilize

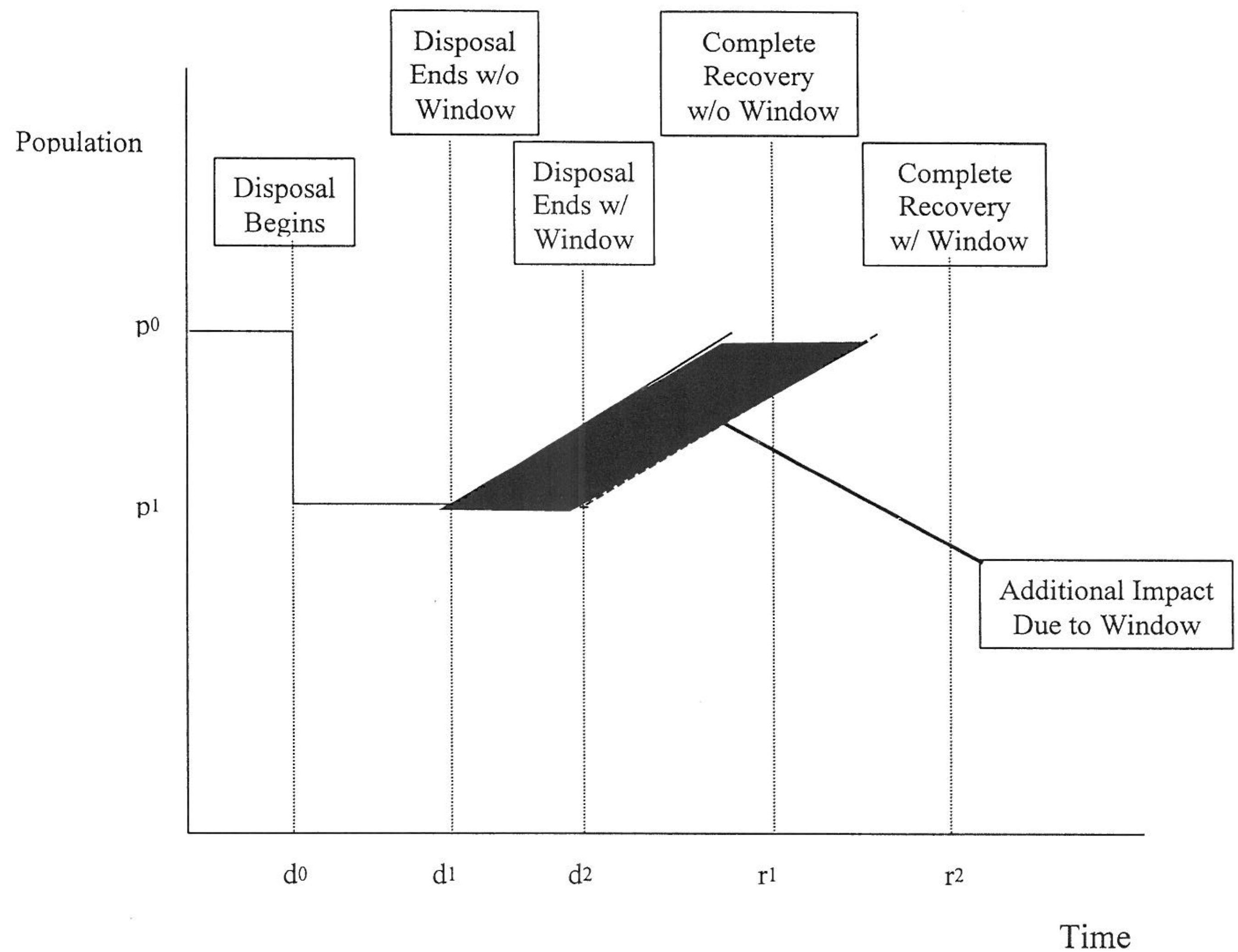


Figure 2. Incremental Impact at Disposal Site Due to Dredging

Table 2. Incremental Losses at Disposal Site Due to Dredging Windows ($ Thousand)

Length of Dredging Activity	1 Year		2 Years		2 Years	
Length of Dredging Window	6 Months	8 Months	6 Months	8 Months	6 Months	8 Months
Narr. Bay ($000)	$162.8	$96.4	$467.0	$281.3	$744.3	$392.5
Percent	8%	4%	19%	11%	27%	14%
RI Sound ($000)	$25.0	$14.9	$71.8	$28.7	$114.4	$60.4
Percent	9%	5%	22%	9%	31%	16%

equipment at the beginning of each subsequent dredging window, which implies an incremental cost due to windows.

For simplicity, assume the total cost for mobilization and re-mobilization is C. With dredging windows, the task will require mobilizing equipment X times rather than once, as in equation (2). Therefore, the present value of the incremental cost in re-mobilization is:

$$EMC = \sum_{t=2}^{X} C/(1+r)^t \qquad (7)$$

So if dredging begins at time d_0, and continues for X periods. Without dredging windows, equipment is mobilized once, at time d_0. In contrast, with dredging windows the equipment is mobilized each year for X years.

Lost Benefits Due to Project Delays

Project benefits include alleviation of vessel traffic congestion, resulting in reductions in transportation costs, possible reductions in the likelihood of vessel accidents and possible reductions in shore-based transportation impacts, such as traffic and air pollution from trucks. Delays in completing the dredging project cost the public because prospective benefits are not realized until the dredge period is completed.

Assume the net benefit that would have been realized from dredging at year t is V_t, then the present value of the cost to the public due to the extended dredging activity (in terms of benefit not realized) is:

$$C_u = \sum_{t=T}^{X} \frac{V_t}{(1+r)^t} \qquad (8)$$

These costs will obviously depend upon the particular project. To provide a rough perspective on the dredging windows issue, we use an illustrative example for the port of Providence (see Grigalunas, Chang, and Luo, 2000 for details). Note that this analysis provides rough estimate of potential cost savings due to dredging, and is not based on a thorough study of the issue of dredging windows.

Currently, approximately 150 million gallons of gasoline are lightered at Narragansett Bay each year, according to the USA COE. This involves an extra transportation cost. Also, delay of some vessels due to waiting on tides, restrictions on use of the federal channel, and shallow depths at some berths also raise costs.

If dredging in and around Providence River and Harbor allowed deeper draft vessels to use the Bay and by that, reduced costs by, say, $0.025 per gallon of oil lightered, then the annual benefit for gasoline alone would be on the order of $3.75 million (=.025 * 150,000,000).

For the case of a project that requires 2 years of dredging activity, a 6-month dredging window would prolong the project to a total period of 3.5 years. This implies a delay of 1.5 years, for a cost on the order of $5.5 million. Note that this includes only delay cost for gasoline delivery. Shipping of other products may also benefit from the dredging project, and there may be other factors to be considered, such as reductions in accident rates.

SUMMARY AND CONCLUSIONS

Dredging windows can be used to protect key target species, and may simultaneously protect some incidental species. But dredging windows increase the overall dredging period, which can result in an increase in a variety of costs. For example, a case that requires two years of actual dredging activity with a six-month window results in dredging occurring over a period of at least 3.5 years. This extension of the dredging period may impose several costs, including (1) increased impacts to some species at the dredging site; (2) a delayed recovery at a marine disposal site for dredged materials; (3) costs of re-mobilizing dredging equipment; and (4) loss of benefit at ports due to delay of transportation-related dredging benefits.

Clearly, much uncertainty exists regarding quantification of the positive and negative impacts of dredging windows. However, it is important to use and improve upon methods and data to provide a perspective on the size of these effects. This paper provides a framework for assessing each of the components listed above, and presents some preliminary quantitative estimates of some of these categories.

An age-class based bio-economic model was used to estimate incremental losses to commercial and recreational fisheries due to the delayed recovery at marine disposal sites. These effects include the short run losses in catch during the disposal period, the long-term effects that extend from the end of disposal through full recovery of the impacted stocks, and the indirect effects that occur through the food web.

Estimates of increased costs due to dredging windows range from 4% for an 8 month dredging window with one year of dredging activity for a site in Narragansett Bay to over 30% for a six month dredging window and 3 years of dredging activity for a site in Rhode Island Sound.

Notable is the cost due to the delay in dredging project benefits from windows. We provide a simple illustrative example in the port of Providence that considers only the potential cost savings of dredging for petroleum product deliveries. Assuming a dredging project that requires 2 years of activity, a 6-month window can result in delay of 1.5 years in project benefits costs. Using a series of simplifying, but not entirely implausible, assumptions, cost savings from dredging are estimated to be $3.75 million per year. A delay in project benefits of 1.5 years results in a total cost on the order of $5 million. Note that this includes lost benefits for gasoline deliveries only. Dredging may also benefit shipping of other product, and there may be other categories of benefits from dredging, such as reduced accident rates.

ACKNOWLEDGEMENTS

The authors greatly appreciate financial support from the Korea-America Joint Marine Policy Research Center at the University of Rhode Island (URI), the URI Transportation Center, the U.S. Army Corps of Engineers, and the Agricultural Experiment Station (AES Contr. #3889). The authors also would like to thank the journal editor and staff for helpful editorial assistance. The opinions expressed herein do not necessarily reflect those of the funding sources.

REFERENCES

Grigalunas, T., Opaluch, J., and Luo, M. (2000). *"Economic Cost for Fisheries from Marine Dredge Disposal".* U. S. Army Corps of Engineers, Lexington, KY.

Grigalunas, T.A., Chang, Y.T., Luo, M. (2000*). "Marine Transportation on Narragansett Bay: Economic Perspective on Uses and Issues"* Paper presented at Narragansett Bay Summit, Narragansett, RI.

Ricker, W.E. (1975). "*Computation and Interpretation of Biological Statistics of Fish Populations.*" Bull. Fish. Res. Board Can., Vol. 191.

ENGINEERING CASE STUDY—WARD COVE SEDIMENT REMEDIATION PROJECT, KETCHIKAN, ALASKA

Mark J. Herrenkohl[1], John Lally[2], Bernadette Johnston[3], Greg L. Hartman[4], Eric Snow[5], Tom Fowler[6], Barry Hogarty[7], Karen Keeley[8], and John Wakeman[9]

ABSTRACT

From October 2000 through June 2001, Foster Wheeler Environmental Corporation (Foster Wheeler), under contract to Ketchikan Pulp Company (KPC), completed construction activities associated with remediation of the Marine Operable Unit (OU) in Ward Cove, Alaska. Remediation activities in Ward Cove included constructing a ponding area for temporary storage and dewatering of dredged material, removing submerged logs, wood debris, and dredging sediments to improve depth for navigation, and placing dredged material and associated wood debris in the dewatering facility. The project remediation also included placing a thin-layer sand cap over selected portions of the bed area in the Marine OU. In total, Foster Wheeler and its contractors removed approximately 680 tons of logs and wood debris and completed dredging of 2.8 acres, for a total volume removal of nearly 12,000 cubic yards (cy). A total of 29.8 acres, at bed surface depths ranging from -10 feet mean lower low water (MLLW) to -120 feet MLLW, were thin capped with 6 inches or more of sand. Based on performance verification measures and acceptance criteria evaluated during construction, all remediation activities were considered effective in meeting the requirements of the Record of Decision (ROD) dated March 2000 and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Consent Decree dated November 2000. The long-term effectiveness of the remedial activities will be evaluated during the long-term monitoring of the site, scheduled to begin in 2004.

INTRODUCTION

This paper describes the construction activities conducted to implement the remedial action set forth in the ROD (USEPA 2000) for the Marine OU of the KPC site. The investigation of the Marine OU of the KPC site and the design and implementation of a cleanup alternative were

[1]Foster Wheeler Environmental, 321 Summerland Road, Bellingham, Washington, 98229; [2]Bean Environmental, 5316 NE 74th Street, Seattle, Washington, 98115; [3]Foster Wheeler Environmental, 1050 NE Hostmark Street, Suite 202, Poulsbo, Washington, 98370; [4]Dalton Olmsted & Fuglevand, Inc., 10705 Silverdale Way NW, Suite 201, Silverdale, Washington, 98383; [5]Foster Wheeler Environmental, 3947 Lennane Drive, Suite 200, Sacramento, California, 95843; [6]Foster Wheeler Environmental, 133 Federal Street, 6th Floor, Boston, Massachusetts, 02110; [7]Consultant to Ketchikan Pulp Corporation, 603 Deumount Street, Ketchikan, Alaska, 99901; [8]U.S. Environmental Protection Agency, Region 10, 1200 Sixth Avenue, Seattle, Washington, 98101; [9]U.S. Army Corps of Engineers, Seattle District, 4735 East Marginal Way South, Seattle, Washington, 98124

initiated under a Clean Water Act Consent Decree dated September 1995, between the U.S. Environmental Protection Agency (EPA) and KPC. The current owner of the former pulp mill assets is Gateway Forest Products (GFP). The remediation work was completed under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 CERCLA Consent Decree between EPA, KPC, and GFP dated November 2000.

As specified in the EPA-approved Remedial Action Work Plan (RAWP) dated October 2000, Foster Wheeler performed the construction and engineering oversight of the remediation activities for the Marine OU in Ward Cove. Remediation activities in Ward Cove included constructing a dike for dewatering dredged material, removing underwater logs and wood debris in areas to be dredged, dredging sediments to improve navigation, placing a thin-layer sand cap over approximately 30 acres of the Marine OU (including approximately 2 acres of area dredged), and disposing of log wood debris and dredged material in the dewatering area. Remedial activities were conducted from November 1, 2000, to March 6, 2001. Disposal of dredged material was completed in June 2001.

This paper provides details of the Ward Cove Sediment Remediation Project and an account of the 2000/2001 remediation and associated activities, including the effectiveness of remediation and lessons learned.

PROJECT SITE AND HISTORY

Ward Cove is approximately 1 mile long with a maximum width of approximately 1/2 mile. The shoreline of the cove consists primarily of basalt rock and is relatively steep. More than 2/3 of Ward Cove is deeper than 100 feet. Sediments in the cove are predominantly subtidal with only a small fraction of the sediments found in the intertidal zone (near the mouth of Ward Creek) (USEPA 2000).

Located on the shoreline of Ward Cove, the KPC mill operated continuously from 1954 until 1997, processing logs into lumber, pulp, and hog fuel. The principal product of the KPC mill was dissolving-grade sulfite pulp. When pulp production began in 1954, effluent from the mill, including spent cooking acid (magnesium bisulfite) and bleaching agent (chlorine caustic), was discharged directly into Ward Cove. After 1971, when federal and state environmental regulations went into effect, effluent was treated in a wastewater treatment plant located at the mill. This treatment resulted in a substantial reduction in the release of spent sulfite liquor, suspended and settleable solids, and oxygen-consuming substances in the cove (USEPA 2000).

The KPC site is divided into two administrative units: the Marine OU and the Uplands OU. The boundary between the two OUs is the mean higher high water (MHHW) line. The response action described in the March 29, 2000, ROD addresses the Marine OU only. The Marine OU consists of approximately 250 acres in Ward Cove (Figure 1).

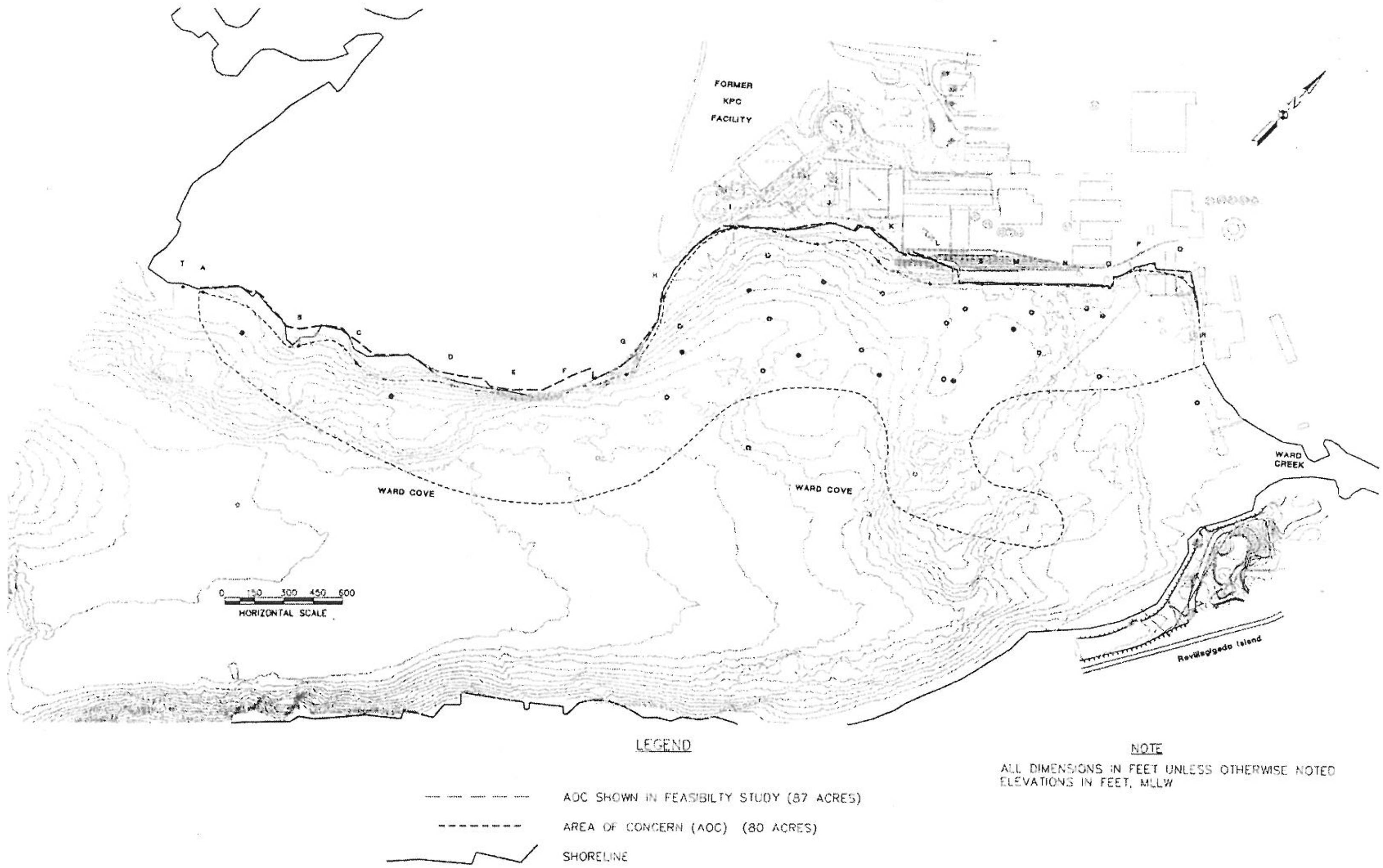


Figure 1. Ketchikan Pulp Company, Area of Concern

Numerous environmental studies of Ward Cove have been conducted to evaluate the potential environmental effects associated with the historical discharges from the KPC facility (USEPA 1975, Jones & Stokes and Kinnetic 1989, EVS 1992, ENSR 1995, E&E 1998, Exponent 1999, Exponent and Hartman 2000a,b). Historical studies focused on water quality impacts and sediment chemistry and toxicity studies. These studies documented a variety of potentially adverse conditions and effects in the water column and sediments in Ward Cove. Spatial variations in sediment characteristics were generally consistent, with elevated levels of chemicals of potential concern (CoPCs) and sediment toxicity found nearest the mill and a cannery that operates on the southern shoreline.

REMEDIATION OVERVIEW

Comprehensive studies of the Marine OU were conducted by KPC in 1996 and 1997, with EPA oversight, to evaluate the extent to which sediments in Ward Cove may pose risks to humans and to the environment and potentially warrant remediation (Exponent 1999). Surface and subsurface sediment samples were taken at various locations throughout Ward Cove and at two locations in Moser Bay (as a reference area). The goal of this investigation was to analyze both vertical and horizontal presence and concentrations of CoPCs, and to further determine the relationship between the CoPCs and the KPC mill site. The sediment data from Ward Cove indicated that sediments were impacted by historical releases from the KPC site, and they are toxic to some marine animals that live in the sediments. The chemicals of concern (CoCs) identified for sediment toxicity were ammonia, sulfide, and 4-methylphenol. However, based on the results of the human health risk assessment, sediments in Ward Cove did not pose unacceptable risk to humans or to wildlife (e.g., marine birds and mammals).

In 1997, an expanded site investigation (E&E 1998) was performed at the KPC site to provide EPA with adequate information to determine whether the site was eligible for placement on the EPA National Priorities List (NPL). The KPC site was not placed on the NPL. The expanded site investigation data were considered in the ROD; however, because of the inaccuracies of the station locations, the data were not used in delineating the remediation areas.

Extensive investigations were also completed at the Uplands OU. As part of those investigations, the potential for releases of contaminants from the upland site to Ward Cove sediments was investigated. Soil removal actions have also been completed at the site. Based on findings of the environmental investigations for the Marine and Uplands OUs, EPA concluded in the ROD that no further physical actions were necessary to control contaminant releases from the upland site to the Cove (USEPA 2000).

Area of Concern

In May 1999, KPC completed a Detailed Technical Studies Report (DTSR) (Exponent 1999) for remediation of contaminated sediments in Ward Cove. The DTSR included a remedial investigation, which documented the nature and extent of sediment contamination, and a feasibility study, which evaluated remedial action alternatives. The DTSR identified an 80-acre area of concern (AOC) where, based on a human health and ecological risk assessment, remedial action may be warranted because sediment contamination poses a risk to benthic organisms (Figure 1). Sediments in the AOC are toxic to benthic biota as a result of *in situ* biodegradation of organic material released by mill operations.

Subsequent to the DTSR, additional remedial design sampling was conducted in Ward Cove in September and October 1999. The results of the design sampling are presented in the Cruise and Data Report (Exponent and Hartman 2000a). Information from remedial design sampling was used to refine the boundaries of the AOC as documented in Exponent and Hartman (2000a). The data from this sampling and the data in the DTSR were used to perform design calculations and computer modeling for a Design Analysis Report (DAR) (Exponent and Hartman 2000b). The DAR was prepared as part of the remedial design phase for implementation of the remedial action set forth in the ROD for the Marine OU (USEPA 2000).

Remedial Action Objectives and Scope

As described in the DTSR (Exponent 1999) and DAR (Exponent and Hartman 2000b), the Ward Cove remedial action objectives (RAOs) were to:

- Reduce toxicity of surface sediments; and
- Enhance recolonization of surface sediments to support a healthy marine benthic infaunal community with multiple taxonomic groups.

Remedial actions for the contaminated sediments in Ward Cove were carried out by means of dredging and thin capping. There was no action taken in some areas within the AOC due to one or a combination of the following factors: thick deposits of soft surface sediments (with high moisture content and low bearing strength), water depths in excess of 120 feet, steep slopes, and a high density of logs. Overall plan views of the remedial action acceptance sections are shown in Figures 2 and 3.

The selected remedy included the following planned elements:

- Log Removal—Prior to dredging, removal of sunken logs in the area to be dredged and removal of logs from the bottom surface of the Shallow Water Approach (barge access channel).
- Navigation Dredging—Dredging material from approximately 4 acres of sub-bottom to accommodate reasonably anticipated future navigational needs, and because a cap could not be placed in these areas without constraining current and potential future navigation needs.
- Thin-Layer Capping—Placement of a 6- to 12-inch thin layer cap of clean sandy material over the problem sediments. The thin-layer cap was estimated in the DAR to be practical for approximately 27 acres.
- Mounding—Where thin capping was found not to be practical because of low bearing capacity, mounds of clean material would be placed. The mounding areas represented a minimum of 0.98 acres, with the potential to place mounds on up to 20 acres should the

thin capping be found not to be effective.

- Natural Recovery—Natural recovery (no construction action) in areas where neither capping or mounding is considered feasible (approximately 50 acres of Marine OU).

Prior to remediation in 2000/2001, no sediment remediation activities had occurred in Ward Cove. Some maintenance dredging operations had been conducted previously near the main dock and mill log lift operation in accordance with U.S. Army Corps of Engineers (Corps) permits.

REMEDIATION ACTIVITIES

The scope of the remedial action construction was designed to meet the Ward Cove RAOs and included the following activities:

- Construction of a dewatering facility onsite for all dredged material;
- Removal of logs and associated debris in areas to be dredged;
- Dredging of the deep draft and shallow draft berthing areas, with dewatering of dredged material onsite prior to upland disposal;
- Placement of a thin-layer cap where achievable, and/or placement of mound material where achievable when thin-layer capping was not achievable; and
- Placement of all dredged material, once sufficiently dewatered, in an industrial landfill at the former KPC site.

Dike Construction

To provide adequate capacity for dewatering of dredged material onsite, the KPC dewatering and temporary disposal, located adjacent to and east of the mouth of Ward Creek, was cleared of equipment, graded, and then retaining dikes were built. Construction of the dewatering area began on October 30, 2000. Approximately 4,000 cy of shot-rock fill was delivered to the site from a local contractor's Ketchikan quarry and placed to form a retaining dike around the perimeter of the dewatering site. Two temporary breasting piles were driven near the MLLW line adjacent to the dewatering site to shore up an existing loading/offloading facility. Filled barges containing logs and dredged material from the deep and shallow draft berthing areas were moored alongside the breasting piles. A Lima 2400 crane outfitted with an 8-cy Cable Arm rehandling bucket was used for dredged material rehandling into the dewatering area. Dredged material from the Ward Cove Remediation Project were stockpiled in the dewatering area for approximately 3 to 4 months and then transported to the KPC upland landfill beginning June 3, 2001.

Log Removal

The first phase of in-water work that was completed was the removal of logs and associated debris in the shallow draft and deep draft berth areas and the shallow draft access channel. The dredge and attendant plant used to complete the log removal operations was the same equipment used to complete the dredging and capping activities for the Ward Cove project.

The following equipment was mobilized to the site and used to perform all in-water work activities associated with the Ward Cove Remediation Project, including log removal, dredging, and capping.

Derrick Barge *Miller 205*:	192 feet x 48 feet x 10 feet Manitowoc 4000 Crane 4-point mooring system Spuds 6-cy Cable Arm environmental bucket 8-cy Cable Arm material rehandling bucket 5-cy clamshell digging bucket 4-tine timber tongs WINOPS Dredge Positioning System
Material Barge *Sunny Point*:	Deck Barge with watertight steel fence 180 feet x 50 feet x 12 feet
Material Barge *KFP-1*:	Deck Barge with watertight steel fence 175 feet x 45 feet x 10 feet
Tug *RV Day*:	67-foot long – 1060 HP
Tug *Buggy*:	42-foot long – 350 HP
Lima 2400 Crane:	Track mounted, 8-cy Cable Arm rehandling bucket

The *Miller 205* derrick barge was equipped with a four-tine log grapple for log removal operations. The dredge began with log removal activities at the eastern end of the barge access channel on November 8, 2000, and proceeded in a general northerly direction. Once the shallow draft barge access was completed, log removal continued in areas D1, D2, and D3. The pre-log removal side-scan sonar survey was used to determine log locations and densities. This information was entered into the WINOPS dredge positioning system for use by operators to locate individual logs or log piles.

Approximately 680 tons of logs were removed from areas D1, D2, and D3, and the shallow draft barge access area during log removal operations (Figures 2 and 3). These logs were stockpiled adjacent to the dewatering site and processed through a trailer-mounted tub grinder into wood chips. On March 5 and 6, 2001, the wood chips were transported and disposed of at the Ketchikan Landfill, as approved by EPA.

Dredging

All dredging was performed between November 13, 2000, and January 16, 2001. Dredging was accomplished using the *Miller 205* derrick barge. Both the 6-cy Cable Arm environmental

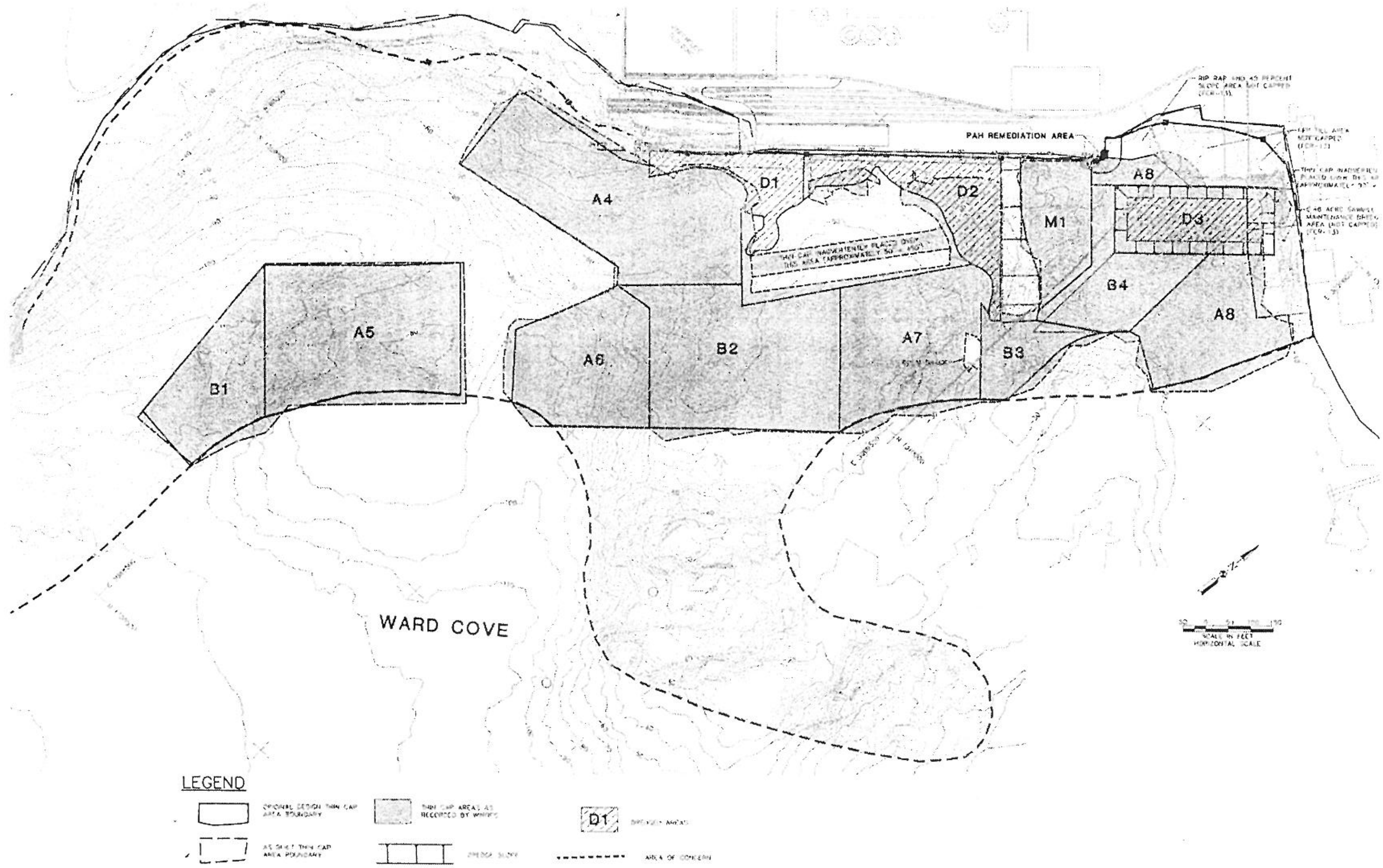


Figure 2. As-Built Thin Cap and Dredging Areas

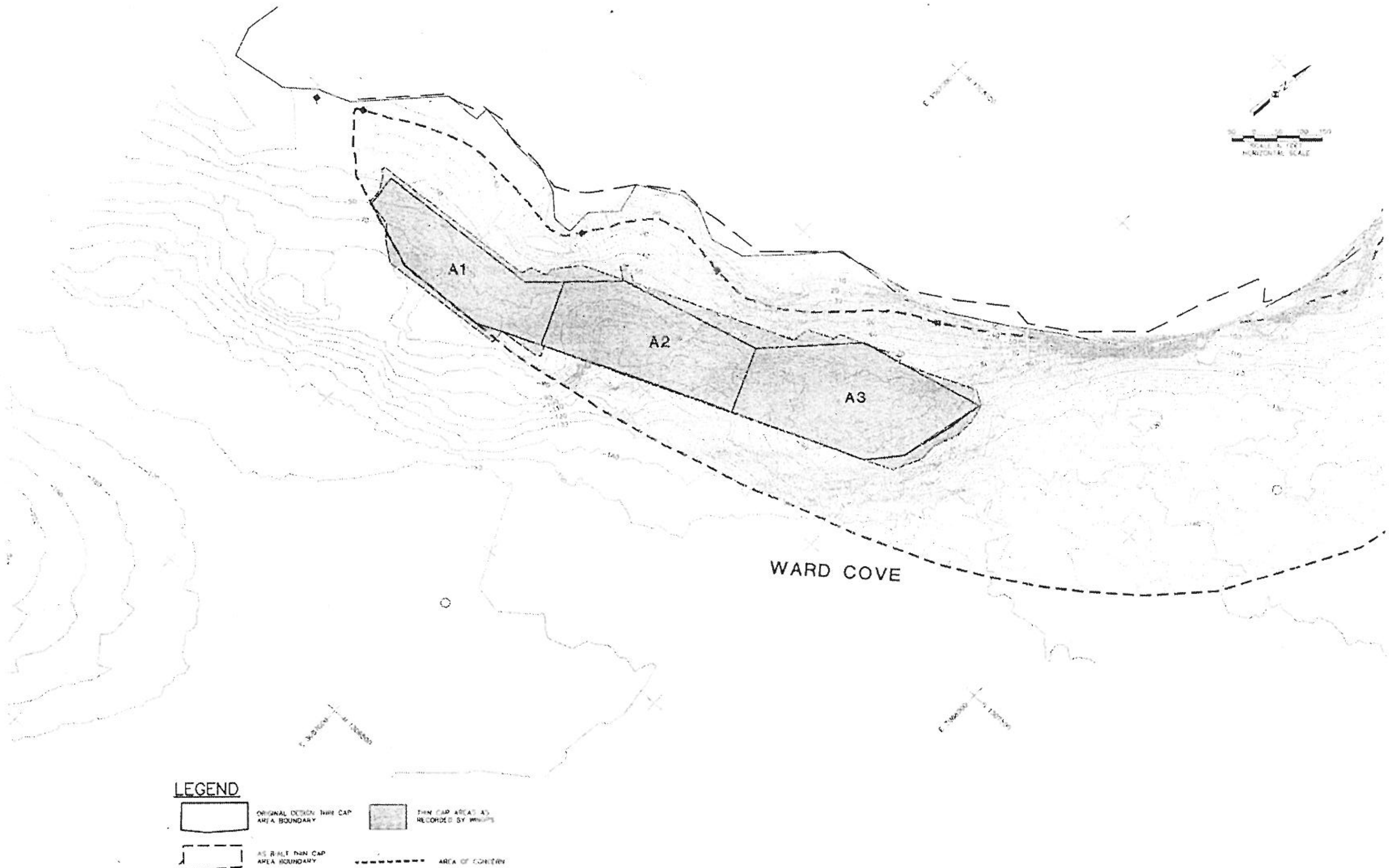


Figure 3. As-Built Thin Cap and Dredging Areas

bucket and the 5-cy digging buckets were used. The digging bucket was used in areas where harder digging or debris was encountered. Dredge materials were placed in one of two 1,500-cy sealed material barges and moved to the dewatering site where the dredged material was rehandled into the dewatering site by a Lima 2400 crane located on shore. Dip tanks were fabricated in the barges in anticipation of bucket washing prior to start of each new grab. However, due to the lack of water quality exceedances, the dip tanks were not necessary. The dredged material was dewatered over the spring and transported to the disposal site.

Dredge positioning was accomplished using the WINOPS dredge positioning and guidance software. The WINOPS system made use of three differential global positioning system (DGPS) receivers. One receiver, located at the top of the derrick, provided the center positioning of the dredge bucket. Two fixed receivers, one near the starboard center spud and one near the center aft of the dredge barge, provided the barge position and heading. The WINOPS software provided a display of the dredge and bucket positions, with the dredge plan displayed on both dredge operator's and deck engineer's monitors, whereby the dredge was moved and positioned over the dredge areas. The dredge advanced into the dredge cut by means of tug assist and was held in place by two spuds located on either side of the barge. Vertical control of dredging was achieved by a conventional marked cable line system. The WINOPS guidance system included a means of determining vertical bucket position, but this system was not used because of its inaccuracy and inconsistency. Better vertical control was achieved with the conventional marked cable line system, whereby the operator viewed line markings on the closing wire and, with adjustment for tides as provided by the automatic tide gauge, could ascertain the depth of the bucket lip in relation to the desired dredge depth.

Periodically and after the DGPS system went offline, the DGPS system onboard the dredge was checked against a point with known coordinates to confirm horizontal control. Similarly, periodic checks of the vertical position of the bucket lip were made to confirm that the operator could control dredging depth within an acceptable vertical accuracy.

Bathymetric progress surveys were conducted daily to provide the site construction managers, Quality Assurance Officer (QAO), and dredge operators with data describing recently dredged areas and to ensure that dredge grade had been achieved and that overdredging was kept to a minimum. These progress surveys were made available to the dredge crew to modify dredging control and, as directed by Foster Wheeler, to identify and return to those high spots that required further dredging.

Once pilings in the dredge areas were removed, navigation dredging activities were initiated in area D3 on November 21, 2000. In total, and based on the original project design, approximately 20,500 cy of material was to be excavated from within the deep and shallow draft navigation dredge areas D1, D2, and D3, including allowable overdredge, unless material such as rock was encountered.

In the -14 foot dredge area (D3 area), the dredge operators used a 6-cy Cable Arm environmental clamshell bucket with horizontal and vertical control provided by the WINOPS dredge positioning and guidance software in an effort to achieve accurate and level dredge cuts. Some logs and harder digging material were encountered. This harder digging material also consisted of recently placed shot-rock fill used for the GFP fill project. Because of this change in conditions, a field change request (FCR) was submitted and approved that reduced the length of the D3 area by 20 feet from the north and provided a radius for the north corner of the area. Dredging of area D3 beyond the allowable overdredge depth did occur because of difficulties with vertical input to the WINOPS guidance system. Progress surveys also revealed the presence of high spots at a few locations, and the contractor returned and dredged to grade. During final high spot dredging, the contractor encountered an undredgeable submerged object. Divers, hired by KPC, determined the object was the remains of a 16-pile dolphin, with top elevation at approximately -8 feet MLLW. The divers cut off the underwater pilings to below -14 feet MLLW.

In all but one area of approximately 10 feet by 40 feet located near the northwest corner of D3, organic material remained on the surface of the dredge area. As a result, all of the D3 dredge area received thin capping.

Once area D3 was completed, the dredge was moved to the southern end of area D1, where dredging continued. After completion of area D1, the dredge moved into area D2. Some adjustments to both the D1 and D2 dredge plan were made to accommodate changes in conditions.

To accommodate changes between expected conditions and encountered conditions, area D1 was dredged to -44 feet MLLW (plus 1 foot allowable overdredge) where organic material was encountered, and to -40 feet MLLW (plus 1 foot allowable overdredge) where native sediment or rock (non-organic material) was encountered. Progress surveys revealed the presence of high spots in a few locations, and the contractor returned to these high spots and dredged to grade. Some hardpan and/or rock was encountered that was undredgeable.

To accommodate changes between expected conditions and encountered conditions, area D2 was dredged to -37 feet MLLW (plus 1 foot allowable overdredge). Progress surveys revealed the presence of high spots in a few locations, and the contractor returned to these high spots and dredged to grade. As in area D1, along some of the slope toe and slope itself, shot-rock was encountered up to 2 to 3 feet above grade and was not removed.

Dredging of areas D1, D2, and D3 was accomplished between November 21, 2000, and January 16, 2001. In total, dredging of areas D1, D2, and D3 was accomplished over 28 actual dredge days. Generally, a 10-hour-per-day, 6-day-per-week work schedule was adhered to. Seventeen dredge days were single-shift days, and 11 dredge days were double-shift days.

All dredging work in areas D1, D2, and D3 was completed in accordance with project contract plans and specifications and applicable FCRs. The contractor completed final post-dredge surveys of the dredge areas on January 19, 2001. In total, 0.73 acres were dredged in Area D1, 0.81 acres were dredged in Area D2, and 1.25 acres were dredged in Area D3.

The final dredge pay volumes and total volumes based on composite method using land development (Softdesk) software are presented in Table 1.

Table 1. Final Dredge Volumes

Area	Pay Volume (cy)	Total Volume (cy)
D1	3,198	3,528
D2	3,647	5,894
D3	1,586	2,443
Subtotal	8,431	
Total*	**8,701**	**11,865**

* Total pay volume including field changes to dredge area boundaries and depths.

Dredged material from the deep and shallow draft berthing areas were rehandled into the dewatering area using a Lima 2400 crane outfitted with an 8-cy Cable Arm rehandling bucket. The dredged material from the Ward Cove Remediation Project remained stockpiled in the dewatering area until adequate dewatering was achieved. The dredged material was transported to the KPC-L-P upland landfill in June 2001.

Test Capping

The largest in-water work activity accomplished as part of the Ward Cove Remediation Project was the thin capping of more than 26 acres of subtidal area in the AOC. Thin capping was accomplished using the *Miller 205* derrick barge with an 8-cy Cable Arm rehandling bucket. EPA-approved capping materials, including both fine-medium clean sand and coarse sand as defined by the contract documents, were delivered to the site on 10,000-ton deck barges from the Construction Aggregates, Ltd., quarry near Victoria, British Columbia. The capping material was offloaded, using an unloader and conveyor system, to the sand stockpiling area located on the eastern shoreline of Ward Cove, across from the mill. Material to be placed in the design test areas and acceptance areas was placed on one of two 1,500-cy sealed material deck barges and, when full, transported by tug to be rafted alongside the derrick barge.

In accordance with the contract plans, capping design tests were conducted prior to production capping to develop a capping placement methodology that would best meet the performance requirement of the Performance Standard Verification Plan (PSVP) (Exponent and Hartman 2000c). The contractor was required to first attempt cap placement with a mechanical dredge equipped with a clamshell bucket. Between January 17 and 22, 2001, the contractor performed system modifications and developed a capping plan to meet the performance standard verification (PSV) requirements of the capping/mounding activities. Nominal 1/3-acre design test areas were delineated in each of the acceptance areas and agreed to by all parties. These approved design test areas were entered into the WINOPS guidance system and a capping pattern developed by the subcontractor that would provide the operator with a plan showing all required individual bucket "swaths." Each bucket discharge would provide for a minimum 6-inch-thick cap over the swath. After the first day's trial capping in the A8 design test area, it was determined that the capping bucket would require modification by welding baffle plates inside the bucket to provide for a consistent grab volume (5.5 cy). It was also determined that the bucket opening chains were not long enough to provide the required force necessary to open the bucket when full of wet capping material. Based on input from the bucket manufacturer, Cable Arm, Inc., the opening chains were lengthened. These modifications served to provide a consistent means of acquiring a uniform volume of approximately 5.5 cy per bucket grab. The WINOPS guidance system was used by the contractor to develop a capping plan that incorporated the operational parameters of 24-foot barge sets, with 6 to 9 bucket swaths per set, and individual cap discharge swaths of 38 feet by 8 feet. The plan, displayed on two onboard WINOPS monitors, provided the operator and deck engineer with the precise locations of the derrick barge position in order to advance and continue thin capping, adjacent to a completed area and within the design test/acceptance area.

The above-described capping method was tested in design test areas A8, B3, A7, B2, A4, A6, and M1, respectively. The thin capping method, which provided 6-inch capping thickness, was successful in meeting the PSVP standard in all areas tested. Approval was then given by the EPA to forego additional 1/3-acre cap tests and proceed with production capping. No use of the proposed additional 3-inch cap was necessary, nor was mounding required. Use of the 10-cy skip box proposed for the alternative capping method was not required, as the original clamshell method proved successful for all of the 6-inch capping effort.

Production Capping

Once design tests in areas A8, B3, A7, B2, A4, A6, and M1 were completed and found to be successful, capping operations shifted into production mode. Thin capping was accomplished over 15 acceptance areas, as described below.

For all production capping, the *Miller 205* derrick barge was used with the modified 8-cy (5.5 cy) Cable Arm rehandling bucket and the WINOPS dredge positioning system. The WINOPS system was used to plan, locate, place, and record the capping discharge location of all buckets over the acceptance area targets.

The derrick barge was moved into an acceptance area by means of tug assist. Once in the acceptance area, the derrick barge advanced into a capping lane and shifted between lanes by means of tug assist or a four-point anchor and wire system. To maintain position over a set area, either the two spuds were used in water depths generally not exceeding 50 feet or, in deeper waters, the four-point anchor and wire system was used. Once the anchor and wire system was optimized for site conditions, the system provided the most efficient means of derrick barge advance. Two forward and two stern anchors were set away from the derrick barge. In general, crossing the two forward wires and the two stern wires provided better anchor forces in response to site currents. The anchor wires precluded the deployment of the bucket beneath the water surface in much of the capping set area. Where the bucket was not encumbered by the anchor wires, placement of the capping material at the surface, with a partially saturated bucket load, provided the most efficient and effective means of thin capping. When a set area, generally consisting of six to nine bucket swaths, was completed, the derrick barge was advanced 24 feet to the next set area and positioned using either the anchor and wires or spuds, depending on water depth. Production increased over the course of production capping as the equipment was optimized and the crew became better experienced. Unusually calm winter weather also assisted in providing good capping production.

To confirm that all capping areas were thin capped successfully, Foster Wheeler performed confirmatory performance standard verification sampling in acceptance areas by means of a modified 0.1-m^2 van Veen shallow grab sampler, diver push cores, and underwater video. PSV sampling results were forwarded to EPA via the weekly Quality Assurance Inspection Reports, showing the thin capping to be successful.

In total, approximately 23,307 cy of thin cap material was uniformly distributed over the acceptance areas requiring thin cap material. Of this volume, approximately 1,952 cy was the coarser thin cap material (3-inch minus), which was placed uniformly over acceptance areas D3 and B4 to provide additional scour protection due to anticipated shallow draft vessel usage. A summary of the areas capped is provided in Table 2.

Production capping was accomplished in 24 days between February 1 and February 24, 2001. The capping production averaged approximately 875 cy per day, or 45 to 55 cy per hour. As the project progressed and the capping methods and operations were optimized, capping production rates on the order of 80 cy/hr were achieved. Generally, a two-shift-per-day, 9-hour-per-shift, 6-day-per-week work schedule was adhered to. Five production capping days were single-shift days, and 19 dredge days were double-shift days.

Table 2. Summary of Thin-Capped Areas

Acceptance Area	Area Thin Capped	
	Square Feet	Acres
A1	60,200	1.38
A2	77,895	1.79
A3	93,256	2.14
A4	142,240	3.27
A5	132,149	3.03
A6	80,103	1.84
A7	92,583	2.13
A8	75,900	1.74
B1	61,883	1.42
B2	134,932	3.10
B3	27,688	0.64
B4	52,066	1.20
D2	30,492	0.70
D3	47,600	1.07
M1	42,605	0.98
Total	**1,151,592**	**26.43**

EFFECTIVENESS OF REMEDIATION ACTIVITIES

The equipment mobilized to the Marine OU to complete the Ward Cove Remediation Project was of appropriate size, adequately equipped, and crewed to perform the main project remediation tasks of log removal, dredging, and capping/mounding. A brief account of the operational difficulties encountered and the successes achieved under this contract are presented. Additional information on the effectiveness of remediation activities is presented in the Final Construction Report (Foster Wheeler 2001).

Log Removal

The log removal activities were conducted in an efficient and effective manner. The pre-log removal side-scan sonar survey of the shallow draft barge access and berthing area (D3), and deep draft berthing areas (D1 and D2), provided an excellent view of the log locations and relative densities and sizes of logs. The side-scan sonar surveys were limited to showing the large surface logs and debris only. Vertical piles and pile clusters were generally not visible due to the beam angle of the side-scan sonar unit. A log or cluster of logs located on the side-scan sonar survey was identified on a log removal plan, which was input into the WINOPS guidance system display. The operator used this information to precisely locate and remove designated logs and log piles. The system worked well, according to the dredge operators. The post-log removal side-scan survey also provided clear evidence of successful log and debris removal.

Dredging

The dredging effectiveness in the three navigation areas (D1, D2, and D3) was variable as a result of variable material types, mechanical delays, and operator/crew experience. The small environmental clamshell bucket was too light for some of the materials encountered and was rendered ineffective by the dredge subcontractor, due to debris, logs, and shot-rock encountered. The heavy digging bucket was the correct tool for that dredging. The digging bucket did not cause exceedances of the water quality standards for the project. The main area for future project improvement was in the dredge operator vertical control. The WINOPS positioning system, as installed, did not provide accurate or consistent vertical position of the bucket by means of a line counter located on the drum. The closing line of the clamshell bucket was marked in 1-foot increments, a conventional method. Using WINOPS, the operator had better location control of the bucket's vertical position, but not the desired 6-inch accuracy. WINOPS, however, did prove to be an effective tool for the horizontal dredge and bucket positioning during dredging and "return" high spot removal. Despite use of these systems, and detailed quality assurance/quality control monitoring, overdredging beyond the allowable overdepth line was experienced.

Material rehandling of the dredged sediment from the material barge to the dewatering facility proved effective and was a clean operation, with very little spillage of material from the barge over water, the shore, and the dike before placement into the dewatering site.

Capping

The success in placement of thin cap across all designated areas, the proposed mounding area, and over 2 acres of the dredged areas is attributable to a number of aspects of the capping operation. The derrick barge was of appropriate size to move into tight areas along the Marine OU boundary, and it supported use of a modified 8-cy bucket that was demonstrated to place capping material well across the range of bottom conditions and depths for the remediation project. The crew gained experience quickly, and by the time production capping was initiated, was familiar with the dredge operation and positioning. The WINOPS system, again, was a key factor in creating real-time knowledge of positioning the dredge and the individual buckets to ensure that all areas were capped, with minimal overlap, while providing the most uniform coverage as possible. The imported sand material used for capping also contributed to the success in placement of the thin cap. The capping material was of appropriate physical composition, such as grain size distribution and specific weight, permitting uniform spreading and placement across the capping acceptance areas without substantive impacts to water quality.

LESSONS LEARNED

The following were the key lessons learned from this project.

Bearing Strength of Soft Sediments

As discussed in the DAR (Exponent and Hartman 2000b), bearing capacity of the organic sediments was expected to be very low based on *in situ* vane shear and laboratory shear testing results. It was determined that the surface layer of organic rich sediment could not support a thin cap greater than 6 to 12 inches. The capping material was therefore placed in a layer of thickness averaging 6 inches, with some areas receiving up to 12 inches.

In all cap areas, including M1, which was originally proposed for mounding because of bearing strength measurements of <6 psf, a 6- to 12-inch layer of cap material was successfully placed with no observed failure during the PSV. The bearing strength of the organically rich sediments was greater than expected. The success of the cap may be attributed to a thin mat of wood fibers and other organic components that make up the first few centimeters of the sediments. This organic mat, observed while sampling the sediment bottom before the start of remediation activities, may create a sediment surface that has a greater bearing strength than the sediments below. Because shear stress measurements did not specifically measure the bearing capacity of this organic surface layer, but rather the entire 2-foot column of sediment, the test results may have underestimated the bearing capacity of Ward Cove surface sediments.

Understanding the shear strength of sediments is an important aspect to engineering the placement of a sediment cap (thin-layer enhancement cap). For future thin-capping projects with soft organic sediments, we recommend testing the surface organic layer (top 6 inches) in addition to sections below the surface sediment to evaluate the range of shear strength and to predict bearing capacity within the underlying sediment. Undisturbed cores collected from the upper 2 feet of sediment can be sectioned over several depths, including the upper 6 inches, and evaluated in the laboratory for triaxial compression (unconsolidated, undrained) in accordance with ASTM D-2850-95. The undisturbed cores must be handled carefully until arrival at the laboratory. During shipment of cores, sediment can become disturbed, possibly reducing the measured shear strength in the laboratory, which may result in an underestimate of the bearing capacity of the sediments.

WINOPS Dredge-Positioning System

The WINOPS system, as installed and used by the contractor, did not provide accurate or consistent vertical positioning of the bucket. At times, the line slippage along the drum due to the movements of the crane created error in the WINOPS vertical measurement. A conventional marking of the closing line attached to the clamshell bucket in 1-foot increments provided the operator better knowledge of the bucket's vertical position.

However, the WINOPS system proved to be an effective tool for the horizontal dredge and bucket position during dredging and return for high spot removal. Furthermore, the WINOPS system was a key factor in positioning the dredge bucket and for the individual bucket release in the next adjacent capping area to ensure that all areas were capped, with minimal overlap, while providing the most uniform coverage possible.

Bucket Capacity

Nominal 1/3-acre design test areas were delineated in each of the acceptance areas and agreed to by all parties. These approved design test areas were entered into the WINOPS guidance system and a capping pattern developed by the contractor was also entered to display all required individual bucket "swaths." Each bucket discharge provided a minimum 6-inch-thick cap over the swath. After the first day's trial capping in the design test area, it was determined that the capping bucket would require modification by welding baffle plates inside the bucket to provide for a more commensurate grab volume (5.5 cy) relative to each bucket swath. It was also determined that the bucket opening chains were not long enough to provide the required force necessary to open the bucket when full of wet capping material. Based on input from the bucket manufacturer, Cable Arm, Inc., the opening chains were lengthened. These modifications served to provide a consistent means of acquiring a uniform volume of approximately 5.5 cy per bucket grab. This was equivalent to a 6-inch thickness over the proposed bucket swath area.

The WINOPS system was used by the contractor to develop a capping plan that incorporated the operational parameters of 24-foot barge sets, with 6 to 9 bucket swaths per set, and individual cap discharge swaths of 38 feet by 8 feet. The plan, shown on both onboard WINOPS monitors, provided the operator and deck engineer the precise locations of where the derrick barge was to advance in order to continue thin capping, adjacent to a completed set, and within the design test/acceptance area.

SUMMARY

In total, the Ward Cove Remediation Project completed dredging for navigation of a total of 2.79 acres, of which 0.73 acres were dredged in Area D1, 0.81 acres were dredged in Area D2, and 1.25 acres were dredged in Area D3. The project also successfully completed thin capping of 26.4 acres, of which 1.8 acres were first dredged. Including the area outside the designated capping acceptance areas, a total of 29.8 acres were thin capped, representing an approximate 14 percent spatial overplacement.

The EPA has concluded that the performance standards for construction activities have fulfilled the requirements set forth in the ROD, CERCLA Consent Decree, and the EPA Statement of Work for Remedial Design, Remedial Action, and Long-Term Monitoring, Ketchikan Pulp Company Marine OU, Ketchikan, Alaska. The effectiveness of the actual remedial activities completed during the project will be assessed by means of implementation of the long-term monitoring plan. Monitoring is scheduled to begin in 2004.

REFERENCES

E&E. (1998). *"Final Ketchikan Pulp Company Expanded Site Investigation Report."* Prepared for U.S. Environmental Protection Agency, Seattle, WA. Ecology and Environment, Inc., Anchorage, AK.

ENSR. (1995). *"Annual Sediment Monitoring Report."* NPDES Permit No. AK-000092-2. Document No. 4025-043-300. Prepared for Ketchikan Pulp Company, Ketchikan, AK. Prepared by ENSR Consulting and Engineering, Seattle, WA.

EVS. (1992). *"Preliminary Environmental Assessment of Ward Cove."* Prepared for Ketchikan Pulp Company, Ketchikan, AK. EVS Consultants, Seattle, WA.

Exponent and Hartman. (2000a). *"Ward Cove Sediment Remediation Project, Cruise and Data Report for Remedial Design Sampling at the Marine Operable Unit of the Ketchikan Pulp Company Site."* Prepared for Ketchikan Pulp Company, Ketchikan, AK. Exponent, Bellevue, WA, and Hartman Consulting Corp., Bellevue, WA, and Hartman Consulting Corp., Bothell, WA. February 2000.

Exponent and Hartman. (2000b). *"Ward Cove Sediment Remediation Project, Design Analysis Report for the Marine Operable Unit of the Ketchikan Pulp Company Site."* Prepared for Ketchikan Pulp Company, Ketchikan, AK. Exponent, Bellevue, WA, and Hartman Consulting Corp., Bothell, WA. September 2000.

Exponent and Hartman. (2002c). *"Ward Cove Sediment Remediation Project Performance Standard Verification Plan for the Marine Operable Unit of Ketchikan Pulp Company Site."* Prepared for Ketchikan Pulp Company, Ketchikan, AK. Exponent, Bellevue, WA, and Hartman Consulting Corp., Bothell, WA.

Exponent. (1999). *"Ward Cove Sediment Remediation Project Performance Detailed Technical Studies Report Volume I and II, Remedial Investigation and Feasibility Study (DTSR)."* Prepared for Ketchikan Pulp Company, Ketchikan, AK. Exponent, Bellevue, WA. May 1999.

Foster Wheeler Environmental. (2001). *"Final Construction Report Ward Cove Sediment Remediation."* Prepared for Ketchikan Pulp Company, Ketchikan, AK. Foster Wheeler Environmental, Bothell, WA. July 2001.

Jones & Stokes and Kinnetic. (1989). *"Ward Cove Water Quality Assessment."* Final. EPA Contract No. 68-02-4381. Jones & Stokes Associates, Inc., Bellevue, WA, and Kinnetic Laboratories, Inc., Santa Cruz, CA.

USEPA. (1975). *"Water quality data during September 10–13, 1974, at Ward Cove and Tongass Narrows, Alaska."* U.S. Environmental Protection Agency, Alaska Operations Office, Anchorage, AK, and Region 10 Surveillance and Analysis Division, Seattle, WA.

USEPA. (2000). *"EPA's Record of Decision, Ketchikan Pulp Company, Marine Operable Unit, Ketchikan, Alaska."* March 29, 2000.

NOTES FOR CONTRIBUTORS

GENERAL

The Journal of Dredging Engineering is a peer-reviewed practice periodical on dredging engineering topics. Prospective authors should submit three (3) copies of the manuscript to the following address: Dr. Ram K. Mohan, Blasland, Bouck & Lee, Inc, 326 First Street, Suite 200, Annapolis, MD 21403-2678, USA; Phone: 410-295-1205; Fax: 410-295-1209; email: rkm@bbl-inc.com

Authors should obtain all necessary approvals for publication from employers or others involved, before submission of the paper. Submission of a manuscript implies that it is not under consideration for publication elsewhere and that original, previously unpublished work is being presented. **The paper should be free from evident commercialism or private interest** Copyright will be the property of the Western Dredging Association, but the author will be granted permission to reprint the paper and third party requests will be passed on to the authors. **Papers should be concisely written and not exceed 20 total printed pages including figures.** The papers will be reproduced directly from the camera-ready manuscripts provided by the authors and bound into a volume. Please give the manuscript preparation instructions to the person responsible for the preparation of the text.

Keywords

Please provide 5 keywords that are not already contained in the title, on a separate sheet of paper.

MANUSCRIPT PREPARATION

Order of contents

Title, author(s), affiliations, addresses, countries
Abstract (not to exceed 300 words).
Introduction, main body, and following text, conclusions, nomenclature (if necessary), and references.
5 keywords that are not already contained in the title (on a separate sheet of paper).
Refer to a previous issue of the journal for general guidelines on format.

Preparation of the text

The text should be submitted on unlined white 8½ x 11 inch paper with **single line spacing**, and top and side margins of 1 inch. Use full justification. **The image area or block of text will then be 6.5 x 9.0 inch.** The bottom margin should be 1½ inch. Page numbers should be marked in pencil and placed at the bottom center of each page. **Do not leave additional margins. Do not use company letterhead paper.**

Fonts

If possible please use proportional, serif font such as Times New Roman 12 point. If such fonts are not available, use a 12 pitch typeface and work to the margins indicated above. Do not use headers or footers or draw a frame around your text. Use a letter quality or laser printer. **Do not use a dot matrix printer**. It may be possible for us to print your text directly from your disc. In this case we shall still require hard copies of your text. The preferred word processing program is Microsoft Word 6.0 or Word 97. If using other programs please also save your text as ASCII files. Discs should be labeled with the file name in both word processed and ASCII forms, the word processing package used, and the operating system.

Headings

Headings should be typed in bold capital letters centered and followed by a double space. Bold capitals and lower case letters should be used for subheadings, which should be preceded and followed by a double space as illustrated by these instructions. Sub-subheadings should use bold capitals and lower case letters and placed at the start of the paragraph.

Equations

All symbols must be defined in the nomenclature section that follows the conclusions. The SI system of units should be used. If units other than SI units are included, they should be given in parenthesis after the relevant SI unit. Equations should be successively numbered (in parenthesis) flush with the right-hand margin (see example below).

$$y = a + b + cx^2 \qquad (1)$$

References

References in the text should be given as: Smith (1988), (Smith, 1988) or (Jones et al., 1986). References should be listed alphabetically in the References section at the end of the paper. Give the names and initials of all authors, followed by the title of the article and publication, the publisher and the year of publication. References to conference papers or proceedings should include the name of the organizers. References to articles published in journals should also include the name of the journal, the number of the issue and page numbers (see example below). References to publications in a foreign language should give all details in the original language followed by a translation of the title.

Hunt, J.B. (1995). "*Environmental Dredging*". Smith & Son, Inc., New York, NY.

Donegan, T.M., and Dinicola, W.J. (1986). "*Turbidity Associated With Dredging Operations*". Technical Report, XYZ Consultants, Inc., Baltimore, MD., 60 p.

Jones, F., Doe, A., Hart, E.J.E., and Next, J.P.J. (1986). "*The Design of Dredged Material Disposal Sites.*" Proceedings XIVth World Dredging Congress, CEDA, Amsterdam, The Netherlands, pp. 350-368.

White, F.K. and Jones, J.M. (1991). "*The Analysis of Flow Fields Around Dragheads.*" Journal of Waterway, Port, Coastal and Ocean Engineering, ASCE, Vol. 121, No. 5, pp. 1-16.

Page numbers

Page numbers should be marked in pencil and placed at the bottom center of each page.

Figures and Tables

High quality figures and tables should be incorporated into the body of the text. Figures must not be placed at the end of the paper. Leave spaces for photographs. Figure captions should be below the figure; table captions should be above the table.

Line drawings

The lines and lettering on the figures should be clearly legible. If originals cannot be supplied, ONLY BLACK AND WHITE COPIES OF VERY HIGH QUALITY are suitable for reproduction. PENCIL AND PHOTOCOPIES OR COPIES WITH A BACKGROUND COLOR ARE NOT SUITABLE.

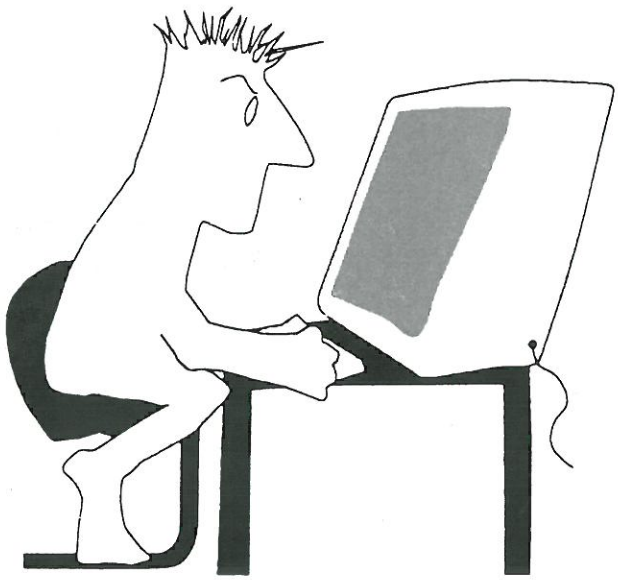
Photographs

Photographs must be sharp, high contrast, glossy prints. Please use a pencil to indicate the title of the paper, figure number and title and top edge on the back of each photograph. Paste in the photographs where they should appear in the final manuscript. Place captions under the photograph as part of the text.

This page is intentionally left blank.

WEDA HOME PAGE INTERNET ADDRESS

WWW.WESTERNDREDGING.ORG



WEDA EMAIL ADDRESS

WEDA@COMCAST.COM

Dredging Creates a Strong Economy and Cleaner Environment