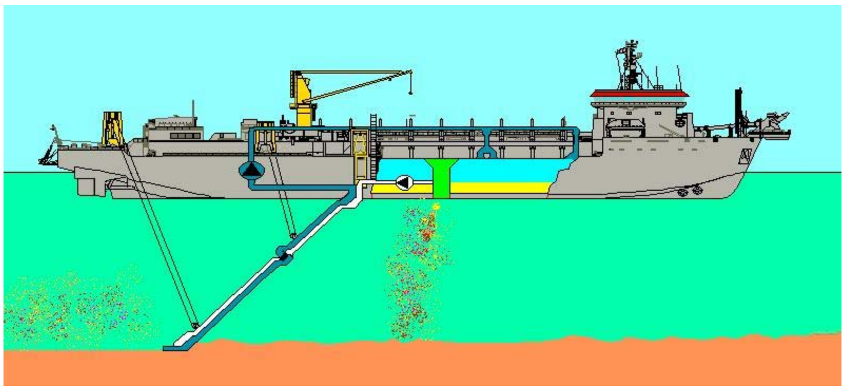
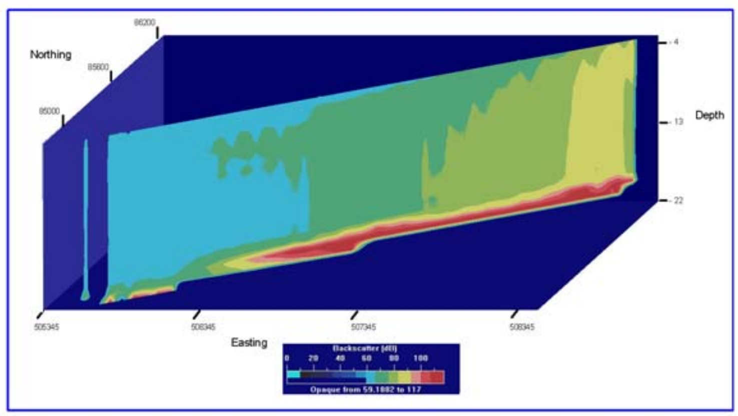
OCS Report
MMS 2004-076

REVIEW OF EXISTING AND EMERGING ENVIRONMENTALLY FRIENDLY OFFSHORE DREDGING TECHNOLOGIES





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November 2004

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Top Image courtesy of Jan de Nul
Bottom Image from Newell and Seiderer (2003)

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REVIEW OF EXISTING AND EMERGING ENVIRONMENTALLY FRIENDLY OFFSHORE DREDGING TECHNOLOGIES

Prepared for:

Leasing Division, Sand and Gravel Unit
Minerals Management Service
US Department of Interior
Herndon, Virginia

Prepared by:

W.F. Baird & Associates Ltd.
Madison, Wisconsin

Research Planning, Inc.
Columbia, South Carolina

November 2004

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF ACRONYMS

ADCP	Acoustic Doppler Current Profiler
ALSF	Aggregate Levy Sustainability Fund
BMAPA	British Marine Aggregates Producers Association
CEFAS	Centre for Environment, Fisheries & Aquaculture Science
COE	US Army Corps of Engineers
CSD	Cutter Suction Dredge
DERM	Miami-Dade County Department of Environmental Resources Management
DOER	Dredging Operations and Environmental Research of the USACE
DRL	Dredging Research Ltd.
DSS	Dredge Specific System
EFH	Essential Fish Habitat
ERDC	Engineering Research and Development Center of the USACE
JTU	Jackson Turbidity Unit
LISST	Laser In-Situ Scattering and Transmissometry
MIRO	UK Mineral Industry Research Organization
MMS	Minerals Management Service
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
NTU	Nephelometric Turbidity Units
OCS	Outer Continental Shelf (here referring to Federal waters)
REMOTS	Remote Ecological Monitoring of the Seafloor
ROV	Remotely Operated Vehicle
SI	Silent Inspector
SPOT	An earth observation satellite
TSHD	Trailing Suction Hopper Dredge
TSS	Total Suspended Solids
USACE	US Army Corps of Engineers
USGS/BRD	US Geological Survey / Biological Research Division
USFWS	US Fish and Wildlife Service
WID	Water Injection Dredging
WES	Waterways Experiment Station, USACE

ACKNOWLEDGEMENTS

This report was prepared under contract to the Marine Minerals Branch, Leasing Division, Minerals Management Service, Contract No. 01-02-CT-85139. Barry Drucker was the MMS Project Manager and contributed significantly to the project objectives and the overall success of the project. Dr. Rob Nairn of Baird and Associates was the Project Manager. The senior authors were Dr. Rob Nairn, Mr. Tim Kenny, and Dr. Fernando Marván of Baird & Associates, Dr. Jacqueline Michel of Research Planning, Inc., Dr. Richard Newell of Marine Ecological Surveys, and Mr. Nick Bray of Dredging Research Ltd. The cooperation of the UK Mineral Industry Research Operation in the survey of the dredging industry in Europe is also gratefully acknowledged.

1.0 INTRODUCTION

1.1 Background

The US Minerals Management Service (MMS) Leasing Division has the responsibility for administering the Department of the Interior's role in mineral resource development other than oil, gas, and sulfur on the US outer continental shelf (OCS). MMS does not develop and maintain a schedule of lease offerings for OCS sand resources. Rather, the leasing process for OCS sand must begin by a request from potential users of the sand. Only recently have OCS sand resources been considered as feasible sources of sand for beach nourishment. Between 1995 and 2001, MMS conveyed 14,600,000 cubic yards of OCS sand for ten projects.

MMS expects that the OCS sand resources will be long-term sources of sand borrow material for coastal erosion management because of:

- The general diminishing supply of onshore and nearshore sand;
- Impact of sea level rise and other natural and human-induced factors leading to increased erosion;
- The re-nourishment cycles for beaches or coastal areas requiring quantities of sand not currently available from State sources; and
- Immediate/emergency repair of beaches and coastal damage from severe coastal storms.

MMS has responsibility for providing environmental analysis and assessment information enabling the responsible management of the OSC sand resources. There is a range of environmental concerns, including both direct and indirect impacts, with the dredging operations necessary for sand borrow extraction. This project was initiated to evaluate the extent to which recent developments in offshore dredging equipment and practices may lead to more environmentally friendly results.

1.2 Project Goals

The goal of the project is to evaluate dredging equipment and techniques on a worldwide basis to identify existing and emerging dredging technologies that aim to reduce or avoid potential adverse effects on the offshore biological and physical environment. Based on the results, recommendations are developed for an implementation strategy for any promising technologies.

1.3 Study Approach

The project approach was comprised of four main areas of activity as described as follows:

- A literature review was completed for two main areas. The first was to update the understanding of the impacts of dredging in order to provide the backbone for the overall study. The second main thrust of the literature review was to assess the existing and emerging environmentally friendly dredging technologies.
- Representatives of the various regulatory agencies at the Federal and State level that are responsible for the offshore environment of concern were interviewed to determine the priority of key dredging impacts.
- The second main area of investigation consisted of obtaining information through direct contact with the dredging industry. This task took the form of questionnaires, follow-up calls, and meetings.
- Finally, the various approaches and techniques were evaluated for their appropriateness, practicality, and effectiveness as they relate to the key impacts. A central activity in this assessment was a workshop attended by regulating agency representatives, consultants, dredging industry representatives, and MMS staff from the Offshore Minerals Management Sand and Gravel Program.

1.4 Team Organization

The project team was comprised of the following firms and staff members:

Baird & Associates
Robert Nairn, Ph.D., M.Sc. P.E., Project Manager
Tim Kenny, B.Sc. Baird, Dredging Specialist – Industry Review, USA
Fernando Marván Ph.D., Literature Review

Research Planning, Inc.
Jacqueline Michel, Ph.D., Impact Evaluation (USA)

Marine Ecological Surveys
Dr. R.C. Newell B.Sc., Ph.D., D.Sc. (Lond), Impact Evaluation (UK/Europe/Worldwide)

Dredging Research Ltd.
Mr. Nick Bray, B.A. MICE, Dredging Specialist – Industry Review, Overseas

1.5 Report Structure

The remainder the report is divided into the following sections:

2. Identification of Dredging Impacts
3. Literature Review of Environmentally Friendly Approaches
4. Dredging Industry Review
5. Analysis of Environmentally Friendly Technology
6. Conclusions and Recommendations

2.0 IDENTIFICATION OF DREDGING IMPACTS

2.1 Introduction

This section describes the development of a prioritized list of key ecologic impacts of offshore dredging activities from the perspective of the regulatory agencies in the USA in 2004. It draws on the literature review of dredging impacts and related previous MMS studies to define the current understanding of the impacts together with direct input from representatives of the appropriate regulatory agencies.

The prioritized list and description of key ecological impacts will be used to evaluate the appropriateness and effectiveness of the various environmentally friendly equipment and approaches. In other words, this information will help answer such questions as:

- Does a specific development in dredging equipment or practice address an important ecologic impact?
- Given our understanding of the impact, to what degree does the specific development mitigate the impact?

In addition, it was necessary to determine a focus for this investigation, specifically addressing areas that were not being considered in other ongoing MMS studies or by other agencies.

2.2 Approach

MMS has been conducting studies of both generic and site-specific impacts of dredging OCS sand borrow sites (Table 2.1). These studies were reviewed and potential physical and biological impacts were summarized in Research Planning, Inc. et al. (2001). For the current study, this initial list was updated with new information from the stipulations required for the 2003 dredging test off Louisiana, discussions during the Louisiana Sand Management Working Group meetings in 2003 and 2004, issues raised during consultations with the US Fish and Wildlife Service (USFWS), the National Oceanic and Atmospheric Administration (NOAA), and the National Marine Fisheries Service (NMFS) as part of the negotiated lease process for recent and pending lease agreements, and the results of new and on-going MMS studies. Also, Newell and Seiderer (2003) prepared a summary of the ecological impacts of dredging for marine aggregates, with emphasis on sand and gravel dredging in the UK, specifically as input to this study (this report is included in its entirety as Appendix A). The UK Mineral Industry Research Organization (MIRO) draft report on best practices to assessing the impacts of aggregates dredging, particularly Sections 5 (Mitigation) and 6 (Monitoring), was also reviewed and found to be very useful (Royal Haskoning, 2004). Potential sand borrow sites off the Atlantic and Gulf of Mexico coasts were the focus of our study.

Discussions were held with researchers and staff from Federal and State resource agencies that are actively dealing with OCS dredging issues to refine and prioritize the list of potential impacts (Table 2.2). Based on these discussions, the prioritized list of concerns from OCS dredging operations on marine biological and physical resources included:

1. Short-term and cumulative impacts from dredging that lead to loss or reduced stability of benthic habitats, including re-colonization by an altered biological community.
2. Injury and death of special species of concern (e.g., sea turtles) from being sucked into the draghead during dredging operations using hopper dredges.
3. Changes in the substrate characteristics (grain size, dissolved oxygen, compaction and organic content) that lead to a reduction or alteration in benthic communities and suitability of the area for future dredging.
4. Changes in bathymetry that can alter the wave climate reaching the shore, resulting in shoreline changes.
5. Sedimentation (burial) impacts to adjacent hard/live bottom or other sensitive habitats.
6. Creation of depressions and furrows from removal of substrate.
7. Impacts from short-term increased turbidity from cutterhead or draghead and overflow from hopper dredges on benthic communities.
8. Spatial and seasonal conflicts between dredging and commercial and recreational fisheries.
9. Potential to cause a break in an active or abandoned pipeline, resulting in a release of petroleum hydrocarbons.
10. Collisions with marine mammals and sea turtles during vessel operations.
11. Damage to archaeological resources.
12. Potential harmful alteration or destruction of Essential Fish Habitat.

TABLE 2.1 Environmental studies on OCS sand resource issues funded or supported by MMS. Copies of completed reports and status reports for ongoing studies are available at: www.mms.gov/sandandgravel.

Site-Specific Environmental Baseline Studies
Environmental Investigation of the Use of Shoals Offshore Delaware and Maryland by Mobile Benthos and Finfish Species. Final Report January 2005
Field Testing of a Physical/ Biological Monitoring Methodology for Offshore Dredging and Mining Operations (being conducted at Sandbridge Shoal, offshore Virginia via Cooperative Agreement with VIMS). Final Report 2005
Environmental Surveys of Potential Borrow Areas Offshore Northern New Jersey and Southern New York and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. Draft Report Spring 2003
Environmental Surveys of Potential Borrow Areas on the East Florida Shelf and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2004-037
Collection of Environmental Data within Sand Resource Areas Offshore North Carolina and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. OCS Study MMS 2000-056
Surveys of Sand Resource Areas Offshore Maryland/Delaware and the Environmental Implications of Sand Removal for Beach Restoration Projects. OCS Study MMS 2000-055
Environmental Surveys of OCS Sand Resources Offshore New Jersey. OCS Study MMS 2000-052
Environmental Survey of Identified Sand Resource Areas Offshore Alabama. OCS Study MMS 99-0051
Use of Federal Sand Resources for Beach and Coastal Restoration in New Jersey, Maryland, Delaware and Virginia. OCS Study MMS 99-0036
Environmental Studies Relative to Potential Sand Mining in the Vicinity of the City of Virginia Beach, Virginia. OCS Study MMS 97-0025
West Florida Shelf Benthic Repopulation Study. OCS Report MMS 95-0005
Wave Modeling/Shoreline Erosion
A Numerical Modeling Examination of the Cumulative Physical Effects of Offshore Sand Dredging for Beach Nourishment – New Jersey, Virginia, North Carolina, Florida. OCS Study MMS 2001-098
Wave Climate and Bottom Boundary Layer Dynamics with Implications for Offshore Sand Mining and Barrier Island Replenishment, South-Central Louisiana. OCS Study MMS 2000-053
Wave Climate Modeling and Evaluation Relative to Sand Mining on Ship Shoal, Offshore LA, for Coastal and Barrier Islands Restoration. OCS Study MMS 96-0059
A Methodology and Criteria to Assess the Impact of Sand Volume Removed in Federal Waters on the Offshore Wave Climate. OCS Study MMS 99-0046
Development of Criteria to Evaluate Wave Refraction Models. OCS Study MMS 99-0096

TABLE 2.1 Cont.

Generic Studies Applicable to all Offshore Marine Mineral Efforts
Analysis of Potential Biological and Physical Dredging Impacts on Offshore Ridge and Shoal Features/Engineering Alternatives and Options to Avoid Adverse Environmental Impacts. On-going
Worldwide Analysis of Shipwreck Damage Caused by Offshore Dredging: Recommendations for Pre- Operational Surveys and Mitigation to Avoid Adverse Impacts. OCS Study MMS 2004-0005
Model Development or Modification for Analysis of Benthic and Surface Plume Generation and Extent During Offshore Dredging Operations. Final model delivered December 2003.
Development and Design of Biological and Physical Monitoring Protocols to Evaluate the Long-Term Impacts of Offshore Dredging Operations on the Marine Environment. OCS Report MMS 2001-089
Integrated Study of the Biological and Physical Effects of Marine Aggregate Dredging. OCS Study MMS 2000-054
Study of the Cumulative Effects of Marine Aggregate Dredging. OCS Study MMS 99-0030
Marine Aggregate Mining Benthic and Surface Plume Study. OCS Study MMS 99-0029
Impacts and Direct Effects of Sand Dredging for Beach Re-nourishment on the Benthic Organisms and Geology of the West Florida Shelf. OCS Report MMS 95-0005
Marine Mining Technologies and Mitigation Techniques. A Detailed Analysis with Respect to the Mining of Specific Offshore Mineral Commodities. OCS Report MMS 95-0003
Synthesis and Analysis of Existing Information Regarding Environmental Effects of Marine Mining. OCS Study MMS 93-0006
Marine Mining Literature Search Study. OCS Study MMS 93-0006

TABLE 2.2 Federal and State agency staff and researchers who were contacted to prioritize the list of physical and biological concerns associated with OCS sand dredging.

Ken Duffy	Louisiana Department of Natural Resources
Syed Khalil	Louisiana Department of Natural Resources
David Burkholder	Louisiana Department of Natural Resources
Heather Finley	Louisiana Department of Wildlife and Fish
Bob Van Dolah	Director, Marine Resources Research Institute South Carolina Department of Natural Resources
Jeff Normant	New Jersey Division of Fish and Wildlife
Mark N. Mauriello	New Jersey Department of Environmental Protection
Ron Williams	Florida Department of Environmental Protection, Bureau of Beaches & Coastal Systems
Russ Watson	US Fish and Wildlife Service, Lafayette, La.
Carlos Mendoza	US Fish and Wildlife Service, Houston, Tx.
Richard Hartman	National Marine Fisheries Service, Habitat Conservation Division, Baton Rouge, La.
Stan Gorski	National Marine Fisheries Service, Sandy Hook, NJ
Tim Goodger	National Marine Fisheries Service
Eric Hawk	National Marine Fisheries Service, Protected Species Division, St. Petersburg, FL
Stan Riggs	East Carolina University
Richard Condrey	Louisiana State University
Woody Hobbs	Virginia Institute of Marine Sciences
Bob Diaz	Virginia Institute of Marine Sciences
Chris Slay	Coastwise Consulting, Inc.

2.3 Review and Description of the List of Key Impacts

In the following sections, each of the impacts identified in Section 2.2 is described and discussed with respect to whether it is appropriate to address the impact under this study. Where there are existing stipulations in use by MMS to address the impact of concern, these are also indicated.

2.3.1 Short-term and Cumulative Impacts From Dredging That Lead to Loss or Reduced Stability of Benthic Habitats, Including Re-colonization by an Altered Biological Community

This concern is based on the direct removal of benthic habitat along with infaunal and epifaunal organisms that are incapable of avoiding the dredge, resulting in significant reductions in the number of individuals, number of species, and biomass. Benthic resources are important in the food web for commercially and recreationally important fishes and invertebrates, and they contribute to the biodiversity of the pelagic environment. Although short-term losses and changes in benthic community structure have been documented to occur following sand dredging (Blake et. al, 1996; Van Dolah et al., 1994), the ecological significance to the benthic community is uncertain. Studies investigating the recovery of benthic communities following dredging (Blake et. al., 1996; Newell et al, 1998; Van Dolah et al., 1994) have indicated that communities of comparable total abundance and diversity can be expected to re-colonize dredge sites within several years. Newell and Seiderer (2003) summarized recovery rates of benthic communities post-dredging for different substrate types (Figure 2.1). Sandy substrates typically recover within 2 to 4 years. However, even though these re-colonized communities may be similar in terms of total abundance and species diversity, their taxonomic composition, in terms of dominant species and species abundance, is often very different from pre- to post-dredging.

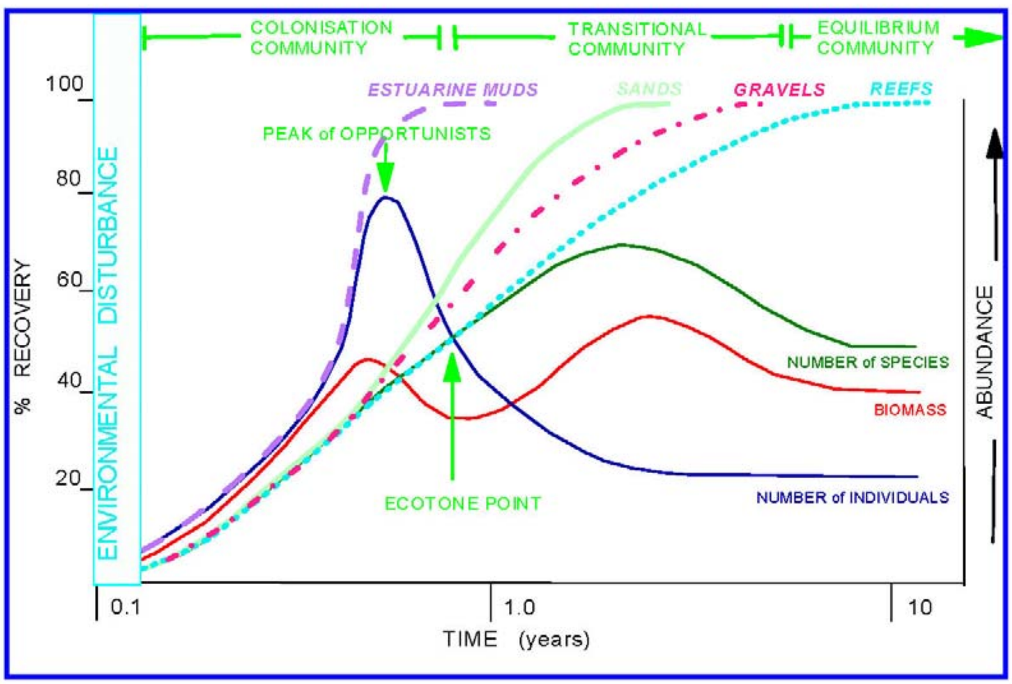


FIGURE 2.1 Schematic diagram showing the likely re-colonization rates for the benthic communities of estuarine muds, sand, gravels, and rocky reefs (Newell and Seiderer, 2003 – see Appendix A).

There are distinct patterns of re-colonization, with initial colonization by mobile "opportunistic" species that have planktonic larvae within days, or even during the dredging process. These species are capable of rapid colonization within months of space being made available for colonization and growth. This phase is followed by an increasing variety of colonizing species, an increase in the population densities of the component species, and finally by growth of the individuals which leads to restoration of the biomass. The rate at which recovery of the species diversity occurs is dependent on the complexity of the fauna and the inter-relationships that control larval recruitment and settlement. Many species do not re-colonize regularly, and most require specific physicochemical and biological cues to induce settlement, implying that even if the deposits in a dredge site post-dredging remain similar to those pre-dredging, there may be a significant interval before all the species components are present in the community (Newell and Seiderer, 2003). Longest recovery rates would be for slow-growing species that do not have planktonic larvae. Also, recovery rates are long for sites that are intensely (repeatedly) dredged. Newell and Seiderer (2003) reported on several studies where there were significant differences in microfaunal assemblages subjected to different dredging intensities. Therefore, impacts to benthic communities are of even greater concern for sand borrow sites that are repeatedly dredged.

The key ecological concern with a change in benthic community is whether the new benthic communities fill the same trophic function and provide the same energy transfer to higher trophic levels, as did the original communities. If they do not, then the potential long-term and cumulative ecological impacts of sand dredging may be far greater than predicted to date, a condition that may be unacceptable as more sites along the coast are dredged and others are dredged on a regular basis. The MMS monitoring protocols (Research Planning, Inc. et al., 2001) were designed specifically to determine the effects of dredging activities on benthic communities and the transfer of energy from benthic communities to fishes.

All resource managers and researchers raised concerns about direct impacts to benthic communities. The greatest concern is in known benthic-associated fishery areas, such as the surf clam fishery off New Jersey and the shrimp fishery in the Gulf of Mexico. There is less concern in areas of general biological productivity or dynamic processes, such as in South Carolina.

In summary, there is a high priority to identify dredging methods that would speed the rate of recovery of benthic communities and reduce the potential for permanent changes in species abundance and dominant species. This potential impact warrants specific focus in the review of potentially environmentally friendly approaches and equipment.

2.3.2 Injury and Death of Special Species of Concern (e.g., sea turtles) From Being Sucked Into the Draghead During Dredging Operations Using Hopper Dredges.

Dredging of navigation channels has been identified as a source of sea turtle mortality since sea turtle deaths were first documented during hopper dredging operations in Canaveral Channel, Florida, in 1980 when 71 sea turtles were killed by hopper dredging over the period of July 11 through November 13, 1980 (NMFS, 1991). Hopper dredges move relatively rapidly and can entrain and kill sea turtles, presumably as the drag arm of the moving dredge overtakes the slower moving turtle. In contrast, there have been no reports of injury or death of sea turtles during cutterhead suction dredging (NMFS, 2004).

Gulf sturgeon is another listed species (Federal, threatened) with documentation of impacts from channel dredging (NMFS, 2004). NMFS and USFWS jointly designated critical habitat for Gulf sturgeon in 2003 (68 FR 13370). All designated critical habitats are in riverine, estuarine, or State marine waters; there are none in Federal waters at this time.

Every Federal agency with management responsibility for species listed under the Endangered Species Act expressed concern about potential impacts to listed species, and to sea turtles in particular. There are existing stipulations for sea turtles that have significantly reduced impacts, but even a single "take" is considered significant. The USACE has an active research program working with all stakeholders to develop new methods to reduce impacts to sea turtles during hopper dredging, primarily from dredging operations in channels. In summary, it was concluded that MMS would review the results of this research as results become available and adopt appropriate methods to reduce potential impacts to sea turtles during OCS dredging activities. Therefore, this current study has not explored in any detail the latest innovative developments related to avoidance of impacts to listed species.

Existing stipulations being used in MMS leases to protect sea turtles include:

- Presence of trained observer(s) for a specified percent of the time who follows specific protocols.
- Use of a rigid sea turtle deflector, such as the one designed by the USACE or similar.
- Operation of the dredge in a manner that will reduce the risk of interaction with any sea turtles that might be present in the dredge area. Keep the draghead on the bottom except: 1) when the dredge is not in a pumping operation and the suction pumps are turned completely off; 2) the dredge is being re-oriented to the next dredge line during borrow activities; and 3) the vessel's safety is at risk.
- Dredge equipped with inflow screening baskets (4-inch mesh) to better monitor the intake and overflow of the dredged materials for sea turtles and their remains. The percent of inflow to be screened varies by region from 50-100 percent.
- Assessment/relocation trawling to further assess/reduce the potential for incidental take during dredging. Trawling is conducted repeatedly in front of the dredge as it moves along the track lines. Any turtles collected are to be relocated. There are specifications for trawl tow time and speed. There may be requirements for flipper tagging and genetic analysis of tissue samples from turtles caught during relocation trawling.

- Filing of detailed reports with the appropriate NOAA office within 30 days of project completion.

No revision to these stipulations is required at this time, however, following the conclusion of the latest USACE research efforts it may be necessary to refine the stipulations.

2.3.3 Changes in the Substrate Characteristics (Grain Size, Dissolved Oxygen, Compaction and Organic Content) That Lead to a Reduction in Benthic Communities and Suitability of the Area for Future Dredging.

There are several conditions where OCS dredging can lead to changes in substrate characteristics. Deep dredging (greater than 3 m) can create pits that may infill with finer-grained sediments. Van Dolah et al. (1998) studied six dredged sites in South Carolina and found that, at three of the sites, the borrow area had filled with muddy sediments forming a cap over clean sand. Infilling with muddy sediments will change the benthic communities, as well as rendering the site unsuitable as a future borrow area (or less suitable due to the potential requirement for stripping and disposal of overlying fine sediment). Newell and Seiderer (2003) looked at recovery rates of benthic communities at a wide range of dredge sites and found that recruitment success was controlled mainly by whether the sediments remain suitable for settlement after cessation of dredging.

Deep pits can also take a long time to infill. Van Dolah et al. (1998) found that infilling at the six sites they studied took from 1.75 years to greater than 12 years. A deep (greater than 10 m) pit dredged 3.6 km offshore Coney Island persisted for more than six years and had a highly modified infaunal assemblage (Barry A. Vittor & Associates, Inc., 1999). In deep pits, there may be decreases in dissolved oxygen levels in the water that could lead to hypoxic or anoxic conditions (National Research Council, 1995).

The physical monitoring protocol for "Sediment" was developed for MMS (Research Planning, Inc. et al., 2001 and summarized in Nairn et al., 2004) to evaluate the potential changes to the sedimentological characteristics of the seabed, including sediment texture and total organic content.

In summary, dredging techniques are needed that will: 1) preserve sediment characteristics similar to pre-existing conditions for the surface substrate; and 2) avoid creation of anoxic conditions within dredge pits. The review of environmentally friendly equipment and approaches should consider these requirements.

2.3.4 Changes in Bathymetry that can Alter the Wave Climate Reaching the Shore, Resulting in Shoreline Changes.

Excavation of sediments from offshore sand ridges and shoals can result in shoreline change in one of two ways: 1) through alterations to the wave transformation pattern, changing the waves that reach the shore, in turn modifying the sand transport related processes and ultimately changing erosion and accretion patterns; and 2) by interrupting or modifying a sand supply pathway from or through the borrow area to the shore. A review of the currently identified OCS borrow sites suggests that many of them are not at risk from the second impact because they are isolated from the sediment budget of the littoral system by large distances and muddy areas (the latter indicating the absence of a sand transport pathway). Nevertheless, this will not always be the case.

MMS has commissioned studies on wave modeling and shoreline erosion at potential OCS borrow sites off New Jersey, Virginia, North Carolina, Florida, and Louisiana (see Table 2.1). The general conclusion of these site-specific studies is that removal of offshore shoals can change the amount of wave energy reaching the shoreline, but no significant changes to longshore sediment transport are likely. Two of the four physical monitoring protocols developed for MMS (Research Planning, Inc. et al., 2001 and summarized in Nairn et al., 2004) were specifically designed to address the potential for shoreline impacts. These were the “Waves” and “Shoreline” Protocols. These protocols included recommendations on monitoring and numerical modeling to avoid the potential for alteration of shoreline erosion and sedimentation patterns.

The importance of this concern varied by region. Where the OCS sand bodies were close to shore and/or shallow enough to influence the wave climate, there was high concern about the potential for increased shoreline erosion as a result of dredging. The orientation, depth, and shape of the sand body and borrow areas should be considered in evaluating the impact of dredging on wave climate.

In summary, the potential for shoreline erosion will be determined by site-specific modeling studies and long-term shoreline monitoring programs as described in the Monitoring Protocols. In other words, these types of impacts will not be specifically reviewed as part of this investigation.

2.3.5 Sedimentation (Burial) Impacts to Adjacent Hard/Live Bottom or Other Sensitive Habitats

Hard/live bottom communities are usually associated with outcroppings of rocks or hard fossil substrates that are richly colonized by algae, sponges, hydroids, octocorals, stony corals, and other attached species. These areas are important for foraging and protection from predation for fish populations, particularly where they occur in sediment-dominated areas. In south Florida, there is particular concern where small sand borrow sites occur between hard/live bottom habitats, as well as the Oculina Bank region in both

State and Federal waters off central Florida. Many hard/live bottom habitats in nearshore areas have been severely damaged by sedimentation and burial associated with beach nourishment projects (e.g., Lindeman and Snyder, 1999).

In potential sand borrow sites off central Florida, hard bottom habitat was mapped as present along 38 percent of the transects through the southern part of the borrow area although previous studies had not reported hard bottom habitat in this area (Byrnes and Hammer, 2004). Hard bottom formations identified off central Florida occurred as ledges or outcrops of limestone generally arranged in north-south trending outcrops usually forming ledges facing west. All hard bottom supported epibiota assemblages of varying taxonomic composition (Byrnes and Hammer, 2004). The results of the central Florida study highlight the importance of conducting surveys to identify the presence of hard/live bottom habitat in sand borrow areas prior to sand mining in regions where there is potential for them to occur.

There are three possible ways that dredging activities in an OCS borrow area may result in sedimentation-related impacts to hard/live bottom habitats: 1) through direct sedimentation associated with the footprint of the sediment from the overflow of Trailing Suction Hopper Dredges (TSHDs) or from the draghead or cutterhead (from Cutter Suction Dredge [CSDs] in the latter case); 2) re-suspension and subsequent transport of fines (specifically, silt and clay) beyond the initial sedimentation footprint; and 3) development of near-bed turbidity plumes or currents that may travel well beyond "normal" bounds of a plume sedimentation footprint. Sedimentation affects hard/live bottom sessile communities by interfering with photosynthesis, respiration, and feeding. In most offshore areas where hard/live bottom habitats occur, the sediment grain size is usually in the sand range, and impacts from dredging are likely to be localized and short-term. Thus, the greatest potential impacts are from sediment deposition, which could bury organisms, clog filter-feeding organisms such as sponges, cause corals to expend energy producing mucous to clear sediment from their surfaces, and reduce hard surface area available for recruitment. NMFS included the following requirement in their Regional Biological Opinion for dredging in the Gulf of Mexico (NMFS, 2004):

> Hardground Buffer Zones: All dredging in sand mining areas will be designed to ensure that dredging will not occur within a minimum of 400 feet from any significant hardground areas or bottom structures that serve as attractants to sea turtles for foraging or shelter. NOAA Fisheries considers (for the purposes of this Opinion only) a significant hardground in a project area to be one that, over a horizontal distance of 150 feet, has an average elevation above the sand of 1.5 feet or greater, and has algae growing on it. The COE Districts shall ensure that sand mining sites within their Districts are adequately mapped to enable the dredge to stay at least 400 feet from these areas. If the COE is uncertain as to what constitutes significance, it shall consult with NOAA Fisheries, Habitat Conservation Division and NOAA Fisheries, Protected Resources Division for clarification and guidance.

In summary, it was concluded that dredging methods are needed to make sure that significant hard/live bottom habitats are not covered by sediments as a result of dredging at sand borrow sites. The review of environmentally friendly equipment and practices will, therefore, consider this potential impact.

2.3.6 Creation of Depressions and Furrows From Removal of Substrate.

This concern was that, under certain conditions, dredging would affect seabed topography or surface roughness enough to interfere with trawling fisheries. Dredging activities can result in lowering of the level of the seabed, creation of trailer marks and depressions on the seabed, and exposure of hard bottom previously covered by sediment. The creation or exposure of these features can lead to difficulties in certain fishing activities, in particular trawling, as the trawl gear can potentially become hung up on these features (Royal Haskoning, 2004). Figure 2.2 shows an example of dredge scars. The images used in this mosaic were collected using a Sea Scan® PC Portable Fieldworks PC System with a 600 kHz Towfish at 20 m range and then mosaiced using SeaSone Mapper software. The dredging operation shown in this mosaic is in Red Brook Harbor, North Falmouth, MA. The images used to create the mosaic were collected by John P. Fish of Ocean Star Systems Inc., Cataumet, MA. Figure 2.3 shows the cross-section of a sand borrow site off Miami Beach, comparing pre- and post-dredging bottom topography.

There is little information on the magnitude of this potential problem for OCS sand borrow sites. MMS has contracted a study entitled "World-Wide Survey of Dredging Impacts on Commercial and Recreational Fisheries and Analysis of Available Mitigation Measures to Protect and Preserve Resources." The study includes ethnographic fieldwork with commercial and sport fishers and the dredging industry, during which actual data on the magnitude of this potential impact will be collected.

It was concluded that this new MMS study would identify the magnitude of the problem and suggest measures appropriate to mitigate potential impacts for this concern. Therefore, this impact will not be a focus of this investigation.

Existing MMS stipulations include:

- To assure that deep pits and furrows are not created, conduct post-dredging hydrographic surveys.
- The dredged area within the offshore borrow site shall not exceed maximum side slopes of 2:1.

FIGURE 2.2 Dredging scars from a CSD operation in Red Brook Harbor, MA.

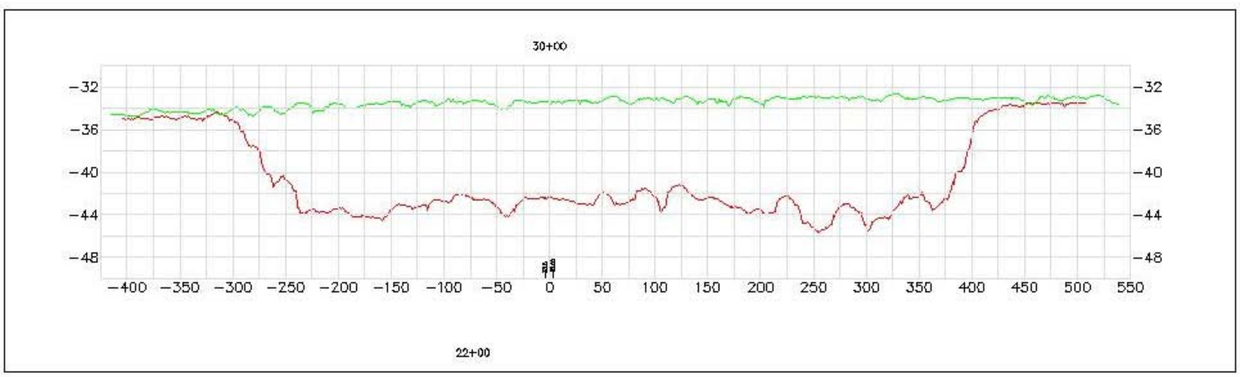


FIGURE 2.3 Pre- and post-dredge surveys borrow pit off Miami Beach (note the vertical exaggeration of 12.5 to 1 and dimensions are in feet).

2.3.7 Short-term Increased Turbidity from Cutterhead or Draghead and Overflow (from hopper dredges) that Affects Benthic Communities.

For TSHDs, increases in turbidity from dredging can be generated at two primary sources as shown in Figure 2.4: 1) the draghead; and 2) from the discharge of hopper overflow. With CSDs, turbidity is only generated at the bed by the cutterhead.

Sediments are suspended at the cutterhead or draghead during the process of removing sediments from the seafloor. Suspended sediments here are usually confined to the immediate vicinity of the cutterhead or draghead and do not reach the surface (LaSalle et al., 1991). In sandy substrates typical of OCS sand borrow sites, the extent of suspended sediments is likely to be very restricted. The exception would be where a fine-grained sediment overburden must be stripped to access the borrow sand.

Increased turbidity results from overflow discharges from hopper dredges. The behavior and persistence of plumes from overflow discharges have been extensively studied in the UK where 20 to 80 percent of the dredged material may be discharged overboard during screening of gravel deposits (Newell and Seiderer, 2003).

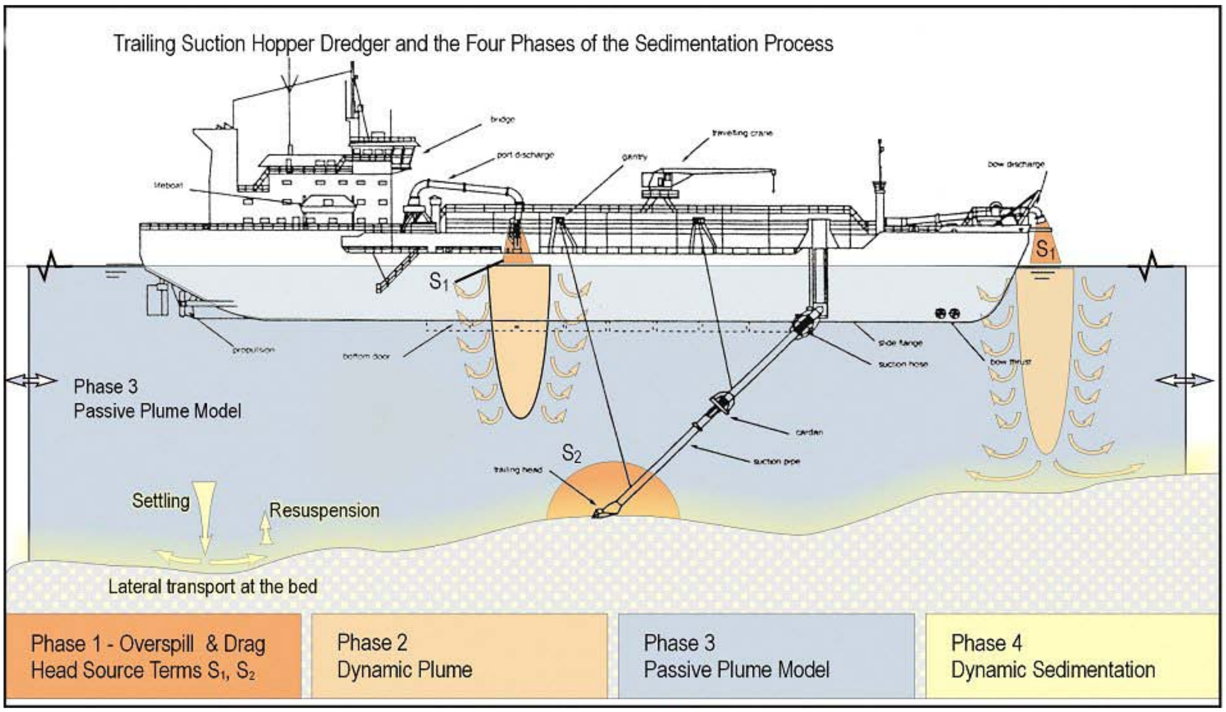


FIGURE 2.4 Hopper dredge sedimentation processes (note this figure shows two S_1 sources at overflows from a screening operation; in almost all US dredges the S_1 source is through the bottom of the hull).

Referring to Figure 2.4, the features of sedimentation associated with TSHDs dredging sand and gravel deposits are described in the following paragraphs.

As mentioned above there are two types of sediment sources: S_1 from the overflow (which for most dredges now is through the bottom of the hull and not directly overboard as shown in Figure 2.4); and S_2 associated with suspension of sediment at the draghead.

Sediment discharged overboard from the hopper overflow moves faster than would be anticipated from simple Gaussian models based on the settlement velocity of component particles. This is due to high sediment concentration and discharge rate of the overflowed material, factors that lead to the development of a density current that moves through the water column in a ‘dynamic phase’ of settlement, at least initially.

As the dynamic plume moves through the water column, sediment is stripped away from the plume. The sediment that is stripped away forms a passive plume that is advected and dispersed by ambient currents, with the particles settling according to Gaussian models. Figure 2.5 shows this process through backscatter measurements from an Acoustic Doppler Current Profiler (ADCP) as a plume dissipates behind a hopper dredge.

In cases of shallow water and/or high discharge rates, the dynamic plume penetrates the water column all the way to the bed. In this case, the plume “pancakes” when it reaches the bottom. There is recent evidence from UK studies that where pancaking occurs, this body of sediment-laden water can travel long distances before dissipating through slowing of the lateral current and settling of the sediment. Newell and Seiderer (2003) cite an example where the travel distance for sediment-laden near bed water exceeded 2.7 km (see Appendix A). This process is captured from the backscatter signal of an ADCP in Figure 2.6. While this plume behavior corresponds to an anchor (stationary) dredge operation that is particularly conducive to this development, it is also possible that this may occur with conventional TSHDs.

In either the case of pancaking or not, sediment that settles on the bed can be eventually re-suspended by wave and current action and transported further afield, particularly where the sediment is finer than the native sediment.

Newell and Siederer (2003) note that UK studies have shown that, in most cases, coarse material up to sand-size particles settles within 200 to 600 m of the point source of discharge, depending on depth of water, tidal velocity, and the velocity of flow from the discharge pipe (it is noted that many of the areas of study in Britain have much stronger tidal currents than along the Atlantic and Gulf coasts of the US, so the 600 m limit noted above may be overly conservative in US waters). Although, as noted above, under some circumstances a highly turbid near-bed flow can develop (i.e. through the pancaking process associated with impact of the dynamic plume and the bed) and transport sediment at least 2.5 km from a dredge site.

The pancaking process where the dynamic plume phase is converted to a laterally spreading turbidity current upon impact with the bed would appear to be a very important one with respect to the potential lateral extent of sedimentation. In order to investigate whether the pancaking process is one that might be expected for offshore sand dredging in waters of 10 to 30 m depth under MMS jurisdiction, the MMS Plume Model for TSHDs (see Baird & Associates, 2004) was applied to evaluate plumes for two of the largest TSHDs operating in US waters: the Stuyvesant (8,250 m^3 hopper) and the Liberty

Island (5,000 m^3 hopper). For these dredges working in medium sand with less than 15% fines the overflow rate would range from 5 to 3 m^3/s, respectively for the Stuyvesant and the Liberty Island, with solids discharge rates in the range of 200 to 400 kg/s and 120 to 220 kg/s, again respectively. At these discharge rates, the Plume Model results indicated that the dynamic plume phase would easily reach and impact the bed in water depths of 10 to 30 m. This would also be the case for the smaller TSHDs operating in US waters.

Whether or not a laterally spreading turbidity current would develop following the impact of the dynamic plume with the bed has not been investigated at a theoretical level in this project or any others found in the published literature, nor is it represented in any numerical models. From the theoretical understanding of turbidity currents, to trigger and sustain a laterally spreading turbidity current, the following conditions are required: an ongoing supply of water with high sediment concentration (i.e., an unbroken supply from the dynamic phase impacting the bed – since the dredge is always moving, this may only be sustainable by larger TSHDs on a long run) and sufficient bed slope and/or ambient flow condition to sustain the turbidity current (see Parker et al., 1986 and Stacey and Bowen, 1988). The ambient current would have to be parallel to the axis of dredging for the supply of sediment-laden water from the dynamic plume to remain unbroken. This pancaking phenomenon and the related potential for a much larger sedimentation footprint (i.e., greater than 2 km) should, therefore, be considered where the ambient currents are strong (and parallel to the main axis of dredging) or where the local seabed slopes are steep.

Nevertheless, it has been assumed in the past that the pancaking process of a laterally spreading turbidity current does not occur in most cases. In these situations, even fine silt-sized particles reach background values within 2 to 2.5 km of discharge, although there is a residual ‘signature’ from the dispersing plume at distances of up to 3.5 km, which may be attributable to organic matter derived from fragmented benthos discharged during the screening process (refer to Figure 2.5).

Existing MMS stipulations include:

- Turbidity shall not exceed background levels by more than 29 Nephelometric Turbidity Units (NTU). If monitoring shows that turbidity exceeds the maximum amount allowable, dredging activities shall cease immediately and not resume until corrective measures have been taken and turbidity has returned to acceptable levels.

This stipulation is not normally or frequently included by MMS, but it has been invoked where an Environmental Assessment analysis indicated some concerns with water quality in the project area. The 29 NTU limit (above background levels) is based on water-quality criteria developed for dredging in Florida waters. Apparently, it originally evolved from a conversion of the EPA Clean Water value of 50 JTU (Jackson Turbidity Units). NTUs

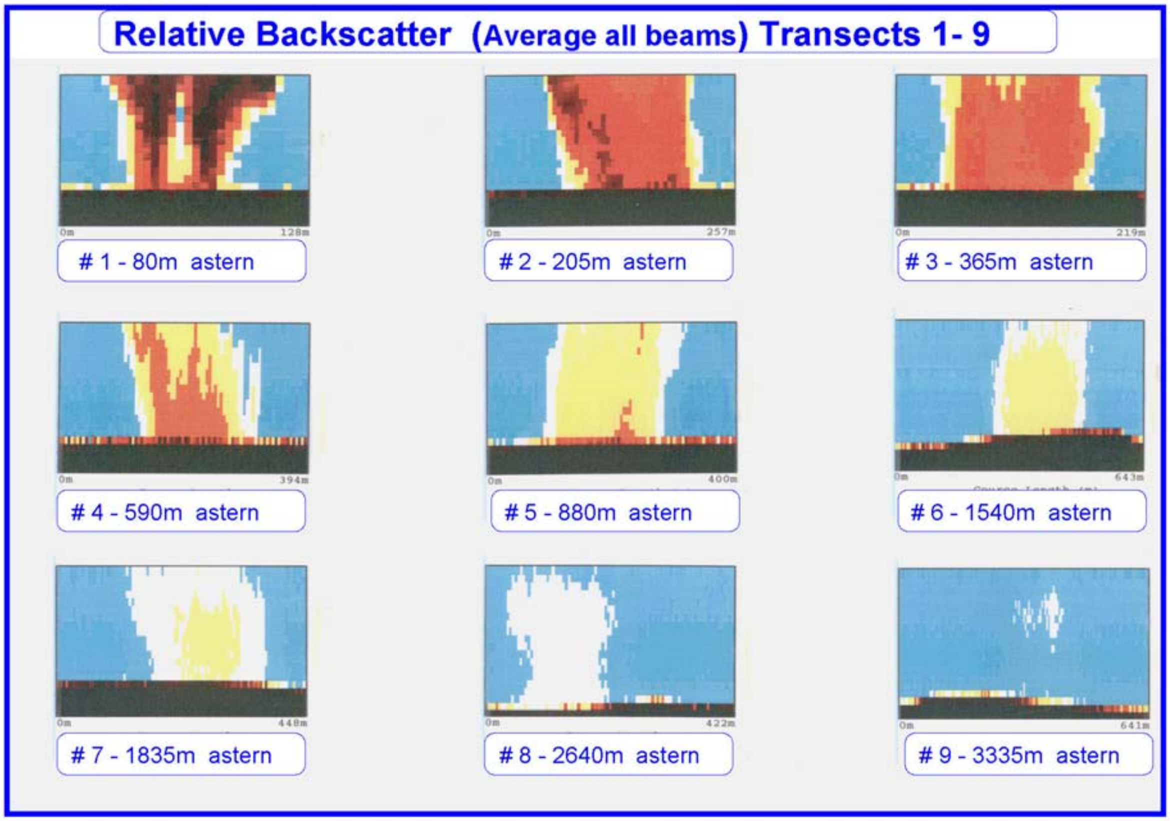


FIGURE 2.5 Acoustic backscatter images across the plume at varying distances downstream of an anchor dredge during loading of a screened cargo at Owers Bank off the south coast of UK. Based on Hitchcock and Drucker (1996). The black band at the seabed is a data corruption zone that precluded assessment of plume morphology at the sediment-water interface. The red signal indicates coarse sand-sized particles; the yellow signal indicates the settlement of silt; and the white signal is considered to represent organic flocculating material.

are measured automatically through instruments that measure the scattering of light whereas JTUs are based on a visual assessment of the fuzziness of a mark at the bottom of a clear tube. It is likely that the original value of 50 JTU resulted from limits associated with avoiding ecological impact in streams and rivers. In Florida, for typical beach nourishment projects, the measurements for turbidity compliance are usually taken 150 m offshore and no more than 150 m downcurrent of the discharge point within the densest portion of any visible turbidity plume. The measurements are taken at the surface, mid-depth and near the bottom. Background levels are specified to be measured 1,000 m upcurrent from the dredging operations. Many investigators have questioned the validity of a general limit for all conditions (see Goldberg, 1989). Based on comparison to more spatially comprehensive ADCP measurements of turbidity, the point measurements of turbidity in space and time have also been argued to add arbitrariness to the evaluation (Doug Clarke, personal communication). Surface water quality limits vary by State in a range of 5 to 150 NTU above background (depending on the State and the location and seasons) but are mostly in the 20 to 50 NTU range (Source: USEPA Office of Water, Office of Science and Technology). In most cases, these limits were developed for freshwater conditions although are often applied to marine conditions as well. Some States have separate marine and freshwater limits. Wilber and Clarke (2004) indicate that few field studies have actually been completed for the low levels of turbidity that exist nearby a dredging operation (much of the data come from acute response tests). In summary, there is limited work in defining a scientific limit of elevated turbidity levels for offshore marine environments. Also, the application of a single point, single value limit is relatively arbitrary and perhaps unsupportable scientifically.

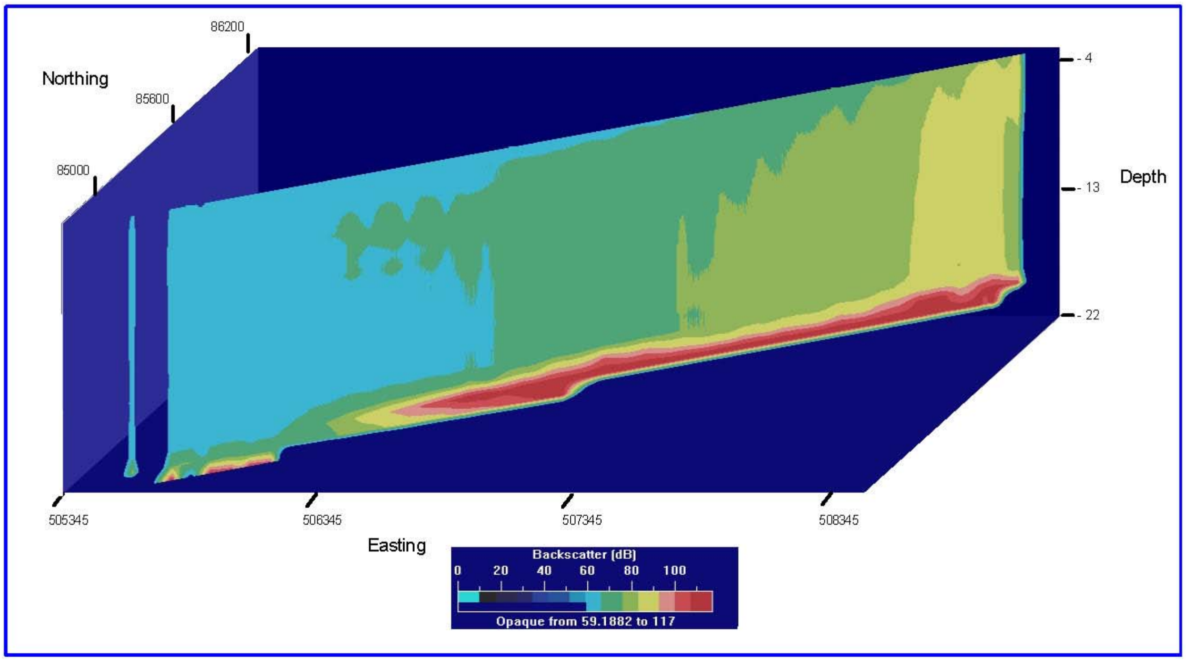


FIGURE 2.6 Longitudinal section of the sedimentation plume from a dredge loading a screened cargo at Owers Bank in 1995. Based on Acoustic Backscatter data from Hitchcock et al. (2002). The red side of the scale indicates high backscatter levels and the blue side of the scale indicates low backscatter levels (depths and Eastings are in meters).

In the UK and Europe the assessment of dredging impacts related to turbidity is almost exclusively focused on sedimentation. There is little concern with the water column turbidity levels as it is assumed fish can easily evade areas of higher turbidity (Desprez, 2000).

It is generally assumed by resource managers in the US that, when OCS dredging occurs in sandy substrates, turbidity would be short-term and animals in the water column would avoid turbid areas. Turbidity might be more of a concern in areas where a fine-grained overburden has to be removed to access the coarser sediment below, although even in these areas the existence of fine sediment on the bed would suggest a relatively high background suspended sediment concentration. However, potential impacts to sensitive benthic habitats, such as hard/live bottom habitats, are still of concern even in sandy substrates.

In summary, there is a need to determine the potential impacts of plumes from overflow discharges on sensitive benthic habitats and appropriate methods to reduce these impacts where they could be significant. However, it would appear to be generally accepted that water column turbidity impacts to marine ecology from dredging operations in sandy substrates are not a significant concern.

2.3.8 Spatial and Seasonal Conflicts Between Dredging and Commercial and Recreational Fisheries.

Dredging in the OCS poses the potential for navigational conflicts with local commercial and sport fishers from the presence of operating dredges at the borrow site and transit to and from the sand discharge points. Such conflicts may result in diminished access to favorable fishing areas and a loss of harvest. Fishery impacts have been identified as being of general concern by several groups, and they have also been of specific concern in some instances such as in New Jersey with the surf clam fishery. Mitigation actions can include lease stipulations, such as avoidance areas, as is done to protect archaeological resources or oil and gas infrastructure in the borrow site. Mitigation actions can also include institutional activities to facilitate communication and cooperation among potentially conflicting entities. Some recommendations made to decrease the likelihood of conflicts have included: identifying the most appropriate fishery industry liaisons to facilitate communications, providing sufficient advance warning of impending dredging activities to fishermen, zoning permitted areas so as to protect the most important fishery grounds, avoiding dredging during peak fishing seasons, setting up relatively small exclusion zones within the larger permit area to shelter sensitive habitats, selection of transit routes that minimize interference with fishing activities, choosing those dredging techniques which have the lowest fishery impacts, limiting extraction rates, regulating the “at-sea” screening of sediments, and effective monitoring of dredging operations to ensure compliance. In the UK, success of the majority of mitigation measures related to the commercial fishing industry relies heavily on communication between the two industries (Royal Haskoning, 2004). To address this concern, MMS has contracted a new study entitled “World-Wide Survey of Dredging Impacts on Commercial and Recreational Fisheries and Analysis of Available Mitigation Measures to Protect and Preserve Resources.”

In summary, it was concluded that the new MMS study would address this concern, and therefore, it is not a focus of this report.

2.3.9 Potential to Break an Active or Abandoned Pipeline, Resulting in a Release of Petroleum Hydrocarbons

Throughout the central Gulf of Mexico, numerous pipelines, platforms, wellheads, and other related oil and gas infrastructure are present in potential OCS sand borrow sites. Given the potential for removal of 3 m or more of sediment in areas near oil and gas infrastructure, there is a potential risk that dredging will result in changes to the sediment stability and seafloor topography that could lead to damage to existing pipelines and structures. The primary mitigation method in practice is to establish no-dredge buffers around known infrastructure. However, there are many questions yet to be answered on the short- and long-term impacts of sediment removal in the vicinity of oil and gas infrastructure, including: How much sediment can be removed from a sand borrow site before the surficial integrity of the site is impacted such that the surface collapses and the structural integrity of facilities are compromised, especially during storm events? What widths are appropriate buffer zones around these facilities to avoid such a compromise? MMS is currently conducting a study entitled "Study to Address the Issue of Seafloor Stability and the Impact on Oil and Gas Infrastructure in the Gulf of Mexico."

In summary, it was concluded that this new study would address this concern. Therefore, this topic is not addressed in this assessment of environmentally friendly approaches to dredging.

2.3.10 Collisions with Marine Mammals and Sea Turtles During Vessel Operations

Vessel collisions with endangered whales (Northern right whale, fin whale, and humpback whale) are one of the major factors limiting their recovery (NMFS, 1991b,c; Reeves et al., 1998). There has never been a report of a whale strike or mortality by a hopper dredge in the US (NMFS, 2004), although there is one report of a right whale calf mortality resulting from a strike by a dredging vessel in South Africa (C. Slay, Coastwise Consulting, Inc., pers. comm., 2004). It is generally thought that hopper dredges move slow enough to minimize the risk of a strike with a marine mammal. In areas where recreational boating and ship traffic is intense, propeller and collision injuries are not uncommon for all sea turtle species.

Existing stipulations include:

- If operating in areas of known whale occurrences, observers are required. If whales are observed, avoid intentional approaches within 100 yards (500 yards for right whales) and slow speeds to less than 4 knots.
- See stipulations for sea turtles.

In summary, it was concluded that existing stipulations are adequate for now, and this potential impact was not addressed further in the evaluation of environmentally friendly approaches to dredging.

2.3.11 Damage to Archaeological Resources

The National Historic Preservation Act requires Federal agencies to protect historic and cultural resources, which include shipwrecks, historic fortifications, and coastal settlements, as well as prehistoric sites that have become submerged due to the global and local rise in sea level. As a Federal agency, the MMS must protect the significant archaeological and historic sites that may be impacted by its activities. MMS requirements for remote-sensing surveys to identify and protect submerged cultural resources in lease areas where oil, gas, and sulfur deposits are being exploited in the Gulf of Mexico Region were identified in the Notice to Lessees 98-06 (MMS, 1998) and revised in Notice to Lessees 2002-G01 on 15 March 2002 (MMS, 2002). MMS guidelines for the conduct of archaeological resource remote-sensing surveys address three basic issues: survey navigation, survey pattern, and data acquisition instrumentation (Notice to Lessees 2002-G01). No requirements have been adopted for the Atlantic OCS and slightly different requirements are in place for the Pacific coast (Notice to Lessees 98-05).

MMS recently completed a review of its current practices and the development of recommendations on dredging methods, protocols, policies, and monitoring requirements to minimize impacts on submerged cultural resources (Research Planning, Inc. et al., 2004). In summary, it was determined that this recent study adequately addressed the concerns and recommended approaches needed to minimize potential damages to archaeological resources. Therefore, this potential impact has not been considered as part of the evaluation of environmentally friendly approaches to dredging.

2.3.12 Potential Harmful Alteration or Destruction of Essential Fish Habitat

The 1996 reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act required designation and conservation of Essential Fish Habitat (EFH) for species managed under existing Fishery Management Plans. EFH is defined as “those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity” [16 U.S.C. § 1801(10)]. Maps of designated EFH for many species cover large areas. For example, Figure 2.7 shows the EFH for adult summer flounder as designated by the Mid-Atlantic Fishery Council. Clearly, OCS sand borrow sites are often located within designated EFH areas. EFH also includes Habitat Areas of Particular Concern (HAPCs) that are narrowly focused habitats with demonstrated direct habitat value for managed species.

The potential effects to fisheries from sand dredging are unknown, having been identified in most of the environmental impact assessments prepared for OCS sand dredging to be minimal or non-existent (Hammer et al., 2003; Louis Berger Group, 1999, Byrnes et al., 2003). This assessment was based on the determination that most of the fish inhabiting the potential dredge areas were characterized as wide-foraging or migratory, spending only part of their life cycle in the dredge borrow area. In addition, the ridge/shoal and shelf features identified as potential sand borrow areas are very large in geographic extent, extending over kilometers of seafloor and the potential borrow area for each dredging event is relatively small. Therefore, it was assumed that the lost or altered habitat area, overall, would probably be minimal.

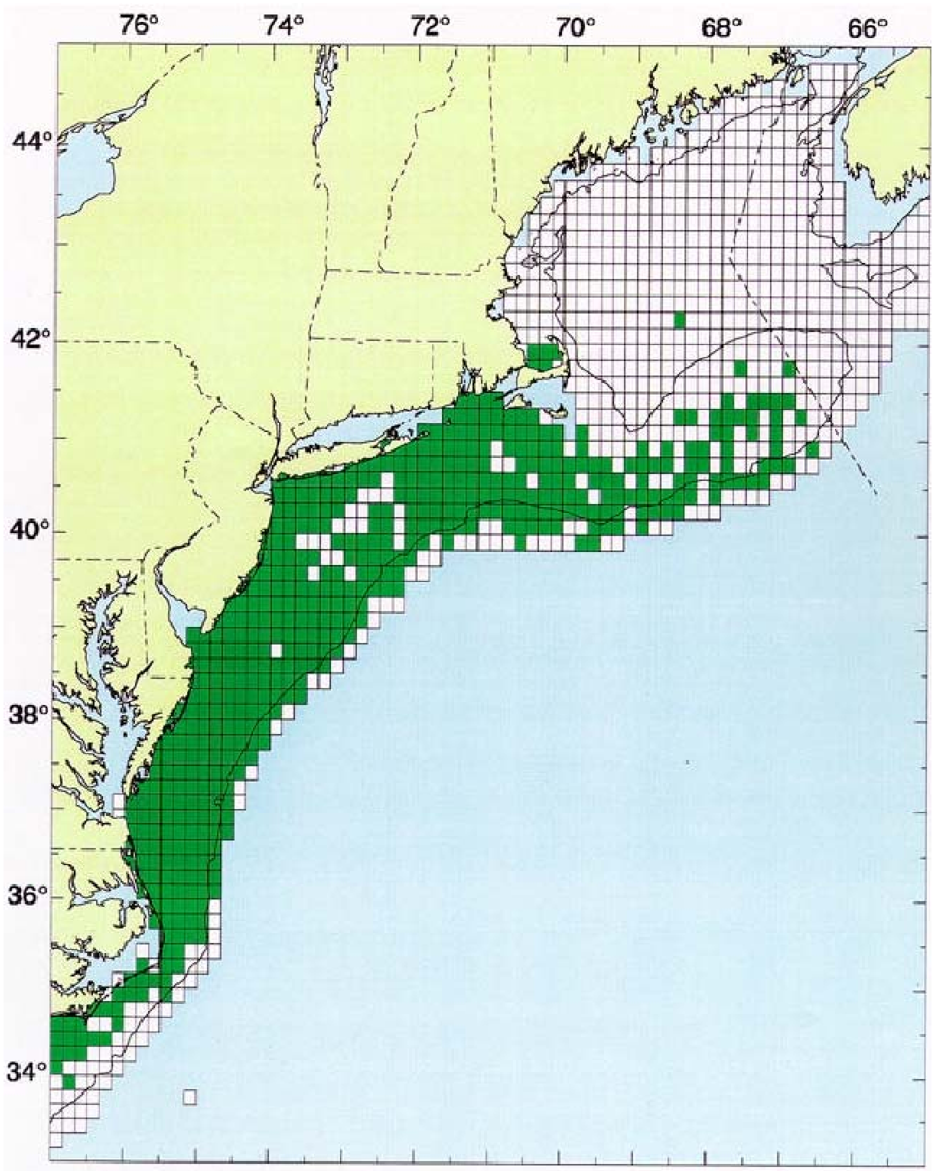


FIGURE 2.7 Map of the essential fish habitat for adult summer flounder, as designated by the Mid-Atlantic Fishery Council.

In the literature review conducted by Research Planning, Inc. et al. (2001), they found that little was known about the ecological utilization of ridge and shoal features by fish species. Anecdotal information suggests that these features are important to fish as feeding, staging, or orientation areas during short-term or long-term migrations. To address this data gap, MMS is conducting studies of shoal features off Delaware and Maryland to determine if they constitute important habitat for fisheries and represent essential fish habitat (first study listed in Table 2.1). MMS is also funding a study of the utilization of Ship Shoal, Louisiana by shrimp and sea trout, through the Coastal Marine Institute at the Louisiana State University. Fish habitat on Sabine and Heald Bank offshore Texas are also being evaluated by USGS/BRD.

Although dredging can impact a wide range of types of EFH, at this time most existing and upcoming areas of dredging are associated with ridge and shoal features. There is a concern that potential impacts from dredging of ridges and shoals may affect their morphologic integrity. Hayes and Nairn (2004) identified the issue that repeated dredging of these features might lead to the deflation or eventual disappearance of the bathymetric feature. They proposed that offshore ridges and shoals are maintained by wave-generated sand transport processes, and they hypothesized that lowering of the feature below some critical depth would disrupt the processes that maintain the feature. To address this concern, MMS is conducting a study entitled "Analysis of Potential Biological and Physical Dredging Impacts on Offshore Ridge and Shoal Features/Engineering Alternatives and Options to Avoid Adverse Environmental Impacts." Therefore, this study of environmentally friendly approaches will not focus on the issue of geomorphic stability of shoal features. Some initial recommendations are provided as this topic was discussed at the study workshop.

2.4 Summary of Potential Impacts and Focus for this Investigation of Environmentally Friendly Approaches

This section provides a summary of the review of various perceived impacts as identified through discussions with the regulatory agencies and the literature reviews. It provides the focus for the evaluation of environmentally friendly equipment and practices presented in Section 5 of this report. Table 2.3 lists the prioritized list of impacts together with comments on which impacts will be considered as part of this investigation. The key focus of this investigation will be on the following impacts in the order of priority determined from the discussions with resource managers in the US: 1. loss of benthic habitat; 3. changes to substrate characteristics; 5. sedimentation and burial of sensitive habitat; and 7. short-term increases in turbidity. The remaining impacts are being or have been addressed in detailed studies by MMS (Impacts 4, 6, 8, 9, 10, 11 and 12) and USACE (Impact 2).

TABLE 2.3 Summary of perceived impacts and focus for this assessment.

Impact	Summary
1. Short-term and cumulative impacts from dredging that lead to loss or reduced stability of benthic habitats, including re-colonization by an altered biological community.	This impact is a key focus for this investigation.
2. Injury and death of special species of concern (e.g., sea turtles) from being sucked into the draghead during dredging operations using hopper dredges	This impact and its mitigation are being addressed in detail by the USACE in an ongoing study. Therefore, it will not be addressed in this investigation.
3. Changes in the substrate characteristics (grain size, dissolved oxygen, compaction and organic content) that lead to a reduction in benthic communities and suitability of the area for future dredging.	This impact will be reviewed as part of this investigation.
4. Changes in bathymetry that can alter the wave climate reaching the shore, resulting in shoreline changes.	This impact was addressed as part of the Biological and Physical Monitoring Protocols developed for MMS and will not be addressed in this investigation.
5. Sedimentation (burial) impacts to adjacent hard/live bottom or other sensitive habitats.	This impact will be reviewed as part of this investigation.
6. Creation of depressions and furrows from removal of substrate.	This impact will not be reviewed as part of this investigation as it will be addressed as part of an ongoing MMS study ("World-Wide Survey of Dredging Impacts on Commercial and Recreational Fisheries and Analysis of Available Mitigation Measures to Protect and Preserve Resources").
7. Impacts from short-term increased turbidity from cutterhead or draghead and overflow from hopper dredges on benthic communities.	This impact will be reviewed as part of this investigation. However, it is generally accepted that this is not an impact of critical concern.

TABLE 2.3 Cont.

8. Spatial and seasonal conflicts between dredging and commercial and recreational fisheries.	This impact will not be reviewed as part of this investigation as it will be addressed as part of an ongoing MMS study ("World-Wide Survey of Dredging Impacts on Commercial and Recreational Fisheries and Analysis of Available Mitigation Measures to Protect and Preserve Resources").
9. Potential to cause a break in an active or abandoned pipeline, resulting in a release of petroleum.	This impact will not be reviewed as part of this investigation as it will be addressed as part of an ongoing MMS study ("Study to Address the Issue of Seafloor Stability and the Impact on Oil and Gas Infrastructure in the Gulf of Mexico").
10. Collisions with marine mammals and sea turtles during vessel operations.	Existing stipulations are satisfactory and this impact will not be evaluated as part of this investigation.
11. Damage to archaeological resources.	This impact will not be reviewed as part of this investigation as it has been addressed as part of an MMS study (Research Planning, Inc. et al., 2004).
12. Potential harmful alteration or destruction of Essential Fish Habitat.	This impact will not be reviewed in detail as part of this investigation as it will be addressed as part of an ongoing MMS study (Analysis of Potential Biological and Physical Dredging Impacts on Offshore Ridge and Shoal Features/Engineering Alternatives and Options to Avoid Adverse Environmental Impacts"). Some initial recommendations are provided as this topic was discussed at the study workshop.

3.0 LITERATURE REVIEW OF ENVIRONMENTALLY-FRIENDLY APPROACHES

3.1 Methodology

A literature review of environmentally friendly dredging technologies was completed in support of this study.

The review was specifically focused on hydraulic dredging techniques. Mechanical dredging approaches were not included in the review as these are almost certainly not practical or economic for offshore dredging in Federal waters. As such the primary focus for the literature review was on Trailing Suction Hopper Dredges (TSHDs) and Cutter Suction Dredges (CSDs). There were some examples of development related to Stationary Suction Dredges. Dustpan dredges were also considered in the review.

A literature review was conducted through the Internet and several information databases were identified including government agencies, research institutes and universities. One of the most extensive data sources was found at the Delft University of Technology in the Netherlands from which a list of approximately 1,200 potential documents was retrieved. The abstracts of these documents were read and the number of documents was reduced to 60 for full paper reviews. The targeted articles were obtained from various online and library sources. A bibliography of all key papers reviewed is included as Appendix B.

Another key source of information was the Dredging Operations and Environmental Research (DOER) Program of the Engineering Research and Development Center (ERDC) at USACE. Reports, technical notes, bulletins, and research briefs were reviewed. It was found that the focus of the USACE research was mostly directed toward issues associated with nearshore and, particularly, navigation dredging, where the primary interest of the USACE resides.

All the documents were reviewed and the relevant information related to environmental friendly dredging technology was documented and is summarized in this section. The summary is subdivided into sections pertaining to the different dredging equipment (TSHDs, CSDs and other devices) and monitoring approaches.

3.2 Trailing Suction Hopper Dredges

The most likely equipment of choice for offshore dredging for beach nourishment sand and aggregates on future MMS projects (i.e., in Federal jurisdiction at least 3 nautical miles offshore in open water) will be TSHDs.

A major part of offshore dredging of sands and aggregates in the US and Europe is currently undertaken with TSHDs. This type of dredge has been under intense scrutiny by the dredging industry lately for two reasons; firstly there has been a large expansion in the TSHD market to accommodate the requirements of major reclamation projects in South East Asia (Tsurusaki et al., 1988; Evans, 1994), and secondly there have been serious efforts in recent years to develop methods of predicting and reducing the effects of sediment re-suspension by these dredges, as part of on-going research projects in several countries.

A description of the sources of suspended sediment from TSHD operations was provided in Section 2.3.7. The primary source of suspended sediment is the hopper overflow. Sediment suspended at the draghead is local in nature and confined to a zone close to the bed. The hopper overflow usually produces a dynamic plume phase (where highly turbid water forms a turbidity plume or current through the water column), a passive phase and, sometimes, a near bed "pancaking" and laterally spreading turbidity current phase. "Pancaking" has been used as a metaphor to describe the effect of the vertical momentum of the dynamic plume phase impacting the bed and with the subsequent transfer of this momentum to spreading in the horizontal plane.

The effects of overflow as a plume are discussed in Bonetto (1995), Sea Technology (1998),Van Dipen (1993), LaSalle et al. (1991), Whiteside et al. (1995), Hirsch et al. (1978), and ERDC-TN-DOER-E15. Conventionally, modeling of the passive phase of plumes has been performed to assess the impact of overflow (Bonetto, 1995; Whiteside et al., 1995; Norem et al., 1990). Only recently have models been developed to evaluate the dynamic phase of settling (see Baird & Associates, 2004).

In terms of vessel design, the most obvious trend is in vessel size. Within a decade the maximum hopper size of TSHDs has moved from around 12,000 m^3 to in excess of 35,000 m^3. This vast increase in size has been accompanied by increased loading capacity, particularly at depth. The large vessels themselves have the ability to support and deploy long suction pipes and these, together with the addition of underwater pumps in the trailing arm, make it possible to dredge sand at high concentration from great depth. A by-product of increasing the size of these vessels is that suction pipes and hopper dimensions become large.

The significance of large, low-friction suction pipes are that high concentrations can be pumped with greater facility. Large hopper dimensions, combined with the use of a single suction pipe rather than the more normal two, allow a considerably better settling efficiency to be obtained in the hopper, with a commensurate increase in the retention of fine materials.

As part of the on-going research into the efficiency of hopper systems and the need to be able to predict, in a quantitative manner, the re-suspension of sediments caused by operating dredges, the industry has recently carried out a number of experiments. The first of these was to measure the flow patterns in a large-scale model of a TSHD hopper (van Rhee, 2001; Ooijens et al., 2001). This research is being used to obtain a fundamental understanding of the hydrodynamic flow processes taking place in a hopper, leading to better modeling of hoppers and thence better hopper design.

At the prototype scale, studies have been conducted to determine overflow losses from working TSHDs and the resulting overflow behavior in the near field. At the same time plumes from dragheads have also been measured (Land et al., 2004). The results of these measurements will not only inform current attempts to model sediment releases, but will also assist in future design of environmentally friendly dredges.

In addition to the above advances in design, TSHDs now have high accuracy positioning and control systems, allowing them to be operated with considerable precision in the dredging area. This in itself makes it possible for more precise zoning requirements to be applied without seriously increasing cost-effectiveness.

Over the last few years, two other areas of development in TSHDs that have been adopted almost industry-wide are under hull release of overflow sediment (except for screening operations) and the use of anti-turbidity valves (Pennekamp and Quaak, 1990; LaSalle et al., 1991; Tsurusaki et al., 1988). The single purpose of these approaches was to reduce the extent of suspended sediment plumes generated by the overflow process.

Dredge equipment manufacturers have developed a closed system where the overflow from hopper dredges is re-circulated and used to feed a jet at the draghead to loosen the bed (McLellan and Hopman, 2000). The approach is sometime referred to as "Green Pipe". This technique has the advantages of: minimizing the sediment discharged through the overflow process; providing for higher load capacity of sediment rather than low density water/sediment mixture; and decreasing the pressure drop inside the draghead which reduces dredge pulling force. A rule of thumb to guarantee the effectiveness of this system is to ensure that the source material to be extracted has a density greater than 1,300 grams per liter (g/l). Lower material density tends to remain in suspension longer periods of time. Some manufacturers claim a 20% increase in efficiency for dredging silty sand with the recirculating system (Francingues et al., 2000). In general, this approach has not been adopted by dredging contractors either in Europe or the US because the cost of retrofitting existing dredge vessels would not appear to be justified by benefits from reduced turbidity in most cases (see Section 5 for further discussion).

An area of intensive development in the US relates to the potential entrainment of organisms by TSHDs, particularly sea turtles. The three key approaches to mitigating this impact are: the specification of environmental windows for dredging operations; trawling surveys and relocation; and turtle deflectors for the draghead. The turtle deflector is a rigid device that is mounted on the draghead and displaces the turtle outside the reach of the suction field (Smits, 1998). A study was carried out at Canaveral harbor using this device and it was found effective although more studies were recommended since the dredge volume was relatively small (Nelson and Shafer, 1996) and the application was limited to relatively shallow waters. The DOER Program is currently undertaking additional research and development to refine the design of sea turtle deflector dragheads.

In Harwich Harbour, England, McLellan and Hopman (2000) report that TSHD operations were scheduled at intervals during peak tidal ranges to disperse the overflow away from the dredge area. Through application of the MMS Plume Model (Baird & Associates, 2004), dredging plans for TSHDs could be developed according to environmental conditions such that dispersion of overflowed sediment was spatially maximized to lower the total sedimentation at any given location, or minimized to reduce the footprint in areas adjacent to sensitive habitat.

3.3 Cutter Suction Dredges

Less attention was devoted to the review of environmentally friendly developments related to equipment and approaches associated with CSDs owing to the fact that their application will be less widespread for dredging in the offshore waters under MMS jurisdiction, mostly due to the long pumping distances from borrow areas in Federal waters to shore (at least 3 miles). Also, sediment plumes generated by CSDs are confined to near bed re-suspension around the cutterhead and, therefore, are generally much more spatially confined than plumes generated by TSHDs. The impacts related to the removal of benthic habitat would be similar to those associated with TSHDs.

Most environmentally friendly developments related to CSDs are associated with modifications to the cutterhead, largely driven by projects to remove contaminated sediments from rivers and harbors. As one example, a low turbidity cutterhead was designed by Jan de Nul to be mounted on cutter suction dredges to accurately remove thin layers of silt, dredge material at *in situ* density, work in shallow areas, and reduce mechanical disturbance of the bed, thus reducing turbidity (McLellan and Hopman, 2000).

The environmental disk cutter device was developed by Boskalis and the Delft University of Technology. Essentially, it is a disk-shaped cutterhead with a closed, adjustable visor system for cutter suction dredges. It operates in a stationary manner and can achieve vertical positioning accuracy up to 5 cm. This device is well suited for dredging thin layers of sediment and has low spillage of sediment and works with a wide variety of sediment mixtures without generating high levels of turbidity. It also incorporates a highly accurate positioning and control system (Pennekamp, 1997). One of the problems with this type of device is the frequency of blockage of the intake due to debris (Smits, 1998).

A gearbox device has been developed to allow diesel pumps to operate underwater on cutter suction dredges, allowing for greater flexibility and eliminating the need for electrical pumps. This system is so efficient that one of the largest manufacturers of dredge equipment, IHC Holland, employs it on all their standard cutter suction dredges

(Francingues et al., 2000). The Ellicot Mud Cat dredge uses a similar approach with a submerged pump mounted directly behind a horizontal auger. The Mud Cat is primarily used for very controlled removal of contaminated fine sediment (The Mud Cat is a registered trademark of Baltimore Dredges LLC, see also the USACE report EM 1110-1-502).

3.4 Other Dredging Devices and Equipment

In this section, a range of dredging devices and equipment that are not associated with the conventional TSHD and CSD approaches are reviewed. Although some of the technologies have only been applied to contaminated sediment removal and environmental dredging, their use could be relevant in some site-specific sand/aggregate mining activities.

One class of innovative development relates to the implementation of "remote" dredging techniques where the dredge equipment is located near to the seabed. One example of this technique is the Punaise approach developed by the PinPoint Dredging Company owned by J G Nelis, Ballast Needam and Boskalis (McLellan and Hopman, 2000). Some of the advantages of being a submerged machine are that it doesn't interfere with navigation and can operate in adverse wave conditions. Also, it does not generate a surface plume. Primary limitations are related to the capacity and productivity of the approach together with the fact that large and deep dredge pits result from the relatively stationary operation of this device, which in many jurisdictions are unacceptable due to the associated ecological impact. This dredge has not been used recently. It is now considered to be technically too complicated for a reliable, remotely controlled operation and is not cost effective compared with other techniques.

Another example of a remote approach is the Underwater Archimedean Screw vehicle, which is a bottom-crawling machine that applies the Archimedean screw principle to excavate material ranging from a few centimeters up to 1 m (Smits, 1998). This equipment can incorporate a Remotely Operated Vehicle (ROV) that assists in guidance, navigation, and control. It uses DGPS for positioning and has an image device which shows where the equipment is at all times. This allows for a high degree of vertical and horizontal positioning accuracy up to 5 cm. This equipment is mainly used to extract fine contaminated sediment.

The Sweep Dredger is another stationary device but allows for some movement by a sweep head similar to a TSHD draghead (Smits, 1998). It can cut layers from 20 to 60 cm deep with an accuracy of 5 cm in the horizontal. The Sweep Dredger was developed by Dredging International (Pennekamp, 1997; Sea Technology, 1998).

Some alternative methods for dredging include the PNEUMA pump, Dry DREdge and Soli-Flo (Romagnoli et al., 1998). These methods have the ability to produce higher solids content and less turbidity than hydraulic dredges. The disadvantages are that they cannot operate in shallower areas and can be more expensive than traditional dredging methods. The PNEUMA uses compressed air to convey sediment through a pipeline. The Dry DREdge is a combination of hydraulic and mechanical methods. It drives a hydraulic clamshell into the bed and encloses the sediment avoiding spillage and turbidity. It captures the sediment with its original moisture content but can only be applied to fine sediment extraction in deeper areas. The Soli-Flo with eddy pump produces a slurry with high solids content (up to 80% solids) and low turbidity. These results can be achieved if the intake nozzle is placed at least 1 to 3 feet deep into the bed (Romagnoli et al., 1998).

Another recent development relates to fluidization techniques. Fluidization techniques (also known as Water Injection Dredging or WID) have been utilized as a dredging approach where a water jet is directed to the bed to fluidize the sediment that in turn is transported away from the dredge area by the current or through the difference in densities and/or the bottom slope (Verweij and Winterwerp, 1999). This method has only been applied at a commercial scale for fine sediments that are capable of behaving as fluid mud. Currently, it would not appear to have a direct application to dredging for beach nourishment sand or aggregates.

3.5 Monitoring Instruments and Approaches

Monitoring is a key component of dredging projects to ensure an environmentally friendly operation and to reduce the impacts significantly (Amann, 1989; Thevenot et al., 1992).

The USACE employs an automated dredge contract monitoring system referred to as "Silent Inspector" (SI). SI has three components consisting of a Dredge Specific System (DSS), a Ship Server, and a Shore Server. The DSS collects and displays standard information on dredging operations that is then transmitted to the Ship Server. Most dredging contractors already have a computer system and sensors onboard for control or positioning that can be used as the DSS. The dredging contractor supplies and owns the DSS and all associated sensors Figure 3.1 represents a screen shot of the on board menu of the DSS from which different functions can be accessed. Figure 3.2 displays the Dredge display which shows real time sensor data. Figure 3.3 displays a load summary report. Unlike manual load summaries, load summaries in Silent Inspector are automatically created from data that is sent directly from the dredge by satellite modem located on the dredge or uploaded from a zip disk.

The Ship Server acts as the dredge based data archive and report creation center as well as performs automated reviews of the data. The Ship Server can produce many different reports including dredge location history, volume history, disposal location history (Figure 3.4) and operational status. Figure 3.5 displays a screen shot of the different plots that can be generated and an example plot is shown in Figure 3.6.

The Shore Server is a larger system operated and maintained by the USACE. SI provides information on dredge location history, quantity history, and status of a given project. SI helps monitor all aspects of dredge operations from contract compliance to assurance that the operation is being performed in an environmentally safe manner (Rosati, 1999). Additional information and specifications regarding the SI can be found at: http://si.wes.army.mil/

Some of the SI capabilities include:

- Monitors and documents where and when different dredging operations take place;
- 24/7 coverage of operations;
- Reduces paperwork and contractor reporting duties;
- Creates detailed production reports;
- Allows for fast responses to public or environmental concerns;
- Allows for flexible scheduling of human inspectors;
- Improves government estimates and planning;
- Improves project management;
- Standardizes data collection and reporting;
- Creates a standard base for dispute resolution and avoidance.

The Silent Inspector Track-plot viewer provides data and graphics of the dredge material disposal aboard hopper dredges. This viewer can be accessed online over a public accessible server. The Track-Plot Viewer allows the position of a hopper dredge to be monitored for any valid time and location (Figure 3.7).

In Belgium, the Maritime Schelde Department has standardized a monitoring system that records real-time data on dredging operations including: location, depth of cut, sediment mixture concentration, and several other parameters that help determine the performance of the operation (Francingues et al., 2000).

A dredging project was undertaken in Hong Kong near a sensitive area (coral) and a dredging plan was described (Evans, 1994) which takes into account tidal influence, overflow control, siltmeter deployment, and weekly dives.

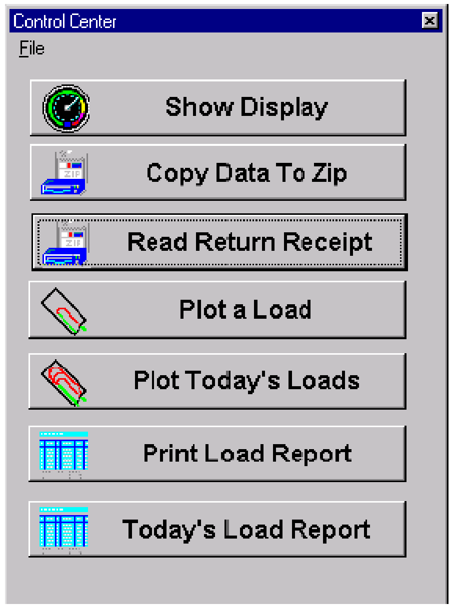


FIGURE 3.1 Control center window.

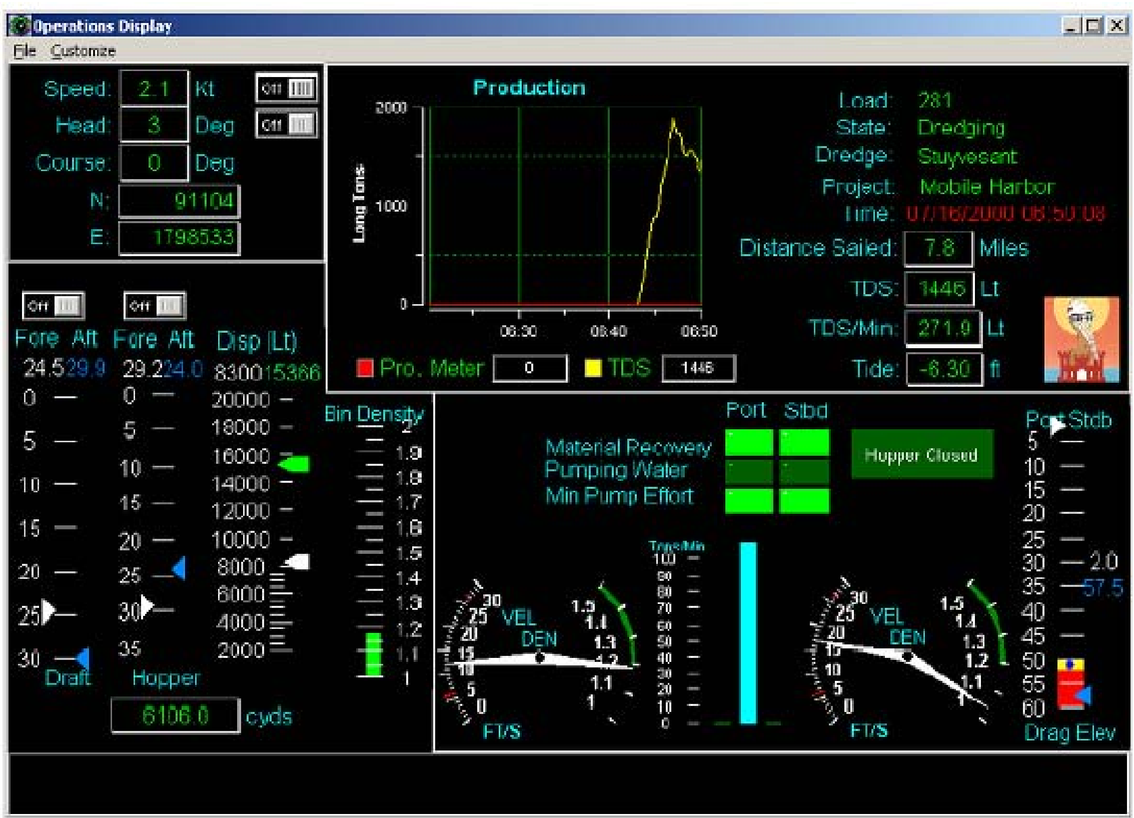
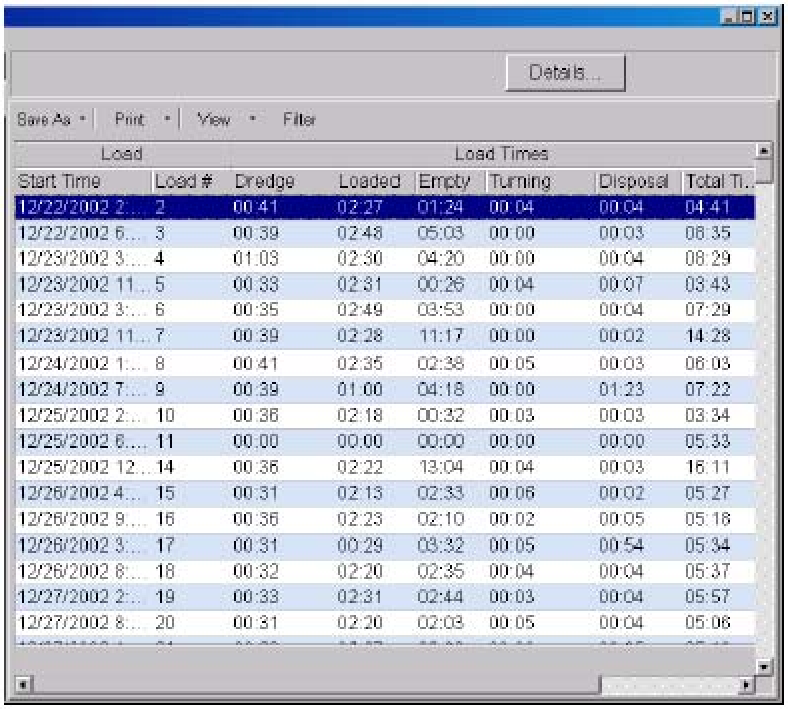


FIGURE 3.2 On board dredge display.



Load		Load Times					
Start Time	Load #	Dredge	Loaded	Empty	Turning	Disposal	Total Ti...
12/22/2002 2:...	2	00:41	02:27	01:24	00:04	00:04	04:41
12/22/2002 6:...	3	00:39	02:48	05:03	00:00	00:03	08:35
12/23/2002 3:...	4	01:03	02:30	04:20	00:00	00:04	08:29
12/23/2002 11...	5	00:33	02:31	00:26	00:04	00:07	03:43
12/23/2002 3:...	6	00:35	02:49	03:53	00:00	00:04	07:29
12/23/2002 11...	7	00:39	02:28	11:17	00:00	00:02	14:28
12/24/2002 1:...	8	00:41	02:35	02:38	00:05	00:03	06:03
12/24/2002 7:...	9	00:39	01:00	04:18	00:00	01:23	07:22
12/25/2002 2:...	10	00:36	02:18	00:32	00:03	00:03	03:34
12/25/2002 6:...	11	00:00	00:00	00:00	00:00	00:00	05:33
12/25/2002 12...	14	00:36	02:22	13:04	00:04	00:03	16:11
12/26/2002 4:...	15	00:31	02:13	02:33	00:06	00:02	05:27
12/26/2002 9:...	16	00:36	02:23	02:10	00:02	00:05	05:18
12/26/2002 3:...	17	00:31	00:29	03:32	00:05	00:54	05:34
12/26/2002 8:...	18	00:32	02:20	02:35	00:04	00:04	05:37
12/27/2002 2:...	19	00:33	02:31	02:44	00:03	00:04	05:57
12/27/2002 8:...	20	00:31	02:20	02:03	00:05	00:04	05:06

FIGURE 3.3 Load summary display.

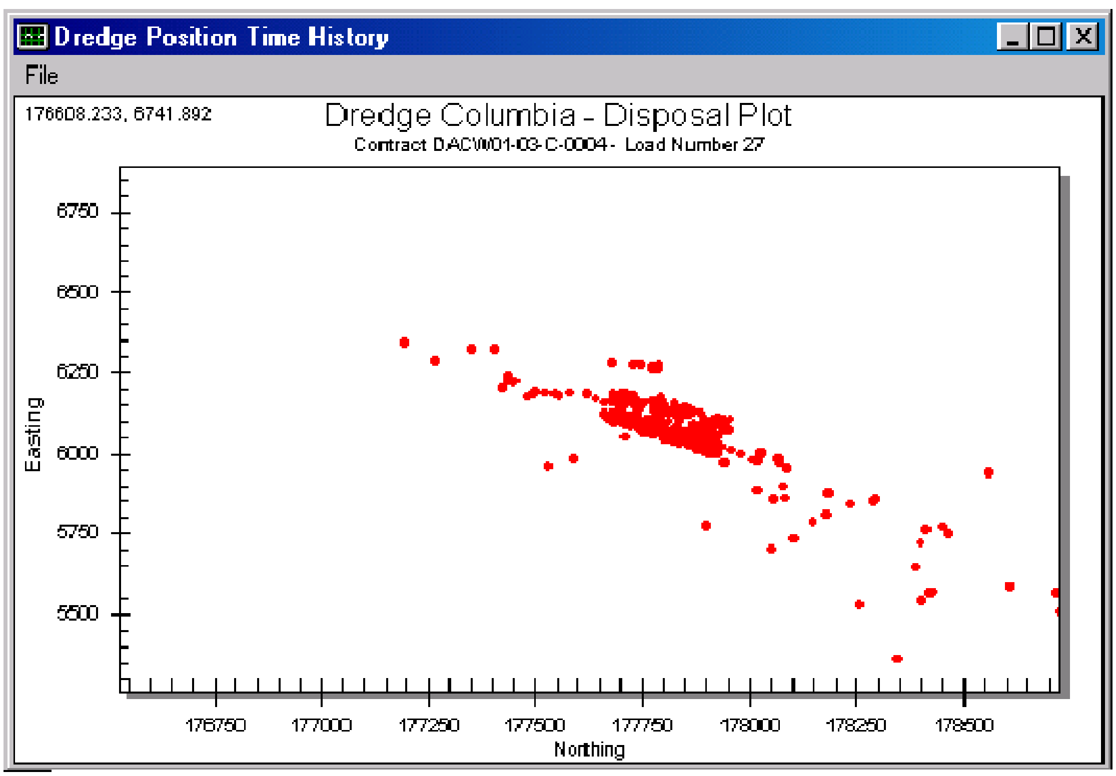


FIGURE 3.4 Dredge disposal history.

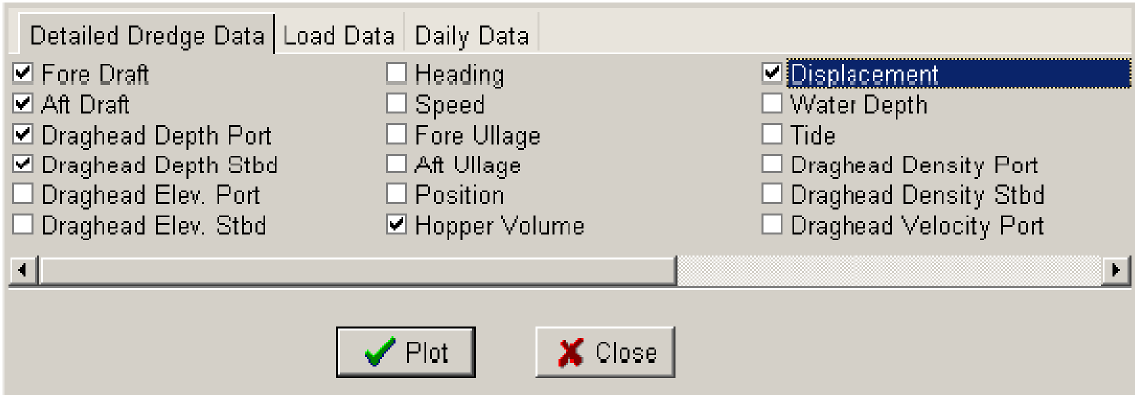


FIGURE 3.5 Plotting options display menu.

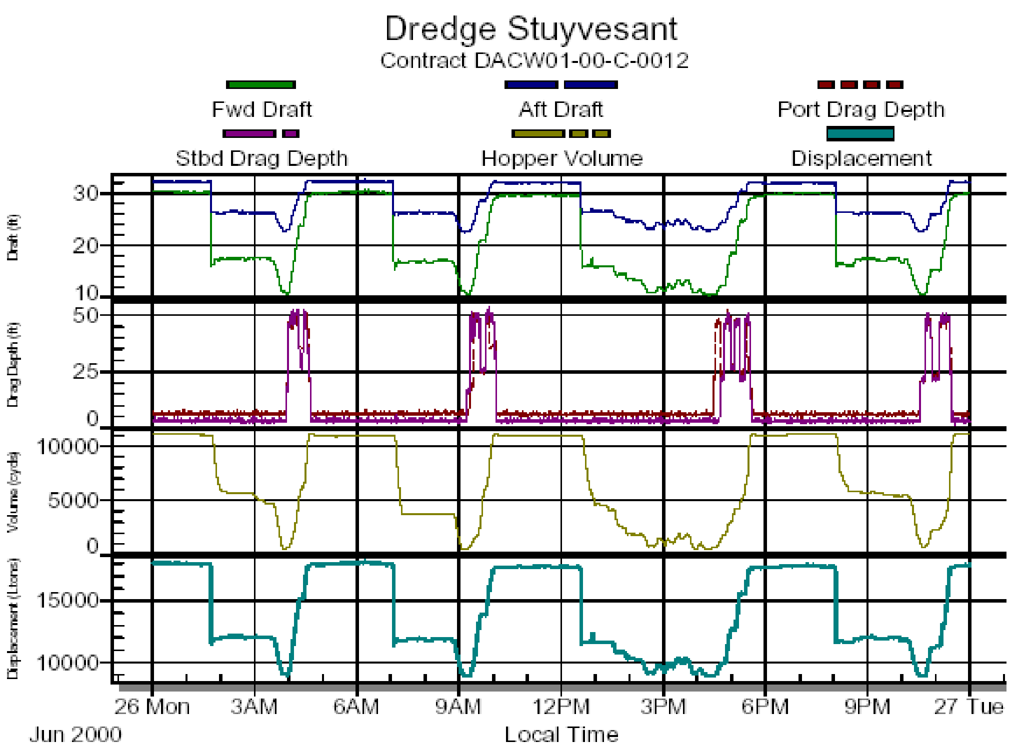


FIGURE 3.6 Plot example (top to bottom: draft, drag depth, volume and displacement).

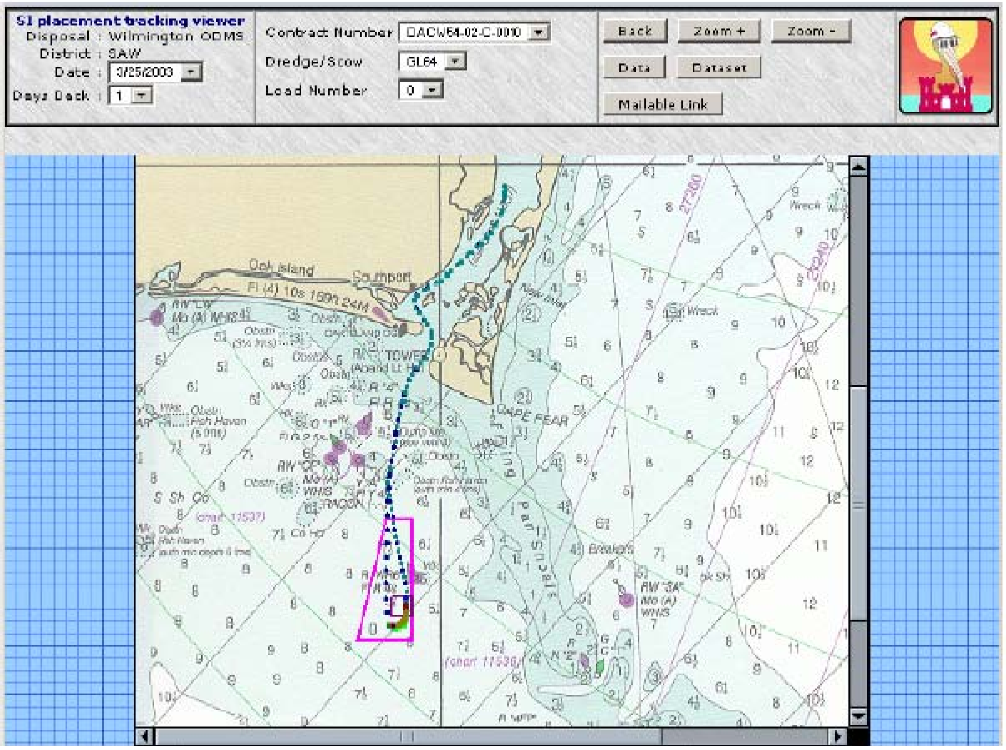


FIGURE 3.7 Dredge track plot.

The standard for monitoring turbidity levels around dredging operations in a spatially and temporally comprehensive manner is with Acoustic Doppler Current Profiler (ADCP) (Land et al., 2004; ERDC-TN-DOER-E15). The ability to get a full water column description of turbidity levels along transects through plumes provides the ability to build a full understanding of the morphology of dredge plumes.

Remote sensing approaches such as air photographs and satellite images can be analyzed to map surface turbidity, however, this water-surface-biased measure of plumes can be misleading and misrepresentative of the actual extent of the plume and sedimentation footprint, particularly with the advent of under hull discharge of overflow sediment. Evans (1994) utilized SPOT images to observe sediment dispersion at the Pearl River and describes the use of color air photography for the evaluation of dredging plumes. Optical instruments only provide a measure of turbidity at a single location. Some laser approaches (such as Laser In-Situ Scattering and Transmissometry or LISST) can provide a description of turbidity through the water column though with a smaller range than acoustic techniques such as ADCP (Gartner et al., 2001).

After conducting a monitoring study of large-scale dredging activities in Hong Kong, it was determined that benthic productivity had not been significantly altered (Evans, 1994). One of the technologies applied in the evaluation of dredge impacts included the application of REMOTS (Remote Ecological Monitoring of The Seafloor), which is an instrument that samples the first 20 cm of seabed for sediment characteristics and biological parameters (Ocean Imaging Systems, 2004). This approach in the US is known as Sediment Profile Imaging (SPI) and consists of a prism that is pushed into the seabed to take an image of the vertical profile immediately below the bed (see Cutter and Diaz, 2000; Cutter et al., 2000). This approach has been recommended as part of the Benthos and Fishes Trophic Transfer Protocol for the MMS Physical and Biological Monitoring Profiles for offshore dredging projects (see Nairn et al., 2004; Research Planning, Inc. et al., 2001).

3.6 Summary of the Literature Review

The primary focus of environmentally friendly developments in the dredging industry has been on a reduction of turbidity levels associated with the dredging process. Most recent developments in this area have been driven by contaminated sediment remediation projects where the sediment is mostly fine-grained and located in nearshore areas. Of these, the developments have mostly focused on modifications to dredge cutterheads to significantly reduce the generation of turbidity at the bed. However there have also been developments related to hopper dredges operating in offshore areas, and these have mostly stemmed from: 1) a need to reduce turbidity levels to address regulatory agency concerns and simple visual perception of impacts; and 2) the trend towards much larger hopper dredges to serve very large land reclamation projects.

Other specific environmental impacts that have been addressed through modifications to dredge equipment include the development of turtle deflectors for TSHDs in order to minimize the potential for turtle takes. This area of development is the current focus for a comprehensive program by the USACE DOER program.

As part of this review, a range of turbidity levels for different approaches and conditions has been compiled based on the work of Pennekamp et al. (1996) and Whiteside et al. (1995). The data from these articles are combined and summarized in Table 3.1. Pennekamp (1997) reports that the dredging equipment is not the primary variable in turbidity levels but instead the key variables are: sediment type; hydrodynamic conditions; and the operators and dredging technique application.

Referring to the discussion in Section 2.4 of this report, it is recalled that the primary focus of this assessment of environmentally friendly approaches to dredging is on the following impacts (in order of priority as established through discussions with resource managers in the US): 1. loss of benthic habitat; 3. changes to substrate characteristics; 5. sedimentation and burial of sensitive habitat; and 7. short-term increases in turbidity. Once again it is noted that other impacts are being or have been addressed by MMS and USACE studies. Of these specific concerns, it has been determined from the literature review that most focus has been on Impact 7 (turbidity) and to some extent its related Impacts 3 and 5 (changes to sediment characteristics and sedimentation). No specific information was found on environmentally friendly approaches to address Impact 1, the loss of benthic habitat, aside from monitoring approaches to assess the form (or quality) and rate of recovery.

Table 3.1 Summary of turbidity generated by different dredge types taken from Pennekamp et al. (1996)[1] and Whiteside et al. (1995)[2].

Dredge type[1]	Sample site	Production rate (m^3/hr)	Background turbidity mg/l	Depth averaged turbidity increase (C) mg/l (on the edge of a 50 x 50m area from dredge point)	Collapse time (T) hrs	Volume of re-suspended water bed material (S) kg/m^3
Large TSHD	Rotterdam	5,500	75	400	1	14
Large TSHD	Rotterdam	5,400	40	150	1	3
Small TSHD (current =0m/s)	Delfzijl	1,750	60	10	0.5	1
Small TSHD	Rotterdam	2,170	23	60	1	8 - 22
Small TSHD (current 0.2m/s)	Delfzijl	1,750	70	20	1	5
Pneuma dredge system	Berghaven Harbour	59	25	0	0	0
Dragline with open clamshell	Rotterdam	90	20	35	1	3
Dragline with open clamshell and silt curtain	River Nieuwerkerk	84	35	35	1	1
Dragline with watertight clamshell	River Nieuwerkerk	166	35	100	1	19
	Zierikzee	220	50	90	1	11
	Rotterdam	121	20	80	1	13
Dragline with watertight clamshell and silt curtain	River Nieuwerkerk	102	35	20	1	3
	Zierikzee	204	50	105	1	11
Environmental disk cutter	Berghaven Harbour	113	25	0	0	0
Auger	Delfzijl	300	20 - 50	0	0.5	0
Siltcutter dredge	Heusden	115	45	10	0.5	2
Water injection dredge	Hellevoetsluis		20	30	0.5	
Prototype water injection dredge	Rotterdam	3,200	45	250	1.5	11
Bed leveler	Rotterdam	610	35	60	1	6
Dredge type [2]	**Sample site**	**Production rate (m^3/hr)**	**Background turbidity mg/l**	**Depth average silt concentration at T=10min**	**Depth average silt conc. at T=30 min**	**Depth average silt concentration at T=60 min**
TSHD (8,255 m^3)	Po Toi Hong Kong (1)		13	65	20	13
TSHD (8,255 m^3)	Po Toi Hong Kong (2)		13	55	20	20
TSHD (8,255 m^3)	Po Toi Hong Kong (3)		13	28	15	9

4.0 DREDGING INDUSTRY REVIEW

4.1 Introduction

In order to determine the current state of dredging equipment and dredging techniques relative to reducing the impacts enumerated in Section 2, a dredging industry review was completed. Dredging publications that annually list the companies that own dredging equipment were reviewed. The Dredging Contractors of America was contacted to obtain a list of contractors that were in the beach nourishment business and recent bids for beach nourishment projects were reviewed. This investigation produced the names of four contractors able and willing to undertake beach nourishment projects. These contractors had a great deal of experience in beach nourishment projects on the East and Gulf Coasts of the United States, the regions under consideration in this study.

As part of the industry review, European dredge contractors were also contacted. It was thought that perhaps the contractors would reply to a questionnaire with more interest if it originated from an organization based outside of the US. Most dredging projects in the US require the dredge hull to be fabricated in the US and the dredging company must be controlled by US owners. This eliminates foreign companies from the US beach nourishment work. However, we have in the past found several foreign dredging companies to be very helpful. The Minerals Management Service agreed to form a liaison with a foreign entity that was interested in the environmental aspects of dredging marine aggregates. Our study partner, Dredging Research Ltd. (DRL), was tasked with selecting a suitable organization that was involved in the aggregate mining or beach reclamation work outside of the United States.

Once the sponsor organizations were identified, a questionnaire was developed with input from all team members. The questionnaire was then sent to each of the identified dredging companies in the US and Europe. Responses were received from most and follow-up calls were made to clarify responses. The keen interest shown by two of the US dredging contractors (Bean Dredging LLC and Great Lakes Dredge and Dock Company) lead to their participation in the workshop segment of the study (see Section 5 for further details).

4.2 Selection of a European Partner

The Mineral Industry Research Organization (MIRO) is the pre-eminent international provider of collaborative research project management to the minerals and related industries. MIRO, based in the United Kingdom, works in partnership with industry, government, research and service providers to identify, influence, fund, transfer, deliver, and communicate information and relevant, innovative research and technology development to address the needs of stakeholders in the sector. MIRO’s role contributes towards improved communication, safety and environmental performance at all stages of the materials life cycle, meeting the challenges of sustainable development and increasing the positive image of the minerals sector.

MIRO was selected to send out a questionnaire to European dredging companies because they were, concurrently with MMS's project, implementing a research project entitled "Best Practice Guide to Assessing the Impacts of Aggregate Dredging". This work was being funded through the UK's Sustainable Land Won and Marine Dredged Aggregate Minerals Programme, which is an aggregate minerals research program established under the terms of reference of the Aggregate Levy Sustainability Fund (ALSF), and implemented by the Office of the Deputy Prime Minister. It was considered that the European contractors would be more amenable to providing information to a European/UK industry supported organization and research initiative, than directly to a US governmental organization in a market place to which they only have indirect access.

4.3 Development of a Questionnaire

An extensive and detailed review of the perceived environmental impacts of dredging together with a literature review of environmentally-friendly approaches to dredging were undertaken as summarized in Sections 2 and 3 of this report, respectively. These reviews allowed us to frame the questions in a manner that would produce thoughtful answers from the dredging contractors. The questions for the most part can be grouped into three broad categories: 1) plume related impacts, 2) impacts to benthic habitats, and 3) impacts on marine mammals. There are a few additional concerns that fall outside these three groups, such as impacts to marine structures or archeologically important sites or conflicts with commercial and recreational fishing.

It was decided to send out two questionnaires, one to companies primarily working in the US and the second to companies working outside of the US. The questions are essentially the same with some changes in wording for companies whose primary business is outside of the US. The Mineral Industry Research Organization's membership has many companies whose business is the offshore mining of aggregates by hopper dredge.

As discussed above, the perceived concerns of researchers and staff from Federal and State resource agencies in the US were prioritized. These were concerns regarding the effects of dredging on the marine biological and physical resources. The focus was on dredging on the Outer Continental Shelf for beach nourishment and land reclamation, and potentially for aggregates. This list has been updated with information contained in stipulations for recent offshore leases.

The concerns were prioritized under twelve headings as described in Section 2 of this report. The questions based on these concerns were phrased to obtain information on the operational restrictions that the dredge is currently working under. The questions were targeted to elicit general and specific information that would be applicable to a wide range of possible dredging scenarios relative to environmentally friendly dredging equipment and procedures. The List of Questions is provided in Appendix C. This appendix includes the cover letter to US contractors (C.1), the questions posed to US contractors (C.2) and the questions sent out to European contractors under the auspices of MIRO (C.3).

The questionnaire was sent to the four largest U.S dredging companies. These companies are equipped to dredge sand in the ocean waters of the Outer Continental Shelf. Each has done beach nourishment work. They are all interested in doing beach work in the future. We also sent the questions to the US Army Corps of Engineers. The Corps owns several hopper dredges although they do not normally provide sand for beach work that has been dredged from the OCS, however, they do administer many of the contracts associated with beach nourishment in the US.

Our study partner, Dredging Research Limited , arranged to have the joint MMS-MIRO foreign version of the questionnaire sent by MIRO to its members. Initially five general dredging contractors received the document and three of these responded, being Westminster Dredging (BosKalis), Dredging International Ltd and Ballast Ham Dredging, all subsidiaries of major European dredging contractors. The last of these responded somewhat briefly as they were at the time in the throes of being taken over by VanOord. Jan de Nul, who's international division had supplied some useful information to the US team in the early days of the study, declined to answer the questionnaire on the basis that they were not interested in aggregate dredging in the UK.

Subsequently, the UK questionnaire was also sent to the main commercial aggregate dredging companies, all of which are subsidiaries of mining and construction materials groups. None of these responded. However, extracts from the MIRO research project relating to the environmental effects of aggregate dredging have been received and these have been approved by BMAPA, the organization that represents the major marine aggregate extraction companies.

4.4 Review of Responses

Overall the responses by the dredging contractors, both US and foreign, were very similar. All four US companies and the Corps of Engineers plus several foreign companies responded. One US Company, Great Lakes Dredge & Dock Company, gave very detailed answers to many of the questions including examples. The Belgian company, Jan de Nul, supplied an explanation of the "anti-turbidity valve" and the "green pipe system" with graphics, two of the more popular and innovative methods of controlling turbidity by equipment modification.

A matrix of the questions and the answers given by the four US companies, two foreign companies and the Corps of Engineers is provided in Appendix C.4.

4.4.1 Discussion of Responses to Plume Related Impacts

This section summarizes the responses received from the various dredging contractors as they relate to potential plume impacts.

There are several equipment groups that can be used to mine and deliver sand. Under the great majority of circumstances the actual mining of the sand on the OCS will be done with a Trailing Suction Hopper Dredge. This is because the typical distance between the borrow area and the beach area makes the hopper dredge the most economical equipment. The hopper dredge also works best in the relatively rougher sea and swell conditions offshore. Figure 4.1 is a schematic drawing representing beach nourishment scenarios where the numbers represent the following dredging equipment combinations:

1. Cutter suction dredge pumping direct to shore;
2. Cutter suction dredge loading barges with pump out to shore;
3. Cutter suction dredge loading barges pumping in front of second cutter suction dredge;
4. Trailing suction hopper dredge digging and unloading through a booster pump to shore;
5. Trailing suction hopper dredge dumping in front of a cutter suction dredge for rehandling to shore;
6. Clamshell dredge loading barges for pump out to shore;
7. Clamshell dredge loading trucks;
8. Trailing suction hopper dredge dumping near shore;
9. Trailing suction hopper dredge pump out to shore;
10. Trailing suction hopper dredge "rainbowing" to near shore;
11. Cutter suction dredge loading barges for dumping near shore;
12. Cutter suction dredge pumping through a spill barge for near shore placement.

The most likely dredging approaches for beach nourishment sand in an OCS borrow area are Number 4, where the hopper dredge digs the sand and pumps the sand to the beach through a booster and Number 10, where the dredge "rainbows" the material to the beach. Approaches 8 and 9 where the hopper dredge dumps or rainbows the sediment near the shore are also a possibility, however, these approaches have not had widespread use in the US. There may be some instances where a Cutter Suction Dredge may be implemented, pumping sand to shore through a pipeline (Number 1 in Figure 4.1).

In order to understand the terminology in the questions and answers to the contractor's questionnaire, Figure 4.2 provides a sketch of an operating hopper dredge. The hopper dredge dragheads loosen the sand and convey the sand/water slurry to the onboard pumps that discharge the material into the dredge's hopper. Some of the material settles into the hopper and some of the sediment is overflowed back into the water, in this case, through the hull below the keel.

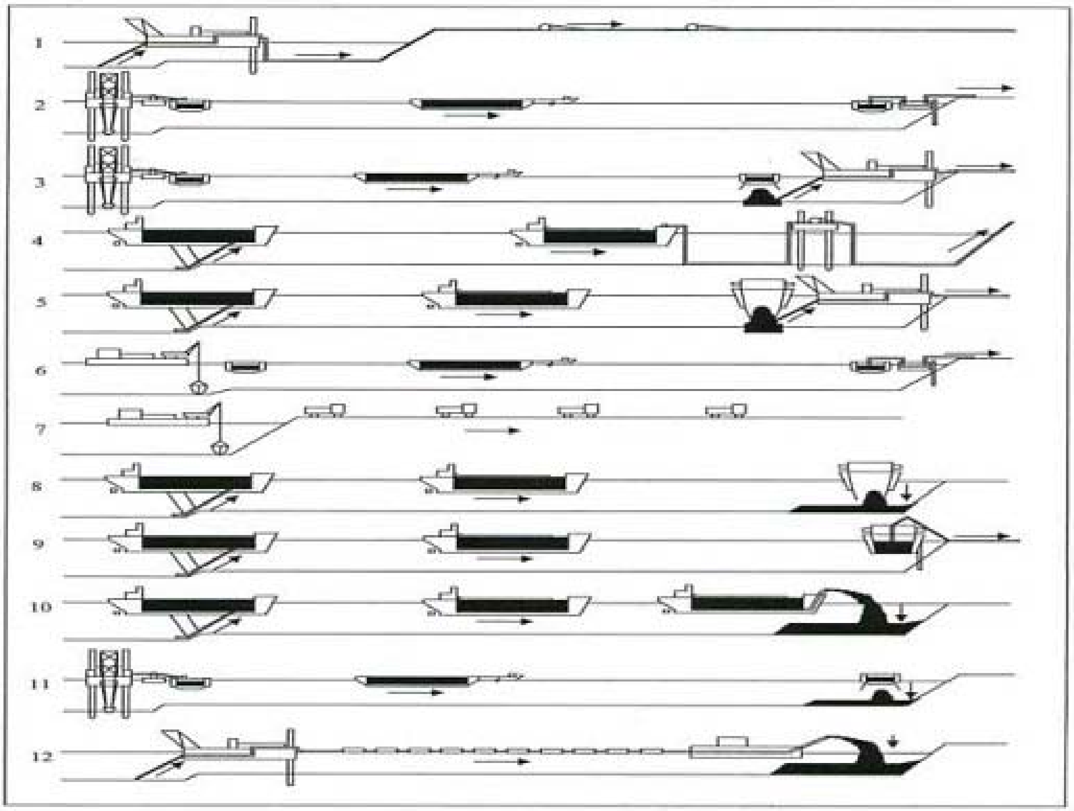


FIGURE 4.1 Beach nourishment scenarios using different dredging equipment combinations (from Randel and Koo, 2003).

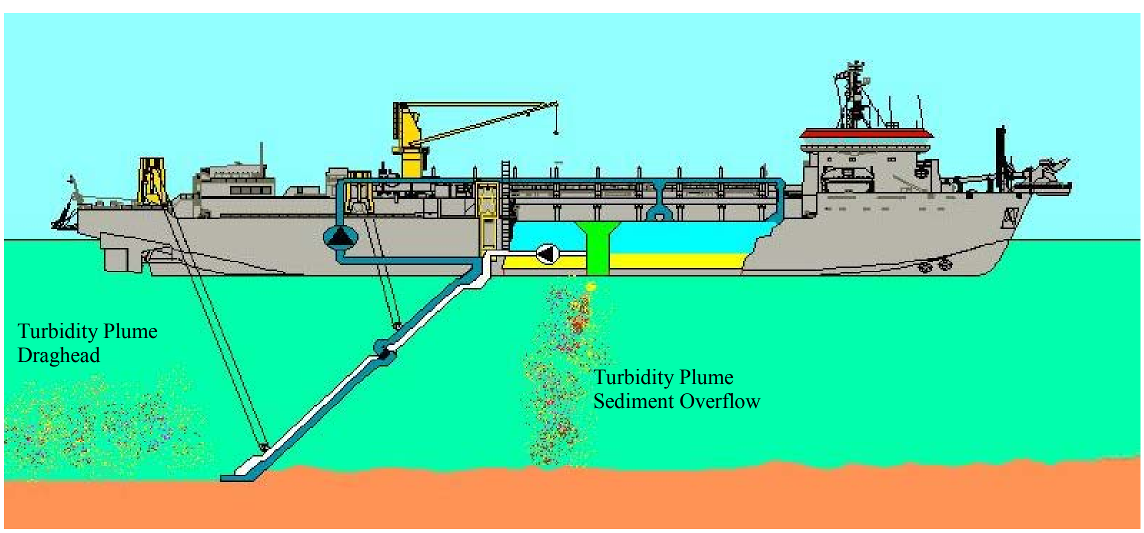


FIGURE 4.2 Hopper dredge in operation showing the sediment overflow and draghead plumes (from Jan de Nul – See Appendix C5).

Unless there are restrictions regarding overflow, the dredge will continue to load sand until it reaches its economic load. The economic load is the relationship of the loading time versus the loading rate versus the overall cycle time of the dredge. In other words, if the sailing (hauling) distance is great, it is usually economically justified to spend extra time loading sand and overflowing finer particles. A very small percentage of fines below the #200 sieve (i.e., D50 less than 0.06 mm) would be retained in the hopper, when a hopper dredge is mining sand on the OCS. The percent of material that overflows the hopper is greatly dependent on grain size of the material and the percent of fines. The percent of material that can overflow the hopper can vary widely even in the same borrow area.

Fines that are lost to the sea through overspilling tend to fall to the seabed as a density current initially, which generally decays into a passive plume that is moved by the ambient currents. Recent observations suggest that a high proportion (85-90%) of the total material overspilled in sand dredging operations is not incorporated into the passive plume and, thus, never leaves the proximity of the dredging site.

There has been considerable research into settlement in - and overflow from - the hopper of a hopper dredge. Recent research conducted by Ooijens et al. (2001) into hopper settlement using large-scale modeling has been used to clarify the hydrodynamic flow processes in the hopper. The researchers constructed a test rig, scaled down from a working hopper dredge. Their test series showed a process comparable to the measurements taken on board a hopper dredge during actual dredging conditions. This test rig provides an opportunity to improve hopper design parameters and to develop mathematical models to improve the performance of hopper dredges. The rig will also make it possible to test different hypotheses that can't be tested with available techniques.

One concern posed to the dredging contractors was the ability of a TSHD to strip an overlying area of fine sediment to expose an underlying sand deposit. Borrow areas are not normally chosen that have a significant amount of silt overburden. It may be possible to dredge sand below a silt layer but this would be highly dependent on the nature of the silt. It may be that a cutter suction dredge will be more suitable for a borrow area condition with significant overburden or stripping the area of overburden first with confined disposal of the silt.

Normally, dredging sand for beach nourishment from an OCS borrow site does not produce increased turbidity (i.e., exceeding the background levels) over the often-applied State of Florida 29 NTU standard. This is, however, highly dependent on many factors. Timing and location of sampling, dilution zone, wind and currents, color of the silt, and chemical composition (carbonates) of the fines all influence the turbidity of the overflow. The amount of fines in the overflow will increase if an attempt is made to recover sand below a layer of fine material. Turbidity from a hopper dredge overflow can be regulated by limiting the overflow, to zero, if necessary. It is unlikely a "no overflow" condition would be required in an OCS borrow site, as this could have significant impact on the cost of dredging the sand. There are dredge systems that recycle some of the overflow water and this will be discussed later in Section 4.6.2. Also discussed later in Section 4.6.1 is the anti-turbidity valve that reduces the air entrained in the overflow. This air causes the turbidity to rise to the surface. It is now standard practice to discharge overflow through the bottom of the hull. The dredging companies, in their responses, were concerned that there is a perception that reducing turbidity is always important. However, the resource agencies did not rank this concern at the top of the priority list of impacts for most OCS borrow sites (see Section 2).

The layout of the borrow site can have an influence on dredging procedures. It may be possible to influence the shape and dispersion of the dredge plume but certain parameters of the dredging process itself must be taken into account. The dredge operates best if it is moving parallel to the wind, waves, or current. This minimizes the rolling of the dredge and loss of bottom contact with the dragheads. In the extreme, requiring a dredge to work perpendicular to the sea/wind/current may cause conditions where the draghead would slip under the dredge causing an unsafe condition. The best shape for a borrow area, all things being equal and geologic conditions being relatively homogenous, is for the area to be set out with the primary dredging direction parallel to the major wind, waves, and current. Dredging companies do not have much data relative to the patterns of sedimentation of material discharged by the dredge. The company's means of making such a measurement is restricted to sounding techniques.

4.4.2 Discussion of Responses to Impacts to Benthic Habitats

There was considerable concern among the stakeholders relative to the loss of benthic community; this was the highest ranked impact (see Section 2). Re-colonization rates are being studied, as are changes in the substrate characteristics such as grain size, dissolved oxygen, etc. that result from dredging operations. It has been suggested that dredging in patterns may speed the re-colonization rate by leaving areas that have undisturbed sediment characteristics and undisturbed benthic communities.

The dredging companies were asked - If dredging in zones proved effective in increasing the rate of re-colonization, what dredging parameters should be considered? The dredging contractors thought a dredge area, a minimum of 100 to 200 m wide by 2000 m long, would be acceptable to the dredge operator. Preferably, the borrow areas would be oriented in a direction parallel to the main wind, wave, and current direction. The contractors did not have firm policies on zone dredging but seemed amenable to this as a possible solution. Some of the contractors work in a modified zone in order to manage the borrow area resources. Several contractors mentioned the "Sandpit" study currently underway in Europe.

The contractors sidestepped the issue of specific known damage to hard bottom areas but these damages are known to have occurred. Everyone agrees that buffer zones should be established around hard/live bottom areas. The buffer zones may need to be determined on a case-by-case basis. The dredging industry has documented several times their ability to track their dredges in real time including the ability to track in x, y, z the positions of the dredge's dragheads (included in their responses to the questionnaire). At times, the Corps of Engineers independently tracks contractor dredges on projects with the use of their Silent Inspector System. Figure 4.3 provides a screenshot of the dredge operator's display from the Liberty Island TSHD. The MMS has recently developed a new stipulation for tracking dredge positions (See Figure 4.4).

There has been some interest on what the bottom of the sand borrow area may look like after dredging has been completed. Figure 2.3 provides an after dredge survey cross section of beach nourishment borrow area.

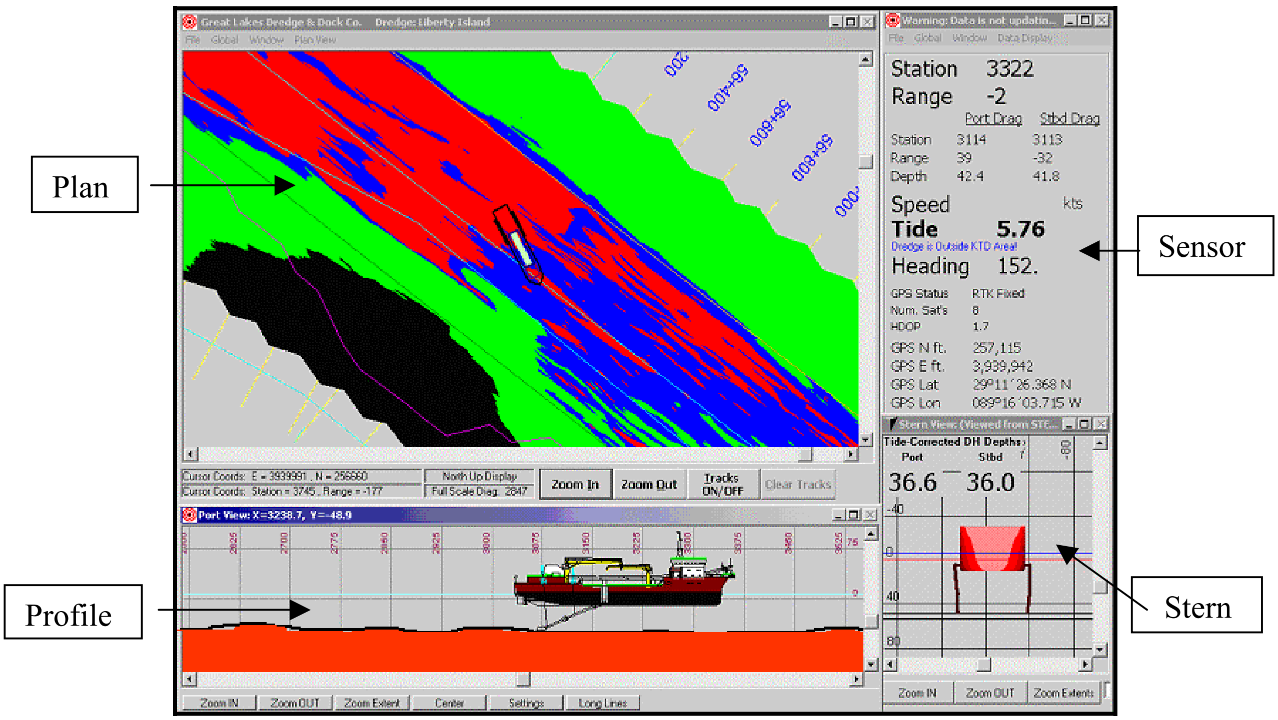


FIGURE 4.3 Dredge operators display from the Liberty Island TSHD (courtesy of Great Lakes Dredge and Dock Company).

Although the bottom looks rough in this section, we must note the horizontal scale is more than 12.5 times the vertical scale. The latest tracks would be visible and parallel. A typical track may be 20 feet wide and 3 to 4 feet deep. It is possible to flatten the bottom further by using navigation dredging techniques but there would be additional cost for this refinement. Depending on site conditions, the bottom will tend to smooth as a result of waves and currents. Survey data are relatively easy to collect because normally the dredge is tended by a survey vessel. Therefore, wherever possible, it is recommended that high resolution (multi-beam acoustic is preferable to fully describe the seabed topography) bathymetry data be collected and delivered to MMS as suggested in the proposed Monitoring Protocols (see Research Planning Inc. et al, 2001).

STIPULATION NO. – Use of Electronic Positioning System on Dredge and Transmittal of Location and Production Information to the Lessor

Use of Electronic Positioning System and Transmittal of Location Information to MMS:

In order to ensure the accuracy of the dredge relative to the borrow area specifications denoted in this lease agreement, during all phases of the offshore operation conducted within the borrow area, the Lessee will ensure that the dredge is equipped with an on-board differential global positioning system (DGPS) capable of maintaining and recording the location of the dredge within an accuracy range of no more than plus or minus 3 meters. The specific system will be approved by the MMS prior to the conduct of any dredge procedures within the borrow area.

Location information (latitude and longitude) in NAD83 must be supplied to the Chief, MMS Leasing Division (MMS-LD) on a daily basis. The information should be sent to the following email address: dredgeinfo@mms.gov.

Submittal of Production and Volume Information to MMS:

The Lessor has a legal responsibility to ensure the accuracy of cut depths and widths, cut slopes and site production (sand volumes removed) within the borrow area as specified in the project's operational plan and this lease agreement. This information is routinely collected continuously throughout the period of dredge operation at a borrow site. The Lessor shall retain all access rights to all operational data at any time during which dredging is occurring within the designated Federal borrow area.

A "certified" summary of all operational, production, and survey activity data will be submitted to the Chief, MMS-LD on a weekly basis, in a format and method agreed t between the Lessor, the Lessee, and the dredge operator prior to the commencement of operations at the borrow site. Any maps and/or profiles submitted to the Lessor will be provided in digital spatial format compatible with ArcGIS. Information pertaining to the volume of material removed must be provided with explanatory text outlining each preceding day's activities and production values.

Following completion of all activities within the lease area, the Lessee, in cooperation with the dredge operator, shall submit to the Lessor, a "certified" copy of the complete operational data set (dredghead tracklines, cut slope angles, cut depth, etc.), outlining any deviations from the original operational design plan. This report should be in MS Word format and can be sent to Ms. Renee Orr, Chief, MMS Leasing Division, 381 Elden Street, MS 4010, Herndon, Virginia 20170, or by email to dredgeinfo@mms.gov.

FIGURE 4.4 New MMS stipulation on tracking dredge position.

4.4.3 Discussion of Impacts to Marine Reptiles and Mammals

The impact of dredging, particularly hopper dredging, to marine reptiles and mammals is a concern of resource agency managers, especially for sea turtles. This impact has been studied and mitigation measures have been employed for many years. The Corps of Engineers, in concert with the dredging industry, has developed a draghead turtle deflector device specifically designed to reduce the "takes" of sea turtles. Reportedly, the use of this device along with a set of operating requirements has reduced the incidence of sea turtle takes. The main requirement is that the draghead must be in contact with the bottom while pumping. Most dredging companies rely on the swell compensator to maintain contact between the draghead and the bottom. The operating requirements stress the need to balance the suction pipe velocities and densities in order to keep from taking sea turtles. One of the dredging companies suggested that it would be relatively easy to redirect flow away from the draghead when it comes off the bottom but also expressed doubt that this would reduce sea turtle takes. The dredging contractors have not encountered sea turtles in the vicinity of offshore borrow areas. The dredging contractors, also, have not experienced any dredge collisions with marine mammals.

In addition to the turtle deflector device, there are also seasonal restrictions on when dredging can take place that result in the specification of environmental windows. The Corps of Engineers generally restricts dredging in channels and harbors to the months of December through March, from North Carolina to the tip of Florida. This restriction may be expanded both in duration and geographic area.

Seasonal restrictions can, and at times do, cause dislocations in the hopper dredging market. This can lead to short-term price increases due to unavailability of equipment. These restrictions can also cause projects to be terminated before they are completed due to the contractor having difficulties that push completion dates past the dredging window. Currently, the seasonal restrictions apply to channels and harbors. Forcing additional work into the worst weather conditions causes marginal increase in prices. If this restriction should be applied to beach work, the weather risk will be magnified due the need to shift discharge pipelines in relatively calm weather. The Corps of Engineers is doing further studies on the effectiveness of seasonal restrictions. It seems that from the direction these studies are going, there may be a decrease in restrictions and a greater emphasis on monitoring.

Observers on dredges don't seem to reduce the sea turtle takes. All the US dredging companies thought trawling was an effective method for reducing sea turtle takes.

4.4.4 Discussion of Miscellaneous Issues

The contractors provided responses to additional miscellaneous questions regarding the dredging process.

The contractors didn't think that conflicts with fishing companies were significant and conflicts can be resolved through the permitting process and any mitigation measures agreed to at that time.

Once the location of a marine structure or archaeological site is located (typically by the owner), the location can be integrated into the dredge operator's display as an avoidance area. A plan is developed to avoid such structures or sites. In Europe, the standard security zone is 500 m on either side of the structure. Projects in areas of potential archaeological resources warrant extensive pre-dredging investigation to determine the precise location of these structures.

The contractors acknowledged that dredging might have adverse impacts on the environment. They expressed the desire to cooperate with all concerned parties to mitigate, minimize, or eliminate these impacts. They also cautioned against over-regulation without scientific need or practicality. In talking to the regulators and the dredging companies, it seems that the whole process is moving toward increased monitoring and decreased or at least more selective regulation.

4.5 Follow-Up Conversations with Dredge Contractors

After the initial review of the contractor's responses, we contacted the US contractors to ask for clarification of some responses and get additional detail. We invited all four of the US contractors to attend a Study Workshop held in Washington. The other invitees included MMS and the Corps of Engineers. There was spirited discussion of all the issues at the Workshop, and the contractors provided valuable commentary. Details on the outcome of the Workshop are presented in Section 5.

Follow-up discussions of a general nature were held with some of the European dredging contractors. It was clear from these that generally the contractors are reactive in a highly regulated market that was somewhat different from the US scene. Much of the aggregate dredging is for gravels rather than sand, and the fines content of these zones is typically low (less than 5%). Marine reptiles and mammals are not perceived to be a problem, as they are rare in these waters, and fisheries concerns are dealt with during the statutory licensing procedures. Much of the knowledge held and research into benthic impact of such operations in the UK is to be found at CEFAS (Centre for Environment, Fisheries and Aquaculture Science), whose publications have been reviewed during this project.

4.6 Discussion of the Anti-Turbidity Valve and the Green Pipe

The dredging company, Jan de Nul of Belgium, sent us graphics that explain the Anti-Turbidity Valve and the Green Pipe System. A more detailed description of these approaches and the information provided by Jan de Nul is included in Appendix C.5. These two mechanical systems are the most noted in the literature for large-scale environmental turbidity control systems.

4.6.1 Anti-Turbidity Valve

Figure 4.5 presents the sketch of the anti-turbidity valve. With the standard dredge overflow, a large volume of air is mixed with the water and sediment due to the high fall height. Below the bottom of the dredge, a density stream of heavier particles moves down while an upward air stream occurs. This causes considerable turbulence and increased spreading of the dredge plume.

When the dredge system includes an anti-turbidity valve, the valve chokes the overflow, which prevents air being mixed with sediment and water leaving the hopper. Essentially, this keeps the overflow pipe completely full, reducing the fall height of the spoil, minimizing the amount of air entering the spoil. This minimizes the turbulence, reducing the visual plume. It is noted that both the size of the plume and the total amount of sediment in the plume are reduced through this device (see Appendix C.5). Most of the contractors think that this is an effective improvement to reduce turbidity and many indicated it is often applied on dredges now.

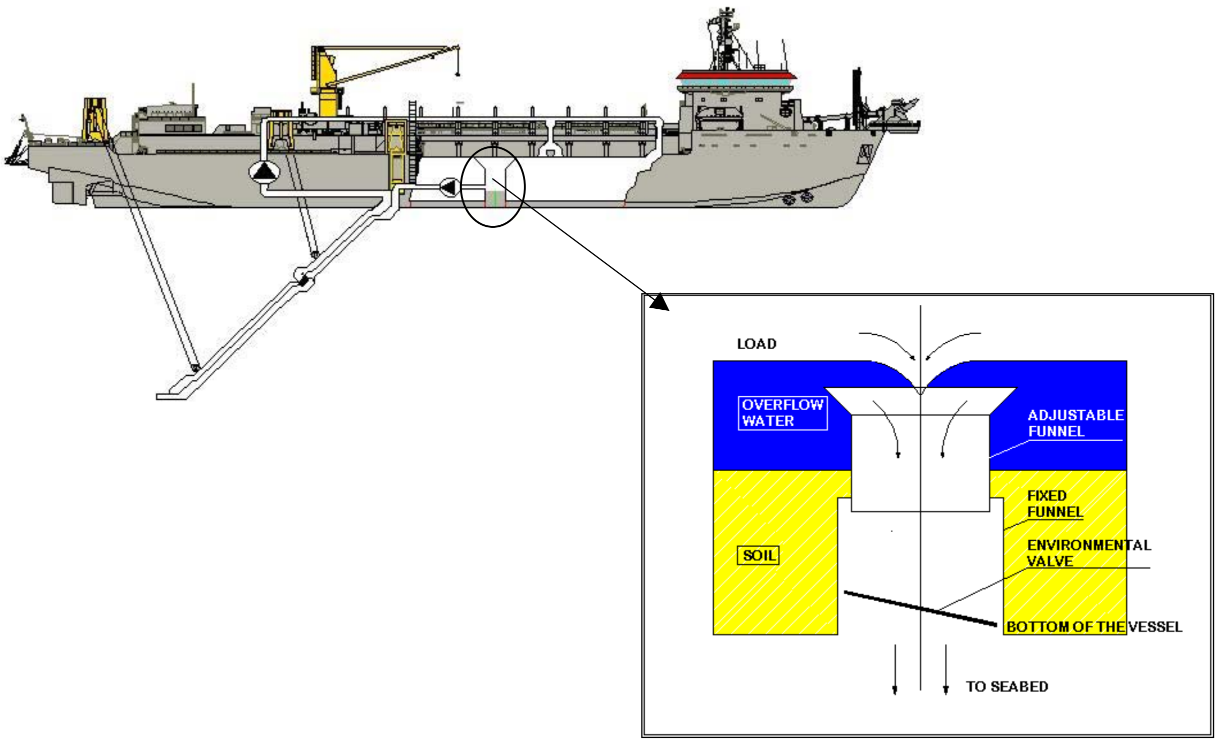


FIGURE 4.5 Sketch showing the Anti-Turbidity or Environmental Valve (courtesy of Jan de Nul – see Appendix C.5)

4.6.2 Green Pipe System

The Green Pipe System utilizes a second pipe system that recycles the overflow water back to the draghead (see Figure 4.6). The water is recycled through the suction head as process water. Using this system, less overflow drops through the water column. This approach is discussed in more detail in Section 3.2 on the literature review.

There were several foreign hopper dredges built in the late 1990s that incorporated the Green Pipe System in their design. Recently built dredges have not included this feature. The US contractors did not have any experience with recycling the water in this manner. They cited large capital costs and increased maintenance cost without a clear benefit to the environment, particularly in dredging sand on the OCS. The European contractors hold a similar view. The green pipe has been available for use on TSHDs for a number of years now and nobody appears to have observed it being used on a project. The general opinion seems to be that it increases energy demand and equipment cost, yet does little in the way of reducing the total amount of fines lost. In addition, due to the low fines nature of many of the European marine dredging sites, there is little call for its use.

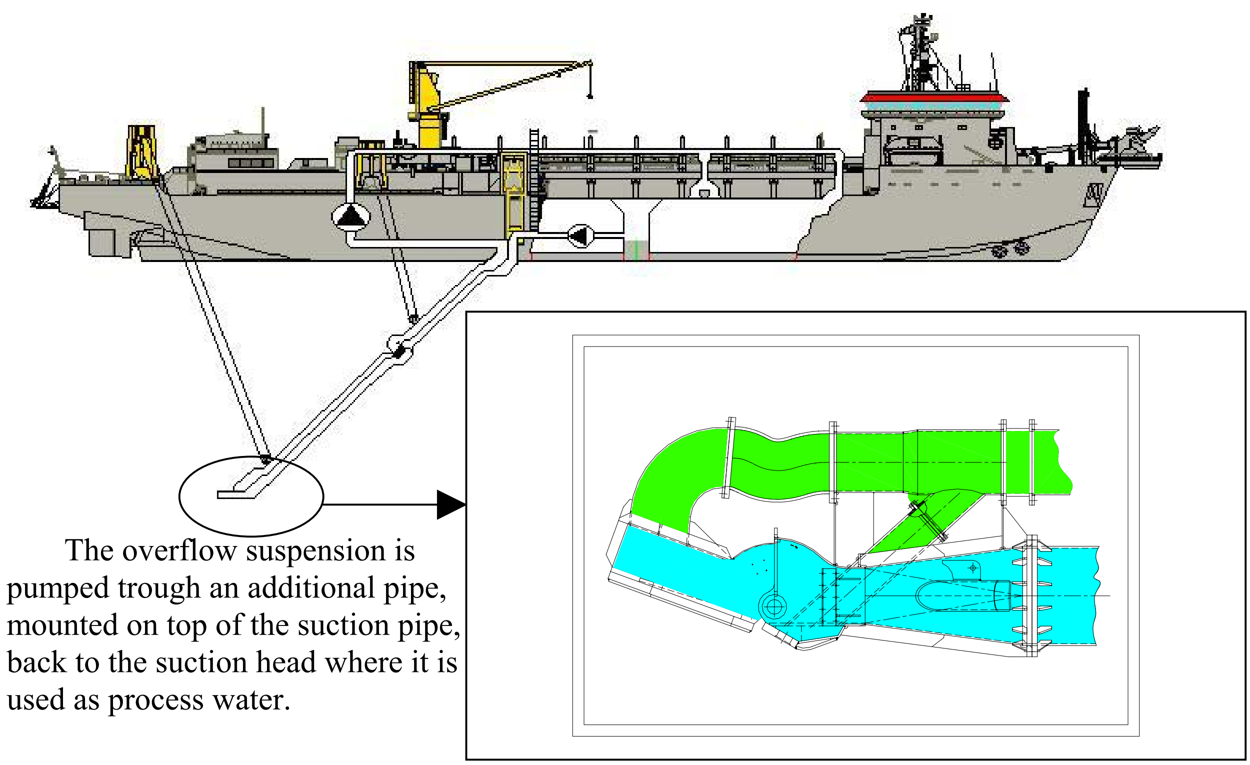


FIGURE 4.6 Sketch showing the "Green Pipe" approach (courtesy of Jan de Nul – see Appendix C5).

5.0 ANALYSIS OF ENVIRONMENTALLY FRIENDLY TECHNOLOGY

5.1 Introduction

Section 2 of the report presented a description and discussion of the key ecological impacts of offshore dredging. A prioritized list was developed and specific impacts that were not being evaluated as part of other ongoing MMS or USACE projects were selected for further detailed investigation under this study.

Sections 3 and 4 of the report presented a summary of the existing and emerging environmentally friendly equipment and approaches as identified from the literature and industry surveys.

The next step was to convene a workshop to evaluate the range of environmentally friendly equipment and approaches for the various targeted impacts. In addition, the workshop provided an opportunity to develop and discuss new approaches that may help address the key impacts of concern designated for consideration under this study.

This section provides a summary of the workshop approach (Section 5.2) together with the findings of the workshop on the evaluation of identified and new equipment and approaches (Section 5.3).

5.2 Workshop Approach

The workshop was organized specifically to consist of a limited number of people to ensure active participation by all attendees. Together with the consulting team, approximately 20 people participated in the workshop (the invite letter and the list of participants are included in Appendices D.1. and D.2, respectively). There were representatives from the USACE (ERDC and District offices), MMS staff, other consultants to the MMS, and US dredging contractors.

Input from the natural resource agencies (e.g., USFWS, NOAA Fisheries, State Fish and Wildlife agencies) on their concerns associated with the potential impacts of OCS sand borrow site dredging was solicited prior to the workshop. In fact, the prioritized concerns of the resource agencies formed the framework for the workshop discussions among the dredging experts. Key resource managers were asked to comment on the detailed minutes of the workshop, as a preliminary review of the workshop results. All review comments were positive.

The workshop was held on April 1 and 2, 2004 in Herndon near the MMS offices. An agenda for the workshop is included as Appendix D.3. The morning of the first day of the workshop consisted of presentations on information presented in Sections 2, 3 and 4 of this report. This provided a context for the workshop and focus for the specific impact that would be reviewed. The Powerpoint presentation given on the first morning is included as Appendix D.4 to this report on a CD.

The workshop was organized specifically to address existing, emerging and possible new environmentally friendly approaches to each of the targeted impacts of concern. Most discussion was focused on the targeted concerns defined in Section 2.4 and repeated below:

1. loss of benthic habitat;
3. changes to substrate characteristics;
5. sedimentation and burial of sensitive habitat; and
7. short-term increases in turbidity.

Some workshop discussion of the issue of alteration or destruction of Essential Fish Habitat (Impact 12) is also reported, particularly with respect to the potential impact of dredging on the geomorphic integrity of ridge and shoal features.

For each type of equipment, procedure or approach that was reviewed, the evaluation was completed for three criteria:

1. Appropriateness. The following issues were considered in evaluating the appropriateness of an approach: the importance of the impact being addressed; whether it was applicable to all settings or just some, and if so, under what conditions;
2. Practicality. This evaluation criterion primarily related to the cost and viability of a given type of equipment or technique. It also considered the constraints that might be imposed on a given dredging operation.
3. Effectiveness. Under this criterion the potential success of a given type of equipment or approach was assessed.

5.3 Evaluation of the Key Equipment and Approaches Discussed at the Workshop

This section provides a summary of the evaluation of the key existing and emerging environmentally friendly equipment and technologies against the criteria described in Section 5.2 for the key impacts discussed at the workshop. While focus was devoted to the key impacts noted in Section 5.2, this section provides a summary for each of the twelve impacts identified in Section 2, based on discussions with resource managers in the US.

The section is subdivided according to each of the twelve impacts. Under each impact more than one type of equipment or approach may be discussed.

5.3.1 Removal of Benthic Communities

As noted elsewhere in this report, this was the most important impact to resource managers in the US. However, it is also the impact that has received the least attention in terms of the development of environmentally friendly approaches. In fact, an understanding of the rate of recovery of communities is an area of active scientific research and is not well defined, as discussed in Section 2.3.1.

Only one possible environmentally friendly approach was identified. The possibility of creating temporal or spatial refuge areas where the substrate (and the benthic community it supports) would be left undisturbed (at least for a significant period of time, if not completely) was the one approach developed by the team prior to the workshop. The idea is to provide nearby undisturbed areas to promote more rapid re-colonization.

5.3.1.1 Creation of Temporal or Spatial Refuge Areas (effectively "environmental windows at a borrow deposit scale")

Appropriateness:

- This is the most direct, prevalent, and measurable impact of dredging, it is appropriate to mitigate in any way possible.
- Is this necessary if the habitat landscape is ecologically uniform or homogenous?
- It may be more appropriate where there is ecologic diversity (e.g., on a shoal feature) where there is a need to preserve certain key habitats/communities in specific areas.
- It may be equally or more important to create temporal refuges whereby areas are allowed to recover before dredging the same area again (this requires a spatial data base updated with time on timing and extent of each dredging project within a borrow area). It also requires knowledge of the time for benthic communities to recover, and this is probably best achieved through monitoring.
- This approach would only be appropriate for types of species where the re-colonization process is assisted by close proximity of nearby undisturbed communities.
- An understanding is required of the context of this impact, recruitment and re-colonization characteristics with respect to site-specific conditions and species, in addition to the influence on higher trophic levels (see proposed approach of MMS Physical and Biological Monitoring Protocols).
- This approach would be most appropriate where recruitment is spatially handicapped.

In summary of the appropriateness of this measure, it would not be a general stipulation and instead would be tied to site-specific conditions (ecologic landscape and recruitment/re-colonization characteristics). The approach requires testing at appropriate locations and should be given consideration where the rate and quality of benthic recovery is a critical concern.

Practicality:

- From a dredging operation perspective, there is not much added cost to leaving un-dredged areas providing the dimensions do not make the dredging operation less efficient. For dredging operation efficiency with TSHDs, this requires a 100 m minimum lane width with a 2 km run length. In other words, this represents a minimum corridor for dredging outside which refuge areas could be established separating adjacent dredge corridors.
- While CSDs could achieve a 100 m minimum lane width, it would come at a cost owing to the fact that CSD operations usually utilize an idler barge, increasing the cut width to a minimum of approximately 200 m. The efficiency and cost of pipeline handling operations could be influenced by specifications on line width and length. The potential bed disturbance associated with anchor wires in CSD operations also needs to be considered (i.e., these would be beyond the 200 m lane width).
- Dustpan dredges could achieve a minimum lane width of 100 m without adding any cost to the operation. However, as with CSDs, both width and length constraints may influence the efficiency of pipeline handling operations.
- There is site specificity to this as it depends on layout of borrow area and other avoidance or exclusion zone considerations.
- Creating refuge areas (spatial and less so temporal) would limit the overall quantity of sediment available within a given deposit (or increase the cost of geophysical surveys to expand the size of the deposit to allow for protected refuge areas), However this is probably not a significant negative consideration with respect to the practicality of this approach at most locations.

In summary, this is not a difficult or costly measure to implement, if appropriate. It may be best to determine the optimal approach for creating refuge areas by considering the selected equipment, site conditions, and benthic community characteristics.

Effectiveness:

- There are limited or no data on the effectiveness of refuge zones. Monitoring should be required when and where this approach is implemented, and some methods of achieving a BACI (Before, After, Control, Impact) standard and/or other performance measures would have to be devised.

- It would be important to consider that refuge areas would experience significant sedimentation, as they are immediately adjacent to the dredging zone. It may be appropriate to design the refuge areas such that they are wide enough to provide a nearby zone that has not been influenced by sedimentation. This could be achieved through application of the MMS Plume model (see Baird & Associates, 2004).
- The effectiveness will be directly related to recruitment/re-colonization characteristics of benthic communities at the site.
- The effectiveness of this approach will also require good baseline mapping initially and then tracking of the date and location of dredged and refuge areas for each dredging operation and borrow site, all within a GIS database held at MMS.

In summary, the effectiveness of this approach is unknown because it has not been specifically or directly evaluated at any location, to our knowledge. Work is required to develop a monitoring plan to evaluate the effectiveness of this possible approach. Thorough and organized mapping and record keeping in GIS is required to effectively implement and test this approach.

Recommendation on Spatial/Temporal Refuge Areas to Promote Re-Colonization of Benthic Communities

It may be appropriate, practical, and effective to impose spatial or temporal refuge areas at locations with one or more of the following characteristics: 1) the presence of a unique assemblage of benthic communities; 2) special commercial significance of a benthic community in a borrow deposit; 3) at locations where the benthic community is spatially limited with respect to recruitment and re-colonization; and 4) where the importance of a benthic community within the borrow area is significant for higher trophic levels or where this relationship is uncertain. In order to develop a layout of refuge areas that is practical and does not significantly influence the cost of the dredging operation, the type of dredging equipment and borrow deposit layout should be considered. The MMS Plume model should be applied to determine the required size of the refuge areas considering the sedimentation footprint from the dredging operations. This proposed approach should be field tested along with a technique to monitor the effectiveness. For this approach to be effective, an actively updated GIS database is required to track dredging and monitoring results.

5.3.2 Entrainment of species of concern

Existing stipulations being used in MMS leases to protect sea turtles include:

a. Presence of trained observer(s) for a specified percent of the time who follows specific protocols.

b. Use of a rigid sea turtle deflector, such as the one designed by the USACE or similar.
c. Operation of the dredge in a manner that will reduce the risk of interaction with any sea turtles that might be present in the dredge area. Keep the draghead on the bottom except: 1) when the dredge is not in a pumping operation and the suction pumps are turned completely off; 2) the dredge is being re-oriented to the next dredge line during borrow activities; and 3) the vessel's safety is at risk.
d. Dredge equipped with inflow screening baskets (4-inch mesh) to better monitor the intake and overflow of the dredged materials for sea turtles and their remains. The percent of inflow to be screened varies by region from 50-100 percent.
e. Assessment/relocation trawling to further assess/reduce the potential for incidental take during dredging. Trawling is conducted repeatedly in front of the dredge as it moves along the track lines. Any turtles collected are to be relocated. There are specifications for trawl tow time and speed. There may be requirements for flipper tagging and genetic analysis of tissue samples from turtles caught during relocation trawling.
f. Filing of detailed reports with the appropriate NOAA office within 30 days of project completion.

This impact and its mitigation are being addressed in detail by the USACE in an ongoing study. Therefore, it was not discussed in detail at the workshop.

5.3.3 Changes in Substrate Characteristics

There are two aspects to this issue: 1) preservation of sediment characteristics similar to pre-existing conditions for the surface substrate; and 2) avoidance of anoxic conditions within in dredge pits. The primary focus is dredge pits because, in most instances on the OCS where sand with a medium grain size is the target, it is likely that surrounding areas will also be relatively sandy and thus changes will not be significant (i.e., by uncovering sediment with significantly different characteristics or by changing the characteristics through sediment overflow during the dredging operation). In contrast, the creation of dredge pits of significant depth can lead to the deposition of fine sediment (silt and clay) changing the nature of the surface texture. This outcome occurred in South Carolina (see Van Dolah et al., 1998) and had a direct impact on the suitability of the borrow area for future dredging (as desired sand was buried by mud), in addition to the direct environmental impacts.

The approaches reviewed include: 1) limitation of pit depths to a single fixed value for all locations; 2) site specific evaluation of pit depth using analytical techniques and numerical models. 3) use of monitoring.

5.3.3.1 Limitation of Pit Depths to a Fixed Value

The first possible approach is to specify a single maximum pit depth for all locations and conditions.

Appropriateness:

- From the feasibility of future dredging in a given borrow area, it is desirable to minimize the potential for burial of a sandy deposit with fine sediment (i.e., silt and clay).
- It is also desirable to avoid the development of anoxic or hypoxic conditions that can impact benthic and fish species.
- A single maximum pit depth may be inappropriate for all locations.
- In some locations sedimentation may be low and thus development of a mud layer may be slow or imperceptible (and this measure may, in that case, be inappropriate).
- At other locations sedimentation may be high and adjacent areas may feature a mud cap over sandy deposits as the natural condition (and this measure may, in that case, be inappropriate).
- In some locations, anoxia may be a prevalent natural condition (i.e., adjacent to the Mississippi River delta) and, therefore, it may not be necessary to avoid this condition (and this measure may, in that case, be inappropriate).

In summary, the appropriateness depends on the local seabed sediment and water quality characteristics, and whether it is intended to revisit the proposed borrow site for future dredging operations.

Practicality:

- Providing the pit limit is greater than about 1- 2 m (depending on whether TSHDs or CSDs are deployed, respectively) this would be a practical measure with respect to typical dredge cut depths.
- Imposing a maximum pit depth rule would significantly limit the reserves of most borrow deposits (i.e., borrow deposits may be significantly deeper or thicker than an imposed maximum pit depth).

Effectiveness:

- The effectiveness may be limited due to the variability of site-specific conditions. For example, while a 4 m pit depth may be satisfactory at some locations, it may be too deep at others.
- Therefore, for a single maximum pit depth rule to be effective, the depth will have to be small and thus overly restrictive at many sites (or larger and not effective at a large number of sites).

5.3.3.2 Site Specific Evaluation of Local Sedimentation Potential and Dissolved Oxygen Conditions Through the Application of Numerical Models or Analytical Methods

This approach consists of using analytical techniques or numerical models to define a site-specific maximum pit depth.

Appropriateness:

- From the feasibility of future dredging in a given borrow area, it is desirable to minimize the potential for burial of a sandy deposit with fine sediment (i.e., silt and clay).
- It is also desirable to avoid the development of anoxic or hypoxic conditions that can impact benthic and fish species.

Practicality:

- Providing the pit limit is greater than about 1-2 m (depending on whether TSHDs or CSDs are deployed, respectively) this would be a practical measure with respect to typical dredge cut depths.
- Imposing a site-specific maximum pit depth rule would significantly limit the reserves of most borrow deposits (i.e., borrow deposits may be significantly deeper or thicker than an imposed maximum pit depth).
- Development of anoxic conditions and prediction of sedimentation requires the application of sophisticated numerical models, preferably coupled with site-specific data.

Effectiveness:

- The effectiveness of developing site-specific pit rules will depend on three key factors including: 1) the ability of the investigators to apply and interpret sophisticated models of complex processes; 2) the availability of data for input to these models; and 3) the local conditions as explained below.

- At some locations where sedimentation potential is low and currents are strong (providing a mechanism for flushing to avoid development of anoxic conditions), it may be possible to develop a relatively deep maximum depth with a high degree of certainty and without the need for sophisticated analysis techniques.

5.3.3.3 Use of Monitoring to Avoid Development of a Mud Layer and/or Anoxic Conditions

This approach consists of using monitoring to define a site-specific maximum pit depth.

Appropriateness: See Section 5.3.3.2.

Practicality:

- Providing the pit limit is greater than about 1-2 m (depending on whether TSHDs or CSDs are deployed, respectively), this would be a practical measure with respect to typical dredge cut depths.
- Imposing a site-specific maximum pit depth rule would significantly limit the reserves of most borrow deposits (i.e., borrow deposits may be significantly deeper or thicker than an imposed maximum pit depth).
- It would be feasible to monitor for development of anoxia through the deployment of instrumentation.
- It would also be feasible to monitor for the development of a mud layer.

Effectiveness:

- The effectiveness of a monitoring approach on its own is limited because once a mud layer is observed, or anoxia develops, it would not be possible to reverse the situation, at least not without significant cost.
- It is possible that monitoring following the completion of the initial dredging of a borrow deposit (and prior to returning to this deposit) may provide an indication of the potential for development of a more severe and unacceptable outcome with respect to sedimentation and anoxia.

Recommendation on Pit Depth Rule:

A blanket maximum pit depth rule is inappropriate. However, it is appropriate to determine a local maximum pit depth to avoid development of a mud cover and/or anoxia, providing the limit is greater than 1 m for TSHDs and 2 m for CSDs. Maximum pit depths should be determined on a site-specific basis through analysis combined with monitoring where necessary (as described above). Monitoring may assist the development of an appropriate maximum pit depth at borrow deposits that are dredged more than once.

5.3.4 Wave Climate Alterations by Changes in Bathymetry

Approaches to avoiding or mitigating this impact are addressed in the Physical and Biological Monitoring Protocols that have been developed for the MMS and therefore are not addressed here.

5.3.5 Damage to Hard/Live Bottom Habitats

There are four possible ways that dredging activities in an MMS borrow area may result in this impact: 1) direct impact of the dredge vessel or dredge head or anchor wires on sensitive hard/live bottom habitat; 2) through direct sedimentation associated with the footprint of the sediment from the overflow of TSHDs or from the draghead or cutterhead; 3) re-suspension and subsequent transport of fines beyond the initial sedimentation footprint; and 4) development of near bed turbidity plumes or currents that may travel well beyond “normal” bounds of a plume sedimentation footprint.

The first concern of direct damage through physical impact has largely been addressed through improved maneuverability and better navigation systems on dredge vessels. These improvements in dredge positioning have meant that any buffer designed to address sedimentation impact will be more than sufficient to address accidental direct contact. Therefore, the focus of this review is on potential indirect damage through sedimentation. There is overlap between these approaches and those that address elevated levels of turbidity as discussed in Section 5.3.7.

The approaches and equipment reviewed include: 1) stipulation of a blanket buffer zone width for all situations; 2) stipulation of region- or habitat-specific buffer zone width; 3) use of analysis or numerical modeling to define a site and project specific buffer zone width; 4) monitoring turbidity to meet a general stipulation; 5) development of site-specific levels based on monitoring of background levels; 6) Green Pipe (or re-circulation of overflow to the draghead); and 7) Anti-Turbidity valve.

5.3.5.1 Implementation of a Blanket Buffer Zone for All Situations

Appropriateness:

- It is certainly appropriate to protect adjacent hard/live bottom and other sensitive habitat where this habitat has special ecologic significance.

- A single blanket buffer is inappropriate as it may be overly protective at some (or all) locations and insufficient at others.

Practicality:

- It may not be practical to develop a single buffer distance that is appropriate for all conditions (this would require a consideration of the worst case condition in terms of level of suspended sediment generation, degree of advection/dispersion and sensitivity of local habitat).

Effectiveness:

- In order for these measures to be effective, it is necessary to have some understanding of lethal or detrimental levels of sedimentation for the most sensitive species.
- It is likely this approach would be ineffective in most conditions (either overly conservative or insufficient to protect in others).

5.3.5.2 Implementation of a Region/Habitat Specific Minimum Buffer Zone Width Together with Monitoring at the Sensitive Habitat

In some jurisdictions, such as Florida (and the Gulf of Mexico), a specific buffer zone distance for dredging sand deposits near hardground habitats is specified under the Endangered Species Act. NOAA Fisheries Regional Biological Opinion requires a 400 ft buffer to protect hardgrounds used by sea turtles for foraging or shelter from sand mining offshore Florida. Recognizing that the width of the buffer zone may be insufficient in some circumstances, real or near real-time monitoring is performed during dredging operations to ensure sedimentation rates do not exceed predefined limits. The monitoring technique is in the form of turbidity measurements or sediment traps. Exceedance of these pre-defined thresholds triggers direction to the dredging vessel to cease or modify operations. Evans (1994) reported on the application of this approach to protect coral for a dredging project offshore Hong Kong.

Appropriateness:

- It is certainly appropriate to protect adjacent hard/live bottom and other sensitive habitat with ecological significance.
- To a large extent the appropriateness depends on the knowledge of the severity of impacts to different habitat types and the uniformity of the habitat of concern (or its sensitivity) within the region of application.
- The appropriateness also depends on whether the conditions at the range of sites within the region of application are indeed relatively uniform (i.e., with respect to advection/dispersion).

Practicality:

- It is practical to specify a minimum buffer zone width.
- At some locations, the specification of a buffer width may make borrow deposits too small to dredge.
- It is more difficult to perform real-time or near real-time monitoring of sedimentation or turbidity, however, with recent advances in underwater telemetry techniques this is possible.
- Sedimentation rates are difficult to measure because of low levels of sedimentation, and difficult to separate from background levels.

Effectiveness:

- As explained above, the effectiveness will depend on establishing reasonable minimum buffer for a geographic area that has: 1) similar level of sensitivity for habitat; 2) similar generation of turbidity and sedimentation levels (associated with dredge type/operation and borrow deposit sediment characteristics); and 3) uniformity in advection/dispersion characteristics.
- The effectiveness will also depend on the ability of the dredging operation to respond to required reduction without significant escalation of costs of the operation.
- This approach has been applied successfully before (see Evans, 1994).

5.3.5.3 Use of Analysis to Determine a Site-Specific Buffer Zone

The Plume model that has been developed for MMS to simulate plumes released by TSHDs (Baird, 2004) could be applied to pre-determine the potential zone of sedimentation impact for the planned dredging operations and accordingly determine a suitable and appropriate site-specific buffer zone width.

Appropriateness: see Section 5.3.5.2.

Practicality:

- MMS now has the MMS Plume model for TSHDs to perform this assessment.
- It would be necessary to determine additional input parameters including: a) sediment characteristics [available]; b) specific dredge vessel characteristics [available only after a dredging contractor has been retained for the work – but a range of representative characteristics could be considered]; c) some indication of the possible tracklines of the dredge [a worst case scenario could be estimated]; and d) local environmental conditions (waves, currents, etc.) – [may be available

for some sites but probably would have to be estimated for some where not available].

Effectiveness:

- The MMS Plume model has only recently been developed and has not been extensively tested against measured data.
- This would provide at least an initial estimate of the possible sedimentation footprint.
- If applied, this approach should be probably combined with some other method of direct measurement.

Recommendation on Buffer Zones to Protect Sensitive Habitat from Sedimentation

Three approaches were assessed with respect to the stipulation of buffers to protect hard/live bottom areas from sedimentation: 1) a blanket buffer; 2) a region/habitat specific buffer together with real-time monitoring; and 3) the use of the Plume model to assist in the definition of an appropriate site-specific buffer. It is appropriate to apply some form of buffer to protect ecologically sensitive hard/live ground habitat from sedimentation impacts. A blanket buffer for all conditions is inappropriate and would not be practical. Real-time monitoring near the limits of pre-defined buffers is now possible as an ongoing test of buffer effectiveness and as a trigger to invoke additional mitigation measures during dredging operations. The MMS Plume model could be applied to pre-define buffers considering site-specific conditions. However, considering the limited validation of this model, it should be combined together with monitoring. Specific information on acceptable levels of sedimentation is required either through direct exposure testing of the site-specific hard/live ground habitat or through background station monitoring.

5.3.5.4 Monitoring Turbidity to Meet a General Stipulation

In many jurisdictions a general stipulation of a maximum turbidity level is specified. For example, the DNR in Florida specifies that turbidity levels cannot exceed 29 NTUs above background levels measured at mid-depth at the boundary of a 150 m mixing zone. Background levels for beach nourishment projects are typically measured 1,000 m upcurrent from the dredging operations. More details are presented in Section 2.3.7. This approach could be applied to limit turbidity to levels that result in acceptable levels of sedimentation in order to protect hard/live bottom habitat. This approach is also discussed under Section 5.3.7 as a measure to address the impact of elevated levels of water column turbidity.

Appropriateness:

- It is certainly appropriate to protect adjacent hard/live bottom and other sensitive habitat, where ecologically sensitive.
- A general stipulation may be inappropriate, as it may not apply to all habitats requiring protection. For example, the 29 NTU limit was based on an original value of 50 JTU developed to avoid ecological impact in streams and rivers in Florida and may or may not be appropriate to protect coral habitat at all locations.
- A general stipulation on turbidity would not translate to the same sedimentation rates at all locations due to variability in environmental conditions (e.g., currents and sea bed topography).

Practicality:

- One difficulty of this measure is associated with where and when the measurements are taken to compare to the stipulated maximum turbidity levels. Turbidity associated with a dredge plume is highly variable in time and space and also background levels are highly variable in time and space.
- In the study workshop for this project, representatives of leading dredging contractors in the US indicated that when dredging for sand in sandy areas the 29 NTU above background requirement, measured 150 m from the dredge, was not difficult to meet (no special measures were required), at least for the way in which this limit is currently applied and monitored.

Effectiveness:

- This approach will only be effective in those areas where the specified turbidity level is low enough to protect the most sensitive habitat in the worst-case conditions.
- In all other areas, this approach will be overly conservative.
- At the study workshop, USACE representatives indicated that point measurements of turbidity seldom provide a reliable estimate of the true range of turbidity. This observation was based on their measurements with ADCP giving a much more thorough picture of the spatial/temporal variability of turbidity. Therefore, it is difficult to measure the temporal and spatial turbidity levels with conventional point measurement techniques, profiling techniques such as ADCP are more effective.
- It is difficult to relate turbidity levels directly to sedimentation rates and the resulting potential indirect damage to hard/live bottom habitat. At the very least, effectiveness in this respect would require ADCP measurements of turbidity variability in space and time.

Recommendation on Turbidity Monitoring to Protect Hard/live Bottom Areas from Sedimentation Impacts

This is a less direct approach than simply monitoring sedimentation rates. Point measurements of turbidity (either snapshots or continuous) are difficult to convert directly to spatially varying sedimentation rates. Once site- or habitat-specific information is developed on acceptable levels of sedimentation, this must be somehow translated to acceptable levels of turbidity. More widespread measurements of turbidity in time and space (e.g., through the application of ADCP) may be necessary for this indirect approach (i.e., linking sedimentation to turbidity levels) to be effective. Data from turbidity monitoring may be useful in calibrating or verifying the MMS Plume model for definition of buffer zones to protect hard/live bottom areas as discussed above.

5.3.5.5 Development of Site-Specific Limits Based on Background Levels

It may be more appropriate to develop limits for sedimentation that are within the range of natural background levels. The approach would consist of analyzing measured sedimentation rates to determine the maximum levels (peak values and persistence), frequency and timing of these events and then to assign appropriate maximum levels (with duration) for the dredging operation (see Section 5.3.5.3). The alternative approach to developing a site-specific limit for sedimentation rates is to evaluate the direct impacts to organisms. This type of work has not been performed in the OCS environment and could involve a very extensive research program compared to the method of evaluating the characteristics of background sedimentation levels.

Appropriateness:

- It is certainly appropriate to protect adjacent hard/live and other sensitive habitat, where ecologically sensitive.
- As dredging events at a given location are generally infrequent (e.g. once every two or more years), if repeated at all, the sedimentation generated by such an event could be compared to that generated by an extreme storm event with return period similar to the frequency of dredging. The rationale is that the natural environment would have adapted to avoid or recover from such events in the natural system.

Practicality:

- The main requirement here is measured sedimentation rates at the proposed dredging site. In most proposed borrow sites or areas in OCS waters, this type of data are not available. A requirement is that the temporal variation in sedimentation rates must be determined (i.e., not only the cumulative sedimentation rate for a period of time). Sedimentation traps are one type of apparatus that could be applied for these measurements.

- Where project lead-time permits, it would be practical to acquire at least one or two years of data prior to dredging at locations where sedimentation may be a concern. The length of the data set required would depend on whether a significant sedimentation event, for example related to the passage of a hurricane or tropical storm, was captured in the monitoring period. However, few OCS projects have lead times of 1-2 years where the exact borrow site is known.

Effectiveness:

- This approach relies on the premise that the natural environment will have adapted to certain levels of sedimentation, and therefore, this should be a reliable approach for preventing negative impacts of sedimentation generated by dredging.
- Understanding the seasonal timing of the natural sedimentation fluctuations and the relationship to the seasonal timing of ecological functions of various organisms would also have to be evaluated for this approach to be effective.
- The possibility of the sedimentation generated through the dredging operations unacceptably contributing to cumulative impacts would have to be considered to evaluate the effectiveness of this proposed approach.

Recommendation on a Site-Specific Limit Derived from Background Levels

The premise of this approach is to define a limit that is within the range of natural variability. The main practical limitation is the lack of sedimentation data, new measurements would have to be made at most locations for a minimum period of one to two years prior to dredging. This approach would be appropriate at locations where there is justifiable concern for sedimentation impacts to Essential Fish Habitat.

5.3.5.6 Use of "Green Pipe" (re-circulation of overflow to draghead)

With the Green Pipe equipment modification, overflow water is fully re-circulated to the draghead eliminating all or most overflow. In theory, this significantly reduces the size of the plume from dredging (by confining the release of sediment to an area close to the bed), and therefore, the sedimentation footprint. However, at the same time, the same amount of sediment is released thereby concentrating sedimentation related to the release or re-suspension of sediment in a smaller area leading to higher sedimentation rates within the smaller footprint.

Appropriateness: see Section 5.3.5.2.

Practicality:

- This would require significant overhaul of existing dredges with very significant capital investment.

- It would require additional pumps and greater weight on the vessel, probably reducing loading capacity.
- These costs would be passed on to the consumer as higher unit dredge costs.

Effectiveness:

- Sediment balance considerations suggest that no less sediment would be "overflowed" or returned to the bed with this approach, the only difference is that it would be released close to the bed.
- There is a concern that this could promote the development of a turbidity current near the bed (i.e., due to the high and concentrated sediment loading at the drag head with this approach). If a turbidity current were to develop at the bed, the sedimentation footprint may extend much further from the borrow site than normally expected.

Recommendation on the Green Pipe Equipment Modification

In most cases the "Green Pipe" approach is likely unjustified. There may be some circumstances where it is desirable to confine the sediment loading associated with dredging to close to the bed. However, there may be other less costly approaches to achieving the same goals.

5.3.5.7 Use of Anti-Turbidity Valve

The anti-turbidity valve is a device, which prevents the entrainment of air into the hopper and overflow discharge, thus improving the settling characteristics of the discharged sediment laden flow (see Section 4.6.1 for more detail). The idea here would be that improved settling will lead to a smaller sedimentation footprint, and therefore less chance of impacts to hard/live bottom areas located outside the dredge area. The dredge contractors that attended the workshop (representatives from Bean Stuyvesant LLC and Great Lakes Dredge & Dock Co.) indicated that most TSHDs are now outfitted with this device.

Appropriateness: see Section 5.3.5.2.

Practicality:

- According to the dredge contractors that attended the workshop, most TSHDs are already equipped with an anti-turbidity valve of some form.
- For this equipment modification to have been widely implemented it must be a relatively straightforward and inexpensive change in relative terms.

Effectiveness:

- This approach reduced both the size of the plume (and thus the sedimentation footprint) in addition to the total sediment released from the hopper.
- There is a concern that this could promote the development of a turbidity current near the bed (i.e., due to promotion of a higher and more concentrating settling process). If a turbidity current were to develop at the bed, the footprint may extend much further from the borrow site than normally expected.

Recommendation on the Anti-Turbidity Valve Device

It is understood that this device has been widely applied to TSHDs in the US. Where it is important to restrict the extent of the sedimentation footprint, such as near to hard/live bottom areas, this would be an appropriate device to require on the TSHD. The possibility of turbidity current development should be evaluated at sites with strong tidal currents or steep slopes in the vicinity of the borrow area (refer to the discussion of Section 2.3.7).

Overall Recommendation on Protecting Sensitive Habitat from Sedimentation

There is a need to establish field-tested sedimentation limits for different types of sensitive habitat. A blanket buffer zone width for all locations is probably unjustified. Another way of defining acceptable site-specific sedimentation levels, that may be more expedient, is through the monitoring of natural sedimentation rates. Once sedimentation limits are established for the local sensitive habitat, the best approach would consist of a pre-dredging assessment of the plume sedimentation footprint using the MMS Plume model (or equivalent), followed by real-time or near real-time monitoring of sedimentation levels as a trigger to invoke additional mitigation measures in the dredging operations, as required (see the recommendations summary for buffer zone approached at the end of Section 5.3.5.3 for more details). Turbidity monitoring may also be helpful to validate the Plume model, however, it is not a suitable replacement for direct monitoring of sedimentation. It would be appropriate to require the Anti-Turbidity valve device at locations where restricting the sedimentation footprint is important. At almost all locations the Green Pipe approach (where the overflow water is re-circulated to the draghead) is likely unjustified. At borrow sites with strong tidal currents or steep slopes, the possibility of the development of a near-bed turbidity current generated through the pancaking effect of the dynamic plume phase should be evaluated (see Section 2.3.7 for details).

5.3.6 Creation of Depressions and Furrows

This was not thought to be an important impact and, therefore, was not discussed in any detail. However, the issue of developing pits was addressed under the discussion of Impact 3 (see Section 5.3.3).

5.3.7 Increased Short-Term Turbidity (Turbidity Limits)

This impact has been partly addressed under Section 5.3.5 above owing to the fact that sedimentation is directly related to turbidity levels. Therefore, some of the techniques presented in Section 5.3.5 are repeated here with some additions to their direct applicability to this concern.

The approaches and equipment reviewed include: 1) stipulation of a maximum turbidity level for all locations; 2) stipulation of a site-specific level; 3) Green Pipe (or re-circulation of overflow to the draghead); and 4) Anti-Turbidity valve.

5.3.7.1 Implementation of a General Stipulation

As discussed under Section 5.3.5.4 related to damage to hard/live bottom habitats, in many jurisdictions a general stipulation of a maximum turbidity level is specified. For example, the DNR in Florida specifies that turbidity levels cannot exceed 29 NTUs above background levels measured at mid-depth at the boundary of a 150 m mixing zone. Background levels for beach nourishment projects are typically measured 1,000 m upcurrent from the dredging operations. More details are presented in Section 2.3.7.

Appropriateness:

- In open ocean OCS areas, restrictions on dredging operations are not typically required as it is believed that adult fish are sufficiently mobile to avoid dredge plumes and levels are almost always sub-lethal and plumes are not persistent or frequent enough to have an effect at the sub-lethal level.
- The concern is generally related to the sedimentation impacts.
- There may be some locations where high levels of turbidity could result in an unacceptable degradation to Essential Fish Habitat.

Practicality:

- One difficulty of this measure is associated with where and when the measurements are taken to compare to the stipulated maximum turbidity levels. Turbidity associated with a dredge plume is highly variable in time and space and also background levels are highly variable in time and space.

- In the study workshop for this project, representatives of leading dredging contractors in the US indicated that when dredging for sand in sandy areas the 29 NTU above background requirement, measured 150 m from the dredge, was not difficult to meet (no special measures were required), at least for the way in which this limit is currently applied and monitored.

Effectiveness:

- This approach will only be effective in those areas where the specified turbidity level is low enough to protect the most sensitive habitat in the worst-case conditions.
- In all other areas, this approach will be overly conservative.
- There has been very little field-testing to determine impacts of elevated water column turbidity at sub-lethal levels. At the workshop, the USACE representatives argued for more investigation of this issue. Without this information, there is no way of knowing how effective limits on turbidity levels (at whatever level they are set) are in protecting the environment.
- At the study workshop, USACE representatives also indicated that point measurements of turbidity seldom provide a reliable estimate of the true range of turbidity. This observation was based on their measurements with ADCP giving a much more thorough picture of the spatial/temporal variability of turbidity. Therefore, it is difficult to measure the temporal and spatial turbidity levels with conventional point measurement techniques. Profiling techniques such as ADCP are more effective.

Recommendation on a General Stipulation for Turbidity Levels

The 29 NTU limit above background levels that is sometimes applied to dredging operations, particularly in nearshore zones, would not appear to be scientifically justified for application to open ocean environments. Little work has been completed on understanding the impact of sub-lethal levels of elevated turbidity on fish and other organisms. It is believed that adult fish are able to avoid the turbidity plume and that other organisms are simply not influenced by this relatively low level of elevation above background levels. Point measurements of turbidity levels in space and time are probably inaccurate and not representative of the variability of actual levels. Nevertheless, the dredging representatives indicated that the 29 NTU limit above background measured 150 m from the dredge at mid-depth is not difficult to achieve.

5.3.7.2 Development of Site Specific Limits Based on Background Levels

It may be more appropriate to develop limits for turbidity that are within the range of natural background levels. The approach would consist of analyzing measured suspended sediment data (TSS or NTU) to determine the maximum levels (peak values and persistence), frequency and timing of these events and then to assign appropriate maximum levels (with duration) for the dredging operation (see Section 5.3.5.3). The alternative approach to developing a site-specific limit for turbidity levels is to evaluate the direct impacts to organisms. This type of work has not been performed in the OCS environment and could involve a very extensive research program compared to the method of evaluating the characteristics of background turbidity levels.

Appropriateness:

- In open ocean OCS areas restrictions on dredging operations are not typically required as it is believed that adult fish are sufficiently mobile to avoid dredge plumes and levels are almost always sub-lethal and plumes are not persistent or frequent enough to have an effect at the sub-lethal level.
- The concern is generally related to the sedimentation impacts.
- There may be some locations where high levels of turbidity could result in an unacceptable degradation to Essential Fish Habitat.
- This approach may be important where a case is made to protect Essential Fish Habitat and it is necessary to determine the acceptable levels of turbidity.
- As dredging events at a given location are generally infrequent (e.g. once every two or more years), if repeated at all, the turbidity generated by such an event could be compared to that generated by an extreme storm event with return period similar to the frequency of dredging. The rationale is that the natural environment would have adapted to avoid or recover from such events in the natural system.

Practicality:

- The main requirement here is measured TSS or NTU at the proposed dredging site. In most proposed borrow sites in OCS waters this type of data is not available. This information could be obtained in tandem with velocity data through the deployment of ADCP. The backscatter signal from the ADCP, together with ground truth TSS measurements consisting of direct water samples, can be used to develop a record of turbidity.
- Where project lead-time permits, it would be practical to acquire at least one or two years of data prior to dredging at locations where turbidity may be a concern. The length of data set required would depend on whether a significant turbidity event, for example related to the passage of a hurricane or tropical storm, was captured in the monitoring period.

Effectiveness:

- This approach relies on the premise that the natural environment will have adapted to certain levels of turbidity, and therefore, this should be a reliable approach for preventing negative impacts of turbidity generated by dredging.

- Understanding the seasonal timing of the natural turbidity fluctuations and the relationship to the seasonal timing of ecological functions of various organisms would also have to be evaluated for this approach to be effective.
- The possibility of the turbidity generated through repetitive dredging operations unacceptably contributing to cumulative impacts would have to be considered to evaluate the effectiveness of this proposed approach.

Recommendation on a Site Specific Limit Derived from Background Levels

The premise of this approach is to define a limit that is within the range of natural variability. The main practical limitation is the lack of turbidity data. New measurements would have to be made at most locations for a minimum period of one to two years prior to dredging. This approach would be appropriate at locations where there is justifiable concern for turbidity impacts to Essential Fish Habitat.

5.3.7.3 Use of "Green Pipe" (re-circulation of overflow to draghead)

With the Green Pipe equipment modification, overflow water is fully re-circulated to the draghead eliminating all or most overflow. In theory, this significantly reduces the size of the plume from dredging (by confining the release of sediment to an area close to the bed). As noted in Section 5.3.5.6, this approach may potentially contribute to significantly expanding the actual sedimentation footprint. Nevertheless, it would create a significant improvement to water column turbidity levels.

Appropriateness:

- In open ocean OCS areas restrictions on dredging operations are not typically required as it is believed that adult fish are sufficiently mobile to avoid dredge plumes and levels are almost always sub-lethal and plumes are not persistent or frequent enough to have an effect at the sub-lethal level.
- The concern is generally related to the sedimentation impacts.
- There may be some locations where high levels of turbidity could result in an unacceptable degradation to Essential Fish Habitat.
- Application of this equipment modification would only be justified where a strong case is made to eliminate any increase in turbidity above background levels to protect Essential Fish Habitat and fish species that were particularly sensitive to relatively small increases in turbidity above background levels.

Practicality:

- This would require significant overhaul of existing dredges with very significant capital investment.

- It would require additional pumps and greater weight on the vessel, probably reducing loading capacity.
- These costs would be passed on to the consumer as higher unit dredge costs.

Effectiveness:

- Measurements provided by the Belgian dredging contractor Jan de Nul showed that this approach was very effective at eliminating any plume higher than about 4 m above the bed. The only source of plume generation with this approach is from the draghead itself.

Recommendation on the Green Pipe Equipment Modification

In most cases the "Green Pipe" approach is likely unjustified. There may be some circumstances where it is desirable to confine the sediment loading associated with dredging to close to the bed. However, there may be other less costly approaches to achieving the same goals.

5.3.7.4 Use of Anti-Turbidity Valve

The anti-turbidity valve is a device which prevents the entrainment of air into the overflow discharge, thus improving the settling characteristics of the discharged sediment-laden flow (see Section 4.6.1 for more detail). The idea here would be that improved settling will lead to a more confined sediment plume (although the total sediment released from the overflow process is not reduced). The dredge contractors that attended the workshop (representatives from Bean Stuyvesant LLC and Great Lakes Dredge & Dock Co.) indicated that most TSHDs are now outfitted with this device.

Appropriateness:

- In open ocean OCS areas restrictions on dredging operations are not typically required as it is believed that adult fish are sufficiently mobile to avoid dredge plumes and levels are almost always sub-lethal and plumes are not persistent or frequent enough to have an effect at the sub-lethal level.
- The concern is generally related to the sedimentation impacts.
- There may be some locations where high levels of turbidity could result in an unacceptable degradation to Essential Fish Habitat.
- Application of this equipment modification is justified where a large plume or a large sedimentation footprint must be avoided.

Practicality:

- According to the dredge contractors that attended the workshop most TSHDs are already equipped with an anti-turbidity valve of some form.
- For this equipment modification to have been widely implemented it must be a relatively straightforward and inexpensive change in relative terms.

Effectiveness:

- Measurements provided by the Belgian dredging contractor Jan de Nul showed that this approach was very effective at reducing the size of the plume and the total quantity of sediment released from the hopper during the overflow process (see Appendix C.5).

Recommendation on the Anti-Turbidity Valve Device

It is understood that this device has been widely applied to TSHDs in the US. Where it is important to restrict the extent of the turbidity plume, this would be an appropriate device to require on the TSHD.

Overall Recommendation on Addressing the Impact of Turbidity

It is generally viewed that elevated levels of turbidity generated from TSHD operations in open ocean waters does not represent a significant ecological impact. It is believed that adult fish can avoid plumes and that other organisms can survive the sub-lethal levels of short-term elevated turbidity. A one-size fits all limit of 29 NTUs above background levels measured at 150 m from the dredging operation is probably scientifically unjustified for the ocean environment. Nevertheless, representatives of the dredging industry that attended the workshop indicated that the 29 NTU limit was not difficult to achieve. At locations where a more scientifically justified level is required, for example where there is a specific ecological concern about turbidity levels, it may be possible to develop a site-specific limit based on measurements of turbidity levels over a minimum period of one or two years.

The Anti-Turbidity valve device is widely applied in the US and significantly reduces the size of plumes from TSHDs and the total sediment overflowed in the discharge process. It would be appropriate to require the use of this device wherever turbidity is a concern. The “Green Pipe” approach consisting of re-circulation of the overflow water to the draghead eliminates the plume above 4 to 5 m above the seabed (i.e. outside of the region of the draghead plume), but it does not reduce the total sediment discharged in the overflow process. However, this approach is not included on any US dredge vessels and would represent a significant and expensive equipment overhaul that would be passed on to the client through higher unit prices and is likely unjustified at most locations.

5.3.8 Commercial and Recreational Fisheries

This impact was not discussed at any length. The MMS has recently awarded a contract to Emu Ltd. of the UK to study this issue and develop recommendations.

5.3.9 Seafloor Pipeline Breakage and Leakage

This impact was not discussed in any detail. The MMS has recently awarded a contract to Baird & Associates to study this issue and develop recommendations.

5.3.10 Collisions With Marine Mammals and Sea Turtles

It was concluded that this potential impact is adequately addressed through the current MMS stipulation listed below.

- If operating in areas of known whale occurrences, observers are required. If whales are observed, avoid intentional approaches within 100 yards (500 yards for right whales) and slow speeds to less than 4 knots.

5.3.11 Archaeological Resources

This impact was addressed through the recommendation of approaches to define buffers in a recently completed project for MMS (see Research Planning, Inc. et al., 2004).

5.3.12 Alteration or Destruction of Essential Fish Habitat

This impact is currently being addressed in an MMS study by Applied Coastal Research Ltd. However, during the workshop there was some discussion of possible approaches to address this issue. In addition, subsequent discussions with Chris Spaur of the Baltimore District office of the USACE have resulted in other possible approaches to addressing this issue. The primary focus is to avoid disrupting the geomorphic integrity of ridge and shoal features that have been targeted for dredging. As noted in Section 2.3.12, there is a concern that removing large quantities of sand from a shoal may disrupt the processes that maintain the shoal and trigger the deflation or disappearance of these features.

The approaches reviewed include: 1) dredge depositional areas on the features; 2) post-dredge monitoring of changes; 3) complete an assessment of sediment dynamics of the shoal feature; 4) limit the sediment removal to some threshold level determined through analytical techniques.

5.3.12.1 Dredge Depositional Areas that are Undergoing Constant Natural Recovery (and Burial) in a Physical Sense

Appropriateness:

- As some areas of shoals (and the features themselves) may represent unique habitat for important and/or commercial species, it will be important to implement protective measures.
- The aggrading section of the shoal is subject to continual deposition and burial of surface dwelling communities, therefore, it may have lower ecological importance (this needs to be verified on a site-specific basis).

Practicality:

- Generally this is the steepest (and thus narrowest or smallest) part of the shoal so it limits the area available for dredging.
- Steepness of the aggrading slope may also cause difficulty for dredging, particularly for TSHDs (however this may not typically be a practical constraint as slopes are usually in the 1:15 to 1:25 range).

Effectiveness:

- The degree to which this measure prevents a possible impact to the geomorphic integrity of the future needs to be assessed on a site-specific basis.
- Some activities that would help evaluate the effectiveness of this approach include: numerical modeling of the sediment dynamics and morphodynamics of the feature; geomorphic review of the sedimentology and stratigraphy of the feature; and monitoring of the changing form of the shoal.

5.3.12.2 Post-Project Monitoring of Changes

Appropriateness:

- As some areas of shoals (and the features themselves) may represent unique habitat for important and/or commercial species, it will be important to implement protective measures.

- Post-project monitoring together with other measures may be appropriate, however this alone does not provide a projection of possible irreversible changes to the morphologic integrity of shoal features.

Practicality:

- The Protocols report completed for MMS by Research Planning, Inc. et al., 2001 (see also Nairn et al., 2004) provides recommendations for monitoring bathymetric changes within and adjacent to borrow areas.
- These approaches are fully practical and based on conventional hydrographic surveying approaches.

Effectiveness:

- This measure is effective in identifying indirect impacts after the fact, at which time it may be too late to avoid an irreversible impact.
- In some cases, this approach may provide a means of avoiding future additional impacts by repeated dredging operations on the same shoal.

5.3.12.3 Complete a Sediment Dynamics Study of the Shoal to Determine the Most Appropriate Areas to Dredge to Avoid or Minimize Impacts

Appropriateness:

- As some areas of shoals (and the features themselves) may represent unique habitat for important and/or commercial species, it will be important to implement protective measures.
- The wave dynamics and sediment dynamics on shoal features are very complex and a site-specific investigation of these processes is fully justified to support the development of a dredging plan that minimizes impacts to the morphologic integrity of the shoal and to areas adjacent to the borrow area.

Practicality:

- The complexity of the wave and sediment dynamics requires the application of sophisticated numerical models, and specifically wave models that are capable of simulating crossing wave patterns over the crest of the shoals. This process has been shown by Hayes and Nairn (2004) to have a key influence on the natural maintenance of these features.
- This class of wave and sediment dynamic models is inappropriate for long-term applications required to assess geomorphic changes and integrity. Therefore, special techniques must be applied to integrate the results of event-based models to predict long-term changes.

Effectiveness:

- The effectiveness of this measure will be strongly influenced by the experience and capabilities of the team to apply the necessary models and address the complexities discussed above.
- In any event, even the best numerical models and the most experienced interpretations of these complex processes have limitations and long-term monitoring is an indispensable component of this measure.

5.3.12.4 Limit Removal of Sediment to Some Threshold Level (to Avoid Deflation or Irreversible Damage to the Morphologic Integrity of the Shoal)

Appropriateness:

- As some areas of shoals (and the features themselves) may represent unique habitat for important and/or commercial species, it will be important to implement protective measures.
- There is a concern (Hayes and Nairn, 2004) that removal of too much sediment from a shoal could lead to dramatic deflation of the shoal eliminating most or all habitat associated with the shoal feature.
- How important is the loss of a shoal if there are other shoals nearby? This can only be answered on a site-specific basis.

Practicality:

- Whether this is a practical approach will depend in part on the total quantity that is determined to be available without creating irreversible damage to the shoal integrity.
- Discussions between R. Nairn of Baird & Associates and C. Spaur of the Baltimore District office of the USACE, subsequent to the workshop, have resulted in the development of some possible guidelines for dredging. From a review of shoals offshore Maryland/Delaware on the OCS it was determined that the existing features had a wide range of volumes from 6,000,000 to 160,000,000 m^3. This may suggest that removal of several million cubic m from the larger shoals may not impact their geomorphic integrity. Spaur also reviewed the length to width ratios of the various shoals and found that the width of the features varied in a relatively small range, mostly between 1.6 and 3.2 km. This may suggest that the width of the feature is the key dimension and that any dredging should be planned to avoid reducing the width below a threshold level, possibly in the range of 1.6 km.

Effectiveness:

- It is unlikely that the approach of evaluating shoal morphometrics would, on it's own, provide sufficient understanding to determine guidelines for removal of sediment at the same time as protecting the geomorphic integrity of the feature.
- Nevertheless, this approach shows promise in supporting the development of appropriate guidelines on where and how much to remove from each shoal.

Recommendation on Protecting Essential Fish Habitat and, Specifically, Shoal Integrity:

There is much to be learned about the processes that maintain the form of shoals, and therefore, the potential impacts of dredging sand from these features. Hayes and Nairn (2004) have summarized the literature on this topic and suggested a new mechanism for the maintenance of OCS shoals; however, the understanding of these features requires more investigation. The new mechanism suggested by Hayes and Nairn (2004) consists of converging and crossing wave patterns (resulting from refraction processes on either side of the shoal) leading to a convergence of sand transport at the crest of the shoal. This convergence of sediment transport maintains the shape of the feature and explains why they fall into the dominant wave direction and migrate in the direction of the dominant wave propagation. This understanding and the development of guidelines for the removal of sand through dredging (specifically, how much and where) will require several lines of investigation including: a review of shoal morphometrics (as C. Spaur of the USACE, Baltimore District has initiated); an investigation of the sedimentology and stratigraphy of these features; and numerical modeling of waves, sediment transport and morphodynamics.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study was commissioned to evaluate on a worldwide basis existing and emerging environmentally friendly approaches to dredging for sand and gravel in offshore waters on the Outer Continental Shelf. The focus was primarily on Trailing Hopper Suction Dredges as these are the most likely vessels of choice for dredging operations where the borrow area and the project site requiring the sediment are several kilometers or miles apart. However, in some cases Cutter Suction Dredges and Dust Pan Dredges may also be utilized so these have also been considered.

Twelve key impacts were identified and prioritized through discussions with the Federal and State resource agencies that are actively dealing with dredging impact issues. Each of these impacts is described in detail in Section 2 of this report. The existing state-of-the-knowledge on these impacts was summarized through a literature review by Newell and Seiderer (2003) commissioned for this study (see Appendix A) and by updating the review of impacts completed by Research Planning, Inc. et al. (2001) and earlier MMS studies.

Of the twelve impacts identified, a short list was developed for detailed investigation by focusing on those issues which were not being actively investigated through other MMS or other agencies, and which did not have sufficient existing MMS stipulations. The list of concerns for focus in this project, in order of priority ranking based on discussions with the resource agencies in the US, is:

1. Short-term and cumulative impacts from dredging that lead to loss of entire benthic communities and possible re-colonization by an altered biological community;
3. Changes in the substrate characteristics (grain size, dissolved oxygen, compaction and organic content) that lead to a reduction in benthic communities and suitability of the area for future dredging;
5. Sedimentation (burial) impacts to adjacent hard/live bottom or other sensitive habitats; and
7. Impacts from short-term increased turbidity from cutterhead or draghead and overflow from hopper dredges on benthic communities.

Other key concerns such as impacts to turtles (ranked 2), shoreline impacts through changes to wave climate (4), spatial and seasonal conflicts with recreational and commercial fishermen (8), potential damage to pipelines (9), damage to archeological resources (11), and potential harmful alteration or destruction of Essential Fish Habitat (12) are being or have been recently addressed in other MMS (and USACE in the case of sea turtle impacts) studies. The impact to Essential Fish Habitat was discussed in a preliminary manner during the project workshop and some other recommendations were developed. Creation of depressions and furrows (ranked 6) was agreed to be of minor concern, or covered by Impact 3, which considered the development of dredge pits. The existing stipulations for collision with marine mammals (10) were determined to be sufficient.

A review of the range of existing and emerging environmentally friendly techniques and approaches to dredging was supported by a literature review and an industry survey. The industry survey included both US and European dredging contractors. In general, this review found that the US dredging industry is not lagging the European market in development of innovative approaches. Two of the key recent developments to address dredging impacts in offshore waters, and particularly the size and extent of dredge plumes, consisted of the use of an anti-turbidity valve to reduce air entrainment in the overflow process and an approach of re-circulating the overflow water to the draghead (a "closed system" sometimes referred to as "Green Pipe"), eliminating the plume from the upper part of the water column. Both the European and US dredging industries had adopted widespread use of the anti-turbidity valve. Neither the European nor US dredging industries had adopted the closed system approach to overflow due to capital and operational costs and lack of justification to eliminate overflow in the upper part of the water column. Another approach that is becoming universally adopted, at least within the US market where aggregate dredging and screening are not carried out, is below hull release of the hopper overflow. This approach also reduces the size of the turbidity plume.

The key area of difference between the US and European dredging industries was the size of hopper dredges. Within a decade in Europe the maximum hopper size of TSHDs has moved from around 12,000 m^3 to in excess of 35,000 m^3. In contrast, in the US, the largest hopper dredges are the Great Lakes Dredge & Dock Liberty Island (5,000 m^3) and Bean Stuyvesant (8,360 m^3). With respect to dredging impacts, the primary implication of this difference is that almost all of the recent research on hopper design (and efficiencies related to the overflow process) has been completed in Europe. However, US dredging contractors ultimately benefit from these developments.

There has also been a tremendous amount of development in dredging equipment related to controlling the release of sediment at the dredge head, particularly for projects involving the removal of contaminated sediments. These techniques were reviewed and discussed as part of this project but do not really contribute to the evaluation of issues and techniques appropriate for most OCS dredging operations.

From the industry survey and the literature review it was apparent that most approaches and equipment development has focused on reducing turbidity levels associated with overflow from hopper dredges. These various efforts have reduced the sedimentation footprint associated with the overflow plume to extending no more than about 200 m beyond the dredge area, at least at locations where ocean currents are not strong. The success of concentrating the overflow plume may be leading to a new problem, at least in some cases, and that is the development of a near bed turbidity current. In these cases, a turbidity current consisting of a highly sediment-laden flow can travel 100's of meters up to several kilometers away from the borrow deposit, significantly expanding the area of impact. Turbidity currents are triggered under certain conditions consisting of a steep seabed slope and/or strong currents (with the dredge operating in line with the currents).

Very little if any development in either equipment or dredging approaches has been devoted to the key issue of loss of benthic communities. Some possible approaches, consisting of setting aside spatial or temporal refuges, were developed by the study team for further evaluation. In other cases, where environmentally friendly approaches or equipment had not been developed to address particular key impacts, some suggestions were generated by the team members for further evaluation.

The final phase of this study consisted of a workshop to evaluate the various environmentally friendly approaches that had been identified under each of the impact headings, with particular focus on the ones noted above. The workshop was attended by representatives of: the study team, MMS, USACE, and the dredging industry. For each type of equipment, procedure or approach that was reviewed, the evaluation was completed for three criteria: appropriateness, practicality and effectiveness. The recommendations for each key impact are summarized in Section 6.2.

6.2 Recommendations

A summary of the recommendations developed through the course of the study workshop is presented below for each of the key impacts identified for review.

6.2.1 Recommendation on Spatial/Temporal Refuge Areas to Promote Re-Colonization of Benthic Communities

It may be appropriate, practical and effective to impose spatial or temporal refuge areas at locations with one or more of the following characteristics: 1) the presence of a unique assemblage of benthic communities; 2) special commercial significance of a benthic community in a borrow area; 3) at locations where the benthic community is spatially limited with respect to recruitment and re-colonization; and 4) where the importance of a benthic community within the borrow area is significant for higher trophic levels or where this relationship is uncertain. In order to develop a layout of refuge areas that is practical and does not significantly influence the cost of the dredging operation, the type of dredging equipment and borrow deposit layout should be considered. Some specific dimensions for minimum feasible dredge areas are presented in the report as a guideline for developing a feasible layout of dredge and refuge areas. The MMS Plume model should be applied to determine the required size of the refuge areas considering the sedimentation footprint from the dredging operations. This proposed approach should be field tested along with a technique to monitor the effectiveness.

6.2.2 Changes to Substrate Characteristics and Recommendation on a Pit Depth Rule

A blanket maximum pit depth rule is inappropriate. However, it is appropriate to determine a local maximum pit depth to avoid development of a mud cover and/or anoxia. The minimum practical pit depth would be greater than 1 m from TSHDs and greater than 2 m for CSDs. Maximum pit depths should be determined on a site-specific basis through analysis combined with monitoring where necessary (as described above). Monitoring may assist the development of an appropriate maximum pit depth at borrow sites that are dredged more than once.

6.2.3 Recommendation on Protecting Sensitive Habitat from Sedimentation

It is appropriate to consider the implementation of these measures at locations where there is nearby habitat that is sensitive to sedimentation, such as hard/live bottom areas or coral habitat with specific sedimentation sensitive organisms. In these cases, there is a need to establish field-tested sedimentation limits for different types of sensitive habitat. A blanket buffer zone width for all locations is probably unjustified. Another way of defining acceptable site-specific sedimentation levels, that may be more expedient, is through the monitoring of natural sedimentation rates. Once sedimentation limits are established for the local sensitive habitat, the best approach would consist of a pre-dredging assessment of the plume sedimentation footprint using the MMS Plume model (or equivalent), followed by real-time or near real-time monitoring of sedimentation levels (for more details see the recommendations summary for buffer zone approaches at the end of Section 5.3.5.3). Turbidity monitoring may also be helpful to validate the Plume model, however, it is not a suitable replacement for direct monitoring of sedimentation. It would be appropriate to require the Anti-Turbidity valve device at locations where restricting the sedimentation footprint is important. At almost all locations the Green Pipe approach (where the overflow water is re-circulated to the draghead) is likely unjustified. At borrow sites with strong tidal currents or steep slopes, the possibility of the development of a near-bed turbidity current generated through the pancaking effect of the dynamic plume phase should be evaluated (see Section 2.3.7 for details).

6.2.4 Recommendation on Addressing the Impact of Turbidity

It is generally viewed that elevated levels of turbidity generated from TSHD operations in open ocean waters does not represent a significant ecological impact. It is believed that adult fish can avoid plumes and that other organisms can survive the sub-lethal levels of short-term elevated turbidity. A one-size-fits-all limit of 29 NTUs above background levels measured at 150 m from the dredging operation is probably scientifically unjustified for the ocean environment. Nevertheless, representatives of the dredging industry that attended the study workshop indicated that the 29 NTU limit was not difficult to achieve. At locations where a more scientifically justified level is required, for example where there is a specific ecological concern about turbidity levels, it may be possible to develop a site-specific limit based on measurements of turbidity levels over a minimum period of one or two years. The Anti-Turbidity valve device is widely applied in the US and significantly reduces the size of plumes from TSHDs and the total sediment overflowed in the discharge process. It would be appropriate to require the use of this device wherever turbidity is a concern. The “Green Pipe” approach consisting of re-circulation of the overflow water to the draghead eliminates the plume above 4 to 5 m above the seabed (i.e. outside of the region of the draghead plume), but it does not reduce the total sediment discharged in the overflow process. However, this approach is not included on any US dredge vessels (nor on most European vessels) and would represent a significant and expensive equipment overhaul that would be passed on to the consumer through higher unit prices and is likely unjustified at most locations.

6.2.5 Recommendation on Protecting Essential Fish Habitat, and Specifically, Shoal Integrity

There is much to be learned about the processes that maintain the form of shoals, and therefore, the potential impacts of dredging sand from these features. Hayes and Nairn (2004) have summarized the literature on this topic and suggested a new mechanism for the maintenance of OCS shoals (see sect. 5.3.12.4 for an explanation of this new mechanism), however, the understanding of these features requires more investigation. This understanding and the development of guidelines for the removal of sand through dredging (specifically, how much and where) will require several lines of investigation including: a review of shoal morphometrics (as C. Spaur of the USACE, Baltimore District has initiated); an investigation of the sedimentology and stratigraphy of these features; and numerical modeling of waves, sediment transport and morphodynamics.

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Appendix A

Literature Review On Ecological Impacts Of Dredging

Report By Newell And Seiderer (2003) Completed For This Study.

ECOLOGICAL IMPACTS OF MARINE AGGREGATE DREDGING ON SEABED RESOURCES

Prepared For

Baird Associates,
627 Lyons Lane, Suite 200,
Oakville, ONTARIO. Canada L6J 5Z7

By

R.C.Newell D.Sc.(Lond.) & L.J.Seiderer Ph.D.

Marine Ecological Surveys Limited
Trewood Cottage, Steeple Lane,
St. IVES. Cornwall TR26 2PF.

Tel: +44 (0)1736-795975
Fax: +44 (0)1736-793727
E-Mail: SEASURVEY@aol.com
Web Site: www.marineecologicalsurveys.co.uk

CONTENTS.

SUMMARY.

Our assessment of the likely impacts of marine aggregate mining on seabed resources is based mainly on the results of impact studies on physical and biological resources in relatively shallow water sites of up to 30m depth in European waters. Most of the conclusions are therefore strictly applicable mainly to seabed deposits that are subject to disturbance by waves and tidal currents, and where the resident organisms are adapted to disturbance under natural conditions. We consider the most likely impacts on benthic biological resources to be the following:-

1. The species variety, population density and biomass of benthic fauna is likely to be suppressed by as much as 60-90% within dredged areas. This suppression will reduce during the recovery process following cessation of dredging, but may be significant in coarse deposits for at least half of the overall recovery time, ie. at least 6-10 years (see below). In sandier deposits, recovery times are likely to be shorter (approximately 2-4 years).

2. There is likely to be a zone extending for a variable distance outside the dredge area (depending on the velocity and direction of the tidal streams at the seabed) where deposition and subsequent seabed transport of material discharged overboard has an impact on biodiversity, population density and biomass of benthos.

3. Studies recently completed in the North Sea in the vicinity of Licence Area 408 show that where sand rejected during the screening process has been returned to the seabed, areas of fine well-sorted sand extend from the dredged sites along the axis of net transport by tidal streams for at least 2km. The distribution of these fine sands varies with local seabed current direction, and is consistent with the deposition and transport of material rejected during the screening process.

4. The biomass of benthic infauna within an actively dredged zone at this Licence Area was suppressed by 82% compared with that at “control” sites well outside any impact of dredging. Biomass is suppressed by as much as 66% within the areas of fine sand outside the boundaries of the dredge site, and approaches that of “control” sites at a distance of 4 km down the axis of net tidal transport to the south-east of the dredged sites. Impacts of deposition of sand rejected during the dredging and screening process can therefore extend for a considerable distance outside the boundaries of a dredge site along the axis of transport of material on tidal currents at the seabed.

5. Some components of the community, such as polychaete worms and small crustaceans, are capable of relatively rapid recolonisation and growth following cessation of dredging. Recovery of the biomass of some of the long-lived components of the equilibrium communities such as larger bivalve species that characterise gravel communities could, however, take as much as 15-20 years even if the deposits remain of a suitable particle size composition for

recolonisation.

6. If removal of coarse material for marine aggregates, and rejection of fine sand results in a long-term change in sediment composition towards more sandy deposits, then the fauna is likely to revert to one with a low species variety dominated by polychaete worms.

7. Impacts on transitory members of the biological community in the vicinity of the dredge sites are less likely than impacts on benthic organisms that cannot evade adverse conditions should they occur. Thus although impacts on plankton and fish have been reported for long-term exposure experiments in the laboratory, under natural conditions most species are likely to evade areas of disturbance or turbidity.

8. We conclude, therefore, that the main impacts of the dredging proposals will be a suppression of species diversity, population density and biomass of benthic animals within the dredge sites and along the axis of deposition of material mobilised by the dredging and screening processes.

9. Benthic communities probably represent an important food resource for fish, but we doubt whether losses to the marine food web from the dredged areas would result in a detectable impact on the carrying capacity of the waters surrounding a dredge site for commercial fish stocks. Of more significance are possible impacts on areas of localised or seasonal importance such as spawning grounds and nursery grounds for fish and shellfish such as scallop and crab.

10. Recent proposals for Risk Assessment to marine resources, including invertebrate communities of conservation significance and commercial fish stocks, take into account both the sensitivity of the resources to the physical impacts of marine aggregate dredging, and their actual vulnerability based on the location of the resources in relation to the dredge site and contours known physical impact. We consider this to be an important approach that allows a full identification of Risk to specific environmental resources located near to a dredge site, before possible mitigation or remedial measures are considered.

11. There are currently few practical or cost-effective ways of minimising the impacts of marine aggregate dredging within the dredge sites themselves, nor in the sedimentation zone which is likely to surround the dredge sites unless restriction of discharge of screened material were a commercially-acceptable option. Experimental studies are being undertaken to determine whether restoration of the seabed surface with a thin layer of gravel could assist in restoration of community composition following cessation of dredging, but the results of this work have not yet been reported or evaluated as a cost-effective option.

1. INTRODUCTION.

In order to assess the likely impacts of marine aggregate dredging on biological resources, it is necessary to summarise the data which are available from impact studies, and to clarify the assumptions inherent in the environmental impact assessment process. This includes features of the extraction process itself, as well as the key points at which an impact on biological resources might be anticipated beyond the immediate boundaries of disturbance by the drag head.

The impact of marine aggregate dredging on seabed resources has been widely reviewed and are comparatively well-documented for coastal sites in European waters (see Dickson & Lee, 1972; Shelton & Rolfe, 1972; Cruikshank & Hess, 1975; Eden, 1975; Millner *et al*., 1977; de Groot, 1979; Van der Veer *et al.*, 1985; Glasby, 1986; Lart, 1991, Gajewski & Uscinowicz, 1993; ICES, 1993; Land *et al.*, 1994; Whiteside *et al.*, 1995; Hitchcock & Drucker, 1996; Newell *et al.*, 1998; Desprez, 2000; van Dalfsen et al., 2000; Boyd *et al.*, 2003). There have, however, been several recent studies that confirm and amplify what is known about the extent and distribution of material discharged during the dredging process, and the impacts that this might have on benthic biological resources.

1.1. THE DREDGING PROCESS.

Most of the sea-going aggregate dredgers are self-contained and use a centrifugal pump to lift aggregates from the seabed into a hopper where the material may be screened before being transferred to a hold of 5000-8000 tonnes capacity. Where the gravel deposits are in a restricted area of seabed, the suction dredger may operate at anchor, a method of dredging that can result in pits or depressions in the seabed that can reach as much as 20m depth and 75m diameter (Dickson & Lee, 1972; Cruikshank & Hess, 1975). These pits formed from 'anchor-dredging' are likely to be persistent features of the seabed for several years except in areas where the sands are mobile (Eden, 1975). In such cases, slumping of the sides of the pit and subsequent infilling by fine particles transported by tidal currents may lessen the physical impact, restoring the pits to their former level. However, this can lead to heavily anoxic sediments within such dredge pits, and to colonisation by a community that differs considerably from that in the original deposits (Dickson & Lee, 1972; Shelton & Rolfe, 1972; Kaplan *et al.*, 1975; Bonsdorff, 1983; Hily, 1983; Van der Veer *et al.*, 1985; Hall, 1994).

The normal process of extraction involves suction dredging whilst the vessel is slowly under way. This process of 'trailer dredging' results in a series of tracks of 2-3m wide and up to 50cm deep (van Moorsel & Waardenberg, 1990; Kenny & Rees, 1994; Boyd *et al.*, 2003), although deeper troughs of up to 2m have been recorded from areas where the drag head had crossed the area several times. Davies & Hitchcock (1992) reported dredge cuts of between 20-55cm depth and 3.0-3.8m width in commercially exploited deposits of the Bristol Channel. Somewhat deeper troughs of up to 70cm were reported for the Baltic (Gajewski & Uscinowicz, 1993). Desprez (2000) reported furrows up to 5m deep separated by crests of shingle in dredged deposits off Dieppe, France. In all these cases removal of the surface 0.5m of the seabed is sufficient to eliminate the benthos from the deposits. The total depth of removal depends on the intensity of dredging at a particular worked site.

In some instances, *in situ* gravel deposits are transferred in bulk into the hold for subsequent use as beach feed or landfill (see Hess, 1971), but in most instances the proportion of sand:gravel in the cargo is adjusted to suit customer requirements by a process of screening which can involve rejection of significant quantities of sand overboard at the site of dredging. The *in situ* reserves that are suitable for economic exploitation generally range from 15-55% gravel whereas the sand:gravel ratio in the final cargo is generally adjusted to between 50:50 and 65:35 depending on customer requirements, local geology and ship performance. This implies that 20-80% of the material dredged may be rejected overboard during the screening process.

If we assume a relatively low figure of 30% for material returned to the seabed following screening, then a total of 6500te of seabed deposits will be dredged to obtain a 4500te cargo load. This process takes 4-6h depending on the type of dredger and nature of the seabed deposits and is likely to be associated with a discharge of a minimum of 1,500te of fine deposits comprising mainly sand-sized particles from the reject chutes following screening.

Settlement of this reject material can result in a significant 'overburden' of sand within production licence areas, the deposits then requiring increased screening compared with newly-exploited deposits to obtain a suitable commercial cargo. In some coastal areas, for example, mass balance studies of emissions from dredgers operating in Production Licence areas such as Owers Bank and in relatively sandy deposits of the North Sea off Southwold show that much higher proportions of up to 1.7 x the cargo load may need to be 'processed' by the dredger to obtain a suitable cargo (Hitchcock & Drucker, 1996; Newell *et al.*, 1998, 1999). The possibility of significantly higher rejection of screened material than the 30% assumed above for typical gravel deposits cannot therefore be excluded if an overburden of sand develops after a period of exploitation of the resource. Discharge of increased quantities of sand by screening is likely to significantly increase the impact of discharged material on benthic biological resources in the immediate vicinity of the dredge site, but is unlikely to settle over a wider area than when smaller quantities are discharged.

Progressive removal of the coarse fraction of deposits, and rejection of fine material by overboard screening can result in significant changes in particle size composition of the deposits both within the dredged area, and along the axis of deposition of material discharged overboard by the screening process. This effect is more marked in undisturbed environments where screened material is not moved rapidly away from the site of deposition by local currents. van Dalfsen *et al* (2000), for example, reported that at a dredge site in the Mediterranean at Costa Daurada, Spain, grain size changed considerably as a result of deposition of material from the spillways during the dredging operation. After two months, scuba divers observed a 5-20cm thick layer of very fine sediment (MD_{50} = 0.016-0.018mm) on top of the native sand (MD_{50} = 0.1-0.15mm). One year later the fine sediment still formed on average 27% of the sediment by weight

(Manzanera *et al.*, 1996). Changes in particle size composition of the sediments following dredging have also been reported for sediments in relatively shallow water off Dieppe by Desprez (2000; for review, see Boyd *et al.*, 2003).

A second source of loss of material from the dredger during the dredging process is fine suspended material which overflows through the spillways once the hold has filled with water and screened cargo. In most aggregate areas the fines comprise at least 1-2%, and often as much as 8-10% of the deposits. Assuming that all of these fines are discharged through the spillways, then even based on the lowest figure of 1-2% silt, the mass of silt likely to be discharged during processing of the 6500te of seabed deposits required to load a 5000te cargo is likely to be 65-130 tonnes, and it could be a good deal higher in some of the dredge sites.

This fraction dominates the overspill material although there is also a varying component of sand that is maintained in suspension by turbulence within the hopper. This can result in an obvious visible 'plume' which carries for as much as 2-3km down-current astern of dredgers operating in deposits that contain significant quantities of silt.

Plate 1. Typical marine aggregate dredger loading a cargo and discharging screened material from reject chutes. Overspill losses from the cargo hold can also be seen. Copyright ©MESL-PhotoLibrary.

A typical suction trailer dredger operating in the North Sea is shown in Plate 1. Overboard losses from the two screening towers and reject chutes can be seen, as well as those from the spillways located along the upper parts of the cargo hold.

1.2. THE FATE OF OVERBOARD DISCHARGES.

Most direct studies on the fate of the material discharged through the overboard reject chutes suggest that coarse material, including sand-sized particles settle rapidly to the seabed as a density current jet. The rate of settlement during this initial 'dynamic phase' depends on the overflow density, the diameter of the discharge pipe, the water depth, the velocity of discharge and the speed of the dredger (Whiteside *et al*, 1995). During its passage through the water column, and following impact on the seabed, the sediment is dispersed into the water column and forms a well-defined plume astern of the dredger. This second, longer phase has been referred to as the 'passive phase' of dispersion by Whiteside *et al* (1995) and starts approximately 10min after discharge. During this phase, the material behaves in a relatively simple settling mode according to Stoke's Law, the plume then decaying to background levels after a period of 2-3h. This dispersing plume is a clearly visible feature of many marine aggregate dredging operations, and is supplemented by losses of fines from the spillways amounting to at least 1-2% of the total material dredged.

Plume generation and decay from dredgers operating at Owers Bank off the south coast of UK has been studied by Hitchcock & Dearnaley (1995; see also Hitchcock & Drucker, 1996). Their results support the view that particles rejected through the screening process move rapidly to the seabed. Conventional water sampling techniques used in this study suggested that concentrations of sand-sized particles were reduced to background levels only 200-300m from the point of release into the water column and that concentrations of silt-sized particles are also reduced to background levels of 2-5mg per litre over this distance.

Acoustic backscatter techniques were also used to define the plume morphology in relation to distance and time down-current of a dredger operating at anchor and rejecting the screened material overboard as described above. These measurements suggest that sand settlement occurs in a zone extending up to approximately 600m astern of the dredger. Silt-sized particles disappeared from the water column at approximately 1800m. Other components, thought to be organic matter, disappear from the water column at 2.5 - 3.0km astern of the dredger.

A series of sections through the outwash plume down-current of the dredger based on Hitchcock & Drucker (1996) is shown in Figure 1.

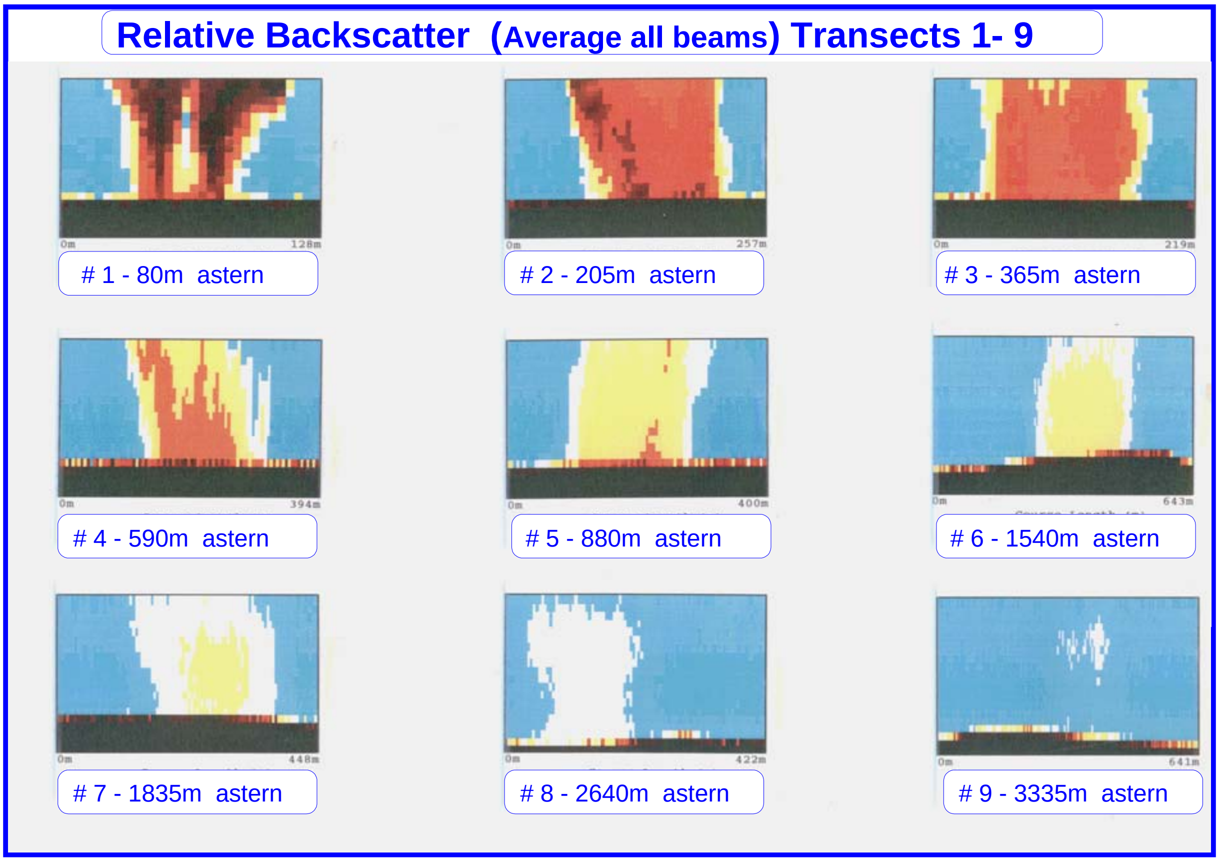

Figure 1. Acoustic Backscatter images across the plume at varying distances downstream of an anchor-dredger during loading of a screened cargo at Owers Bank off the south coast of UK. Based on Hitchcock & Drucker (1996). The black band at the seabed is a data corruption zone which precluded assessment of plume morphology at the sediment-water interface. The red signal indicates coarse sand-sized particles; the yellow signal indicates the settlement of silt; and the white signal is considered to represent organic flocculating material.

Several features of interest emerge from these results:-

- Although suspended sediment concentrations in the plume were not significantly different from background levels beyond 200-300m from the point source of discharge using conventional water sampling and optical transmissometer techniques, it is possible to track the plume using acoustic backscatter techniques for a distance of up to 3.5km. Subsequent studies suggest that this far-field effect reflects the presence of organic material derived from benthos fragmented by the dredging and screening process (Newell *et al.*, 1999).

- The sedimenting plume is approximately 200m wide and 3000m long in the region where settlement from the water column is occurring.

- The technique is useful for identifying the zone of settlement from the water column, but there is a data corruption zone at the sediment-water interface amounting to approximately 6% of the water depth, where further tracking of subsequent deposition and movement of material is not possible.

Because the benthic organisms are likely to be mainly affected by heavy sedimentation loads on the seabed, direct studies showing the relatively rapid sedimentation of particulate material within 600m from the point of discharge have until recently suggested that most, if not all impacts of the rejection of screened material are likely to be confined to the immediate vicinity of the point of discharge and are unlikely to have a potential impact beyond the boundaries of the dredge site itself.

Recent studies suggest, however, that at some sites the potential impacts of screened material are not confined to the relatively small zone of initial sedimentation from the water column. Dickson & Rees (1998) deployed a series of 'mini-POD' samplers located approximately 50cm above the seabed in the vicinity of Area 107 off Skegness in the southern North Sea. They have shown that marine aggregate dredging in that area is associated with a benthic plume of mobilised sediment that extends along the sediment-water interface for as much as one tidal excursion (ie., as much as 10km) along the axis of the tidal stream in that area (Dickson & Rees, 1998). Simultaneous deployment of a mini-POD near the Area 107 South Coast Shipping dredge site and on Race Bank approximately 6.5km away from the dredge site in May-June 1995 allowed some estimates of the transport of material between the dredge site and adjacent areas.

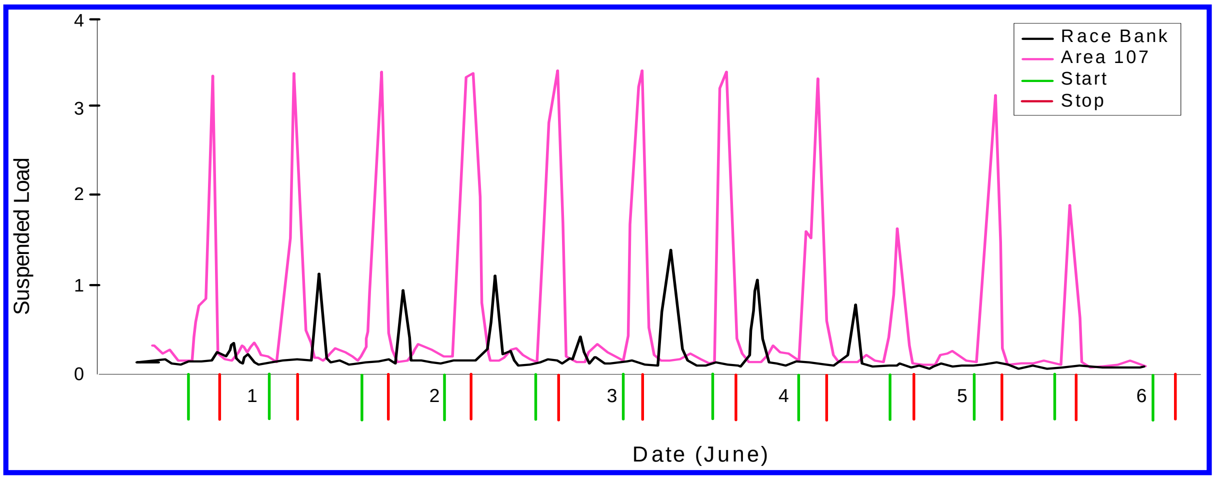

Figure 2. Mini-POD records showing suspended sediment spikes at dredge Area 107 (magenta) and at Race Bank (black) at a distance of 6.5 km from the dredge site in 1995. Redrawn after Dickson & Rees (1998).

Figure 2 shows the suspended sediment load measured at a mini-POD located on the seabed at the site of dredging at Area 107 and at Race Bank approximately 6.5km downstream. Each period of dredging activity by the dredger '*Sand Weaver*' (shown in green for the start and red for the stop below the X-axis in Figure 2) is followed by a high concentration of suspended sediment at the dredge site mini-POD, followed approximately 5h later by the arrival of a smaller spike at Race Bank. The speed of travel of the pulse of sediment at the sediment-water interface is therefore approximately 1.3km per hour.

A deployment of 4 mini-PODs was then made in June 1996 to record the passage of a sediment plume from the site of dredging at Area 107 to Race Bank. The dredger used in this experiment was the modern '*Ham 311*'. The results shown in Figure 3 provide the first clear and unequivocal evidence of an individual outwash plume passing in sequence from one mini-POD to the next across the whole distance from the dredge site to Race Bank.

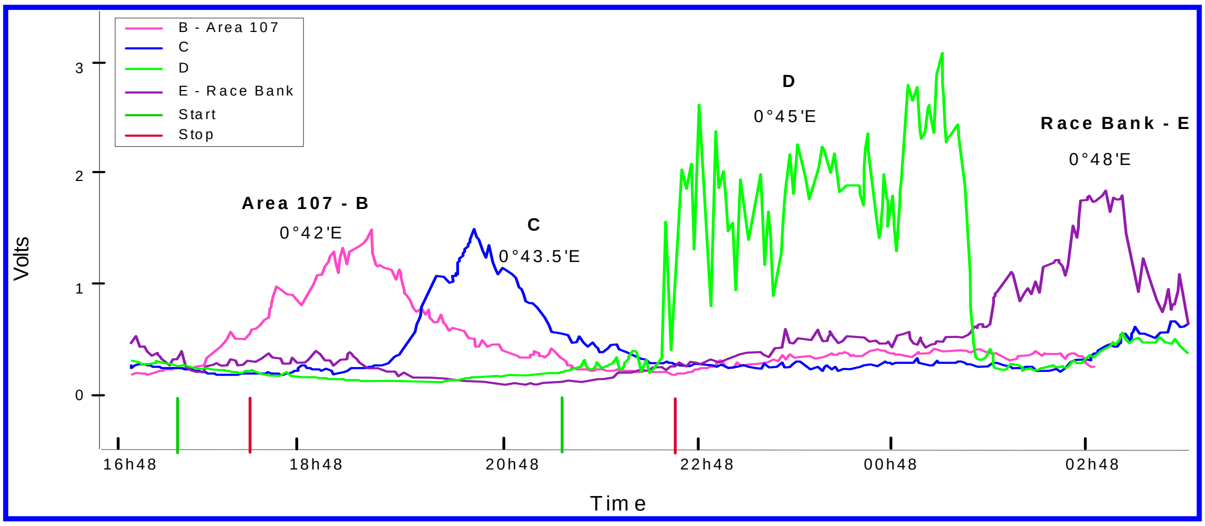

Figure 3. Traces from 4 Mini-PODs recording the passage of a benthic sediment plume from a site of dredging at Area 107 to Race Bank in June 1996. Redrawn after Dickson & Rees (1998).

Impacts at the sediment-water interface are of particular significance to marine benthos because activities such as larval settlement, irrigation and feeding occur at the surface of the seabed. It is therefore of interest to know the particle size spectrum of the material carried from the dredge site at the seabed. Dickson & Rees (1998) used event-triggered syringe samplers and passive sediment traps to provide a calibration of Miniature Optical Backscatter Sensors (MOBS) by gravimetric analysis and analysis of particle size spectrum at a mini-POD site within dredge Area 107 and at a site approximately 8.5km to the south at Nut and Spanner Buoy on Docking Shoal. This is the furthest site at which dredge plumes from Area 107 have been detected at Spring tide conditions.

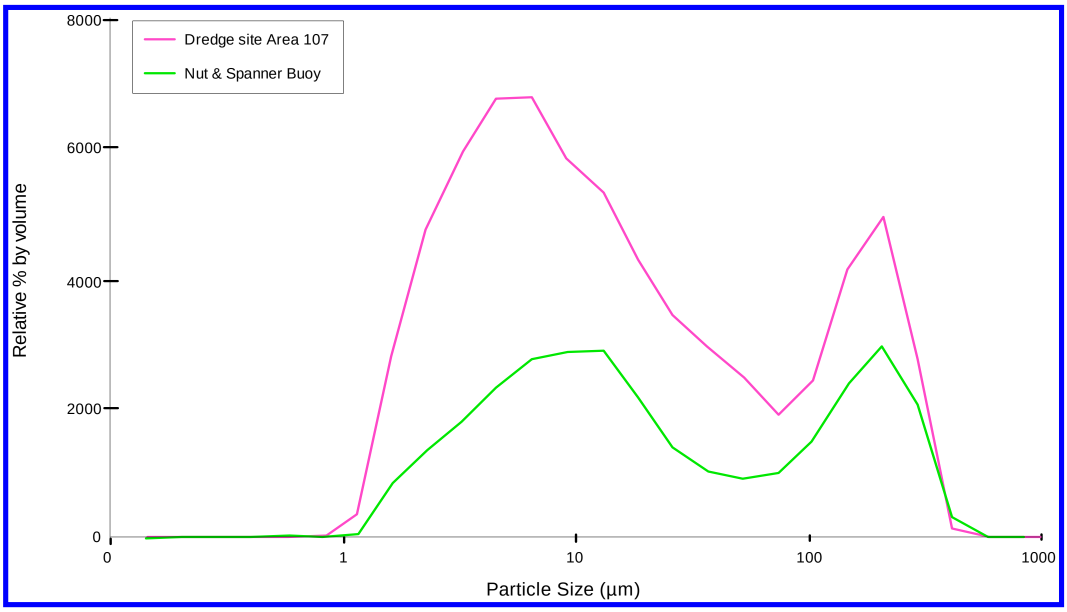

Figure 4. Relative Particle Size composition of the benthic boundary plume at the dredge site at Area 107, and at Nut & Spanner Buoy 8.5 km to the south of the dredge site. Redrawn after Dickson & Rees (1998).

Figure 4 shows that the main difference between the benthic plumes at the dredge site in Area 107 and that at the Nut and Spanner site 8.5km to the south is an overall reduction in the concentration of material. This probably reflects progressive losses by sedimentation to the seabed along the axis of the plume. There is, however, no evidence of a relative loss of coarse-sized particles (0.2mm) at the extreme of the plume. This suggests a relatively uniform loss of material along the length of the plume, rather than a differential settlement based on particle size. It suggests that the generation of a seabed plume may be more like a density current generated by material discharged to the seabed from the reject chute, rather than a simple settlement of material from a dispersing sediment plume. Very little further work has been carried out at other sites to investigate whether the results of this important study apply to other dredge areas, and the extent to which the scale of the seabed plume is related to local hydrographic conditions and the amounts of material rejected by screening within the dredge site.

These results were used by Dickson & Rees (1998) to show that dredging on Area 107 had a potential to deliver an extra 50-150mg/l to the near-bottom sediment layer at Race Bank during about 7% of the Spring/Neap tidal cycle. The Race Bank is an important over-wintering ground for berried brown crab (*Cancer pagurus*) typical landings being reported as £300,000 p.a in 1997-8 (Dickson & Rees, 1998). Since the sedimented material was carried towards this sensitive resource area on the ebb tide, agreement with the dredging company to confine dredging of Area 107 to the flood tide only, successfully minimised potential impacts on biological resources of economic significance.

Cancer pagurus ©MESL-PhotoLibrary

These direct measurements on the characteristics of near-bed sediment plumes in the southern North Sea are supported by a recent re-analysis of the acoustic backscatter data originally reported by Hitchcock & Drucker (1996) for marine aggregate dredging at Owers Bank on the south coast of UK. These also provide some evidence of a plume at the benthic boundary layer which extends along the axis of dispersion outside the zone of deposition of sediment from the water column Hitchcock *et al.* (2002).

Acoustic Backscatter Profiler ©MESL-PhotoLibrary

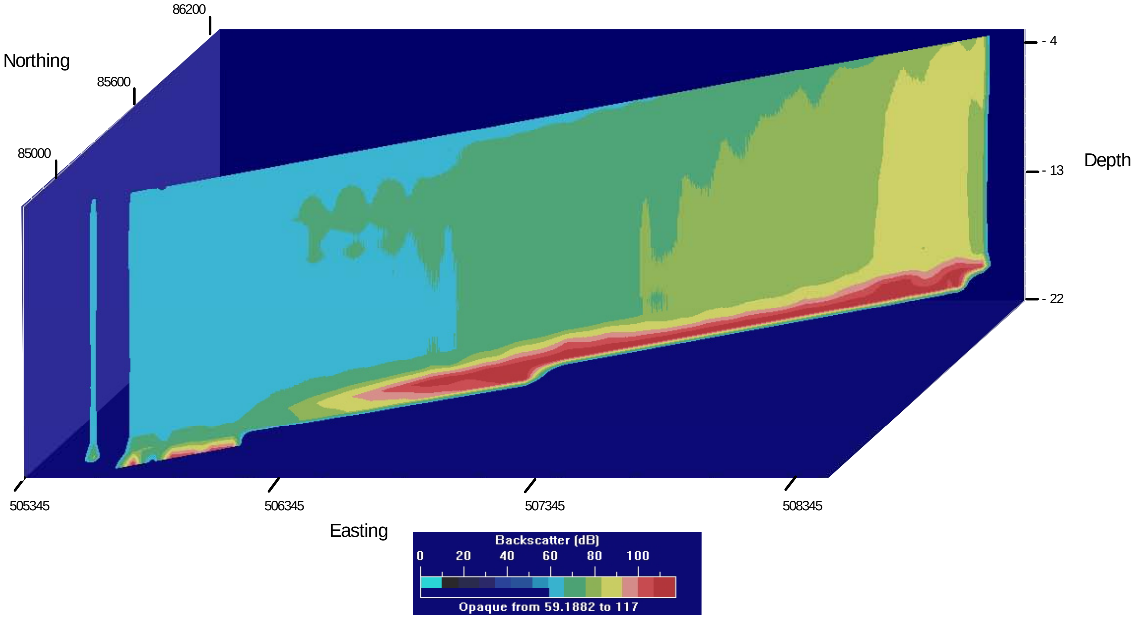

Figure 5. Longitudinal section of the sedimentation plume from a dredger loading a screened cargo at Owers Bank in 1995. Based on Acoustic Backscatter data from Hitchcock *et al*, (2002). The red side of the scale indicates high backscatter levels and the blue side of the scale indicates low backscatter levels.

Figure 5 shows a longitudinal section of the sedimentation plume from the dredger *'City of Rochester*' during loading of a screened cargo at Owers Bank in 1995. The near-site sedimentation of sand and the subsequent loss of finer material from the water column with distance downstream from the dredger corresponds with that shown in Figure 1. There is, however, also a strong signal along the benthic boundary layer, indicating the presence of a sediment plume located at the sediment-water interface. This extends outside the zone of sedimentation from the water column to the limits of measurements at 2.7km from the dredger, and may correspond with that described by Dickson & Rees (1998) from mini-POD measurements of benthic plumes in the southern North Sea.

This pattern of sedimentation and subsequent dispersion on the seabed is not confined to dredgers discharging screened material overboard during the loading operation. Figure 6 shows a longitudinal section of the acoustic backscatter profile from a large dredger *'Geopotes'* of 8000te hopper capacity loading an 'all-in' cargo at Owers Bank in 1995 (from Hitchcock *et al* 2002). Again, it is clear that there is an initial rapid sedimentation of material from the water column near to the point of discharge, but there is also an extended dispersion plume at the sediment-water interface and this extends downstream to the limits of measurements at least 4km from the dredge site.

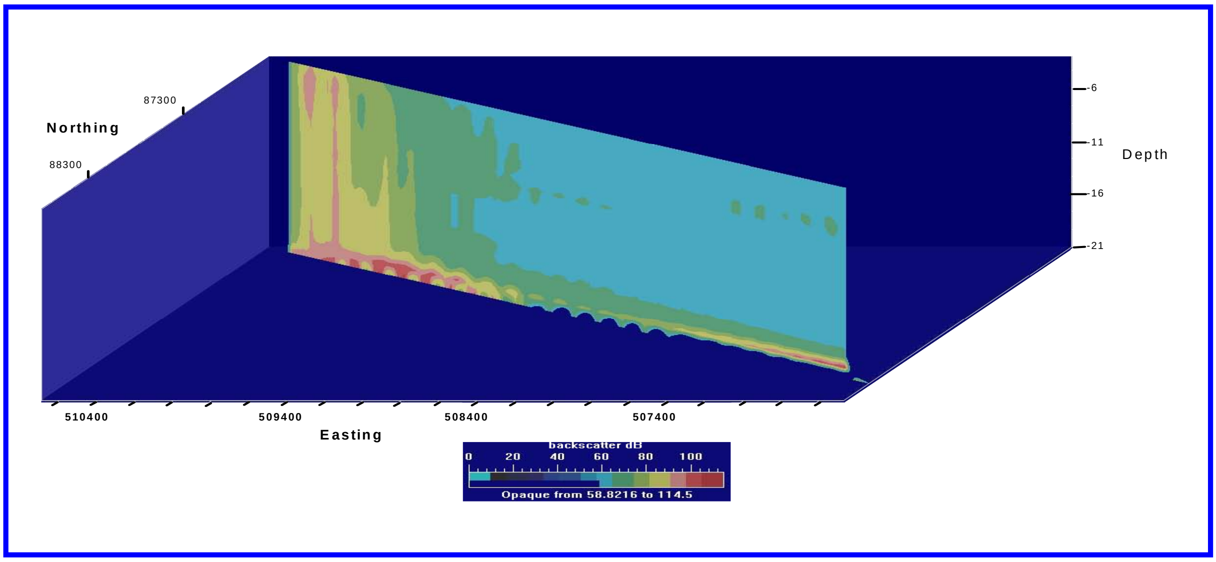

Figure 6. Longitudinal section of the Acoustic Backscatter profile from a dredger loading an "all-in" cargo at Owers Bank in 1995. Based on Hitchcock *et al*, (2002). The red side of the scale indicates high backscatter levels and the blue side of the scale indicates low backscatter levels.

Studies recently completed in the North Sea in the vicinity of Licence Area 408 support the view that fine sands rejected during the screening process, and mobilised by tidal streams, may be transported considerable distances along the seabed outside the boundaries of the dredge site. Net sediment transport at Area 408 is to the south-east, with local variations due to the influence of topographic features on the tidal streams in the west of the survey area. Newell *et al* (2002) and Evans (2002) have shown that areas of fine well-sorted sand with a sorting coefficient of <0.5 phi extend from the dredged sites within the Licence Area for at least 2km along the axes of local net sediment transport towards the south-east in the survey area. These areas of well-sorted fine sand overlay seabed sediments with a more variable composition, and could be associated with remobilised material.

The distribution of sediment with a sorting coefficient of <0.5 phi is superimposed onto the seabed morphology of the study area from high resolution side-scan sonar data acquired during 2000 in Figure 7. This shows the actively-dredged site where the seabed is disturbed by draghead trails, and an area of fine, well-sorted sediment extending along the net transport direction to the south east of the dredged site. Since the samples reported for Area 408 were taken with a Hamon grab, and therefore represent material averaged down to 20-30 cm depth, it is probable that thin surface layers of fine sand may extend further along the axis of tidal transport than is recorded from conventional grab samples.

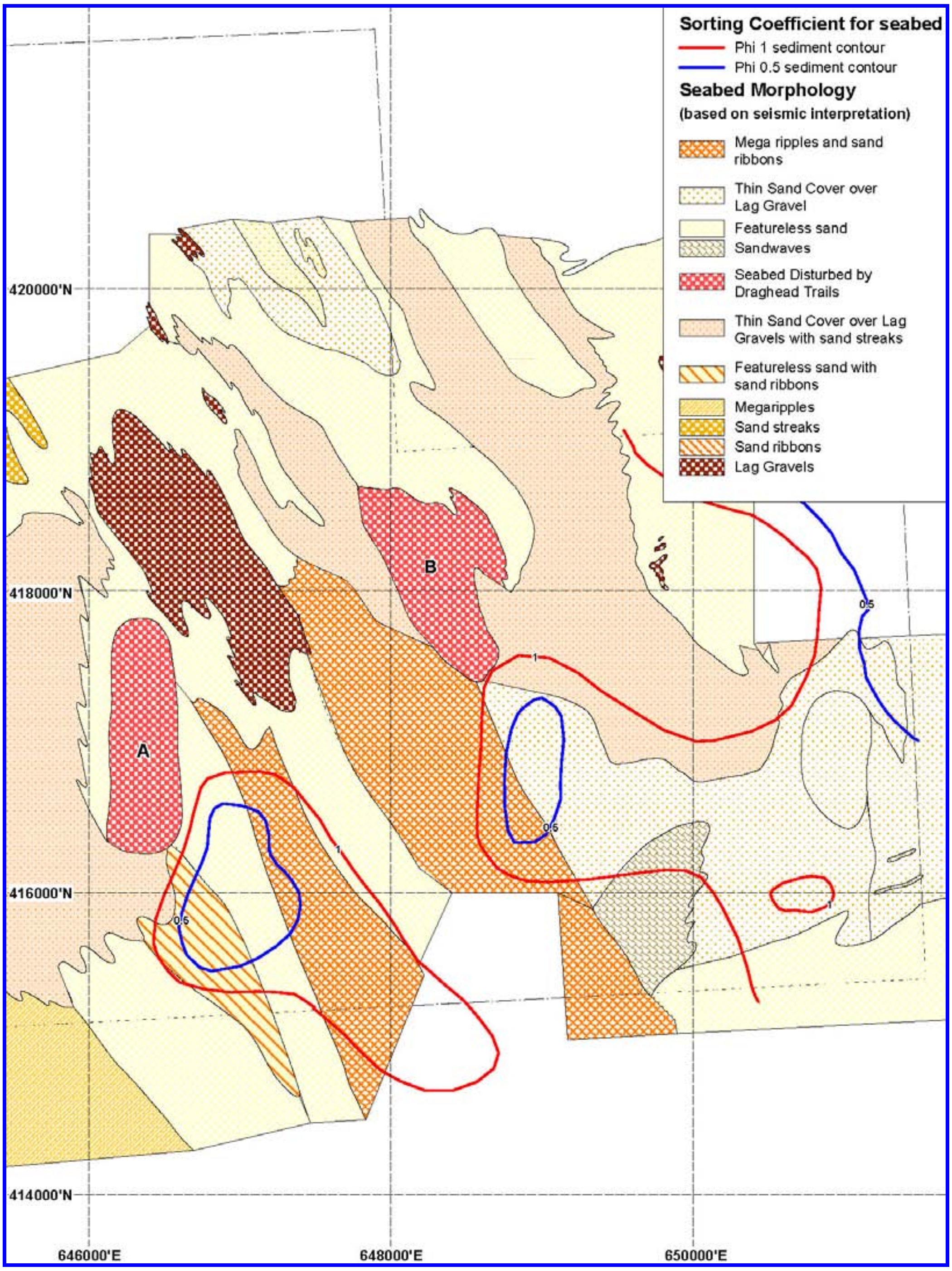

Figure 7. A section of the Licence Area 408 in the North Sea showing the seabed morphology based on seismic interpretation. Superimposed on the map are contours of sorting coefficient for seabed sediments with grain size finer than 0.5phi. The currently dredged area is represented by the letter **A**. The letter **B** represents an area where dredging ceased in 1999. Based on Evans (2002).

Areas of fine sand were also recorded outside the boundaries of zones at Licence Area 408 where dredging had ceased at least 12 months previously. Such patches of fine sand that may be derived from deposition of material rejected and returned to the seabed during the screening process thus appear to be relatively persistent, despite the movement of sediment that occurs naturally at the seabed. These results support those reported by Manzanera *et al* (1996) for a site at Costa Daurada, Spain.

In summary, all recent information suggests the following features of the dredging and sedimentation-dispersion profiles for material released from marine aggregate dredgers relevant to the assessment of impact on biological resources on the seabed:-

- Sedimentation of all components of material discharged overboard is faster than would be anticipated from simple Gaussian models based on the settlement velocity of component particles. This is due to cohesive properties of the discharged material which forms a density current that enters the water column in a 'dynamic phase' of settlement.
- Coarse material up to sand-size particles settles within 200-600 m of the point source of discharge, depending on depth of water, tidal velocity and the velocity of flow from the discharge pipe.
- Even fine silt-sized particles reach background values within 2-2.5km of discharge, although there is a residual 'signature' from the dispersing plume at distances of up to 3.5km which may be attributable to organic matter derived from fragmented benthos discharged during the screening process.
- Settlement from the water column in the vicinity of the dredge site is only part of the potential impact on benthic resources. There is now some evidence supporting the view that recently-sedimented material is mobilised at the sediment-water interface to form a benthic plume which can extend for as much as one tidal excursion in each direction from the dredge site.
- This benthic plume is of potential importance as a source of impact and is likely to affect a zone of up to one tidal excursion (10km in the North Sea near Area 107) in each direction on the Spring tide. The width is likely to be approximately 200m based on acoustic backscatter measurements of the sedimented material in coastal dredge sites.

1.3. IMPACTS ON BIOLOGICAL RESOURCES.

The impacts of both the dredging process itself and the subsequent deposition of material from the dispersing plume on biological resources beyond the boundaries of the dredge site are likely to be complex. Impacts are affected not only by physical features of the dredge site and adjacent zone of deposition of material rejected by the screening process, but also by the nature of the biological communities that naturally occur on the seabed. Different components of the biological communities in the vicinity of dredge sites are known to have differing thresholds of sensitivity to such deposited material (Sherk, 1971; Sherk *et al.*, 1974; Moore, 1977; Matsumoto, 1984; Holme & Wilson, 1985: for review, see Newell *et al.*, 1998).

Sediment stability is also known to have an impact both on suitability for recolonisation and the type of communities that are initially established in recently sedimented material (Holme & Wilson, 1985; Newell *et al.*, 1998) and is a feature of potential impacts that is poorly understood. The type of community that inhabits shallow water wave-disturbed deposits under natural conditions generally comprises mobile 'opportunistic' species with a high rate of growth and reproduction. Conversely, communities that occur on more stable coarser deposits comprise communities that are dominated by a wide range of 'equilibrium' species that have a slow rate of recolonisation and growth. The rate of recolonisation and recovery following cessation of dredging is thus partly dependent on the type of substratum and partly on the natural community which is available to colonise the deposits (see van Dalfsen *et al.*, 2000; for review, see Newell *et al.*, 1998).

The nature and scale of impact of aggregate dredging on seabed resources can be assessed by addressing the following key issues in relation to the physical features of the dredging and screening processes described above:-

- *The impact of dredging within the dredged area itself.*
- *The rate of recovery following cessation of dredging.*
- *The extent of likely impact outside the boundaries of the dredged area.*

2. IMPACTS WITHIN THE DREDGING AREA.

The impact of dredging on benthic communities within dredged areas varies widely depending, among other factors, on the intensity of dredging in a particular area, the degree of sediment disturbance and recolonisation by passive transport of adult organisms and the intrinsic rate of reproduction, recolonisation and growth of the community that normally inhabits the particular deposits (for Reviews, see Newell *et al.*, 1998; ICES, 2001; Boyd *et al.*, 2003).

Some examples of the impact of dredging on the species variety, population density (number of individuals) and biomass of benthic organisms from a variety of habitats ranging from muds in coastal embayments and lagoons, to oyster shell deposits, and to sands and gravels are summarised in Table 1.

Table 1. Table showing the impact of dredging on benthic community composition from various habitats. Based on Newell *et al*, (1998).

LOCALITY	HABITAT TYPE	% REDUCTION AFTER DREDGING			SOURCE
		Species	Individuals	Biomass	
Chesapeake Bay	Coastal Embayment Muds-sands	70	71	65	Pfitzenmeyer, 1970
Goose Creek, Long Island, NY	Shallow Lagoon Mud	26	79	63-79	Kaplan *et al*, 1975
Tampa Bay, Florida	Oyster shell	40	65	90	Conner & Simon, 1979
Moreton Bay, Queensland, Australia	Sand	51	46	-	Poiner & Kennedy, 1984
Dieppe, France	Sands-gravels	50-70	70-80	80-90	Desprez, 1992
Klaver Bank, Dutch Sector, North Sea	Sands-gravels	30	72	80	van Moorsel, 1994
Lowestoft, Norfolk, UK	Gravels	62	94	90	Kenny & Rees, 1994
Hong Kong	Sands	60	60	-	Morton, 1996
Lowestoft, Norfolk, UK	Sands-gravels	34	77	92	MESL, 1997
Dieppe, France	Sands-gravels	80	90	90	Desprez, 2000
Bayou Texar, Florida	Mud	55	77	-	Lewis *et al*, 2001
North Nab, UK	Gravels	66	87	80-90	Newell *et al*, 2001b; 2003 Hitchcock *et al*, 2002
Area 408, North Sea.	Sandy gravel	0	0	82	Newell *et al*, 2002

Clearly, the extent of impact within a particular dredge site is likely to reflect the net balance between the rate of removal of benthos at a particular dredging intensity, and the rate of recolonisation of the deposits by inward immigration of adults and settlement of juveniles. The rate of recolonisation can be fast in deposits where the benthic community is naturally-adapted to high levels of sediment disturbance.

In a recent study of the composition of benthic communities in the vicinity of an actively dredged site at Licence Area 408 in the North Sea, we found that the rate of immigration of colonising individuals in the mobile deposits of the study area was evidently in equilibrium with the rate of loss by dredging (Newell *et al.*, 2002). Hence we could detect no significant difference in population density and species diversity between dredged sites and undredged (control) sites. There were, however, major differences in body size of individuals within dredged sites compared with those in the surrounding deposits, reflecting the small size of the recently-colonised individuals compared with those in undredged areas. In most other sites, however, a major suppression of species abundance and population density has been reported, as well as changes in species composition that may reflect changes in sediment composition following removal of the coarse fraction by aggregate dredging (Desprez, 2000; van Dalfsen *et al.*, 2000; Boyd *et al.*, 2003; Boyd & Rees, 2003).

Despite the wide differences in habitat type, and the nature of the benthic communities in the dredged areas, it is clear from Table 1 that the dredging process itself can be expected to result in a 30-70% reduction in species variety, a 40-95% reduction in the number of individuals, and a similar reduction in the biomass of benthic communities in the dredged area.

Generalisations on the impact of dredging on the number of individuals or component species is complicated further by the fact that some components of the benthos are likely to recolonise dredged deposits faster than others, and to therefore dominate the community in the initial phases of the recolonisation process. This process can result in a community that is initially dominated by a small variety but large numbers of mobile 'opportunistic' species that are supplemented with time by other more slow-growing species that characterise the surrounding deposits.

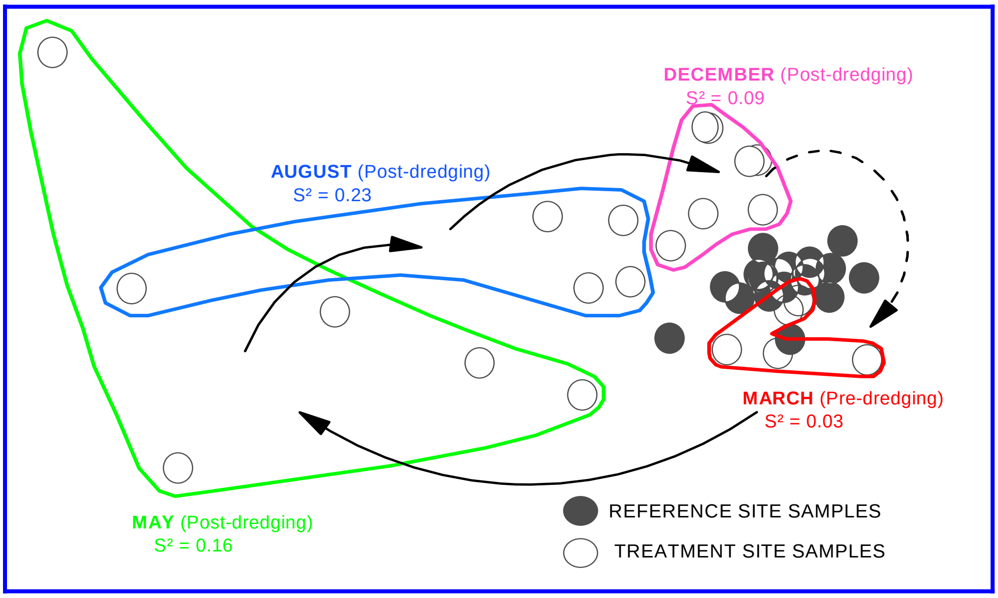

Figure 8. Two-dimensional multidimensional scaling (MDS) ordination for the benthic communities in a Norfolk (UK) experimental survey area in **March** 1992 prior to dredging, and in **May**, **August** and **December** 1992. (After Kenny & Rees, 1994).

Figure 8 shows the output of a multidimensional scaling (MDS) ordination for macrofauna sampled before dredging of an experimental dredge site in the North Sea off the East coast of UK in March 1992, and in the 7 months after dredging (Kenny & Rees, 1994). Their work shows that the community at the site prior to dredging in March 1992 formed a small 'cluster' on the MDS-ordination. This indicates that the communities sampled within the experimental site were similar to one another, and were evidently also similar to those at the reference site since they are close to one another on the MDS-ordination shown in Figure 8.

The experimental site was again sampled in May 1992, one month after completion of dredging. Figure 8 shows that the communities in all the samples from the dredged site were well-separated in the MDS-ordination from those recorded prior to dredging. This implies a major change in community composition within the dredged site following dredging. The communities within the dredged site were evidently very different from one another. This is indicated by the increased variance (S^2) between samples and the wide spacing of the dredged samples on the MDS-ordination (see also Warwick & Clarke, 1993).

Much of the initial process of recolonisation and recovery of the benthic community composition at this site off the Norfolk coast was evidently accomplished within 7 months following cessation of dredging. Figure 8 shows that the community in the dredged area became more similar to those in the surrounding undredged deposits and to those in the pre-dredged deposits, and also had a closer internal similarity to one another (S^2 reduced to 0.09) in the months following cessation of dredging. This suggests that many of the commoner species present in the deposits prior to dredging in March 1992 had recolonised by December 2002. The clear difference from both the reference site and the community prior to dredging suggests, however, that many of the rarer components of the community had not yet colonised the dredged area in the following 7 months. Subsequent studies reported by Kenny & Rees (1996) suggested that the community composition at this site was not fully restored even 2 years after dredging, a result that has been confirmed in studies by others at several commercially-exploited dredge sites.

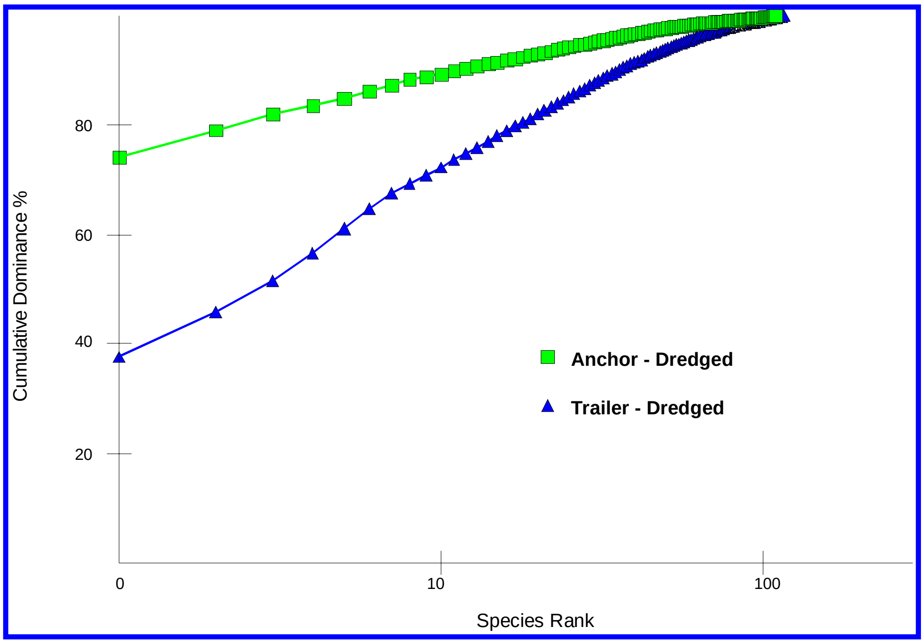

Figure 9. Dominance curves for pooled samples of macrofauna within an anchor-dredged site and within a trailer-dredged part of North Nab Production Licence Area 122/3. Based on Newell *et al*, (2001b: see also Hitchcock *et al*, 2002).

The relative contribution of the component species to a community can be illustrated by means of '***k***-dominance curves' (see Lambshead *et al.*, 1983). These show the cumulative representation of each of the component species (Y-axis) plotted as a function of the number of species in the community (X-axis). The ***k***-dominance curves in Figure 9 show the relative contribution of component species to the total species complement in an anchor-dredged site and in an adjacent trailer-dredged site at North Nab Production Licence Area 122/3 to the east of the Isle of Wight. The data show that the intensively exploited anchor-dredge site was dominated by one species (*Balanus* sp) which represented almost 80% of the species recorded in the deposits. In contrast, the adjacent trailer dredged site supported a wider variety of species which were less dominated by one or a few species (from Newell *et al.*, 2001b, 2003; Hitchcock *et al.* 2002).

The inference from these results is that the deposits within the anchor-dredged site were dominated by species capable of rapid recolonisation by planktonic larvae (see also Van Dalfsen *et al.*, 2000) whereas the community in the less intensively exploited trailer dredged site had a wider variety of species reflecting the lower rate of removal by the drag-head of the dredger. The results show that a relatively low level of exploitation by trailer-dredging at the North Nab site had a smaller impact on the diversity of biological resources than intensive production by static dredging.

Recent studies by Boyd & Rees (2003) and Boyd *et al* (2003) have confirmed and amplified the relationship between dredging intensity and impacts on benthic biological community composition. Boyd & Rees (2003) have shown that dredging intensity is an important determinand of macrofaunal community composition in actively-dredged sites in the English Channel to the east of the Isle of Wight, increasing dredging intensity resulting in an increase in the proportion of species affected. These impacts appear to persist for several years in the relatively stable deposits of the study areas in the English Channel, and may be related to restoration of complex features of the deposits such as stability of the seabed sediments (see also Kenny & Rees, 1996; Kenny *et al.*, 1998, ICES, 2001).

Boyd *et al* (2003) studied an area in the English Channel to the east of the Isle of Wight at which dredging had ceased 4 years previously. They showed that there were significant differences in the macrofaunal assemblages between areas subjected to different dredging intensities. As might be anticipated, the area that had been previously dredged at a high intensity had a reduced number of species and lower numbers of individuals than the surrounding deposits. As in the case of the experimental dredge site off the Norfolk coast referred to above, replicate samples taken from the formerly heavily-dredged site were dissimilar from one another in terms of species composition - a common feature of communities in disturbed habitats (see also Clarke & Warwick, 1994; Kenny & Rees, 1994, 1996). Correlation analysis suggested that at this site, the dominant factor associated with macrofaunal community composition was dredging intensity in the area four years previously. Although the precise physical forcing functions are unknown at present, it is clear that the time required for restoration of community composition may depend on complex features of the seabed and may also vary according to the physical conditions to which the resident organisms are adapted.

In wave-disturbed shallow water environments such as the North Sea, recolonisation by opportunistic species is reported to be rapid, with even the biomass of the benthic community being restored within 2-4 years (see van Dalfsen *et al.*, 2000, Desprez, 2000; Desprez & Duhamel, 1993; de Groot, 1979; Kenny *et al.*, 1998; Newell *et al.*, 1998; Van Moorsel, 1993). In some areas of the North Sea which are subjected to natural disturbance of the sediments, and where the benthos comprises mainly small mobile ('opportunistic') species with a high rate of reproduction and growth, the rate of invasion of the deposits even within actively-dredged sites, is sufficiently fast that there is no detectable net reduction in species diversity or population density compared with non-dredged deposits (Newell *et al.*, 2002, see also Table 1).

Elsewhere, in deeper waters or where wave energy is lower, dredge tracks may take 3-7 years to infill and a correspondingly longer time is required before community composition approaches that of the undredged deposits (see Boyd *et al.*, 2003). Coarse stable deposits are characterised by long-lived and slow-growing components which have a slow rate of reproduction (for review, see Newell *et al.*, 1998). The benthic fauna in low-energy environments off the Mediterranean coast of Spain, for example, comprises a number of slow-growing components and recovery takes longer (van Dalfsen *et al.*, 2000). In such areas a "footprint" of impact on species variety, population density and biomass might be anticipated both within actively dredged sites and in the zone of deposition of material rejected during the screening process for several (or many) years after cessation of dredging.

The following section reviews the nature and rate of the recovery process in different types of deposits including those which are more typical of the deep water shell gravels and coarser deposits that are commonly dredged for marine aggregates in the coastal waters of the United Kingdom. This information is then used to predict the likely rates of recovery of biological resources following cessation of dredging in coastal deposits of different composition.

3. RATE OF RECOVERY FOLLOWING CESSATION OF DREDGING.

The rate of recovery of biological resources following capital and maintenance dredging, disposal of dredged spoils and marine aggregate dredging has been widely studied and conforms with well-known general principles of ecological succession. That is, communities that inhabit fine semi-liquid and disturbed sediments comprise mobile opportunistic species (‘*r*-strategists’) that have a high rate of recolonisation and which can reach high population densities within weeks or months of a catastrophic mortality (see MacArthur, 1960; Grassle & Grassle, 1974; Osman, 1977). Conversely, communities that inhabit less disturbed deposits of deeper waters or coarse substrata have complex associations and are characterised by large slow-growing species that are selected for maximum competitive advantage in a habitat that is already crowded. These large slow-growing *K*-selected equilibrium species recolonise only slowly following disturbance and may take several (or many) years for recovery of full species composition and biomass (MacArthur & Wilson, 1967; Gadgil & Bossert, 1970; McCall, 1976). These general features of community structure have been reviewed in relation to the impacts of marine aggregate dredging by Newell *et al* (1998).

The question of ‘recovery’ of biological resources following cessation of dredging is not an easy one to define for complex communities whose composition can vary over time, even in areas that remain undisturbed. The situation is further complicated by the fact that the deposits in an area at which dredging has ceased may not be sufficiently similar following dredging to allow recolonisation and establishment of a similar biological community to that which occurred prior to removal of the coarse aggregate fraction.

Estimates of the rate and nature of the recolonisation process may therefore be considered under two different scenarios:-

- *The deposits that remain after dredging has ceased are either sufficiently similar to the pre-dredge deposits to allow recolonisation by a similar biological community immediately, or sediment composition recovers following loss of overburden sands by tidal currents over a period of time.*

- *The sediment composition of the deposits is permanently altered towards a more sandy substratum following removal of the coarse components and deposition of fine material rejected during the screening process.*

3.1. SCENARIO 1.

THE SEDIMENT COMPOSITION OF THE DEPOSITS REMAINS SUBSTANTIALLY UNALTERED FOLLOWING CESSATION OF DREDGING.

Table 2 shows the rates of recovery of benthic biological resources following dredging in various habitats. We have included semi-liquid muds from freshwater tidal areas and have arranged the data along a gradient of increasing environmental stability and predictability through estuarine and coastal muds to sands, gravels and reef assemblages.

Table 2. Table showing the rates of recovery of the benthic fauna following dredging in various habitats. Examples have been arranged along a gradient from disturbed muds of freshwater-tidal estuarine conditions to stable reef assemblages. From Newell *et al*, (1998).

LOCALITY	HABITAT TYPE	RECOVERY TIME	SOURCE
James River, Virginia	Freshwater semi-liquid muds	±3 weeks	Diaz, 1994
Coos Bay, Oregon	Disturbed muds	4 weeks	McCauley *et al*, 1977
Gulf of Cagliari, Sardinia	Channel muds	6 months	Pagliai *et al*, 1985
Mobile Bay, Alabama	Channel muds	6 months	Clarke *et al*, 1990
Chesapeake Bay	Muds-sands	18 months	Pfitzenmeyer, 1970
Goose Creek, Long Island, NY	Lagoon muds	>11 months	Kaplan *et al*, 1975
Klaver Bank, Dutch Sector, North Sea	Sands-gravels	1-2 years (ex-bivalves)	van Moorsel, 1994
North Sea (Area 408)	Sands-gravels	1 year	Newell *et al*, 2002
English Channel (North Nab)	Coarse gravel	>2 years	Newell *et al*, 2001b Hitchcock *et al*, 2002
Dieppe, France	Sands-gravels	>2 years	Desprez, 1992
Lowestoft, Norfolk, UK	Gravels	>2 years	Kenny & Rees, 1994, 1996
Dutch Coastal Waters	Sands	3 years	de Groot, 1979, 1986
Tampa Bay, Florida	Oyster shell (complete defaunation)	>4 years	US Army Corps of Engineers, 1974
Tampa Bay, Florida	Oyster shell (incomplete defaunation)	6-12 months	Conner & Simon, 1979
Boca Ciega Bay, Florida	Shells-sands	10 years	Taylor & Saloman, 1968
Beaufort Sea	Sands-gravels	12 years	Wright, 1977
Florida	Coral reefs	>7 years	Courtenay *et al*, 1972
Hawaii	Coral reefs	>5 years	Maragos, 1979
Area 222 Isle of Wight, English Channel	Gravel	>4 years	Boyd *et al*, 2003

Inspection of the data summarised in Table 2 shows that the recovery of the benthic fauna in highly-disturbed semi-liquid muds can occur within weeks. This is associated with an ability for the resident species to migrate through the surrounding deposits and to recolonise disturbed muds as adults (see van Dolah *et al.*, 1984); tidal currents may also transport juveniles into the dredged area (see Hall, 1994). However settlement of larvae from the plankton is probably of dominant importance in controlling the rate of recolonisation and sequence of colonising species in most coastal gravel deposits (Boyd & Rees, 2003).

Inspection of the recolonisation rates reported in the literature and summarised in Table 2 suggest that a period of 2-4y is a realistic estimate of the time required for recovery of species diversity and biomass of the benthic fauna in coastal gravels and sands, especially those where the resident organisms are ones that are naturally adapted to dynamic conditions in mobile deposits. But this time may be increased to more than 5y in coarser deposits where the species diversity is high and where the resident organisms are mainly sessile with a relatively slower rate of growth and reproduction.

The data also suggest that the intensity of dredging may have an influence on the rate of recovery of species diversity at some dredge sites. Areas in Tampa Bay, Florida that had been dredged for oyster shell, suggest that a period of as much as 10y may be required for recovery following complete defaunation whereas a recovery time of only 6-12 months was required for recovery following partial dredging and incomplete defaunation (Benefield, 1976; Conner & Simon, 1979). This suggests that areas of undisturbed deposits between dredged furrows may provide a source of colonising species that enable faster recovery than might occur solely by larval settlement and growth from spawning adults located in the deposits surrounding the dredge site (see also van Dolah *et al.*, 1984; van Moorsel, 1993, 1994).

The likely recolonisation rates for the benthic community of estuarine muds, sands, gravels and reef areas have been superimposed onto a generalised colonisation succession in Figure 10. This allows some predictions to be made on the rates of recovery of deposits following dredging.

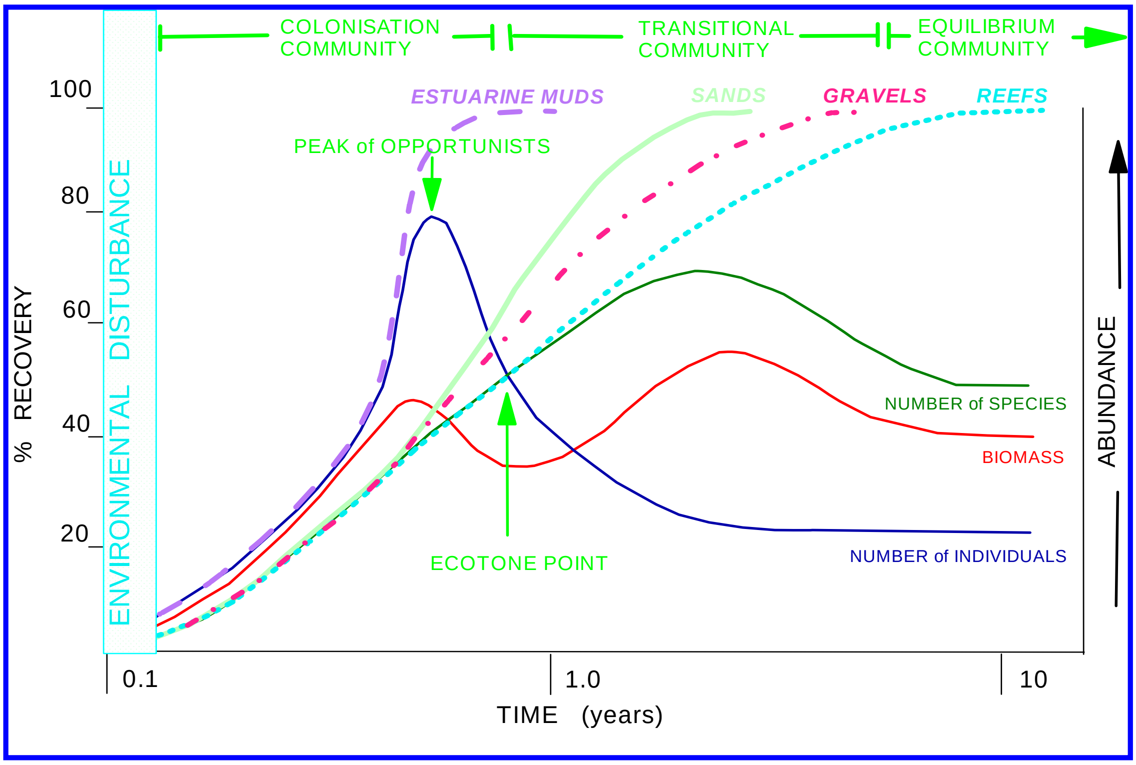

Figure 10. Schematic diagram showing the likely recolonisation rates for the benthic community of estuarine muds, sands, gravels and rocky reefs. Based on Newell *et al*, (1998).

The fine muds which characterise coastal embayments, estuaries and lagoons are likely to be colonised by large populations of a relatively restricted variety of "opportunistic" ***r***-selected species which are capable of rapid colonisation within months of space being made available for colonisation and growth. Because such deposits are subject to regular disturbance under natural conditions, the ecological succession recovers to the colonisation phase shown in Figure 10, but does not proceed to the development of ***K***-selected slow-growing "equilibrium" species within the community. Recovery of the "normal" community in disturbed deposits such as muds can therefore be achieved within months of cessation of dredging, or disposal of spoils.

The natural communities of gravel and sand deposits, however, contain varying proportions of slow-growing, ***K***-selected equilibrium species, depending amongst other factors on the degree of disturbance by waves and the speed of tidal currents. In this case, the "tail" of the sigmoid recovery curve becomes more pronounced because the rarer components of the equilibrium community may take several years to recolonise the deposits, even after the main components of the community have become established. Where the deposits are sandy, periodic mortality of the long-lived components may result in major seasonal changes in community composition such as occurs in the North Sea on the Klaver Bank (van Moorsel, 1994), and as has been reported for the sediments of Liverpool Bay by Eagle (1975). Under these conditions, the community will be held in a transitional state by natural environmental disturbance, and is likely to recover within a period of 2-3 years after cessation of dredging.

As might be expected, the recolonisation sequence is a good deal more complex than indicated in Table 3. Studies on the rate of recolonisation of sands and gravels following dredging off Norfolk, U.K. by Kenny & Rees (1994, 1996), off Dieppe, France by Desprez (2000), as well as at the North Nab site to the east of the Isle of Wight (Newell *et al* 2001b; Hitchcock *et al.*, 2002) and at Area 408 in the central North Sea (Newell *et al.*, 2002) show that restoration of species richness and population density is achieved relatively rapidly compared with restoration of the biomass.

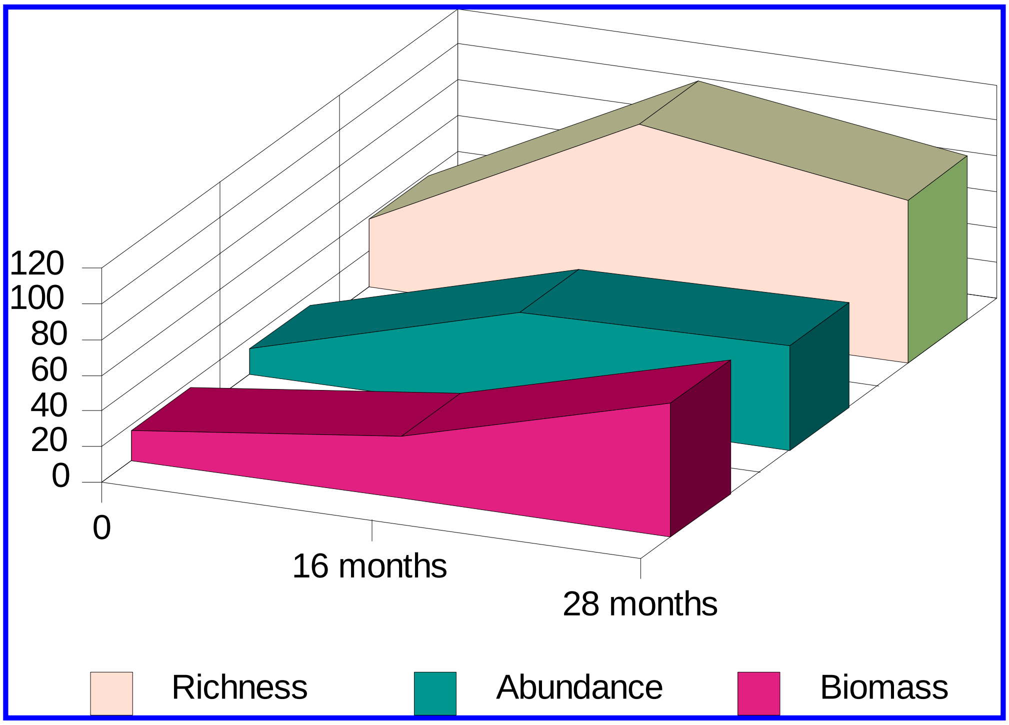

Figure 11. Diagram showing the percent recovery of species richness, abundance and biomass of benthic fauna following cessation of dredging at a site off Dieppe, France. Based on Desprez (2000).

Figure 11 shows that both species diversity and population density of benthic invertebrates was restored in deposits off Dieppe within 16 months after cessation of dredging. The biomass values were continuing to increase even 28 months after cessation of dredging at the Dieppe site. In contrast, in the North Sea site at Area 408 restoration of biomass was complete after 12 months (Newell *et al.*, 2002).

A generalised scheme showing the likely recovery time for the benthos in shallow water coastal deposits, based on data from the North Nab study site is shown in Figure 12.

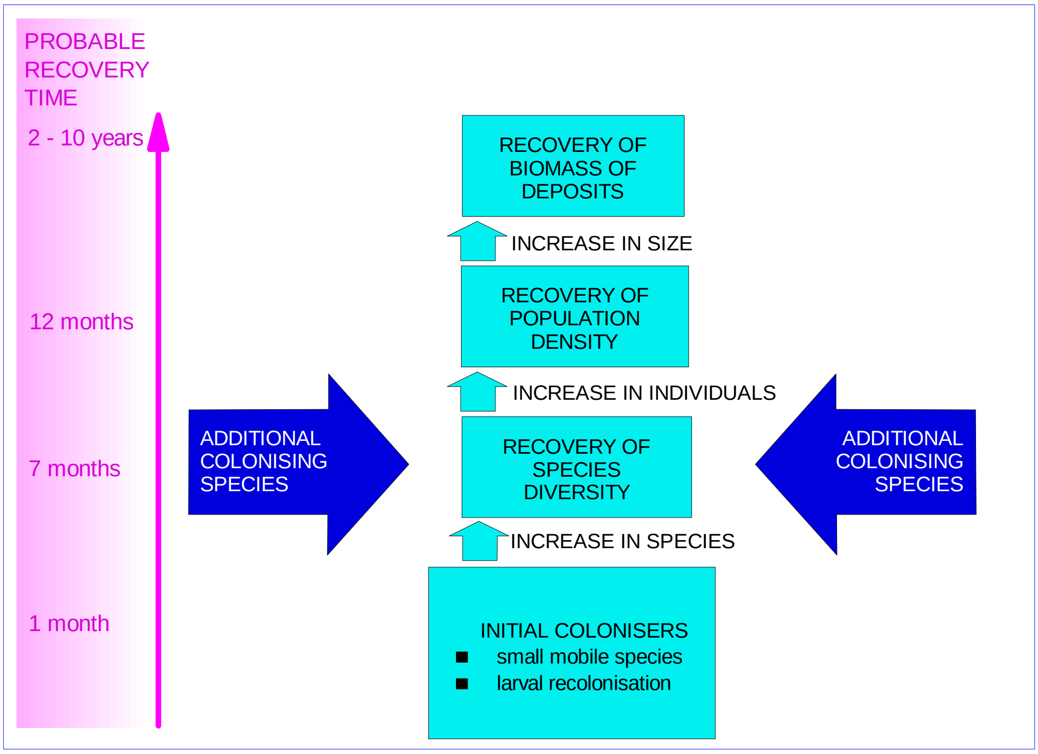

Figure 12. Generalised sequence showing the nature and rate of recolonisation of benthic macrofauna in coastal deposits following cessation of dredging. This sequence is applicable only to mobile sandy gravels. Note that the recovery of long-lived components of the community can take more that 10 years in stable coarse deposits. Based on Newell *et al*, 2001b; see also Hitchcock *et al*, 2002.

This indicates an initial colonisation by mobile 'opportunistic' species within days, or even during the dredging process. This can lead to communities dominated by mobile species such as the amphipod crustacean *Ampelisca* sp or by species such as barnacles that can rapidly recolonise from the plankton, in the initial phases of recolonisation of deposits disturbed by dredging. This phase is followed by an increasing variety of colonising species, an increase in the population densities of the component species and finally by growth of the individuals which leads to restoration of the biomass.

Ampelisca sp ©MESL-PhotoLibrary

Obviously, the rate at which recovery of the species diversity occurs is dependent on the complexity of the fauna and the inter-relationships that control larval recruitment and settlement. Many species do not recolonise regularly, and most require specific physico-chemical and biological cues to induce settlement (for review, see Newell, 1979). This implies that even if the deposits in a dredge site after cessation of dredging remain similar to those prior to dredging, there may be a significant interval before all the species components are present in the community.

The community recovery curve for stable reef communities shown in Figure 10 indicates that a period of at least 10-years may be required for the process of establishment and growth of the long-lived and slow-growing ***K***-selected equilibrium species and for the development of the biological interactions which characterise undisturbed deposits. This long process of establishment of an equilibrium community reflects partly the time required for colonisation by rarer components of the community, but is also influenced by the nature and stability of the substratum following cessation of dredging, and the time required for complex stabilisation processes involving both physical compaction and biological interactions.

Benthic communities in coarse stones and gravels generally comprise a significant proportion of sessile and slow-growing 'equilibrium' species characteristic of stable substrata. As an example of the likely time scale for recolonisation by one of the characteristic long-lived components of the community of marine gravels, we have recently analysed the size-frequency distribution and age structure of the dog cockle (*Glycymeris glycymeris*) in a survey which covered much of the deposits characteristic of the central part of the eastern English Channel (MESL, 2002). This species is widely distributed in gravel deposits and is a typical component of biotopes described for the central part of the English Channel.

Glycymeris glycymeris ©MESL-PhotoLibrary

Figure 13a shows the relationship between the age and shell size of *Glycymeris glycymeris* within the area surveyed in August 2001. Shell heights for the population ranged from 1-6cm. The age of the shells can be estimated from growth bands and indicate that the largest members of the population are as much as 15 years in age.

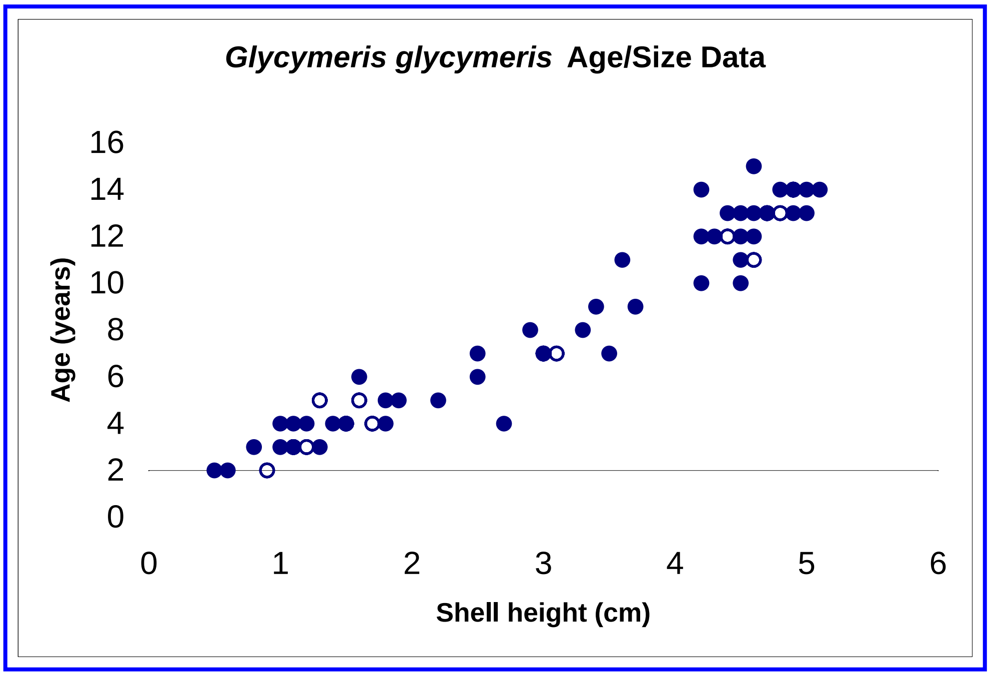

Figure 13a. Graph showing the relationship between the shell height (cm) and age (years) of the dog cockle *Glycymeris glycymeris* from deposits in the East Channel Region in August 2001. Based on MESL, (2002).

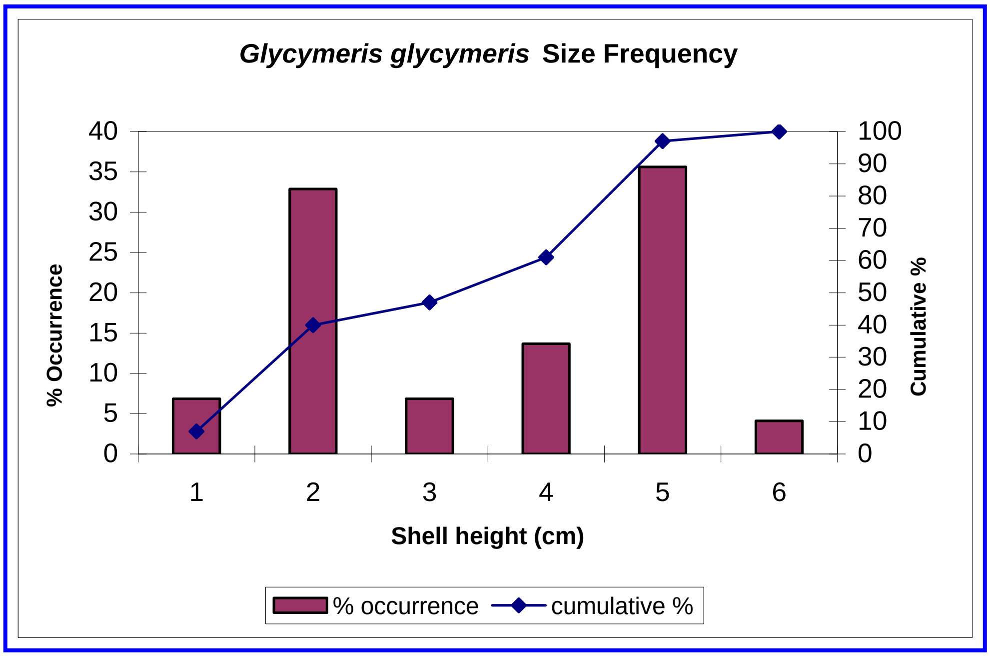

Figure 13b. Size-frequency histograms and cumulative curve showing the percentage occurrence of different sized *Glycymeris glycymeris* in deposits of the East Channel Region in August 2001. Based on MESL, (2002).

Figure 13b shows that the dog cockle population comprises a large group of individuals of 5cm shell height (ie., approximately 14 years old) and another large proportion at 2cm shell height (ie., approximately 5 years old). This implies that for this species, there was a major recruitment of young cockles 5-6 years prior to the survey in August 2001, and another major recruitment approximately 14 years prior to the survey.

The population structure thus suggests that there is an intermittent pattern of settlement by post-larvae of *Glycymeris glycymeris.* These events evidently occurred mainly in 1987 and 1996 in the East Channel Region survey area. Furthermore the relatively slow growth rate achieved by the oldest cohort in the population suggests that restoration of the biomass of this species is likely to require a period of at least 15 years after successful settlement by post-larvae from the plankton.

If we assume that the deposits in the dredged area remain sufficiently similar to those prior to dredging to support the original benthic community type, it can be inferred that a period of 5-10 years might be required for initial establishment of a population of juvenile *Glycymeris glycymeris* and that a further period of 12-14 years would be required for restoration of the biomass of this component of the community. An estimate of 17-24 years for restoration of the population density and biomass of the slowest-growing components of an equilibrium community conforms well with estimates based on the curve for reef communities shown in Figure 10.

Clearly, many of the components of the benthic communities that occur in the sands and gravels of the East Channel region will have a shorter life-span and faster growth rate than the dog cockle. It is probably safe to assume that at least 50% of the species diversity, population density and biomass is likely to be restored within 4-6 years after cessation of dredging, with a gradual restoration of the full species complement and biomass in the following years.

3.2. SCENARIO 2.

THE SEDIMENT COMPOSITION OF THE DEPOSITS BECOMES SANDIER FOLLOWING REMOVAL OF COARSE COMPONENTS AND REJECTION OF FINES.

3.2.1. Short-Term Impacts.

The interaction between sediment composition and biological communities within a dredged area and in surrounding deposits where sedimentation of screened material occurs has been studied in relation to a marine aggregates dredging site off Dieppe, France by Desprez (2000).The effects of extraction within the boundaries of the dredge site itself were a decrease of species richness by 63%, 86% in abundance and 83% in biomass. His results also give an important indication of the type of changes in community composition that can occur following discharge of screened material to the sea bed.

He reported that the structure of the community had fundamentally changed after several years of intensive extraction, with decreased densities of crustaceans, echinoderms and bivalves. The population density became dominated by errant polychaetes and the biomass by echinoderms. On a basis of a survey carried out in 1993, the benthic community within the dredged area off Dieppe had changed from one of coarse sands characterised by the lancelet *Branchiostoma* to one of fine sands dominated by the polychaetes *Ophelia borealis, Nephtys cirrosa* and *Spiophanes bombyx*, with the heart urchin *Echinocardium* as a complementary characteristic species.

Ophelia borealis ©MESL-PhotoLibrary

The effects of sand deposition approximately 200m from the site of extraction were studied in 1996. The results are of considerable interest because they show that sand deposition surrounding the dredge site resulted in a greater impact on the benthic biological resources than dredging itself. Presumably this reflects the patchy impact of the drag-head within the dredge site, in contrast to the wider and more uniform impact of deposition of material rejected from the dredger.

Table 3. Comparison of the percent composition of the sediments and main population parameters for the three sampling areas of the dredging site off Dieppe (in 1996). After Desprez, 2000.

	Dredging Area	Deposition Area	Reference Area
Shingles and gravels	26	11	47
Coarse sands	8	12	34
Fine sands	54	63	18
Very fine sands	19	13	1
Silts	1	1	0
Biomass ($g.m^{-2}$)	2.4	0.3	6.8
Density ($ind.m^{-2}$)	810	230	1440
Species richness	44	17	39

Table 3 shows that significant differences exist between the sediment composition of the dredged area compared with that of the surrounding zone of deposition and with a non-dredged reference area. There was an increase in fine sands in the deposition area compared with either the dredge area or a non-dredged reference area. The biomass of invertebrates was lower in the deposition area than in the dredged area, and this in turn was lower than in the non-dredged reference area. Table 3 shows that similar differences exist between the three areas in terms of both the number of individuals and the species richness of benthic fauna.

The community composition of the benthic fauna in the zone of deposition was also different from that characteristic of gravels and shingles. The community in the sediment deposition zone was dominated by species characteristic of fine sands. These included the bivalve *Tellina pygmaea* (29%) and the annelid *Nephtys cirrosa* (22%) along with other sand-dwelling species such as the polychaetes *Scoloplos armiger* (3%) and *Spiophanes bombyx*.

Scoloplos armiger ©MESL-PhotoLibrary

Species that are characteristic of coarse sands comprised only 1% of the community and included the echinoderms *Echinocyamus pusillus* and *Amphipholis squamata* and species characteristic of gravels were absent.

Echinocyamus pusillus ©MESL-PhotoLibrary

These results show that the impacts of deposition of material rejected overboard during the screening process can have a significant impact on both nature and abundance of benthic macrofauna.

3.2.2. Long-Term Impacts.

It is well-known that the species variety of benthic communities in mobile sands is often sparse compared with stable communities such as occur on coarse gravels and reefs. This can be only partially accounted for in terms of differences in the particle size composition of the sediments (Seiderer & Newell, 1999; Newell *et al.*, 2001a). Differences between the biological communities recorded in sandy deposits and in gravels can, however, be used to make some predictions on the type of marine communities which might be anticipated if there were a permanent or long-term alteration in sediment type associated with the dredging and extraction process and with discharge of screened material.

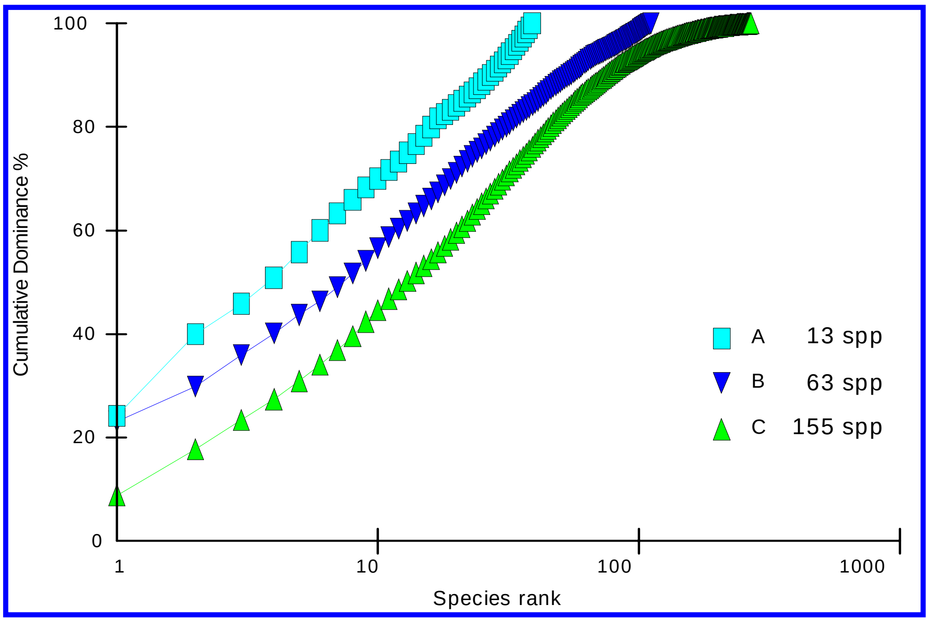

Figure 14. ***K***-dominance curves for the 3 main macrofaunal communities identified by multi-variate analysis of the fauna in deposits of Licence Application Areas 458 & 464 (West Bassurelle). MESL, (1999).

Figure 14 shows a series of ***k***-dominance curves for the three principal communities of benthic macrofauna identified in a baseline survey of West Bassurelle Licence Application Areas 458 & 464 (MESL, 1999). Curve A is for a community that characterised sandy deposits within the survey area, Curve B characterised communities that occurred in gravely sands whilst Curve C represents a community that occurred in coarse gravels within the survey area.

The total number of species recorded for the sandy community (curve A) was 13 species, that for the gravely sand was 63 species, and that for the coarser gravel deposits was 155 species per 0.2 m^2 Hamon grab sample (Recalculated from MESL, 1999). One species, a paddle worm (*Eteone* sp) accounted for approximately 22% of the community of the sandy and mixed sands and gravels whereas this same species formed a smaller proportion of the wide species variety recorded in gravels.

The sequence of change in species diversity and community composition associated with a transition from coarse deposits to ones that are dominated by sand-sized particles is shown in Figure 15. The upper part of the figure shows a two-dimensional Multi-Dimensional Scaling (MDS) ordination for the biological communities of West Bassurelle Licence Application Areas 458 & 464. Superimposed on the ordination is the relative abundance of gravel-sized particles of 4.0mm diameter and above where the size of the symbol represents the relative proportion of gravel at each site. Also shown in Figure 15 is a list in order of importance of the genera that account for 75% of the similarity of each of the three communities of macrofauna identified in the survey area.

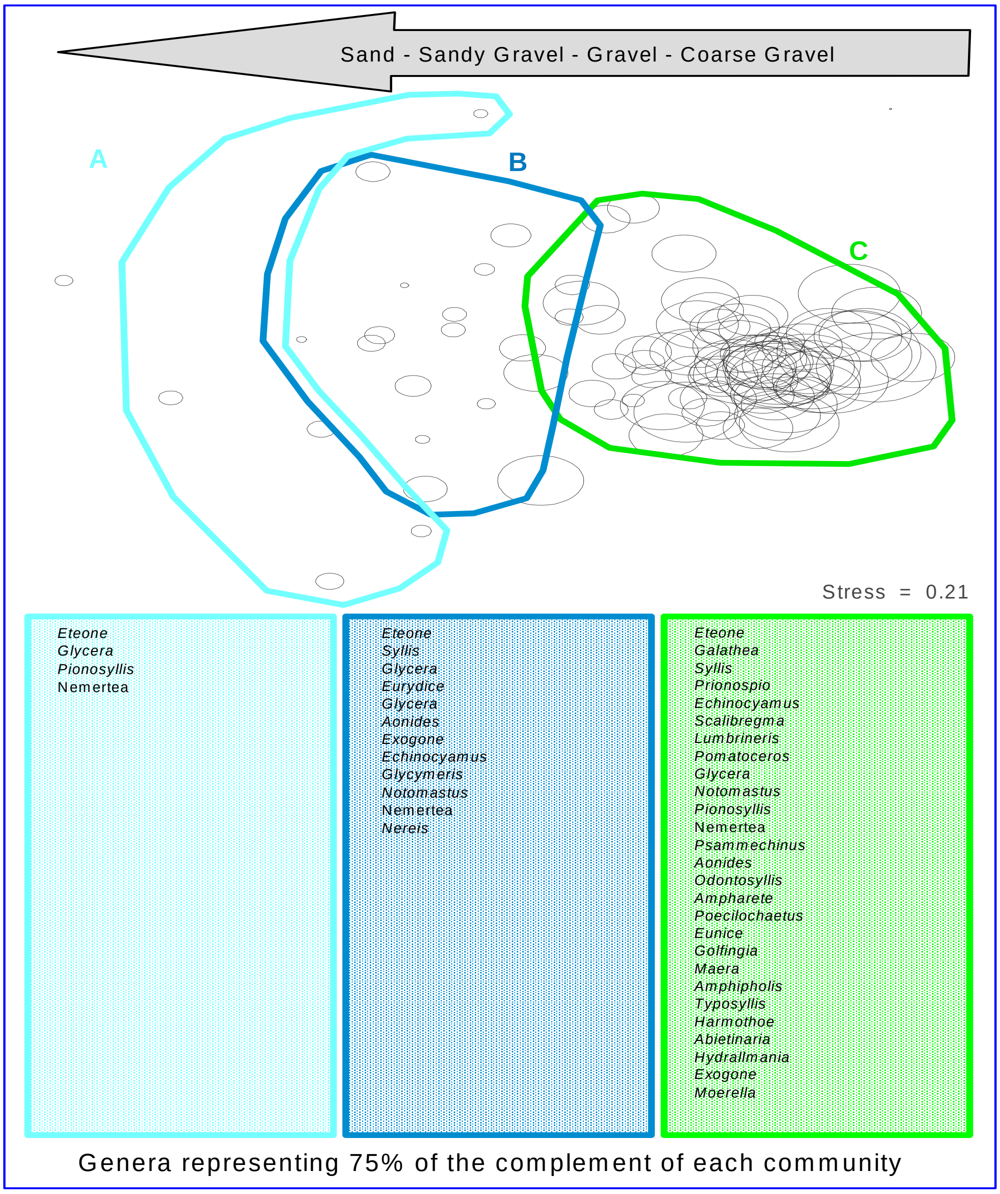

Figure 15. Two-dimensional multi-dimensional scaling (MDS) ordination for the macrofauna assemblages in the West Bassurelle Areas 458 & 464. Circles show the relative proportion of particles >4mm at each site. The lower part of the figure shows the genera of macrofauna accounting for 75% of the similarity of the communities in gravel (Group C), in sandy gravel (Group B) and in sandy deposits (Group A).

Figure 15 shows a wide range of species including polychaetes, crustaceans and echinoderms characterised the gravel community (Group C) whereas the mixed sandy gravel deposits were characterised by fewer species accounting for 75% of the similarity within the community. Finally the Group A community which characterised sandy deposits within the survey area, was dominated mainly by a few species of polychaete worms.

These data suggest that if marine aggregate extraction and discharge of screened material results in an alteration of sediment composition from coarse deposits towards sandy ones, then this is likely to be associated with a decrease in species diversity from approximately 155 species to only 13 species per 0.2 m^2 within the zone of sediment deposition, and by an increased dominance by components of the community such as polychaetes that can survive in sandy deposits.

In high-energy habitats such as the North Sea, winnowing of the sediments in the dredged site and sediment transport from outside the boundaries of the dredged area may result in sufficient restoration of particle size composition of the deposits to allow substantial restoration of the benthic community composition following cessation of dredging. This appears to be the case at the experimental dredge site studied off the east coast of Norfolk, UK by Kenny & Rees (1994. 1996; see Figure 8). At this and most dredge sites, however, the gravel-sized fraction is not capable of being mobilised by waves and tidal currents at the seabed, so dredge trails and pits left from marine aggregate dredging will generally be infilled by fine sand and silt-sized material depending on the depth of water and prevalent wind and current conditions (see also Dickson & Lee, 1972; McGrorty & Reading, 1984; Millner *et al.*, 1977; van der Veer *et al.*, 1985). The seabed deposits in dredged sites are therefore generally unlikely to recover to their pre-dredge particle size composition unless this is artificially adjusted by deposition of surface aggregate.

The main conclusions currently available from the results of work carried out on biological communities within dredge sites in UK waters may be summarised as follows:-

- The process of dredging can result in a 50-90% reduction of species richness, population density and biomass of benthic invertebrates within the boundaries of the dredged area.

- In wave disturbed sites the natural population of benthic organisms comprises 'opportunistic' species that are well-adapted for recolonisation and growth in deposits that are disturbed. This leads to rapid recolonisation of deposits that are disturbed by dredging to an extent that at some sites the rate of restoration of species richness and population density within a dredge site is evidently in equilibrium with the rate of removal by dredging. The net impact of dredging within the boundaries of a dredge site thus reflects an equilibrium between the rate of colonisation and the intensity of dredging at a particular site.

- Restoration of biomass is achieved by growth of the colonising species. This is always slower than initial restoration of species composition and population density. Generally a time of 2-4 years is characteristic of restoration of biomass in shallow water environments, but a period of 10-20 years may be required for some of the slowest growing components of stable 'equilibrium' communities which have a wide species variety and which are characterised by a slow rate of growth and reproduction.

- The process of removal of coarse material from a dredge site and the return of sand-sized particles following screening can result in long-term changes in the particle size composition of the dredged deposits. Studies off Dieppe suggest that the deposition of sand from the dredging process results in a greater suppression of species variety, population density and biomass than occurs from the dredging itself. This suppression of the benthos is associated with significant changes in community composition, leading to an impoverished community that is dominated by polychaete worms.

- Differences in the species richness and community composition is gravels and sands of the East Channel Region allow some realistic estimates of the changes which might be anticipated in that area if dredging and screening were associated with a long-term shift in particle size composition towards more sandy deposits. The results suggest that the community would change from one with at least 155 species per 0.2 m^2 to one with only 13 species per 0.2 m^2 and that the sandy community would be dominated by polychaetes.

3.2.3. Approaches to the Assessment of 'Recovery'.

The results summarised above raise the question of whether it is necessarily a practical objective to expect benthic communities to revert to the same community composition to that which existed in the deposits prior to dredging. We know that removal of the coarse fraction and return of fine sands to the seabed will result in a change in the particle size distribution of the deposits in a relatively small area of seabed corresponding with the dredged site and zone of deposition and transport of material. It is also well-established that sandy deposits tend to have a reduced species diversity compared with more complex habitats including cobbles and gravels. It is therefore to be expected that benthic communities in sites from which the coarse fraction of the deposits has been selectively removed are likely to be different from those prior to dredging.

One approach to the question of 'recovery' of benthic biological resources is to define 'recovery' as the establishment of a community that is capable of maintaining itself, and in which at least 80% of the species diversity and biomass has been restored (Newell *et al.*, 1998). This implies a substantial restoration of the carrying capacity of the benthic food webs leading to fish, even though the precise composition of the benthic community may not be identical to that recorded in the pre-dredged system.

Ellis (1998, 2003) has developed the concept of 'sustainable ecological succession' in assessing the recovery of seabed biodiversity in relation to mine tailings disposal in fjord sediments off Vancouver Island, Canada. This is based on the recognition that:-

- *once ecological succession is established, it will progress to an eventual complex and variable climax community in equilibrium with a range of features of the habitat unless setback by another perturbation.*

- *measures of sustained succession are easier to obtain and clearer to interpret than measures of climax community establishment and its range of variability.*

He reported that effective prediction of the time required for sustainable restoration of benthic communities at the Island Copper Mine submarine tailings placement site during three years of monitoring following closure of the mine could be achieved using two criteria:-

- *the numbers of species and the total number of organisms must fall within, or above the ranges at unaffected stations (at the Island Copper Mine site the values were 20 or more species per 0.15m², and more than 1000 individuals per m²).*

- *several rapidly colonising (opportunistic) species must have sustained themselves in large numbers for one or more years (at the Island Copper Mine site values were more than 3 species had sustained themselves at a population density of >100 per m² for 2 or more years).*

Although the criteria used to define 'recovery' will be different for other locations and ecosystems, this does represent a practical approach to defining what is meant by 'recovery' in the context of biological communities that vary in space and time, and where the environment may in any case have been significantly modified by dredging activities on the seabed.

4. IMPACTS OUTSIDE THE BOUNDARIES OF DREDGED AREAS.

The effects of deposition of sand-sized particles on the benthic macrofauna approximately 200m outside the boundaries of a dredge site off Dieppe, France, based on the work of Desprez (2000) have been summarised in Section 3. These agree well with the differences between *in situ* biological communities in sands and gravels elsewhere in the East Channel Region, and probably provide a reliable basis for predicting the impacts of the dredging and recovery processes within the boundaries of individual dredge sites and in the immediate zone of deposition of material rejected during the screening process.

Generalised predictions of the biological impact of discharge of sand-sized particles outside the boundaries of dredged sites following screening depend to a large extent on whether such material settles over a similar area to that described for shallower waters, and the rate at which the sand is transported away from the initial site of deposition. Currently our best estimate based on work summarised above is that there is likely to be a zone of approximately 200m width and up to 800m length, reflecting a zone of primary deposition and extending in each direction from the dredge site along the axis of the tidal streams. This material may then be remobilised and transported away from the site of initial deposition, with the possibility of impacts on benthic communities where these lie in the path of the transported material.

We can be reasonably confident that long-term changes in sediment composition from gravels to more sandy deposits in the immediate zone of sediment deposition surrounding a site of dredging and screening will result in a paucity of benthic macrofauna and a change in community composition to one that is dominated by polychaetes. There is, however, much less information on whether the subsequent remobilisation and transport of material from the near-site deposition areas elsewhere along the tidal current stream is likely to have an impact on biological communities.

Many of the macrofauna that live in areas of sediment disturbance are well-adapted to burrow back to the surface following initial burial (Schafer, 1972). Studies by Maurer *et al* (1979) showed that some benthic animals could migrate vertically through more than 30 cm of deposited sediments, and this ability may be widespread even in relatively deep waters, as well as in estuarine sediments. Kukert (1991) showed for example, that approximately 50% of the macrofauna of the bathyal sea floor of the Santa Catalina Basin were able to burrow back to the surface through 4-10cm of rapidly deposited sediment.

More recently, Elliott *et al* (2001) showed that many estuarine invertebrate species are able to survive relatively high rates of sedimentation, the rate of survival being dependent on the depth of sediment. As an example, survival of the bivalve *Macoma balthica* was as high as 95% following deposition of 1-7cm depth of mud. Under a single deposition of 15cm mud only 66% survived whilst only 25% survived burial by 25cm mud. Other studies also summarised in Elliott *et al* (2001) suggest that the polychaete *Hediste diversicolor*, and molluscs such as *Retusa obtusata* and *Hydrobia ulvae*, as well as Oligochaete and Nematode worms are capable of migrating up through as much as 20cm of dredged material. Survivorship in these species was reported to be >90% irrespective of whether the sediment was added as a single layer of up to 20cm depth, or whether it was deposited at intervals of 4 days to give a total of 20cm of consolidated sediment.

Macoma balthica ©MESL-PhotoLibrary

A recent study carried out by Newell *et al* (2002) in the vicinity of a heavily screened dredge site in the North Sea at Production Licence Area 408 was partly designed to investigate whether there was any evidence of impact of discharge of screened material on benthic biological resources surrounding the dredge site. Quantitative estimates were made of the species composition, population density and biomass of benthic invertebrates at a series of as many as 167 sampling stations in August 2000 including areas that had been dredged, those which had been abandoned for known times, and along the axis of the tidal streams from these dredge sites. The results showed that although the species richness and population density were evidently restored rapidly in the mobile deposits of the survey area, the dredged site was characterised by an 82% suppression of biomass, reflecting the presence of small colonising species.

The biomass of benthos in previously-dredged sites that had been abandoned for 12 months prior to the survey in August 2000, was generally similar to that in "control" sites. This suggests that recolonisation and subsequent growth of the benthos was substantially complete 12 months after cessation of dredging at this particular site. Of particular interest is that "non-dredged" sites outside the boundaries of the dredged areas, but within the zone of potential impact of fine sands mobilised by the screening process, also show a significant suppression of biomass. The average biomass for such sites was 0.4356 g (AFDW) compared with 1.2763 g (AFDW) per 0.1 m^2 for the control sites. That is, the zone of deposition and transport of material outside the boundaries of the dredged sites was associated with a suppression of biomass by approximately 66%.

The study at Licence Area 408 showed that this zone of suppression of biomass extended for as much as 3km to the south-east of the actively dredged site, but for only 100m to the north-west. This is consistent with the net south-east transport of sand rejected during the screening process. It suggests that even in deposits where the marine community is well-adapted to rapid recolonisation and growth, there is evidence of a residual "footprint" on the biomass of the benthos for up to 3km from the dredge site. This corresponds in general with the zone of settlement and transport of material rejected during the screening process (see also Section 1.2.).

We are not aware of any other studies which provide sufficient information to assess the likely far-field impacts of marine aggregate dredging and overboard screening on benthic biological resources apart from those cited above for a dredge site off Dieppe (Desprez, 2000) and that at Area 408 in the North Sea (Newell *et al.*, 2002). Studies adjacent to a sand dredge site at Moreton Bay, Queensland, Australia by Poiner & Kennedy (1984) have shown, however, that there can be an enrichment of species diversity and population density of benthos immediately outside the boundaries of the dredged area.

They attributed this to the effects of enrichment from organic matter released from the sediments during the dredging process. Similar enrichment of benthos along the axis of the tidal stream adjacent to a dredged site at North Nab has recently been described by Newell *et al.*(2001b; also Hitchcock 2002), as well as at other sites off the east coast of the Isle of Wight in the eastern English Channel (Boyd & Rees, 2003) and close to a dredge site at Area 408 in the North Sea (Newell *et al.*, 2002). This may reflect settlement of organic matter derived from benthos fragmented during the dredging process (Newell *et al.*, 1999), or an impact of organic matter released at the sediment-water interface.

The results cited above are for relatively shallow water sites where the sediments are subject to natural disturbance and where the fauna is adapted for rapid recolonisation and growth. Any assessment of the likely scale of impacts on the stable equilibrium communities that characterise the coarse shell gravels and current-swept reefs and cobbles elsewhere and in deeper waters is therefore largely anecdotal. Studies of the macrofauna of reefs and stones in the central English Channel by Holme & Wilson (1985) show that the anemone *Urticina felina*, various hydroids, and the bryozoan *Flustra foliacea* are able to withstand abrasion by mobilised sand and intermittent burial. *Urticina felina* can extend its column to maintain its disc above the sand surface and similar behaviour has been described for the anemone *Anthopleura elegantissima* (Taylor & Littler, 1982; Littler *et al.*, 1983).

Flustra foliacea ©MESL-PhotoLibrary

Holme & Wilson (1985) also showed, however, that areas of abrasion by mobilised sand are associated with relatively impoverished epifaunal communities compared with rocks and reefs which are not subject to sand scour. Some impacts of mobilised sand on the epifaunal communities associated with rocks and reefs in the vicinity of dredge sites are therefore to be anticipated, although the nature and scale of any such impacts are unclear, particularly in view of the complexity of the faunal associations described for some of the adjacent habitats of the eastern English Channel and elsewhere (see Sanvicente-Añorve *et al.* 1996).

The possible impacts of marine aggregate dredging on biological resources outside the boundaries of the dredged area, based on studies in relatively shallow water coastal sites, may be summarised as follows:-

- Best estimates of the size of the zone of sand deposition surrounding a dredged area is that the screened material will be deposited as an ellipse of approximately 200m width and extending for up to 600-800m in each direction along the length of the tidal stream
- Within this zone there is likely to be an impoverished fauna in terms of species richness, population density and biomass. The community composition is also likely to be different from that in gravel deposits and to be dominated by polychaete worms.
- Little is known of the fate of this material following initial sedimentation. Studies in the North Sea and on the south coast of UK show that there is a benthic plume at the sediment-water interface that may extend for up to one tidal excursion in each direction along the axis of the tidal stream from the site of dredging. But there is very little information on whether this is likely to occur at other dredge sites, or the extent to which it is related to the return of screened material to the seabed during the dredging process.
- Studies on the benthos associated with a heavily screened site at Production Licence Area 408 in the North Sea has established an impact of screened material on the biomass of benthic invertebrates up to a distance of approximately 3km along the axis of net sediment transport from the dredge area.
- We are unable to provide firm estimates of the possible impacts of abrasion and possible intermittent submersion by sand mobilised from the near-site sedimentation zone on the relatively complex “equilibrium” communities that characterise stable reefs and gravels that occur near to some dredge sites. This is because the impacts on community structure are likely to be complex. However the “footprint” of impact on biological communities is likely to extend for up to 3km along the axis of transport of material from the dredge sites, based on results for the North Sea.

5. CUMULATIVE IMPACTS.

Potential cumulative effects of marine aggregate dredging have been reviewed in a Report by Oakwood Environmental (1999). This review includes recommendations on existing policy framework, a framework for the assessment of cumulative effects on marine and coastal environments, and a review of 'Good Practice Methodology' for the assessment of cumulative impacts on biological and physical resources. The review also includes the results of impact assessments for a Pilot Study Area on the south coast of U.K. The reader is referred to this review for general aspects of cumulative impacts associated with marine aggregate dredging in coastal waters.

Our best estimate of the likely cumulative impacts of marine aggregate dredging, based on what is known for the impacts and rates of recovery for the coastal Production Licence areas described in the previous sections is as follows:-

- Within the boundaries of any one production area, there is likely to be a 50-90% reduction in species richness, population density and biomass of marine invertebrates.
- This impact is likely to extend for a distance of at least 400-600m outside the boundaries of each dredge site along the axis of initial settlement of reject material.
- It is possible that dredging may also be associated with production of a benthic plume at the sea bed and extending for up to one tidal cycle along the axis of the tidal currents. Studies to date suggest that dredging is associated with a detectable impact on the biomass of benthic fauna for up to 3km along the axis of net tidal transport of sediments mobilised during the screening process.
- Recovery of biological community composition is generally initiated by an increase in species diversity and population density and is followed only later by restoration of biomass. Because the species characteristic of 'equilibrium' communities in coarse stable deposits have a slow rate of reproduction and growth, the process of restoration of community structure and biomass of the benthos is likely to take as much as 15-20 years for some long-lived components.
- In its simplest form, therefore the cumulative area of impact of the proposed dredging works for any one year can be estimated from the area dredged within each Licence Area plus the area likely to be affected outside the boundaries of the dredge site at each side of the tidal stream multiplied by the number of sites dredged.
- The cumulative area impacted over time will be the figure for one year, multiplied by the number of years required for recovery. It is likely that the earliest dredged sites will be in a stage of partial recovery within months, but species such as the dog cockle (*Glycymeris glycymeris*) may take as much as 15-20 years for colonisation and restoration of biomass following cessation of dredging. We estimate that at least 50% of the species variety, population density and biomass is likely to be achieved within 4-6 years after cessation of dredging, even in coarse deposits characterised by equilibrium communities.
- Added to this likely impact zone are the (unknown) potential impacts of seabed sediment plumes on both the physical features of the sea bed, and on the biological resources including fish eggs. Not enough is known to assess whether such plumes have a potential impact on seabed resources. However the fact that benthic plumes may extend well outside the boundaries of the immediate deposition zone implies that the areas of impact from adjacent dredge sites may overlap one another at some stages of the tidal cycle.

- We have also provided estimates of what might be anticipated if the sediment composition of the worked areas and surrounding deposits were to become sandier following removal of the coarse components and discharge of fine components by overboard screening. Again there is good evidence from both studies of impacts in nearshore Production Licence areas, and from communities resident in more stable offshore sands and gravels, that discharge of sands has an important impact on both the richness and community structure of the benthos.

- Reversion towards a sandy deposit is likely to result in a suppression of biodiversity and the replacement of a heterogeneous assemblage of benthic invertebrates to one which is dominated by a small species variety comprising mainly polychaetes. The area affected in any one year is likely to be similar to that estimated above.

- However the rate of recovery of sandy deposits is faster than in complex 'equilibrium' communities, so a less-diverse sandy substrate community may come into equilibrium with the new environmental conditions within a period of 2-4 years, based on results for sandy gravels in the North Sea.

6. IMPACTS ON FISHERIES.

The impacts of suspended sediments on a wide variety of animals including plankton, benthic invertebrates and fish species has been reviewed by Sherk (1971) and Moore (1977). Early studies by Loosanoff (1962; see also Collinson & Rees, 1978) showed that different species of commercially significant filter-feeding molluscs were differently affected by suspended sediment. Subsequent studies by Sherk (1971) and Sherk *et al* (1974) showed that, as in the case of bivalves, fish species have varying tolerances of suspended solids, filter-feeding species being more sensitive than deposit-feeders and larval forms being more sensitive than adults (see also Matsumoto, 1984).

Estimates based on trophic food web models suggest that as much as 30% of the total exploitable fish yield to man in waters of the North Sea are derived from benthic food webs (Steele, 1965; Newell *et al.*, 1998). Indirect effects on fish stocks thus include a reduction or alteration in the food available from benthic resources (Daan *et al.*, 1990), as well as potential direct effects on vulnerable stages of the life cycle such as the eggs and larvae. It should also be noted that a reversion from a mixed invertebrate assemblage which is characterised by a high species diversity, towards one which is dominated by a less diverse community that is dominated by polychaetes, may not necessarily result in a loss of commercially significant fish stocks (Millner *et al.*, 1977). Fish are opportunistic feeders, and a relatively uniform food availability comprising mainly polychaetes may enhance some stocks such as Dover sole (*Solea solea*) at the expense of others.

Solea solea ©MESL-PhotoLibrary

The likely impacts of marine aggregate dredging on fisheries resources have been summarised by Desprez (2000). He concluded that in general, fish are less affected by dredging activities than shellfish and other sessile benthic species because fish can evade the area of disturbance. However, some fish species, particularly demersal spawners such as herring and sandeel, may be vulnerable to damage through smothering of fish eggs on the spawning grounds (Westerberg *et al.*, 1996). Changes in the sea bed topography caused by dredging and by exposure of oversize material on the sea bed may also have an impact on the suitability of the sea bed for subsequent commercial fishing activities (de Groot, 1979), although the presence of more heterogeneous conditions on the sea bed may also favour the creation of new habitats for epibenthos and fish communities (Desprez, 2000).

The consensus view is that the impacts on commercial fishing activities are mainly related to exclusion from traditional fishing grounds, and to potential losses of eggs and larvae of demersal species, rather than to damage of commercially significant target species. It should however be noted that alteration in sediment composition may have complex effects not only on benthic food resources leading to fish, but may also inhibit settlement and survival of larvae of commercially significant shellfish. Partly for this reason, any 'Risk Assessment' for fish and shellfish resources needs to include a wide range of potential impacts as described in Section 8.

7. ASSIGNING SIGNIFICANCE TO IMPACTS.

Assigning significance to impacts on environmental resources is essentially a subjective judgement based on the professional experience and objectivity of those involved. It is therefore important to present as much information as possible on the reasons for arriving at a particular assessment for each of the environmental resources concerned.

The following sections summarise the key features of environmental resources that can be used in the assessment of potential impacts of marine aggregate dredging. Where appropriate, the following criteria should be taken into account:-

The Extent of Impact:

- A **Small** Impact - localised within the immediate dredge site.
- A **Limited** Impact - over an area extending up to 1km from the dredge site.
- A **Local** Impact - extending up to 5km.
- A **Regional** Impact - an impact over a relatively wide area >10km.

The Duration of Impact:

- A **Temporary** Impact - existing for less than 1 year.
- A **Short-Term** Impact - existing for 1-5 years.
- A **Medium Term** Impact - existing for 5-10 years.
- A **Long-Term** Impact - existing for more than 10 years.

The significance ratings assigned to the impacts can be as follows:-

An Impact is of **High Significance** if:-

- the extent is regional
- the duration is long-term
- the impact is on species or communities afforded Statutory protection
- the impact is on resources of high economic or conservation significance

An Impact is of **Moderate Significance** if:-

- the extent is local
- the duration is medium-term
- the impact is on species or communities afforded Statutory protection
- the impact is on resources of high economic or conservation significance

An Impact is of **Low Significance** if:-

- the extent is small or limited
- the duration is temporary
- there is unlikely to be an impact on species or communities afforded Statutory protection.
- there is unlikely to be an impact on resources of high economic or conservation significance

An Impact is of **No Significance** if:-

- there is no predicted effect on environmental resources.

The significance of the impacts can then be incorporated into a tabular summary of impacts and used as the basis of a Risk Assessment for each of the main environmental resources located in the vicinity of a particular dredge site. The Risk Assessment process takes into account both the sensitivity of the resource in question, and the actual vulnerability of the resource based on its distribution in relation to the dredge site.

8. RISK ASSESSMENT.

There have been a number of proposals to derive a numerical assessment of 'Risk' to environmental resources based on what is known of their sensitivity to disturbance, and the likely scale and sources of impact by man (Department of the Environment, 1995; Department of the Environment, Transport & the Regions, 2000; Associated British Ports, 1997). Estimates of Risk for activities such as marine aggregate dredging to important economic resources such as fisheries can be derived from a matrix that relates the potential sensitivity of species or communities to each component impact of the dredging operation and the actual vulnerability at a particular site (Carlin & Rogers, 2002). In other cases, impacts on resources of conservation significance have been related to both biotope sensitivity and recoverability (MarLIN, 2003).

8.1. RISK ASSESSMENT FOR COMMUNITIES & HABITATS

The sensitivity of particular communities or species to the relatively complex impacts imposed by man are not easy to quantify, and often involve a subjective assessment based on experience and judgement. In the case of biotopes, sensitivity can be defined in terms of species that are considered to be important components of the community as follows:-

- ✓ ***Key Structural Species.*** Species that provide a distinct habitat that supports an associated community. Loss or degradation of the species would result in a loss or degradation of the biotope, eg. *Sabellaria spinulosa*.

- ✓ ***Key Functional Species.*** Species maintaining community structure and function through interactions with other members of the community (eg by predation, grazing and competition). Loss or degradation results in change to the biotope.

- ✓ ***Important Characterising Species.*** The species are characteristic of the biotope and are important in the classification of the biotope. Loss or degradation would result in a loss of the biotope.

- ✓ ***Important Structural Species.*** The species which interact with the key or characterising species and are important for their viability. Loss of these species may reduce the viability of the key, or characterising species. Structural species may prey on epiphytes and parasites of the key characterising species.

- ✓ ***Important Functional Species.*** These are the dominant source of organic matter or primary production within the ecosystem. Loss could result in changes in community function and structure.

The following scales have been used to define the sensitivity and recoverability of marine biotopes to disturbance by man:-

Biotope Intolerance Scale (based on MarLIN 2003).

- **High Intolerance** - Key structural or functional species are likely to be killed and/or the habitat is likely to be destroyed.

- **Moderate Intolerance** - The populations of key structural or functional species may be reduced or degraded, the habitat may be partially destroyed, or the diversity and population density of a community may be reduced.

- **Low Intolerance** - Key structural or functional species are unlikely to be killed, but the viability, diversity and functionality of a community may be reduced.

- **No Intolerance** - The factor has no detectable effect on structure and functioning of a biotope or the survival and viability of key structural or functional species.

Biotope Recoverability Scale (based on MarLIN 2003).

- **None** - Recovery is not possible.
- **Very Low** - Partial recovery in 10 years, but full recovery time may be at least 25 years, or never.
- **Low** - Partial recovery in 10 years, but full recovery time up to 25 years.
- **Moderate** - Partial recovery within 5 years and full recovery up to 5-10 years.
- **High** - Full recovery complete within 5 years.
- **Very High** - Full recovery is within 6 months.
- **Immediate** - Full recovery within a few days.

The 'Intolerance' and 'Recoverability' can then be combined into a single scale that can be used to give some indication of the sensitivity of marine communities to environmental change. A 'Sensitive' community or habitat may then be regarded as one that is easily adversely affected by human activity, and is expected to recover only over a long period of time. This method of risk assessment has not, so far been widely applied to marine habitats and communities.

8.2. RISK ASSESSMENT FOR FISHERIES RESOURCES

A rather similar approach of combining the perceived 'sensitivity' of marine resources with the actual vulnerability at any particular site has been proposed for risk assessment of Fisheries resources by Carlin & Rogers (2002). They propose a matrix that relates the potential sensitivity of particular fish components or stages in the life cycle to the actual vulnerability based on the occurrence in a particular area. The scales in this case for both sensitivity and vulnerability are:-

- Very high
- High
- Moderate
- Low

They propose that the risk assessment for Fisheries should be assessed under the following key headings:-

1. Temporal & Spatial Scale of the Operation.
2. The Method of Aggregate Extraction.
3. Plume Effects.
4. Cumulative Effects.

Impacts on the following need to be listed under each of the above headings:-

1. The Benthic Fish Community.
2. Breeding & Spawning Grounds.
3. Nursery Grounds.
4. Over-wintering Grounds.
5. Migratory Routes.
6. Reduction in Income.

The Fisheries Impact Assessment can then be summarised into an Evaluation Protocol as outlined by Carlin & Rogers (2002). This comprises a table summarising the potential sensitivities of the fisheries resources to potential impacts of marine aggregate dredging. The data for a typical North Sea aggregate licence area are summarised in Table 4.

Table 4. Evaluation Protocol for Fisheries Resource Risk Assessment at a typical aggregate dredging area in the southern North Sea.

1. Temporal and Spatial Scale of the Operation	
Benthic Community	Survey carried out at 38 sites with triplicate samples at 12 sites. Trawl samples taken at 14 sites. Benthic community rich with an average of 40 species and 470 individuals per 0.1 m^2. *Sabellaria* present mainly as isolated tubes, but in large quantities possibly forming biogenic reef structures mainly well outside boundaries of the dredge site.
Breeding & Spawning grounds	Not known to be a spawning ground for commercial fish. Possibly suited for herring outside boundaries of the dredge site Likely to be important lobster resources and potentially significant pink shrimp spawning grounds to the east in deeper water.
Nursery Grounds	Not known to be an important nursery ground for any commercial fish or shellfish resources.
Over-wintering Grounds	Not considered to be an important over-wintering ground for any fish or shellfish.
Migratory Routes	Not a specific migration route for any commercial species, although pink shrimp, herring, roker and several other species that move between deeper water and coastal waters to reach breeding and nursery grounds probably pass through the area.
Direct Mortality	Most fisheries exploitation is by potting for crab and lobster outside the boundaries of the dredge site. Risk of direct mortality on these resources is zero.
Reduction of Income	Assuming complete exclusion of vessels currently exploiting the general vicinity of the dredge site, the losses are estimated to be £120K per year split amongst 6 vessels. However we consider the estimate of value of catches is either too high (based on the productivity of the seabed elsewhere in the region) or represents an unsustainable level of exploitation.
Displacement of Vessels	The 6 local vessels reported to operate in the vicinity of the dredge site may be displaced from parts of the licence area, depending on zoning agreements. However the evidence from the benthic ecology surveys suggests that the most important areas for commercial fisheries resources are located well outside the boundaries of the dredge site

2. Method of Aggregate Extraction	
Benthic Community	The infaunal invertebrates are likely to be removed by suction trailer dredging within the dredged zones. The structure of the community suggests that recovery will be achieved in 2-4 years after cessation of dredging. The temporary loss of potential invertebrate food species is unlikely to affect the 'carrying capacity' for fish because population densities of fish are well below historical levels due to commercial fishing pressure. Hence the remaining fish stocks are unlikely to be limited by food availability.
Breeding & Spawning grounds	The area is not regarded as an important spawning ground for any commercial target species. The risk of a direct impact on fisheries resources outside the boundaries of the dredge site is negligible.
Nursery Grounds	The area is not regarded an important nursery ground.
Over-wintering Grounds	The area is not considered an important over-wintering ground.
Migratory Routes	There is likely to be some generalised movement of fish and shellfish species between shallow coastal waters and deeper waters through the dredge site. But this occurs over a wide area and is not specific to the dredge site.
Reduction of Income	Trailer hopper dredging results in relatively shallow furrows in the seabed that are infilled with sand over time, depending on the rate of transport of material on the seabed. Most fisheries exploitation is by potting, although some foreign beam trawlers are reported in the area. The method of dredging is unlikely to detract from the suitability of the seabed for fisheries exploitation after cessation of dredging.
3. Plume Effects	
Benthic Community	The high gravel content of the seabed resources implies that the amount of material returned to the seabed following screening will be relatively small. Plumes of dispersing material have been described for some areas extending up to 600m along the axis of transport. There is likely to be a temporary impact on the benthic community in the immediate vicinity of the dredge site, but there is currently little evidence to suggest impacts on the benthic community beyond 200m.
Breeding & Spawning grounds	There is no evidence that the dredge site, or the deposits potentially affected by sediment mobilised by the dredging and screening process are of importance as a breeding ground for commercial fish or shellfish.
Nursery Grounds	Mobilised material will be moved for a limited distance outside the dredge site along the axis of the tidal currents. The only potentially significant nursery grounds lie to the east across the axis of the tidal streams. It is considered unlikely that dredging in zoned sites within dredge area will result in potential sediment transport across the tidal currents into potential nursery ground areas, or that the quantities of material will be significant.
Over-wintering Grounds	The dredge site does not constitute a known over-wintering area for fish or shellfish. The relatively small quantity of material likely to be rejected during screening is unlikely to have an effect on over-wintering species.
Migratory Routes	The dredge site does not constitute a migratory route for fish or shellfish. The relatively small quantity of material likely to be rejected during screening is unlikely to have an effect on migratory species.
Reduction of Income	The relatively small amount of material likely to be rejected by screening is unlikely to have an impact beyond the immediate boundaries of the site being dredged. Potential reduction of income (if any) is mainly likely through displacement of vessels from actively dredged sites within the dredged area.

4. Cumulative Effects	
Benthic Community	The total area under licence for aggregate dredging in the region as a whole has been reduced by 50% in recent years, and there are plans for further reductions. The risk of cumulative impacts from other dredging activities is now significantly less than it was in the past.
Breeding & Spawning grounds	The area is not known to be of importance as a breeding or spawning ground for any commercial fish or shellfish species. Cumulative effects (if any) will be significantly less than in the past.
Nursery Grounds	The area is not known to be of importance as a nursery ground for any commercial fish or shellfish species. Cumulative effects (if any) will be significantly less than in the past.
Over-wintering Grounds	The area is not known to be of importance as an over-wintering ground for any commercial fish or shellfish species. Cumulative effects (if any) will be significantly less than in the past.
Migratory Routes	The area is not known to be of importance as migratory route for any commercial fish or shellfish species. Cumulative effects (if any) will be significantly less than in the past.
Reduction of Income	A reduction of income from the combined dredging activities in the area is a lower risk than in the past following a 50% reduction of the area under Licence in recent years. Part of the proposal is to further reduce the area under Licence by progressively relinquishing depleted sites in the adjacent dredged areas.
Displacement of Vessels	Displacement of fishing vessels can occur if the occupancy of an area by dredging increases. The area dredged is, however reduced by more than 50% compared with previous years, and is set to be reduced further by relinquishment of depleted areas nearby. The risk of displacement is therefore now significantly less than in the past.

The second stage in the Risk Assessment is to assign a value to the actual vulnerability of the fisheries resources to each of the potential impacts of marine aggregate dredging at the particular site in question. This involves a balance of judgement between the sensitivity of the resource in question to particular impacts, and the distribution and abundance of the resource in relation to the proposed dredge site. This is a subjective process, but is based on the data summarised in the Impact Assessment and in Table 4.

The actual vulnerability of the resources are then allocated to one of the four following categories :- Very High, High, Moderate and Low. These are shown for the typical dredge site in the southern North Sea in Table 5 and provide the basis for a Risk Assessment Matrix.

Table 5. Fisheries Resources: Risk Assessment Matrix for a typical aggregate dredge site in the southern North Sea.

1. Temporal & Spatial Scale of the Operation.		Actual vulnerability			
	Potential Sensitivity	Very High	High	Moderate	Low
Benthic Community	Very High			1	
Breeding & Spawning Grounds	Very High				1
Nursery Grounds	Very High				1
Over-Wintering Grounds	Very High				1
Migratory Routes	Moderate				1
Direct Mortality	Low			1	
Reduction in Income	High				1
Displacement of Vessels	Low			1	

2. Method of Aggregate Extraction.		Actual vulnerability			
	Potential Sensitivity	Very High	High	Moderate	Low
Benthic Community	High			1	
Breeding & Spawning Grounds	High				1
NurseryGrounds	High				1
Over-Wintering Grounds	High				1
Migratory Routes	Moderate				1
Reduction in Income	High			1	
3. Plume Effects.		Actual vulnerability			
	Potential Sensitivity	Very High	High	Moderate	Low
Benthic Community	Very High			1	
Breeding & Spawning Grounds	Very High				1
Nursery Grounds	Moderate				1
Over-Wintering Grounds	Very High				1
Migratory Routes	Moderate				1
Reduction in Income	High			1	
4. Cumulative Effects		Actual vulnerability			
	Potential Sensitivity	Very High	High	Moderate	Low
Benthic Community	High			1	
Breeding & Spawning Grounds	Very High				1
Nursery Grounds	High				1
Over-Wintering Grounds	High				1
Migratory Routes	Low				1
Reduction in Income	High			1	
Displacement of Vessels	High			1	

The final stage in the Risk Evaluation is a matrix that combines the scores for the potential sensitivity of each component of the fisheries resource to each of the potential impacts, with the actual vulnerability of those resources at the particular site in question. This matrix is shown in Table 6.

Table 6. Table showing the total scores for actual sensitivity of fisheries resources in relation to their potential sensitivity to impacts from marine aggregate dredging at a typical dredge site in the southern North Sea. Compiled from Table 5.

Potential Sensitivity	**Actual Sensitivity**			
	VERY HIGH	HIGH	MODERATE	LOW
VERY HIGH			2	6
HIGH			6	6
MODERATE				4
LOW			2	1

This gives the final scores shown in Table 7 for Environmental Risk to the Fisheries Resources at the dredge site.

Table 7. Table showing the final summed scores for Environmental Risk to fisheries that is likely to be posed by marine aggregate dredging at a typical dredge site in the southern North Sea. Compiled from Tables 5 & 6.

OVERALL ENVIRONMENTAL RISK	SCORE
HIGH	0
HIGH-MEDIUM	2
MEDIUM	6
MEDIUM-LOW	12
LOW	4
NEAR ZERO	3

Table 7 shows that the assessed risk to Fisheries Resources posed by marine aggregates dredging for the typical dredge site in the southern North Sea used as an example is mainly in the MEDIUM-LOW category. This is similar to Risk Assessments for Fisheries at Area 407 in the English Channel to the south of the Isle of Wight, UK, but poses a significantly lower assessed risk than at some other Licence Areas where this form of evaluation has been carried out (Carlin & Rogers, 2002).

9. MITIGATION.

United Kingdom policy guidelines for the marine aggregate dredging industry have been summarised in:-

- Office of the Deputy Prime Minister (ODPM) 2002. *Guidance on the Extraction by Dredging of Sand, Gravel and Other Minerals from the English Seabed. Marine Minerals Guidance Note 1.* (ISBN 0 11 7536342 Her Majesty's Stationery Office 30 pp).

This gives detailed guidance on Policy Objectives relevant to applications for marine aggregate dredging as follows:-

- *The careful location of new dredging areas*
- *Considering new applications for Dredging Permissions in relation to the findings of an Environmental Impact Assessment (EIA).*
- *Minimising the total area permitted for dredging.*
- *Controlling dredging operations through the use of legally enforceable conditions attached to Dredging Permissions.*
- *Requiring operators to monitor, as appropriate, the environmental impacts of their activities during, and on completion of dredging.*
- *Adopting dredging practices that minimise the impact of dredging.*

Several mitigation measures are potentially available to protect environmental resources adjacent to dredging areas in coastal waters, and to enhance recolonisation after cessation of dredging. Whether these are cost-effective depends on a commercial decision on the importance of the resources and the costs and feasibility of mitigation measures. Typically these include the following:-

- ***Reduction of Overboard Screening***. It has been shown that one of the main sources of impact on benthic biological resources is the practice of overboard rejection of screened material. The fact that this material accumulates within the dredged site means that an increasing amount of dredging (and screened discharge) is required as the dredge area is exploited over time. Studies cited above show that the deposition of screened material on the sea bed may have a more serious impact on sea bed resources than dredging itself. The screening process must therefore be viewed as a major source of impact on sea bed resources. Obviously the option on whether screening is essential depends on a commercial decision whether there is a beneficial use for sands on this scale, and the costs implications of bulk transport of 'all in' cargo compared with screened cargo suited to customer needs.

- ***Adjustment of the timing of exploitation***. Some areas close to the sites of dredging may support biological resources of conservation significance, or resources that are of importance as a spawning ground or nursery area for commercially significant fish and shellfish species. Successful mitigation of potential impacts of seabed plumes on breeding areas for crab has been achieved by dredging only when the tidal stream transports sediments away from the sensitive area. In other areas, there may be a seasonal variation in importance for fish and shellfish. If it is established that some parts of the seabed surrounding a potential dredge site are of importance as a habitat for fish spawning, and if these areas lie within potential sedimentation plume zones, it may be necessary to consider cessation of dredging close to these sensitive areas during the breeding season.

- ***Establishment of 'Refuge Areas' to enhance recolonisation.*** Our review of the literature shows that significantly faster recolonisation and recovery rates have been reported for shell deposits in which non-dredged areas were left between strips of dredged sea bed. The presence of patches of non-dredged deposits within a dredge site may assist recolonisation. It should be pointed out, however, that recolonisation by planktonic larvae is likely to be of more importance than migration of adults from the surrounding seabed in most gravel deposits. In general we view the establishment of 'refuge areas' as a positive proposal, but not one which is seriously likely to represent the primary source of recolonising larvae for a particular dredge site.

In line with Policy Objectives summarised above, proposals to reduce the impacts of marine aggregate dredging generally centre on minimisation of the dredged area, and the amounts of material likely to be rejected by screening. The principal options for a typical marine aggregate dredge site are:-

- *Minimise the dredged area*
- *Manage the dredging operations*
- *Liaison & reporting*

9.1. MINIMISE THE DREDGED AREA.

Resources of sufficient depth and quality need to be located within the potential dredge site. This will:-

1. *Minimise the area to be dredged*
2. *Reduce the amount of screened material returned to the seabed*
3. *Minimise direct impacts on benthic biological resources*
4. *Allow maximal access for fishing vessels to use the surrounding seabed*

9.2. MANAGE THE DREDGING OPERATIONS.

Dredging operations can be managed with the following objectives:-

1. *Avoid formation of depressions on the seabed that might interfere with fishing once the site is relinquished*
2. *Minimise loading times to avoid interference with other legitimate users of the sea*
3. *Resources to be worked to depletion in small zones before moving to a new zone, allowing maximal time for recovery of benthic biological resources in each dredged zone without further disturbance*
4. *The deposits on the seabed to be left in a similar condition to assist recovery of biological resources in relinquished areas*

9.3. LIAISON & REPORTING.

As part of the proposals to minimise conflicts with other legitimate uses of the marine environment management proposals can include:-

1. *Minimise interference with fishing activities by proper liaison protocols with Fisheries representatives*
2. *Inform other potential users of the area by provision of information on dredging activities and other relevant information*

We consider that there are not any practical or cost-effective ways of minimising the impacts of marine aggregate dredging within the dredged zones themselves, nor in the 400-600m primary sedimentation zone, unless a reduction of material returned to the seabed following screening were a commercially-acceptable option. It is also unlikely that there are cost-effective measures that could be taken to enhance the rate of recolonisation and recovery of the complex and slow-growing equilibrium communities that typically occur in coarse gravels that characterise many aggregate extraction sites.

Such communities probably represent an important food resource for fish, but we doubt whether losses to the marine food web from the dredged areas, even when summed over a 10-20y time period, would result in a detectable impact on the carrying capacity of the surrounding seabed for commercial fish stocks. This is because the area dredged is very small compared with the feeding habitat available for fish, and partly because pressure on commercial fish stocks in UK waters has been so great that currently the feeding requirements of the fish population is well below the potential 'carrying capacity' of the seabed resources for commercial fish species. Of more significance are possible impacts on areas of localised or seasonal importance such as spawning grounds and nursery areas for fish and shellfish including scallop and crab. This implies that the dredging strategy for a particular site needs to take into account the seasonal sensitivity of the seabed resources, and the likelihood of 'Risk' to those resources bearing in mind what is known of the physical impacts of dredging both within the dredge site and on the surrounding deposits.

10. MONITORING.

A common objective of monitoring studies has been to assess the nature and sensitivity of benthic biological resources to potential disturbance by dredging activities within the proposed dredge site, and to identify resources or communities of conservation significance that warrant special protection. Most surveys include an assessment of the significance of the areas for commercial fishing, and as a breeding or nursery ground for young fish. However because of the strong seasonality of fisheries data, and the fact that most fisheries investigations require a long series of surveys extending over several years, it has not generally been cost-effective or practical to carry out primary fisheries investigations as part of the normal environmental impact process.

The first requirement of the environmental resource survey is to carry out an assessment of resources over a relatively wide area to establish the 'baseline' conditions prior to dredging and to assess the likely 'risk' based on what is known of the sensitivity of the resources and their location in relation to likely impacts from the dredge site. The most common form of survey has been to establish a box-grid of sampling stations which generally extends for a distance of at least one tidal excursion at each end of the proposed dredging area. It also includes stations located across the axis of the tidal stream as well as 'control' stations located well outside the boundaries of any likely impact of dredging activities within the proposed Production Licence Area. The information is then used to predict what might be the impact of dredging activities, and to make proposals on how any impacts might be minimised.

A secondary objective is to identify sites which, because of the sensitivity of their communities, or because of their location in relation to the dredge site, can be used as 'monitoring' stations. The main purpose of a monitoring survey is to confirm whether or not the predictions of impact made in the initial dredging licence application are correct, and to trigger mitigation measures if impacts exceed those accepted as part of the project proposal. In general, the number of 'monitoring' sites is fewer than that used in the baseline survey grid, but there is a need to include an assessment of the variance of the samples at each site. Apparent impacts might otherwise merely reflect the well-known variability, particularly of biological samples, on the sea bed.

The procedures commonly used in baseline surveys for the marine aggregates industry in recent years have been summarised in some detail in a Report on *"Procedural Guidelines for the Conduct of Benthic Studies at Aggregate Dredging Sites*" (Department for Environment, Transport & the Regions (DETR) 2001). A further study on the use of mapping techniques suitable for the identification of marine biotopes has been reported in "*Mapping of Gravel Biotopes and an Examination of the Factors Controlling the Distribution, Type and Diversity of their Biological Communities"* (Brown *et al.* 2001).

The following sections outline a general procedure for establishment of a benthic biological monitoring survey for a particular Production Licence area. However it is recommended that reference is made to the above Reports for much background information on suitable survey gear, analytical methodology and recommendations for reporting of data. A general procedure based on common practice to date is given below.

10.1. NUMBER AND POSITION OF MONITORING SITES.

Most studies on the benthic communities of sands and gravels suggest that a minimum of 2-3 replicate samples of 0.1 m^2 are required to identify the majority of the species present in sandy deposits of the North Sea whereas at least five replicates are necessary for more complex communities that characterise stable substrata such as rocks and cobbles (see Newell *et al.*, 2001a & 2003). Clarke & Green (1988), Warwick & Clarke (1996) and more recently Somerfield & Gage (2000) have addressed the problem of the number of replicates and the appropriate spacing between samples to accommodate the patchiness that occurs in the macrofauna of marine deposits.

Retrieval of 0.1m^2 Hamon grab ©MESL-PhotoLibrary

Somerfield & Gage (2000) studied the macrofauna of Scottish sea lochs and concluded that there was a need to understand and guard against the problem of 'pseudoreplication' (Hurlbert, 1984) in the design of a sampling strategy. They recommended that samples to be taken as replicates should be taken at least 40 m apart. By ensuring this, an investigator is unlikely to collect samples more similar to one another than they should be and reduce the chances of concluding that a difference exists when it does not.

We have shown above that there is evidence of an impact of marine aggregate dredging on benthic biological resources within a dredged site, and that an impact has been reported for the zone of deposition of material rejected during the screening process. This zone is likely to be between 400-600m on each side of the dredge site along the axis of the tidal streams. We have also shown that there is evidence for the presence of a benthic sediment plume which may extend as much as one tidal excursion along the axis of the tidal streams on each side of the dredge site.

The distribution of sample sites for a 'monitoring' survey should thus take into account the need for replicate samples to assess variance, and the need to cover an area of sea bed that extends for up to one tidal excursion on each side of the proposed dredge site. 'Control' sites situated perpendicular to the axis of flow of material from the dredge site are also required to assess the natural variations in benthic biological resources against which any impacts need to be assessed.

Figure 16 shows a schematic diagram of an idealised dredge site together with recommended positions and numbers of replicates for monitoring sites both within the dredge site and along the axis of probable dispersion of material from the dredge site.

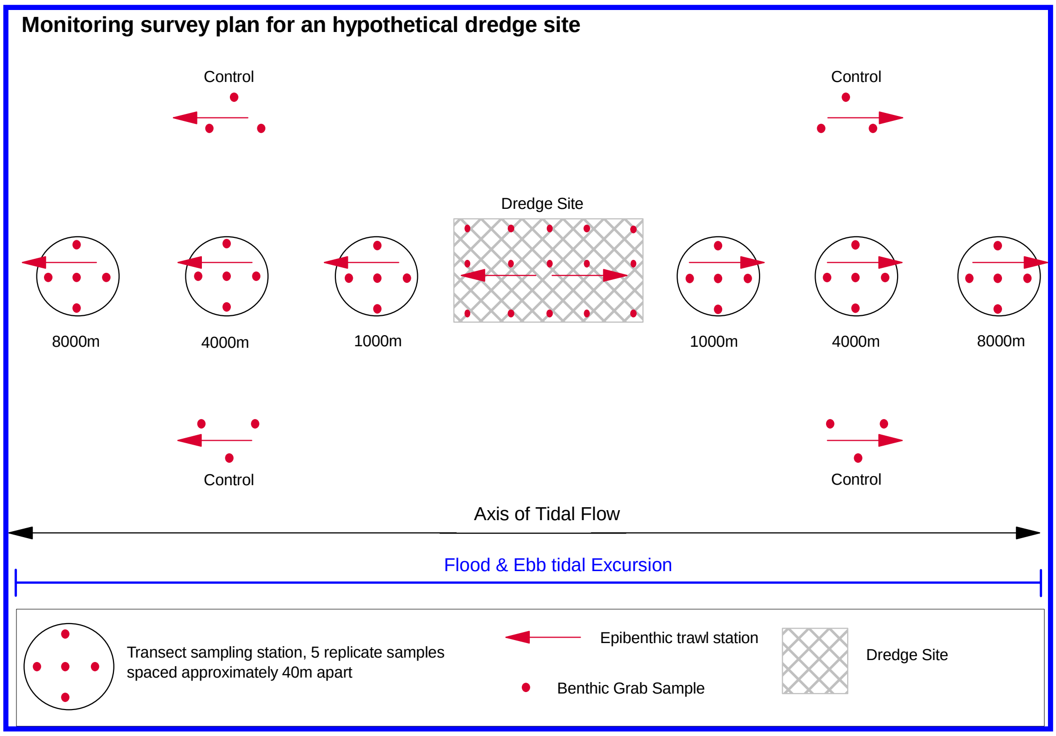

Figure 16. Monitoring survey plan for an hypothetical dredge site. The sites of benthic grab sampling stations including monitoring and control sites (spots) are shown, together with trawl sites for epibenthos (arrows).

Ecologists will have their own preferences, but the following general recommendations can be made on a basis of Figure 16:-

1. In order to monitor impacts within the dredge site itself, we recommend at least 15 sample sites. This is because it is difficult to locate dredge tracks within a trailer dredge site and one needs to have sufficient samples to locate impact areas within the Production Licence area. The data from these samples can be pooled to give an estimate of impact and variance of benthic communities within the dredge site as a whole.

2. Monitoring stations have been arranged at 1000m, 4000m and 8000m on each side of the dredge site along the axis of the tidal streams. Each monitoring station comprises a target area of 200m, within which 5 replicate samples can be taken at distances of 40m to avoid the problem of 'pseudoreplication' of patchy organisms referred to above. The results from these samples can be used to express mean population characteristics and variance between samples at each site in relation to distance from the dredge site.

3. Control stations have also been indicated across the main axis of the tidal stream. It is considered unlikely that these will be impacted by the dredge site shown in Figure 16, but clearly the position will need to be located away from possible impacts of adjacent Production Licence Areas. Note that we have indicated a minimum of triplicate samples in these 'control' stations, but that this might need to be increased to 5 replicates if the substrate comprises a gravel with rich fauna.

4. The epifauna comprises organisms that live on the surface of the sea bed and which are not sampled quantitatively with conventional grabs. We recommend a series of single epibenthic trawl samples should be taken within the dredge site and at each of the monitoring stations. These sample site are indicated by arrows in Figure 16.

5. There is a serious lack of information on the size and scale of the sedimentation processes and no information on the extent to which screened material may accumulate on the sea bed, or whether benthic turbidity layers occur at the sediment-water interface in relatively deep water sites. We consider that monitoring of the quantities and fate of overboard screened material is an important component of the monitoring programme, and that direct measurements of plume characteristics by seabed mini-pods coupled with side scan sonar and appropriate visual techniques could make a significant contribution to our understanding of the likely scale of impact of this project on biological resources surrounding aggregate dredge sites.

The generalised scheme for a monitoring survey of biological resources thus involves 57 grab samples and 12 epibenthic trawl samples. Clearly the number of stations may be reduced if it is shown that the impact along the axis of the tidal streams is significantly less than one tidal excursion. All evidence from dynamic environments is that any impact on benthic biological resources is confined to distances of up to 400-600m from the dredge site, corresponding with the zone of deposition from the discharge plume. But in view of the unknown impact of a probable benthic plume at the sediment:water interface, monitoring should be carried out for a full tidal excursion until the limits of impact are established for the dredge site at a particular location.

10.2. BENTHIC INFAUNA

10.2.1. __Sampling Methods__.

The benthic infauna are commonly sampled with either a $0.2m^2$ or, more recently a $0.1m^2$ Hamon grab. Use of this grab has the advantage that loss of material by 'washout' from the jaws experienced with conventional grabs is reduced (Holme & McIntyre, 1984; Sips & Waardenburg, 1989; Kenny & Rees, 1994; van Moorsel, 1994; DETR, 2001). The larger $0.2m^2$ grab takes approximately 16 litres of sediment whereas the smaller $0.1m^2$ grab takes approximately 9 litres of sediment. The latter is easier to sort and has been increasingly used in recent studies of the benthos.

$0.1m^2$ Hamon grab ©MESL-PhotoLibrary

The samples taken with the grab may be sieved aboard the survey vessel to separate the macrofauna from the bulk of the deposits. However it is often preferable to carry out the entire separation of the macrofauna from the sediment sample ashore, rather than partially at sea as recommended in the Guidelines referred to above.

This is for the following reasons:-

1. *Collection of samples at sea often involves long hours in rough sea conditions and poor lighting. Samples are often taken at night because larger survey vessels operate a 24h shift system. This reduces the effectiveness of initial sorting aboard the survey vessel.*
2. *Sorting at sea can significantly reduce the rate of sample collection. Because of the costs of a survey vessel and the short weather 'window' often available for sampling, the time taken for collection of samples at sea needs to be kept to an absolute minimum.*

3. *If sorted alive aboard the survey vessel, many of the benthic infauna (especially the polychaetes) can escape collection through the apertures of the sieve mesh.*
4. *Although transport of the whole sample ashore for sorting involves a significant amount of material, the quantitative extraction of the fauna is maximised under ideal lighting in the laboratory.*

Once the sediment sample has been taken with the grab, a small sub-sample is taken for particle size analysis of the sediments. The remainder is transferred to a 15 litre bucket, agitated with formalin and sealed with a lid before being transported to the laboratory for subsequent separation and identification of the macrofauna.

Sediment sub-sampling ©MESL-PhotoLibrary

10.2.2. __Laboratory Identification and Analysis__.

On arrival at the laboratory, the samples are thoroughly washed with tap water and the supernatant poured through a 1mm mesh sieve to collect the smaller macrofauna. The residual sediment is then washed on to a 1mm mesh sieve and the larger stones and shells retained on the sieve are carefully sorted by hand to remove the larger macrofauna and organisms attached to stones and pebbles.

Sorting on a 1mm mesh sieve ©MESL-PhotoLibrary

The biological material is then preserved in methanol for subsequent separation in to major faunal groups, identification and enumeration. Biomass is commonly expressed as ash-free dry weight (AFDW) for marine organisms. However measurement of the ash-free dry weight results in destruction of the samples which are not therefore available for subsequent Quality Assurance control if required. The normal procedure is therefore to measure the blotted wet weight of either the individual species or the main phyletic groups in the sample, and to estimate the AFDW from standard conversion figures. A reference collection is kept and the identified material is retained for use in Quality Assurance procedures if required.

Identification & enumeration in the laboratory ©MESL-PhotoLibrary

10.3. BENTHIC EPIFAUNA.

Although the methods used for sampling the benthic infauna are similar for most of the baseline surveys carried out as part of the Environmental Impact Assessment process for marine aggregate dredging areas, very few have used compatible methods for analysis of the motile epifauna. In some cases samples have been taken with a scallop dredge, in others a small 2m beam trawl has been used. Few have quantified the catches sufficiently to allow use of multivariate statistical techniques to assess community structure.

CEFAS 2m beam trawl ©MESL-PhotoLibrary

Recent studies by Ellis & Rogers (2001) show, however, that analysis of the community composition of the epifauna sampled with a commercial sized beam trawl can give an insight into this important component of the benthos. Furthermore, the data include both fish and epibenthos, and thus give information on the epibenthic community as a whole as well as information on commercially exploitable fish stocks at the time of the survey. Some recommendations on the suitability of gear to sample the epibenthos is also given in the Guidelines referred to above (DETR, 2001).

We recommend that a series of trawl samples should be taken in the survey area as part of a comprehensive monitoring survey that includes both benthic infauna and the epibenthic community as a whole. The length of haul needs to be adjusted to obtain a representative sample of the mobile epifauna, without obtaining so much catch that sub-sampling is required. Generally a haul of 5-10 minutes yields sufficient sample for macrofauna analysis. The entire sample should be transferred to a sealed bucket, immersed with seawater and preserved in formalin for separation and analysis ashore. The position of the deployment and hauling of the net from the sea bed should be recorded and used to estimate the numbers of epifauna per unit area trawled.

Cod end sample release ©MESL-PhotoLibrary

On arrival at the laboratory, the main components of the macrofauna are washed over a 1mm mesh sieve, identified and weighed. These data are not quantitatively compatible with those for the infauna collected with a Hamon Grab. But the data are suitable for community analysis and can be used to establish spatial and temporal variations in community structure using similar methods to those suitable for the benthic infauna.

Weighing epibenthic macrofauna ©MESL-PhotoLibrary

Three points are worth noting in relation to the use of trawl surveys to study the distribution and abundance of the epibenthos:-

1. *The nature of the catch varies a good deal with the type of gear used and the way it is rigged, as well as with the speed of the vessel and other factors. A trawl suited to capture of small epibenthic invertebrates will not capture larger more mobile fish species. Therefore although a beam trawl rigged with a fine mesh net will give compatible results within one survey area for the epibenthic invertebrates, it will seriously under-record fish. If fish catches are of primary interest, it is recommended that a small commercial otter trawl or beam trawl is used, and that the by-catch of invertebrates is used for analysis of epibenthic invertebrates.*
2. *The epibenthos and fish vary a great deal seasonally. In contrast to the benthic infauna, it is probably necessary to take several epibenthic trawl surveys per year to establish the variation in baseline conditions that occurs in the absence of impact by man.*
3. *If surveys are carried out using a small mesh suitable for capture of undersize fish, Fisheries Regulations may apply.*

10.4. DATA RECORDING & ANALYSIS OF RESULTS.

The analytical procedure for interpretation of community structure in marine benthos is now widely agreed and adopted in all of the baseline surveys carried out in UK waters. These are reviewed in some detail in the Guidelines (DETR, 2001). A recommended procedure for the recording format is as follows:-

1. The species identification should be recorded in a standard format using Picton B.E. & Howson, C.M. (1999). *The Species Directory of the Marine Fauna and Flora of the British Isles & Surrounding Seas*. CD-Rom version. Published by The Marine Conservation Society and The Ulster Museum. (ISBN 0-948150-11-4). Note that the coding in this latest version differs somewhat from the 1997 hard copy.
2. Data for the sediment characteristics, positions of the sampling stations, species variety, population density, biomass and all other relevant physical and biological data obtained in the survey should be recorded on an EXCEL format.
3. The analysis of sediment types and biological data should be carried out using multivariate methods or compatible methods. The most convenient and purpose-designed statistical software package for use in marine benthic surveys in the UK is the Plymouth Routines in Multivariate Research (PRIMER) version v5 (Clarke & Gorley, 2001). This version has additional features that allow calculation of biodiversity indices based on ‘taxonomic distinctness’ of the species comprising a quantitative sample or species list. These indices have statistical properties that are robust in relation to variations in sampling effort and may therefore be considerably more useful than some of the more conventional indices used in earlier studies. Other software packages including TWINSPAN & DECORANA and, more recently, CANOCO for Windows are also widely used for ordinating multivariate species data and for providing insight into the structure of biological communities and their relationship with environmental determinands (see Hill & Gauch, 1980; ter Braak & Šmilauer, 2002).
4. The presentation of the results should be in electronic format using a suitable GIS system. We have found MapInfo 7.0 to be well-suited for coastal surveys as it allows data from dredging vessels and bathymetric data to be superimposed on to the results of baseline and monitoring surveys. Obviously use of an EXCEL spreadsheet in the Report allows other software packages such as ArcView to be used without difficulty.
5. The full Report should be made available on CD-ROM as a PDF file. This allows electronic transmission without the Report being inappropriately modified.

10.5. IDENTIFICATION AND MAPPING OF MARINE BIOTOPES.

Because of the need to identify and manage coastal zone resources, there has been some interest in the development of methods for the rapid assessment and mapping of marine biotopes in recent years. These have varied from relatively crude assessment of the main types of sea bed substrata, coupled with sporadic assessment of communities associated with the main sediment types to a sophisticated combination of methods including grab sampling, acoustic ground discrimination systems (AGDS) such as RoxAnn and QTC-View, sidescan sonar and photographic methods (see Brown *et al.*, 2001).

The use of these methods is outside the scope of this Review. However several points are worth noting in the context of monitoring marine aggregate dredging and other impacts of man on marine resources.

1. *Remote sensing systems have obvious attractions for overall habitat mapping for management of coastal resources. However it is clear from most detailed benthic surveys that community composition can vary significantly within particular substrate types. Consequently fine-grained resolution of marine community structure is likely to require relatively large numbers of epibenthic and grab samples to 'ground-truth' the remote sensing data. Brown et al (2001) therefore emphasise the need for survey techniques to be used in combination when producing high-resolution biotope maps of an area. In particular they caution against the use of acoustic methods in isolation as a tool for predicting biological and physical traits on the sea bed.*

2. *Such systems (used in conjunction with several other techniques) have some potential value in baseline surveys, especially in areas where rocky outcrops and reefs prevent suitable sampling by grabs or trawls.*

3. *It is unlikely that remote systems, even when used in combination, will provide sufficient discrimination to monitor changes in community composition associated with potential 'far-field' impacts of marine aggregate dredging. Neither is it likely that they could be used as an effective tool to quantitatively demonstrate the nature and rate of recovery in marine deposits after cessation of dredging. They may, however, be useful in establishing the gross near-site impacts of dredging and overboard screening on physical and biological resources on the sea bed.*

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Appendix B

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Appendix C

Dredging Industry Survey Questions And Responses

- **Appendix C1 -** Cover Letter to US Dredging Contractors
- **Appendix C2 -** List of Questions For US Dredging Contractors
- **Appendix C3 -** MIRO Sponsored Questions To European Dredging Contractors
- **Appendix C4 -** Summary of All Industry Responses
- **Appendix C5 -** Document and Powerpoint Presentation Provided by Jan de Nul

Appendix C1

Cover Letter To
US Dredging Contractors

February 4, 2004

Dredging Contractor
1234 Easy Digging Way
Anytown, World

Gentlemen:

W.F. Baird & Associates has been retained by the U.S. Department of the Interior, Mineral Management Service (MMS) to conduct studies relative to the mining of sand for beach nourishment and construction aggregates. The borrow areas are located on the Outer Continental Shelf (OCS) under Federal jurisdiction.

The United States (U. S.) Government, and specifically, the MMS, a bureau within the U. S. Department of the Interior, has jurisdiction over all mineral resources on the Federal OCS. The MMS has the authority to convey, on a noncompetitive basis, the rights to OCS sand, gravel, or shell resources for shore protection, beach or wetlands restoration projects, or for use in construction projects funded in whole or part or authorized by the Federal Government. MMS has provided Federal sand for beach nourishment projects in New Jersey, Maryland, Virginia, Florida, South Carolina, and Louisiana.

Offshore sand-dredging for beach nourishment projects employ hydraulic dredges almost exclusively and are normally either cutterhead or hopper dredges. The process may result in adverse effects on various components of the marine or coastal environment.

The offshore-dredging industry is constantly changing as the industry strives to make operations more efficient. New advances in offshore-dredging technology are leading to more environmentally-sensitive offshore operations. Researchers are actively increasing the knowledge base relative to physical processes involved in dredging procedures. Physical and mathematical modeling of these processes is being conducted with the aim to reduce the negative environmental aspects (biological and physical) associated with the offshore removal of sand. New engineering technologies currently used overseas are now contemplated for use in U.S. waters.

As the Federal agency responsible for regulation of OCS sand resources, the MMS must ensure that sand and gravel dredging operations conducted under its jurisdiction are conducted in a safe and environmentally-sound manner. This may, in some instances, entail the required use of particular dredging equipment or techniques. Thus, MMS must have sound knowledge of the most current dredging technologies available.

The objective of the study is to review and analyze dredging equipment and projects on a worldwide basis to identify both existing and emerging dredging technologies that aim to lessen or avoid potential adverse effects on the offshore biological and physical environment.

Contacts were made with Federal and State natural resources agency staff and others involved in research on the impacts of dredging, studies of the life history of special species of concern, and permit approvals to determine the direct and indirect impacts that are of greatest concern for dredging operations in the OCS. Recent MMS-sponsored reports and environmental assessments on dredging impacts in the OCS were also reviewed. This identification of the perceived environmental impacts of greatest concern will be used to evaluate the advances in dredging techniques and equipment to measure their success in reducing the degree of such impacts.

The prioritized list of perceived concerns from OCS dredging operations on marine biological and physical resources is shown below. For the concerns that are currently being addressed by stipulations in the MMS lease for a site, the stipulations are summarized for ease of review.

1. <u>Short-term and cumulative impacts from dredging that lead to loss or reduced stability of benthic habitats, including recolonization by an altered biological community</u>. All resource managers raised this concern. The greatest concern was in known benthic-associated fishery areas, such as the surf clam fishery off New Jersey and the shrimp fishery in the Gulf of Mexico. There was less

concern in areas of general biological productivity or dynamic processes, such as in South Carolina.

2. Injury and death of special species of concern (e.g., Sea Turtles) from being sucked into the draghead or cutterhead during dredging operations. This concern was raised by every Federal agency with management responsibility for T&E species. Most agency staff thought the existing stipulations were effective, but even a single "take" was considered a significant impact.

   Existing stipulations include:

   a. Presence of a trained observer following specific protocols.
   b. Use of a rigid Sea Turtle deflector (i.e., one designed by NRDC or similar.)
   c. Operation of the dredge in a manner that will reduce the risk of interaction with any Sea Turtles, which may be present in the dredge area. Keep the draghead on the bottom except: 1) when the dredge is not in a pumping operation and the suction pumps are turned completely off; 2) when the dredge is being reoriented to the next dredge line during borrow activities; and 3) the vessel's safety is at risk.
   d. Dredge equipped with inflow screening baskets (4-inch mesh) to better monitor the intake and overflow of the dredged materials for Sea Turtles and their remains. These screens should sample at least 70% of the overflow area and should be installed at the applicable area.
   e. Assessment/relocation trawling to further assess/reduce the potential for incidental takes during dredging. Trawling is conducted repeatedly in front of the dredge as it moves along the track lines. Any turtles collected are to be relocated.

3. Changes in the substrate characteristics (grain size, dissolved oxygen, compaction and organic content) that lead to a reduction in benthic communities AND suitability of the area for future dredging. This concern was identified in South Carolina where 3-to 40m of sediment was removed. The depressions persisted for many years and filled with fine-grained sediments.

4. Changes in bathymetry that can alter the wave climate reaching the shore. The importance of this concern varied by region. Where the OCS sand bodies were close to shore and/or shallow enough to influence the wave climate, there was high concern regarding the potential for increased shoreline erosion. The orientation, depth, and shape of the sand body and borrow areas should be considered in evaluating the impact of dredging on wave climate.

5. Damage to hardbottom habitats: physical damage during dredging; burial by suspended sediment during dredging; and altered sediment processes that could bury hardbottom. This issue was of concern when dredging smaller sand bodies in between hardbottom habitat, even though these areas are supposed to be avoided.

6. Creation of depressions and furrows from removal of substrate. Though MMS has a "no pits" stipulation, there was still concern that furrows might interfere with bottom fishing. At least one responder thought that the furrows acted as recruitment sources, supporting the idea of leaving strips of undredged areas.

   Existing stipulations include:

   a. To assure that deep pits and furrows are not created, conduct post-dredging hydrographic surveys.

7. Short-term increased turbidity from cutter head on benthic species. Most responders assumed that OCS dredging occurred in sandy substrates, thus turbidity would be short-term and animals would avoid turbid areas. However, turbidity might be more of a concern in areas where a fine-grained overburden has to be removed to access the coarser sediment.

   Existing stipulations include:

   a. Turbidity shall not exceed background levels by more than 29 Nephelometric Turbidity Units. If monitoring shows that turbidity exceeds the maximum amount allowable, dredging activities shall cease immediately and not resume until corrective measures have been taken and turbidity has returned to acceptable levels.

8. Spatial and seasonal conflicts between dredging and commercial and recreational fisheries.

9. Potential to break an active or abandoned pipeline, resulting in a release of petroleum.

10. Collisions with marine mammals and Sea Turtles during vessel operations.

    Existing stipulations include (and are probably adequate):

    a. If operating in areas of known whale occurrences, observers are required. If whales are observed, avoid intentional approaches within 100 yards and slow speeds to less than 4 knots.

    b. See stipulations for Sea Turtles.

11. Damage to archaeological resources.

    Existing stipulations include:

    a. Identification (by remote sensing) and avoidance of potential archaeological site locations (minimum avoidance ratios around potential site.)

Our current study is focused on Atlantic and Gulf Coast sand borrow sites. The sites range from 5 kilometers to 20 kilometers offshore. The water depth at these sites varies from 5 meters to 25 meters deep. The material to be dredged for borrow is assumed to be sand with an average grain-size of 0.30 mm and less than 10% passing the 200 sieve. As a part of this study, we are reviewing the current scientific data to determine which of the perceived concerns enumerated above are real and need to be addressed.

With this letter, we intend to inform the dredging industry of this study and request comments from the industry. This study is to focus on new and emerging technologies and operational techniques that are designed to reduce the degree of adverse impacts to the environment from dredging offshore borrow sites.

We would greatly appreciate your answering the enclosed questions by February 24. Please return your comments to me at WF Baird & Associates, 2981 Yarmouth Greenway, Madison, Wisconsin, 53711 or email me at tkenny@baird.com. Feel free to include any comments you feel are germane.

Sincerely,
W. F. Baird & Associates

Thomas F. Kenny

enc: as stated
File No. 10687

Appendix C2

List Of Questions
For US Dredging Contractors

Please reply by February 24.

We appreciate you taking the time to answer our questions concerning new and emerging technology and techniques designed to reduce the adverse environmental impacts of dredging sand in Federal offshore borrow areas. Some of the questions are of a scientific nature and are asked to see if you have any information that will contribute to the database

For the following questions, please give an estimate of cost differential due to environmental restrictions where appropriate?

<u>Plume Related Impacts</u>

Much of the perceived concerns were due to the plume resulting from hopper overflow and the bottom agitation at the draghead.

1) What percent of material overflows the hopper while digging sandy, low-silt content material, assuming a 10 km sailing distance to pump ashore?

2) Can a hopper dredge mine sand from below a 1-meter silt overburden without removing the overburden? Does this result in significantly increased material overflow and consequently an increase in turbidity?

3) In mining sand with a low-silt content, with a turbidity requirement not to exceed 29 NTUs above background, is it necessary to take special measures to meet this maximum turbidity requirement?

4) What measures do you employ to minimize turbidity?

5) If you use measures such as recycling overflow water back to the draghead, is there a reduction in dredging production?

6) Have you completed research on passive and dynamic plume processes associated with overflow and is this information publicly available?

7) Do wind, wave, and/or current forces offshore determine the direction the dredge works? What are the consequences of dredging perpendicular to the current in order to influence the shape and dispersion of the dredge plume? Do

you have any data to demonstrate the direction and rate of deposition of material discharged by the dredger during dredging operations?

8) Given a mandate to reduce turbidity, what are the most cost effective ways of accomplishing the reduction? We understand this is a question of degree. Please explain the consequences to us.

9) What are your views on requiring overflow to be discharged below the hull?

Impacts to Benthic Habitats

Considerable concern was expressed relative to the loss of benthic community. Recolonization rates are being studied, as are changes in substrate characteristics such as grain size, dissolved oxygen, etc. It has been suggested that dredging in patterns may speed the recolonization rate by leaving "refuge" areas (that have undisturbed sediment characteristics and undisturbed benthic communities).

10) If there is a stipulation in the specifications that required that only 70% of a borrow area can be used and the unused portion cannot be on the boundaries, what would be the most efficient use of the area? What is the minimum width cut that a hopper can dig efficiently? The reason for this proposed stipulation is that the benthic community will recolonize faster if the area is dredged with intermittent non-dredged areas. Do you have any comparative data to show whether dredging in strips to leave recolonizing adults in the dredge site enhances recovery rates compared with sites where all the surface deposits are removed?

11) Are you aware of any damage to hard bottoms caused by dredging including covering by sediment? If yes, was a buffer or exclusion zone applied and was it sufficient?

12) Are your dredges capable of tracking and recording the position of each draghead? Have you done tracking relative to a buffer zone? Would you have a problem providing this information to the regulatory agencies?

13) When offshore sand dredging is completed for a beach project, what does the bottom look like? Are there draghead tracks, (width and depth?) throughout the area? Are the tracks parallel or crossing? Can you provide examples to us of high resolution mapping of pre- and post-dredging seabed conditions for offshore dredging with TSHD?

14) When mining sand off shore, is the dredge tended by a survey boat?

There is an ongoing concern with marine mammal/dredge collisions and entrainment of Sea Turtles.

15) Other than turtles, has your dredge ever been in a collision with a marine mammal? Do marine mammals have a tendency to swim near an operating dredge?

16) When appropriate, does your dredge use a draghead designed to reduce the probability of entraining sea turtles? Is this use mandated by the Owner? Does the use of these dragheads reduce the productivity of the dredge? Is the modified draghead effective? Do you have any recommended changes to the design of the turtle deflector? Do you have any recommendations on operating techniques to avoid entraining turtles during offshore dredging operations?

17) What effect do the seasonal requirements restricting dredging due to the proximity of turtles have on the overall annual dredging schedule?

18) Does your dredge have a system to reduce pressure/flow at the draghead when the draghead is off the bottom? How does it work?

19) How effective are observers and trawling to reducing turtle takes?

Additional questions

20) What has been your experience dredging in a fishing ground? Has any fisherman or commercial fishing company complained about any aspect of the dredging process? Did you modify your operation to accommodate the fisherman?

21) What measures do you, the dredge operator, take to insure that the dredge does not damage underwater pipelines and cables, or archaeological resources?

22) Some operating companies have a policy of dredging localized zones to exhaustion before moving to further zones within the dredge area. This assists management of the resource, but it also helps to minimize occupation of seabed and allow maximum time for recovery of seabed resources. Does your company have a policy of zoned dredging, and what are your reasons for dredging policy? Do you have any information that documents the impact of your dredging operations on marine organisms in specific dredge sites? Do you have any information on the rates of recovery of biological resources at your sites following cessation of dredging?

23) Do you have any comments, general or specific, regarding dredging equipment and procedures and the reduction of adverse impacts on the environment?

Appendix C3

MIRO Sponsored Questions To European Dredging Contractors

Minerals Management Service

Mineral Industry Research Organisation

A REVIEW OF EXISTING AND EMERGING ENVIRONMENTALLY-FRIENDLY OFFSHORE DREDGING TECHNOLOGIES

We appreciate you taking the time to answer our questions concerning new and emerging technology and techniques designed to reduce the adverse environmental impacts of dredging sand and gravels in offshore borrow areas.

For any appropriate question below, could you give an estimate of cost increase due to the application of environmental restrictions?

A. PLUME RELATED IMPACTS

Many of the perceived concerns are due to the plume resulting from hopper overflow and the bottom agitation at the draghead.

No.	Question	Response
1	What percent of material overflows the hopper while digging sandy, low silt content (5% less than 63 micron) material, assuming a 10 km sailing distance to pump ashore	
2	Can a hopper dredger excavate sand from below a 1-meter silt overburden without removing the overburden? Does this result in significantly increased overflow losses and consequently an increase in turbidity?	

No.	Question	Response
3	In mining sand with low silt content (5% less than 63 micron), with a turbidity requirement not to exceed 29 NTUs above background, is it necessary to take special measures to meet this maximum turbidity requirement?	
4	What measures do you employ to minimize turbidity?	
5	If you use measures such as recycling overflow water back to the draghead, is there a reduction in dredging production?	
6	Have you completed research on passive and dynamic plume processes associated with overflow and is this information publicly available?	
7	Do wind, wave, and/or current forces in licensed exploitation areas determine the direction the dredger works? If so, at what level do they begin to influence operations?	
8	What are the consequences of dredging perpendicular to the current in order to influence the shape and dispersion of the dredge plume?	
9	Given a mandate to reduce turbidity, what are the most cost effective ways of accomplishing the reduction? We understand this is a question of degree. Please explain the consequences to us.	
10	What are your views on requiring overflow to be discharged below the hull?	

B. IMPACTS TO BENTHIC HABITATS

Considerable concern has been expressed relating to the loss of benthic community. Recolonization rates are being studied, as are changes in substrate characteristics such as grain size, dissolved oxygen, etc. It has been suggested that dredging in patterns may speed the recolonization rate by leaving "refuge" areas (that have undisturbed sediment characteristics and undisturbed benthic communities).

No.	Question	Response
11	If there is a stipulation in the specifications that required that only 70% of a borrow area can be used and the unused portion cannot be on the boundaries, what would be the most efficient use of the area? What is the minimum width of cut that a hopper dredger can dig efficiently? The reason for this proposed stipulation is that the benthic community will recolonize faster if the area is dredged with intermittent non-dredged areas. Assume a borrow area 1000 meters x 2000 meters.	
12	Are you aware of any damage to hard sea bed caused by dredging, including covering by sediment? If yes, was a buffer or exclusion zone applied and was it sufficient?	
13	Are your dredgers capable of tracking and recording the position of each draghead? Would you have a problem providing this information to the regulatory agencies?	

No.	Question	Response
14	When sand dredging is completed for a beach project, what does the bottom of the dredging area look like? Are there draghead tracks, (width and depth?) throughout the area? Are the tracks continuous or crossing? Can you provide examples to us of high resolution mapping of pre- and post-dredging seabed conditions for offshore dredging with TSHD?	
15	When mining sand, is the dredger tended by a survey boat?	

There is an ongoing concern with marine mammal dredge collisions.

C. IMPACTS ON MARINE MAMMALS

No.	Question	Response
16	Has your dredger ever been hit by a marine mammal or turtle? Do marine mammals or turtles have a tendency to swim near an operating dredge?	
17	When appropriate, does your dredger use a draghead designed to reduce the probability of hurting mammals or turtles? Is this use mandated by the Owner? Does the use of these dragheads reduce the productivity of the dredger? Is the modified draghead effective?	
18	What effect do the seasonal requirements restricting dredging due to the proximity of mammals or turtles have on the overall annual dredging schedule?	

No.	Question	Response
19	Does your dredger have a system to reduce pressure/flow at the draghead when the draghead is off the bottom? How does it work?	
20	How effective are observers and trawling to reducing mammal or turtle takes?	

D. ADDITIONAL QUESTIONS

No.	Question	Response
21	What has been you experience dredging in a fishing ground? Has any fisherman or commercial fishing company complained about any aspect of the dredging process? Did you modify your operation to accommodate the fisherman?	
22	What measures do you, the dredger operator, take to insure that the dredger does not damage underwater pipelines and cables?	
23	Do you have any comments, general or specific, regarding dredging equipment and procedures and the reduction of adverse impacts on the environment?	

No.	Question	Response
24	Some operating Companies have a policy of dredging localized zones to exhaustion before moving to further zones within the Licensed dredge area. This assists management of the resource, but is also stated to minimize occupation of seabed and allow maximal time for recovery of seabed resources. Does your Company have a policy of zoned dredging, and what are your reasons for dredging policy?	
25	Do you have any information that documents the impact of your dredging operations on marine organisms in specific dredge sites?	
26	Do you have any data to demonstrate the direction and rate of deposition of material discharged by the dredger during dredging operations? Do you have information on the amounts of material discharged overboard as a proportion of that removed from the seabed?	
27	Do you have any information on the rates of recovery of biological resources at your sites following cessation of dredging?	
28	Do you have any comparative data to show whether dredging in strips to leave recolonising adults in the dredge site enhances recovery rates compared with sites where all the surface deposits are removed?	

No.	Question	Response
29	What steps do you take to identify archaeological material in the dredged material? What steps do you take if such material is observed?	
30	How do you determine the width of any ‘exclusion zone’ that might be required to protect archaeological or biological resources of conservation significance within your dredge site?	
31	Have your dredging operations been subjected to any form of environmental window / seasonal constraint related to the natural marine environment, i.e. fish spawning/migration? If so, what is the main basis for such restrictions?	
32	How have post-dredging conditions been monitored as part of your operations? How have these results been disseminated following analysis?	

Contact details of your organisation	
Your Organisation	
Your Name	
Your Position	
Your Contact Details	

Contact details for return of the questionnaire
R N Bray Dredging Research Ltd High Pines Hoe Lane Peaslake Surrey GU5 9SW United Kingdom Telephone: +44 1306 730867 Fax: +44 1306 730882 E-mail: nickbray@drl.com **RETURN DATE: End January 2004**

Appendix C4

Summary Of All Industry Responses

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
1.	What percent of material overflows the hopper while digging sandy, low-silt content material, assuming a 10 km sailing distance to pump ashore?	We have not conducted an exhaustive study of this because it is not generally required. In dredging sand for beach projects or for other uses it is usually desirable to have a coarser product than a finer product. Therefore, unless there are restrictions regarding overflow, loading typically continues until the dredge obtains an economic load measured in displacement of the vessel. If silt or very fine-grained sands are part of the materials being dredged a considerable quantity may overflow. We have not conducted specific studies of this although I would suspect that the Corps of Engineers or others have studied or modeled these items over the years for various purposes. In rule of thumb type thought it is very difficult when loading sand to the ships maximum tonnage to retain more than a few % of particles smaller than the 200 sieve (ie. .076mm). Sands with grain sizes between .076mm and 150mm are not well retained in a hopper. As the grain size increases they become more easily retained. Sands in the range of 150- 200mm become increasing retained within the hopper and above 200 mm I believe that most are retained. Other factors impacting overflow losses are loading concentration, flow rate, method of loading, hopper size, hopper layout / configuration. On a beach project in San Diego with a 3600 cy hopper dredge we experienced retention rates of between 16 and 100%. The majority of loads retained between 40 and 65% of the quantity discharged into the hopper. The average retention percentages and grain size distributions were as follows: Retention D15mm D50mm D85mm 90%. 3 .56 .9 60% na .2 na 31 na .09 na	The percentage of material overflowed is the result of many different factors, the most important of which is the % fines (i.e. silts and clays) in the material being dredged. The other factors that come into play are the overall grain size distribution, the overflowing method (overflow type and location) and the duration of overflowing. The greater the sailing distance the longer the overflowing duration in order to achieve an economic load, The % overflow increases with increasing overflow duration.	Unable to answer with any accuracy due to a lack of information provided. Overflow losses are a function of several variables. The terms "sandy" and "low-silt content" is used to describe the material. A grain-size distribution curve is needed to determine both the grain size and the percentage of fines that are to be expected in a representative sample. Sand is classified as having a grain size between .06mm and 2mm. Obviously, the higher the concentration of fines, the greater the losses will be. Additionally, it is impossible to determine the percentage of silts from the information provided without a grain-size distribution curve, although, one could expect that most if not all of the silts will be lost via overflow. Sailing distance noted in the question has no bearing on overflow losses expected.	Material less than 200 sieve will be lost in the overflow as the dredge loads.	The amount of fines overflowing during the hopper loading process depend on grain size distribution of the incoming material, the method of overflowing (function of vessel design and of operational settings) and especially of duration of overflowing (in order to obtain an economic load). The amount of overflow is not dependent on sailing distances.	Very little. Any silt overflowing during sailing is not dependent on the sailing distance, probably more dependent on prevailing sea condition.	Little or none. Sandy material becomes a "dry load" (No spillage to dump)

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		With respect to sailing distances, generally, the greater the distance the longer the vessel will overflow attempting to achieve its maximum load. 10 kms is a relatively short distance and therefore the vessel may depart the borrow site with somewhat less than a full load. I have attached a research paper from MTI Holland on overflow losses. Please reference <u>04-*06 Research on Hopper Settlement*</u>.						
2.	Can a hopper dredge mine sand from below a 1-meter silt overburden without removing the overburden? Does this result in significantly increased material overflow and consequently an increase in turbidity?	Depending on the nature of the silt it may not be necessary to strip an area of silt before dredging the sand below it as the drag heads will penetrate through some of the silt. However it is likely that in dredging an area over time that the silt will eventually pass through the pumps and be returned as overflow. Where this silt settles will depend on currents and sea conditions in the area. Much of it may settle back very close to where it was originally dredged and may even be dredged and overflowed many times during subsequent dredge passes through the same area. Turbidity will be related to the volume of silt overflowing. If overflow occurs near the surface it will be more visible than if it overflows at a lower elevation such as through overflows which discharge beneath the hull. However since hopper dredges normally dredge when underway to avoid potholing, the ships propulsion propellers may tend to spread the turbidity out even making it more visible at the surface. Air entrained in overflow water columns may also tend to bring turbidity to the surface increasing its visibility.	This is possible but generally leads to a significant increase in the turbidity created during dredging as part of the overburden material is sucked in during the dredging process. In addition the characteristics of the silts must be such (very soft and low density) that the draghead be able to penetrate the overburden by means of its own weight. Yes, as explained above, some overburden will get mixed into the mixture leading to more fines being overflowed. These additional fines will lead to more hindered settling and a higher percentage of fine sands being overflowed.	A hopper dredge is not suited to remove material below a layer of silt without removing the overburden first. If the overburden must be removed first, any overflow of material will create increased turbidity.	It is likely to increase turbidity by entraining the silt along with sand as dragheads work by erosion.	In principle, yes, depending on silt properties. Whether this is an effective operation, in relation to environment and to quality of the load, is doubtful. Turbidity would most likely increase.	No. For aggregate dredging purposes we would not entertain exploitation without having first removed the overburden. Consequently we would not normally choose an area with an overburden for exploitation.	No.
3.	In mining sand with a low-silt content, with a turbidity requirement not to exceed 29 NTUs above background, is it necessary to take special	It can require measures to meet a 29 NTU standard. Generally the only very successful means is to restrict overflow time. This can result in reducing the load size dredged. This	This is highly dependent upon the exact location and timing of the turbidity sampling relative to the working area and dredge. In low-silt material the settling	Again, the percentage of silt encountered will greatly affect the turbidity created during dredging operations. One special measure which could be	For 29 NTU, with a low silt material, no special precautions are necessary.	Depends on where measurements are taken, at what distance from the (moving) dredge, relative to current, both velocity and	No experience of dredging in open sea conditions with such an imposition.	No, but probably depends on the dilution zone 150 – 200 feet.

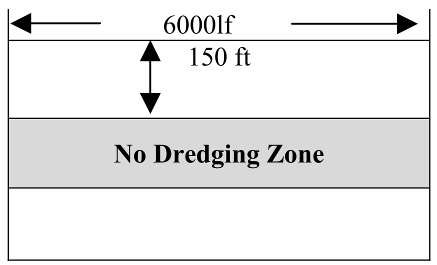
Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
	measures to meet this maximum turbidity requirement?	can have severe economic effect on a project. Properties such as color of silt and other items may also have significant effect on measurement of turbidity. In near shore borrow areas, the background NTU level is highly influenced by wind and current conditions on a day-to-day basis. Our understanding of the 29 NTU standard is that it came originally from State of Florida Statutes for industrial discharges. What science the 29 NTU standard was originally based on I do not know. I am also unaware of any studies that indicate that 29 NTU's is a significant level in effecting species at an offshore dredging site. It may be that levels significantly higher within a limited area or over a short duration may have little effect on organisms.	of the fines is generally quick enough to remain within turbidity requirements.	implemented to reduce, to the point of not exceeding turbidity is to reduce time overflowing. A second measure would be to eliminate overflowing entirely. A third measure would be to recycle overflow water into the drag arm jet system.		direction. If silt content is low, sand is mainly quartz, and fines are not lime, 29 NTU should in general not be a problem		
4.	What measures do you employ to minimize turbidity?	Typically turbidity at offshore borrow areas has not been a big problem. Primarily the borrow areas utilized have been picked because they are known to contain primarily clean sand with low silt or clay content. Since the primary uses of the borrowed materials have been for beach nourishment and for construction aggregates, sites have been chosen which have quality materials. Also in an offshore environment the dispersal zone for turbidity is large enough that mixing occurs rapidly. Dredging in more confined areas such as channels, very near shore or in bays and rivers can be more problematic. Dredging near known reef areas or near highly sensitive environmental areas has increased immensely. In recent years we have performed several projects in the Dade County, Florida area where the borrow sites were in close proximity of reefs. The Department of Environmental Regulation Miami (DERM) has closely monitored impacts to the reefs during dredging and has worked with contractors to modify dredging	By far the most effective is to reduce the overflowing time if necessary to nil, This reduces or eliminates the turbidity produced by the pumping process but costs can as much as double due to reduced loads. There also exist various 'limited overflow' systems which modify the dredging process in such a way that the dimensions and characteristics of any turbidity plume are reduced.	Reduction of time pumping material past overflow or elimination of time pumping past overflow are two measures that will minimize turbidity.	Limit overflow as necessary, depending on permit conditions.	Assumed this question relates to hopper dredges: limitation of overflow, or ultimately allowing no-overflow at all, is most effective, but leads to significant cost increases (add 50 to 100%). Application of 'green overflow' systems does not reduce the amount of material brought in suspension, but modifies the way the fines are released in the environment in such a way that turbidity plumes are considerably reduced, both in dimension, dispersion and content.	We would employ underkeel overflow.	Anti turbidity values, restricted overflow.

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		techniques as needed to minimize impacts. This has included limiting work in certain areas of the borrow site periodically, reducing overflow time when necessary, and even changing the boundaries of the borrow site as actual conditions require.						
5.	If you use measures such as recycling overflow water back to the draghead, is there a reduction in dredging production?	We have not recycled overflow water back to the drag head because it has not been necessary to meet the needs to date. The costs of equipping or retrofitting a dredge to recycle all the excess water would be very expensive. For example if a dredge loads approximately 30% solids, you would have to have a system which must recycle as much as 70% of its flow back to the drag head. This would take an additional piping and pumping system not much smaller than the existing dredge pump loading equipment. It might be accomplished without a large loss of pump production, there would be a huge Capital cost in equipping the dredge and significantly higher wear and maintenance costs for the equipment. Additionally the weight of the additional equipment would reduce the tonnage available for the Cargo and therefore reduce the load size causing an increase in the number of loads to complete a project. The maintenance and wear to the additional equipment would also add somewhat to downtime for the dredge thereby also negatively impacting the production. There were several foreign vessels built in the late 90's equipped with recycling systems. However, recent US and Foreign new builds have not included this equipment on the vessels.	By recycling part of the overflow water the volume of suspended sediments discharged is reduced as part of them are recirculated. This won't affect productions in sands but will lead to increased costs due to the wear and tear of those components involved in the recirculation.	Typically no, however, there is an increase in wear to the jet water systems.	It is impractical to recycle all overflow back to dragheads. It will result in silt being recirculated and could increase turbidity over a smaller area.	In principle re-cycling of overflow to the draghead will not influence dredging productions in sand.	We do not use such measures. They would significantly increase energy requirements and time on the dredge area.	N/A
6.	Have you completed research on passive and dynamic plume processes associated with overflow and is this information publicly available?	We have not conducted research. We have provided turbidity-sampling results to the owner of a project. However I know that the Corps engineering station (WES) in Vicksburg has done studies and some research on hopper overflow and Turbidity. This information should all	Studies such as those mentioned are generally carried out by large research institutes that develop the theoretical models and then turn to leading dredging firms such as Bean Stuyvesant for the collecting of field measurements.	The Norfolk District COE in conjunction with VIMS (Virginia Institute of Marine Sciences) did an extensive research project on this subject in 1988 at the deepening of the York Spit Channel project.	Have not done any research.	Some studies have been undertaken by research institutes. The mathematical part of the subject is normally covered by these institutes themselves; the practical part of the study, field measurements around	No.	No.

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		be available. DERM may have some specific information on the projects, which they have monitored which they would be willing to share.	A good outline of this type of studies can be found in the Report CIRLA C547 'Scoping the assessment of sediment plumes arising from dredging'.			dredging and disposal project is often made on instruction of and in co-operation with dredging contractors. Most of this information is published, the best overview is given in the CIRIA C547 Report, "Scoping the assessment of sediment plumes arising from dredging".		
7.	Do wind, wave, and/or current forces offshore determine the direction the dredge works? What are the consequences of dredging perpendicular to the current in order to influence the shape and dispersion of the dredge plume? Do you have any data to demonstrate the direction and rate of deposition of material discharged by the dredger during dredging operations?	Yes, typically it is best to dredge stemming the current and seas. The ship is much more easily controlled in this manner. If dredging broadside to heavy seas the ships will roll causing difficulty in maintaining bottom contact with the drag heads as they are dropped and snatched off the bottom with each roll of the ship. The ship's hull also tends to set over the down current drag head and away from the up current drag head. This forces the drag tender to continuously raise each head and reset it on the seabed, which impacts loading production. It is much more difficult to maintain a course if seas, current, or swells are effecting the ship from a beam direction. We have worked in such conditions with difficulty and at times have been unable to continue dredging operations when we certainly could have if the borrow site layout was conducive to stemming currents, seas or winds. We do not posses any data showing the direction and rate of deposition of the overflow plume. However, the WES or DERM may possess such information.	Wind and wave conditions only determine the dredging direction when they reach borderline magnitudes. At this point the captains orient their dredgers parallel to the wave directions in order to avoid excessive roiling of the vessel. If strong currents are also encountered a compromise is reached that leads to minimum rolling while avoiding damage to the suction pipes. Dredging perpendicular to a current requires the vessel to sail at an angle to the dredging direction. The greater the current the greater the angle. This can lead to the dragheads slipping under the vessel with the consequent increased risk of damage to the equipment. Though there have been a number of attempts to model this process, to the best of our knowledge there is no hard data on this subject. This is in great part due to the considerable difficulties involved in tracking and recording an ever expanding plume with suspended solids barely above background levels.	All three elements (wind, wave and current) have an impact on a hopper dredges ability to maneuver and maintain position while dredging. As such, the dredge will often dredge in different orientations to the winds, waves, and currents, as conditions (both physical and environmental) will allow. A consequence of dredging perpendicular to the current is the vessels possible restricted ability to maneuver and stay on course during dredging operations depending upon the speed of the current encountered. Yes but only some bathmetry, change of which may be attributable to other factors.	The dredge typically works against current or sea conditions. Perpendicular approach requires the dredge to "crab" which can lessen production by 10 – 20 %.	Hopper dredging is preferably executed parallel to the current and with head or tail waves. This will not always be possible if current and wave directions are different. Depending on dominance by one or the other optimal working directions are defined. Depending on the force of the current when working perpendicular to the current, the risk exists that the dredge is pushed over the draghead, which might lead to damage to the vessel of the dredging system, if not properly managed by accurate maneuvering. Our company does not have any data other than some theoretical modeling studies. The direction of material dispersion might be derived from visual plume observations. The relatively limited quantity 'spilled' during dredging and the way this material is dispersed make it practically impossible to monitor deposition within the accuracy of state-of-the-art survey systems. Also the dynamic behavior of the seabed makes these assessments virtually impossible. Theoretical sediment plume	The influence of wind, wave and current are to an extent linked to characteristics of the vessel itself. The direction the dredger works is normally determined by geological factors. We would not choose to work perpendicular to the currents but the determining factor is the geology. Yes but only some bathmetry, change of which may be attributable to other factors.	Yes. Depends on sea state. The angle of dredging is determined by shiphandling concerns.

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
						modeling is sometimes undertaken as part of the consenting process. Some projects in sensitive locations do require model validation with field measurements.		
8.	Given a mandate to reduce turbidity, what are the most cost effective ways of accomplishing the reduction? We understand this is a question of degree. Please explain the consequences to us.	A concern that we have is that there will always be a perception that reducing turbidity is important. This can easily translate into a mandate even though scientifically some turbidity can be easily tolerated. The most effective way to reduce turbidity is to not allow overflow. However when dredging sand, this will seriously reduce the volume of sand the ship carries on each load. In some compact sands the loading density of the slurry may be as low as 10%. Obviously, if a ship can carry for example 2400 cubic yards of sand in a 3600 cubic yard hopper but is restricted to no overflow and therefore can only haul 360 cubic yards (10 %) of its hopper capacity there is a huge impact as it will have to make almost 7 times the number of cycles to obtain the same quantity. Even if loose coarse sand can be loaded at 50 % solids in the slurry it would nearly double the number of loads with a commensurate cost increase. A reduction in the time of overflow will also lessen the turbidity somewhat, with less but still likely very significant impact. The loading time reduction necessary to bring turbidity into acceptable levels will be dependent on the character of the materials being dredged, the conditions encountered at the borrow site (ie: currents, seas, water depths, background turbidity levels, proximity and character of environmental resources to be protected), as well as the levels and duration of turbidity produced. These will be very difficult to model and predict in advance of actual work and therefore will cause extreme risk and perhaps contingency in bids on	Eliminating overflow eliminates virtually all turbidity but at a very high cost. Limited overflowing (e.g. I hour) puts an effective ceiling on turbidity at reduced cost. These costs are inversely proportional to the duration permitted. Use of 'limited overflow' systems would have some cost impact depending on the method chosen.	The most cost effective way to reduce turbidity during dredging operations is probably to refit the vessel to be able to recycle overflow water and not limit pumping times to the point of reaching overflow.	The real way to limit turbidity is to reduce overflow time. This results in a lesser load being carried which increases the cost proportionately. For example, most dredges reach overflow at about 10 minutes and full loads in about 60 minutes. If a dredge can carry 3000cy of material it could load 500cy in 10 minutes and 3000cy in 60. If the remainder of the cycle (sailing ,discharging and sailing) amounts to 150 minutes, then the dredge can deliver 500cy in 160 minutes or 3000cy in 210 minutes. Assuming a cost of $2,000. Per hour, this results in a cost of $10.66/cy with no overflow compared to $2.33/cy with overflow allowed. The above are just hypothetical numbers.	No overflow, with considerable cost consequences; limited overflow duration with pro rata cost consequences; application of 'green overflow' systems, with limited cost impact. See also response to question 4.	See 4. Above	Limited to dredging due to overflow. Silt curtains/may not be able to maintain effective control in ocean – minimize overflows – poor production.

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		projects. Requiring overflow to be discharged beneath the bottom of the hull will reduce turbidity in the upper water column. Some systems can be employed at a cost to reduce the amount of air that is entrained in the overflow. This reduction of air that helps lift some of the turbidity to the surface will further lessen turbidity in the upper water column, although commensurately it may increase the turbidity in the lower water column as the sediments will be spread throughout a lower volume of seawater. This system is called an anti-turbidity valve. Re-circulation of water back to the drag head may also have an impact in reducing the visible turbidity in the upper water column. However the particles that cause the turbidity still are not retained in the hopper and eventually are returned to the sea. Typically multiple dredging passes are made in a borrow site and these particles will be moved around within the area regardless of what technique is employed. While it may reduce visible turbidity at the surface, it may cause increased turbidity concentration in the lower water column or at the sea floor. I have attached a paper from MTI Holland on overflow systems. Please reference 04-09 Overflow Design.						
9.	What are your views on requiring overflow to be discharged below the hull?	This is the normal practice within the industry except where the goal is to deliberately agitate material in order to have currents carry the material away. For example at the Mississippi River Southwest Pass, the Corps deliberately uses agitation dredging and requires that overflow occur at or near the water surface.	This is a simple and effective way of reducing turbidity by reducing the settling distance and settling time of any sediments released through the overflow. All Bean Stuyvesant hoppers are equipped accordingly.	Unsure if this question means discharging at the drag head or at the bottom of a thru hull overflow system (as opposed to a water surface overflow system).	It's not a problem.	This is a standard feature on most of our hopper dredgers. It contributes to the reduction of dispersion of suspended overflow material, and it improves the direct visual aspects	See 4. Above	This is our standard practice.
	Question Impacts to Benthic Habitats							

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
10.	If there is a stipulation in the specifications that required that only 70% of a borrow area can be used and the unused portion cannot be on the boundaries, what would be the most efficient use of the area? What is the minimum width cut that a hopper can dig efficiently? The reason for this proposed stipulation is that the benthic community will recolonize faster if the area is dredged with intermittent non-dredged areas. Do you have any comparative data to show whether dredging in strips to leave recolonizing adults in the dredge site enhances recovery rates compared with sites where all the surface deposits are removed?	In general, borrow sites of approximately 6000 feet in length are ideal. They allow the hopper dredge to trail at 2kts, making one pass in each direction to obtain a full load. If only 70% of the site could be utilized, a 'no-dredge' zone in the middle of the area would be preferred, as shown in the following drawing.  The minimum width of the dredging lanes should be 150 feet. This will allow positioning of both drag heads within the dredge area at all times and eliminate any 1-arm dredging. We do not have any data with respect to the effect of strip dredging on recolonizing adults. However, WES and DERM may have such information	It would be viable to define dredging areas interspaced with non-dredging areas so long as the work areas have the necessary characteristics not to limit the standard dredging process. To this end each dredging area should be roughly rectangular with its long axis aligned parallel to the predominant currents and a minimum width of 500 ft at the maximum dredging depth. Ideally this area should also be at least 5000 ft long. An area less than 300 ft wide (at the maximum dredging depth) would lead to reduced productions due to increased maneuvering as well as leading to an inefficient removal of all the available sands. The reason for this proposed stipulation is that the benthic community will recolonize faster if the area is dredged with intermittent non-dredged areas. It is our understanding that there is currently a study being carried out in Europe under the name 'Sandplt' that addresses this issue. The Dutch Bijlcswaterstaat-NL has also looked into this and a conference was held on the issue in 2003 (see EMSAGG 2003 conference).	There is not enough information to answer this question. What is the total surface area (length and width) that "70%" would be used. There is an enormous difference between using 70% of a borrow area that is 500' X 5,000' and 70% of a borrow area that is 5,000 X 50,000'. The minimum width that a dredge can dig efficiently is dependent on wind, wave, and current, but in general, a hopper dredge of 300' length and 55' width can dredge efficiently in a cut width of 300 – 500 feet. We have no date for the final question on this item.	The best way to work a site would be in rectangular strips, typically 300-500' with by 5,000-6,000' lengths. No data is available from Manson.	A division of the borrow area into dredging zones and no-dredging zones is feasible. This can be achieved by allowing for relatively long dredging zones, parallel to the main current direction, of sufficient width and allowed dredging depth. A dredging zone should minimally be some 200 m wide at the bottom of the cut, with no-dredging zones of some 100 m at bed level, slope distances to be defined as function of cut depth and slope angle. A dredging width less than 100 m might reduce operational freedom for a larger type hopper dredge. The question is whether it is environmentally more attractive to take a thin layer off a large area, or to affect a smaller area only by dredging deeper for a thicker layer. This topic is presently being studied under a European Research program 'Sandpit' (check the website with that name). Side research at national level is known to be executed by CEFAS-UK and by Rijkswaterstaat-NL. Also much of this information is in the public domain. A useful overview is given in the proceedings of the EMSAGG 2003 conference. Wherever possible we try to minimize the area impacted by dredging. This can include the adoption of strip zoning. However, we do not have any site specific monitoring information on recolonisation.	We would normally anticipate dredging in lanes. Current practice is that the footprint of dredging should be less than 10 sq km No but we are advised that this would tend to promote recolonisation.	Don't know. Can be done with Dynamic Position Dredging (cost $ high)
11.	Are you aware of any damage to hard bottoms caused by	There have certainly been cases, although the technology of monitoring	Beyond the damages caused by one of our competitors in the	No. When pumping silty borrow material directly from a	Unknown.	We are not aware of any damage to hard seabed	No.	No.

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
	dredging including covering by sediment? If yes, was a buffer or exclusion zone applied and was it sufficient?	has improved dramatically over the years. I cited earlier the projects in Dade County Florida. These were Corps projects that were closely monitored by DERM. Partnering between the Corps, DERM and the Contractor has been very successful at minimizing impacts. The borrow areas were first established with designated buffer distances from hard bottoms and then these buffers were modified as necessary during the project in order to account for actual conditions encountered	very sensitive habitats of south Florida we are unaware of any additional impacts arising from dredging operations. In the case of Florida we do not recall if buffer zones were used. None the less, it is evident that due to the heavy activity taking place in the dredging area and the nature of the dredging process there is always a high probability of encountering noticeable side effects in the contiguous areas. As a result, based on the specific characteristics of each situation, buffer zones should be defined where limited impact of dredging is acceptable.	borrow site, the concern is greater, however on such projects we have never seen it occur.		caused by dredging.		
12.	Are your dredges capable of tracking and recording the position of each draghead? Have you done tracking relative to a buffer zone? Would you have a problem providing this information to the regulatory agencies?	Yes, tracking and recording of positional information is standard operating procedure for our TSHD operations. Great Lakes' TSHD fleet is equipped with real-time monitoring electronics and positioning software enabling us to effectively position our dredges at all times. Because the systems incorporate project control criteria and real-time dredge orientation our operational staff can efficiently plan and manage of precise dredging operations. Each of our TSHD's use a combination of the following electronic equipment for dredge position monitoring. • Navigation / Guidance System. - Compaq Workstation with Great Lakes' Hopper Positioning Software. • DGPS Receiver. - Trimble Navigation 4000 GPS receiver (or like) using RTCM corrections from US Coast Guard Beacon Transmitter or site specific Reference Stations. • Electronic Water Level Receiver. - Valeport VTM-710 or Hazen HTG 5000. • Heading Sensor. - Sperry Marine MK-37VT Gyro Compass or like. • Drag Head Depth Sensors. -	Yes, all our hopper dredgers are equipped with this capability. It is often the situation that we must track the draghead position relative to a known feature or area, be that a buffer zone, shipwreck or submerged pipeline. No problem, this is pretty much standard procedure. In addition the USACE often uses a 'silent inspector system' to track this kind of information independently of our own systems.	Yes, the dredge guidance system and Silent Inspector System is capable of tracking and recording the position (X,Y) and elevation (Z) of each drag head. Drag head and vessel tracking has been performed on every project for several years. Information can be provided up request.	We typically track and record position of dredge, draghead and other parameters and furnish info to COE on almost every project.	Some of our dredgers have the facility and can track the draghead relative to buffer zones or other features. As far as we are aware this information is not normally required for UK projects. However, the position and status of any dredger is required when operating within Crown Estate marine aggregate dredging licenses within UK waters. The Crown Estate holds this data.	Yes but only with a special installation	Yes. Would not provide directly to agencies. Reports through PM or COR.

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		Various sensors used to attain depth readings can include: differential pressure observator device on the drag head and gimbal, angle measurement devices, and hull mounted vessel draft / pressure sensors. Great Lakes' hopper positioning system provides real-time displays of the dredge and contoured channel plans for reference by the dredge operators. Dredge sensor information such as DGPS information, heading, drag head depth, tide, pump production information, etc, is compiled for the system through several interfaces and Program Logic Controllers (PLC). In addition, relevant dredge data, such as dredge and drag head coordinates, is displayed and may be stored at user-specified intervals. **<u>See Figure 1 Attached.</u>** Examples of the type data stored include: Load No., Date mm/dd/yy 1/27/98,Time 24hr hh:mm:ss, Northing of GPS Ant., Easting of GPS Ant., Port Drag Head Depth, Stbd Drag Head Depth, Fwd. Draft, Aft Draft, Port Density, Stbd Density, Port Velocity, Stbd Velocity, Port Pump RPM, Stbd Pump RPM, Tide Ft., Gyro, Speed, Port Gimbal Depth, Stbd Gimbal Depth, Easting of Bow, Northing of Bow, Easting of Port Drag Head, Northing of Port Drag Head, Easting of Stbd Drag Head, Northing of Stbd Drag Head. At user-defined intervals the data is written to the hard drive of the positioning systems computer in comma separated form. For example: 135, 12/19/03, 00:00:15, 171929.66, 929651.55, -36.3, -36.8, 18.9, 20.3, 1.00, 1.00, 0.00, 0.00, 218, 200, 5.76, 152.2, 6.92, 15.7, 16.3, 171874.00, 929815.30, 172078.80, 929759.80, 172121.50, 929829.10						

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		Dredge operations staff utilize these track data files to pinpoint where the dredge has traveled throughout the previous days operations. As shown in Figure 2, the dredge's draghead locations and depth is compiled into a track plot indicating the dredge area limits, project stationing, etc. To the question "Have you done tracking relative to a buffer zone?" Yes our TSHD positioning / tracking systems track relative to any user defined zone provided the "buffer zone" means some area calling for special dredging or non-dredging areas. Lastly, to the question "Would you have a problem providing this information to the regulatory agencies?" No, we would not. The process of providing information to regulatory agencies is standard practice on every project administered by the U.S. Army Corps of Engineers. As you may know, a majority of our domestic operations are for the Corps so such a requirements is expected. **See Figure 2 Attached.**						
13.	When offshore sand dredging is completed for a beach project, what does the bottom look like? Are there draghead tracks, (width and depth?) throughout the area? Are the tracks parallel or crossing? Can you provide examples to us of high resolution mapping of pre- and post-dredging seabed conditions for offshore dredging with TSHD?	I have attached before and after dredging plan view maps and cross section overlays of the Miami Beach / Sunny Isles North Borrow Area taken in late 2001 and summer of 2002. The cross sections clearly show drag head tracks and multiple pass trenches. These tracks / trenches are typically 10 to 20 feet wide and 3 to 4 feet deep. **See Miami Beach Survey Data attached.**	After offshore dredging in sands the bottom is generally somewhat more uneven than before dredging. The average roughness (i.e. difference between the highest and lowest spots in an area) will depend on the original layer thickness to be removed and the characteristics of the borrow area (length, width, currents) A high quality survey would allow individual tracks to be recognized though currents and wave action would steadily smoothen the bottom until it is difficult to distinguish from the surface encountered before dredging As mentioned previously, a narrow borrow area will lead to parallel tracks and a higher roughness.	Unsure what the bottom looks like at completion of the project.	Offshore borrow areas will have tracks. The size and condition will depend on dimensions off the borrow pit and how the vessel works.	If you could take a direct look, you would be able to recognize the tracks of the latest series of trails. Depending on morphologic activity a smoothing of the area will occur sooner or later. The direction of the tracks will be mainly parallel, refer to question 10. But depending on contract requirements additional effort might be made to deliver a flat bed. This is normally applied in dredging for navigational purposes, but is not standard procedure in sand mining. It would be possible against some additional cost. As a matter of course we collect pre and post dredge data although this is generally	This is as much a question of geology, prevailing currents etc. as it is of operations. Normally the dredger would follow parallel tracks.	Yes. We have the tracks on the bridge display (see Essayons Bridge).

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
			Though rarely done in borrow area, this roughness can be reduced at the cost of diminished productions. That information can be provided to you separately as it will entail very large tiles.			commercially confidential.		
14.	When mining sand off shore, is the dredge tended by a survey boat?	Normally, there is a survey boat utilized. Most project owners require at least before project and after project surveys. Contractors typically will survey for their own purposes in managing the resource. This vessel is typically employed on a 12 hour/day basis	The availability of a survey boat will generally depend on the contract specifications and the necessary level of follow up. The regularity of the surveys may vary between twice daily or only for before and after dredging surveys.	A Survey/Crew boat is assigned to each dredge during all projects.	Yes a survey boat is used.	Within UK waters there is generally no stipulation for a dredge to be tended by a survey boat when winning sand or aggregate.	No.	Our launch is our survey boat.
15.	Other than turtles, has your dredge ever been in a collision with a marine mammal? Do marine mammals have a tendency to swim near an operating dredge?	We have never noted any collisions with marine mammals, nor am I aware of any collisions between a hopper dredge and a marine mammal in the United States. I did hear several years ago that a dredge off of South Africa collided with a whale, and there certainly are documented collisions of ships with Marine mammals. However there is quite a difference between an ocean going ship sailing at 20-30 knots and most hopper dredges that typically attain maximum speeds of 10-15 knots. It should be noted turtle takes occur from contact with the dredge drag head at or near the sea floor not due to contact from the hull of a sailing dredge. We recently saw a permit that restricted dredge sailing speed when turtles were in the area. When checking with the permit agency we were told that they didn't request the restriction or think that it was necessary but that it had been in the proposed application. Such a restriction put in by an uninformed person can have a huge impact on a project. We have not noted that marine mammals are attracted to dredges.	To the best of our knowledge this has never happened. In order to reduce this risk we generally employ biological observers to carry out a constant lookout for such fauna in the areas of operation and if any arc spotted we modify our operations to minimize the risk of collision. Based on experience the only mammals with a tendency to swim near a dredge are dolphins and seals. The former tend to escort sailing ships of any kind and the latter are known for their curiosity and tendency to sunbath on floating lines and auxiliary equipment.	No incidents with other marine mammals. In Ft. Pierce, Manatees have been seen in the vicinity of the dredge while it was dredging and transiting to/from the dig area.	No, Not in our experience.	No, this is not an issue in UK waters.	No.	No.
16.	When appropriate, does your dredge use a draghead designed to reduce the probability of entraining sea turtles? Is this use mandated by the	The following is the Corp turtle exclusion devise specification from our present dredging project in Kings Bay Georgia. Hopper Dredge Operation:	Yes. In most cases. Yes, in many cases it does.	When mandated by contractual requirements, the dredges drag heads are outfitted with NMFS designed and approved TED's (Turtle Excluder Devices). The use of TED's does reduce	We use draghead deflectors on most projects. The best change would be to allow the deflector to float on the bottom.	No, this is not an issue in UK waters.	No special measures employed	This is an East Coast problem. No. No Sea Turtles on Pacific

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
	Owner? Does the use of these dragheads reduce the productivity of the dredge? Is the modified draghead effective? Do you have any recommended changes to the design of the turtle deflector? Do you have any recommendations on operating techniques to avoid entraining turtles during offshore dredging operations?	(1) The Contractor shall operate the hopper dredge to minimize the possibility of taking sea turtles and to comply with the requirements stated in the Incidental Take Statement provided by the National Marine Fisheries Service in their Biological Opinion. (2) The turtle deflector device and inflow screens shall be maintained in operational condition for the entire dredging operation. (3) When initiating dredging, suction through the drag heads shall be allowed just long enough to prime the pumps, then the drag heads must be placed firmly on the bottom. When lifting the drag heads from the bottom, suction through the drag heads shall be allowed just long enough to clear the lines, and then must cease. Pumping water through the drag heads shall cease while maneuvering or during travel to/from the disposal area. (Information Only Note: Optimal suction pipe densities and velocities occur when the deflector is operated properly. If the required dredging section includes compacted fine sands or stiff clays, a properly configured arrangement of teeth may enhance dredge efficiency, which reduces total dredging hours, and "turtle takes." The operation of a drag head with teeth must be monitored for each dredged section to insure that excessive material is not forced into the suction line. When excess high-density material enters the suction line, suction velocities drop to extremely low levels causing conditions for plugging of the suction pipe. Dredge operators should configure and operate their equipment to eliminate all low level suction velocities. Pipe plugging in the past was easily corrected, when low suction velocities occurred, by raising the drag head off the bottom until the suction velocities increased to an appropriate level. Pipe plugging cannot be corrected by raising the drag head off the bottom. Arrangements of teeth and/or the reconfiguration of teeth should be made during the dredging	Though no hard evidence is yet available, all signs indicate a greatly reduced incidence of sea turtle takes, It might be questioned if this is due to the effectiveness of the design or a drop in turtle density but anecdotal evidence suggests a slight increase in turtle numbers. No, none at this time though we have made some practical modifications to reduce wear and tear. Our present operating procedures for eliminating takes apply equally well to inshore and offshore activities.	productivity. Uncertain if the TED is or is not effective as it is designed. No recommendations on changes to design or operating techniques.				Coast.

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		process to optimize the suction velocities.) (4) Raising the drag head off the bottom to increase suction velocities is not acceptable. The primary adjustment for providing additional mixing water to the suction line should be through water ports. To insure that suction velocities do not drop below appropriate levels, the Contractor's personnel shall monitor production meters throughout the job and adjust primarily the number and opening sizes of water ports. Water port openings on top of the drag head or on raised stand pipes above the drag head shall be screened before they are utilized on the dredging project. If a dredge section includes sandy shoals on one end of a tract line and mud sediments on the other end of the tract line, the Contractor shall adjust the equipment to eliminate drag head pick-ups to clear the suction line. (5) Near the completion of each payment section, the Contractor shall perform sufficient surveys to accurately depict those portions of the acceptance section requiring cleanup. The Contractor shall keep the drag head buried a minimum of 6 inches in the sediment at all times. Although the over depth prism is not the required dredging prism, the Contractor shall achieve the required prism by removing the material from the allowable over depth prism. (6) During turning operations the pumps must either be shut off or reduced in speed to the point where no suction velocity or vacuum exists. (7) These operational procedures are intended to stress the importance of balancing the suction pipe densities and velocities in order to keep from taking sea turtles. The Contractor shall develop a written operational plan to minimize turtle takes and submit it as part of the Environmental Protection Plan. (8) The Contractor must comply with all requirements of this specification						

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		and the Contractor's accepted Environmental Protection Plan. The contents of this specification and the Contractor's Environmental Protection Plan shall be shared with all applicable crew members of the hopper dredge. The use to TED's is mandated by the Owner and dredging permit. The use of TED's negatively impacts the productivity of the dredge. The leading edge of the TED is held a minimum of 6 inches in the seabed and in effect plows sand away from the drag head visor. Occasionally, the TED will plow into the seabed, burying the drag and slowing the vessel. When shell or gravel is encountered, the inflow screens plug up and have caused hopper deck piping plugs. There is no hard data on the effectiveness of TED's. There is no way of knowing what the number of takes would be if TED's were not employed. Operating a hopper dredge with one drag head TED equipped and one head unequipped has not been tested. The only testing we are aware of was done by Scripts Institute and involved the use of concrete turtles. Our recommendation would be to conduct dredging operations during the low turtle population season. We typically only encounter turtles in near shore borrow areas or shipping channels and do not have many problems when working in offshore borrow sites. *Please reference attached TED Operational checklist.*						
17.	What effect do the seasonal requirements restricting dredging due to the proximity of turtles have on the overall annual dredging schedule?	The seasonal effects have had a very large impact on the hopper dredging industry. Currently there are seasonal restrictions enforced by the US Army Corps on their projects in the South Atlantic area. For maintenance and new work channel dredging it effects the Harbors from North Carolina south	The use of seasonal restrictions, either due to turt1es or other factors, lead to a disproportionate volume of the total annual dredging work being restricted to a limited time period. As a result of this there is a lack of dredging	Seasonal requirements increase the cost of our services some years, and some years it does not.	It bunches some of the work.	This is not an issue in UK waters.	If such should apply the implications are on shore installations where additional storage and buffer capacity would be required.	N/A

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		through the East Coast of Florida. The allowable operating windows in these areas run from December through March with some of the Ports restricted to Dec15-February. There is also movement to extend these restrictions to Virginia on the North and into the Gulf of Mexico. This concentrates dredging requirements in these areas to a short winter time period. This if coupled with a considerable amount of new work, heavy dredging needs on the Mississippi River which sometimes occur during this period, or with other heavy demand elsewhere can occasionally cause a short term demand for hopper dredges which strains capacity. However, during the remainder of the year there can be serious overcapacity with a lot of idle plant. During the past few years there was overcapacity and considerable idle plant even during this time period however. Of more concern to contractors is that with such tight contract periods there is often little or no flexibility in scheduling equipment. If a dredge unexpectedly has a significant problem requiring repair they can be hard pressed to meet the schedules. With windows it no longer is a matter of being a few days late and perhaps having some penalties, there can be a risk that the project won't be completed. As regards maintenance and deepening work, there is an effect that these winter months are the worst weather months. This can moderately lower time efficiencies somewhat and make surveying to monitor projects more problematic. However, if and when, beach projects are restricted to this window these effects are much more severe because the laying and moving of pipelines offshore and connecting to offshore pumpout connections requires much better sea conditions to be	capacity (i.e. equipment) during part of the year leading to higher prices and. sometimes insufficient capacity to complete all projects. This is in the interests of neither the clients nor the contractors, both of whom would benefit from a reduced overlap in the seasonal restrictions of different regions.					

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		accomplished safely. Waiting for calmer seas to safely place, repair or move an offshore pipeline can cause weeks of delay to a project.						
18.	Does your dredge have a system to reduce pressure/flow at the draghead when the draghead is off the bottom? How does it work?	When the drag head is raised off the bottom as can be evidenced by the seating of the swell compensator ram, the drag tender manually reduces the dredge pump speed. Raising the drag head off the seabed is typically not a problem in borrow sites since there is generally plenty of material to dredge above the specified maximum depth, if one is stipulated. In channel dredging where a grade elevation must be achieved and the contractor is not paid for excess dredging, drags do occasionally hang off above the seabed	In the event that the draghead comes off the bottom we have various technical solutions that would apply. One possibility is to redirect the flow so that it doesn't come through the draghead, Another more attractive possibility is to stop the flow completely. Both these solutions would require relatively minor adjustments to the equipment. None the less, the effectiveness of a reduced flow in reducing turtle takes is questionable. The system determines if the draghead is off the bottom by means of sensors on the draghead and swell compensation system. The flow is then interrupted by use of valves or the pump control.	No such system exists on our dredges.	No	Yes, the so called swell compensator. A hydraulic buffer system keeps a constant tension on the draghead wire. As soon as the draghead loses contact with the bed, either through a depression in the bed or by an upward move (wave induced) of the dredge, the head hangs with a higher weight in the wire, causing the swell compensator to veer out an additional length of wire, until the draghead is in contact with the bed again, at the pre-set pressure. If the distance between bed and vessel is reduced, by bed elevation or wave trough, the wire could come slack, which again is prevented by the swell compensator paying in some wire length.	No.	Pump is stopped.
19.	How effective are observers and trawling to reducing turtle takes?	There is no relation between observers and the number of turtle takes. Observers may occasionally see turtles on the surface, but turtle takes occur on the seabed. Observers inspect the drag heads, inflow and outflow screens and document / identify any takes. We believe trawling can be an effective method to reduce the number of turtle takes. Great Lakes was involved on an emergency contract in Canaveral where trawling was performed by 2 vessels on a 24 hour / day basis for 3 days prior to the start of dredging and in front of the vessel during dredging operations. Canaveral is one of the most populated turtle areas and no turtles were taken during the dredging operations	The only contribution of 'observers' is to inspect the turtle cages at the hopper inflows for any evidence of a take. In addition, if turtles are spotted at the surface you may draw the conclusion that there is a high density of turtles in the vicinity. This often triggers the requirement for turtle trawling. Trawling follows special guidelines (e.g. net type and size) and often lead to the capture of turtles in the general area which reduces the density of turtles in the vicinity of the dredging though by no means does it eliminate the risk of turtle takes.	Observers have not proven to reduce turtle takes. Trawling has proven to be effective in some instances.	Trawling when working in a channel seems to help. Observers just record results.	This is not an issue in UK waters.	Not understood.	N/A Trawling is not effective. Turtles will swim back to nesting ground. That is what they do!
	Additional Questions							

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
20.	What has been your experience dredging in a fishing ground? Has any fisherman or commercial fishing company complained about any aspect of the dredging process? Did you modify your operation to accommodate the fisherman?	We have conducted hopper-dredging operations near identified fishing grounds. The majority of problems involve contact with nets or traps within the dredging area or the disposal route. In some cases, the disposal route was modified to avoid concentrations of nets / traps. The Portland Corp District has investigated the impact of dredging on the commercial crabbing industry in several West Coast Ports.	Designated dredging areas are always very clear-cut and it is very rare that permission be given to operate in a designated fishing ground. In such an event it would be the responsibility of the authorities to communicate to the fishermen that such a permission had been given and to deal with any conflicts of interest that might arise from it. Fishermen, despite a lack of evidence, often feel threatened if dredging is carried out in or close to their fishing grounds. Contrary to these complaints, the release of additional nutrients into the water column often attracts shoals of small fish and game fish leading to an improvement in the local sports fishing. In some cases small changes have been made to the operating methods in order to resolve a potential conflict with fishermen, The responsibility for any additional costs arising from these was determined from the contract. Our company takes a pro-active stance with the fishing industry. Any conflict of interest is usually resolved prior to the issue of any permission to dredge and mitigation measures adopted where appropriate. Fishing liaison officers we often employed at particularly sensitive sites.	No experience dredging in a fishing ground. Have experienced isolated encounters with crap pots, lobster traps, and fishnets in the North East area, which has resulted in complaints from commercial fishermen who claimed to have lost equipment due to our operations.	No real problem as most work is done in navigation channels.	Our company takes a pro-active stance with the fishing industry. Any conflict of interest is usually resolved prior to the issue of any permission to dredge and mitigation measures adopted where appropriate. Fishing liaison officers are often employed at particularly sensitive sites.	This is an on-going feature of operations. Normally dealt with by consultation pre license and regular dialogue.	Disposal impacts are more important than dredging impacts to our agencies.
21.	What measures do you, the dredge operator, take to insure that the dredge does not damage underwater pipelines and cables, or archaeological resources?	As shown in previous examples, our TSHD positioning displays provide real-time dredge orientation at all times. Using this system, operations staff can integrate pipeline locations, archeological resources, cables, etc., into the heads up displays such that the dredges operator can avoid such hazards. In Figure 3, a screen shot of our positioning system displays, the	Assuming that accurate of such obstacles are known with some accuracy, The coordinates of each obstacle, assuming that they are known with some accuracy, are used as a basis for defining a no-dredging zone which is input into the onboard computer system. The dimensions of this zone are	With respect to pipelines or cables, we make every effort to contact the owners of them and request detailed location and elevation information. We also ask them to mark the location of their utilities (sometimes marked with buoys..etc) and give them the option of placing their own representative on board to	Notify owners and obtain information on locations that cross the work area.	We make every effort to ensure that all known positions of cables and pipelines are highlighted in our navigation package and appropriate safety zones are adopted. Safety zones of 500m either side of cables and pipelines are industry standards within the UK	Such services would normally be identified on the charts and track computer with the operation of security zones normally 500 m either side of a pipeline.	Not an issue in Fed nav. Channels. Pre-Con-Solve all these questions.

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		area highlighted in BLACK is an avoidance area. In this instance it is for shallow depths that could ground the ship but the same application is indicative to any predefined caution area or obstruction. **See Attached Figure.** As a precautionary measure, some projects warrant hydrographic survey investigation prior to dredging activates to determine the locations of underwater obstructions. Such surveys are supported with a compliment of equipment that could include Cesium Magnetometers, side scan sonar, cable tracking devices, or high resolution multibeam / swath bathymetry systems. In most US government contracts, such underwater pipelines and cables, or archeological resources are previously located. Once the underwater obstruction locations are verified, operations staff integrates the information into the dredges positioning systems for dredge operator reference throughout dredging activities. Further, project meetings are held prior to dredging activities to discuss the plan for avoiding such obstructions.	adapted to the local operating conditions to include sufficient safety margin, both in horizontal and/or vertical direction. This no-dredging zone then shows up on the operator's screen and in certain cases activates a proximity alarm signal. Depending on the level of automation the draghead will be hoisted automatically if coming within the safety zone. The dimensions of these safety zones are based on risk and will generally be in the order of 50m – 100m in the proximity of cables or pipelines.	witness our operations while dredging over or in the vicinity of their property. Should the pipeline or cable crossing be shown on the contract drawings, or the owner provide sufficient location information (X,Y, Z), that data is used to plot the utility on the dredge guidance screen so both the operator navigating the vessel and the drag tender operating the dredging gear can visually see where the utility is located. Typically, the customer (COE, State, or Private) will give us written direction to dredge over the utility, lift the dredging gear while navigating over the utility while dredging, or avoid the area completely where the utility is located (buffer zone provided). Archaeological resources typically are noted on the contract drawing with an avoidance buffer zone placed around it. These noted areas are also put on the navigation screen and are avoided.		aggregate dredging industry.		
22.	Some operating companies have a policy of dredging localized zones to exhaustion before moving to further zones within the dredge area. This assists management of the resource, but it also helps to minimize occupation of seabed and allow maximum time for recovery of seabed resources. Does your company have a policy of zoned dredging, and what are your reasons for dredging policy? Do you have any information that documents the impact of your dredging operations on marine organisms in specific dredge sites?	Our standard operating procedure is to dredge in specified lanes. In this way we can move the dredge to an adjacent lane while surveys and volume computations are run to check progress and output in the initial dredging lane. This procedure is also beneficial during clean up dredging and helps limit over dredging. We do not have any information in house on the impacts of lane dredging on marine organisms. WES and DERM have conducted extensive monitoring studies of impacts to marine organisms and rates of recovery in borrow areas and should be contacted.	Our company does not have a firm policy on this subject. Dredging strategies are project specific and aim to achieve the best possible economic and environmental situation. The collection of such information is normally done by the project client independently of the dredging contractor. In addition these studies often extend well beyond the completion of dredging making it difficult to follow up on. As mentioned above, the results of these studies are not always easy to come by, depend on	We have no "policy" regarding zone dredging as you note. Given a borrow area to dredge, we follow the contract specifications which typically give directions for material removal. Should no directives be given, we typically seek to find areas of the borrow area which have the best production and dredge that area to exhaustion before moving on to less productive areas of the borrow area. No additional information available regarding additional questions listed.	Our work plans are typically dictated by the owner as to what areas we work. All info concerning biological resources would be accomplished by the permitting agency.	The development of new UK marine aggregate licenses is largely guided by the policies identified in MMG1 2002 (Marine Minerals Guidance Note 1). This document offers guidance on best practice which includes the adoption of zones as a means of reducing environmental impacts in addition to the exhaustion of resources before moving zones. All companies now work with MMG1. No. We do not have site specific information on recovery	Yes, this is specifically targeted to reduce dredging footprint and mitigate effects on surroundings. No but this is likely to be the subject of future monitoring. No.	No.

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	Do you have any information on the rates of recovery of biological resources at your sites following cessation of dredging?		many different factors and are very variable in their results. The European studies mentioned in the answer to question 10 showed recovery periods that ranged between a few months and a few years.			rates.		
23.	Do you have any comments, general or specific, regarding dredging equipment and procedures and the reduction of adverse impacts on the environment?	While special precautions are obviously necessary when working in proximity of highly sensitive resources, these need to be addressed on a project specific basis. Often mandating restrictions and procedures is unnecessary and based on "feel good" perceptions rather than scientific need or practicality. We should be cautious about over regulating a situation where the benefits are not well founded.	It is essential that all parties involved pool their knowledge in an open discussion to achieve a balanced result that best achieves the interests of all. This process is also essential in building the mutual trust and understanding that will ensure the successful solution of any hurdles that might arise. Our company recognizes the adverse impacts that dredging might have. Every effort is made to minimize the impacts. Mitigation might include seasonal restrictions, minimization of impacted area and developing site specific procedures just to name a few. It is in the interest of all to define a feasible methodology that allows often critical projects to proceed without delay.	We have dredged +/- 50,000,000 cubic yards of sand from offshore borrow areas for beach nourishment in the past 10 years. We have damaged (1) utility cable, taken 0 turtles from borrow areas and have not damaged the environment or archeological resources to the best of our knowledge.	A typical hopper dredge operation in clean sand is probably the least disruptive to the environment.	Our company recognizes the adverse impacts that dredging might have. Every effort is taken to minimize the impacts and mitigation might include seasonal restrictions, minimization of impacted area and developing site specific procedures.	See 4. Above.	For the most part routine maintenance dredging occurs in regularly impacted navigation channels, so benthic communities are transient in nature. Disposal site issues are the main focus of our coordination with agencies, with the exception of entraiment of salmonid. This is avoided by turing off pumps when dragheads are more than 3' above bottom.

Appendix C5

Document And
Powerpoint Presentation
Provided By Jan de Nul

JAN DE NUL
Group of Companies

Specialised Alternative Dredging Methods

INDEX

SLIDES

1. Intro

2.
3.
4.

JAN DE NUL Group is one of the mayor dredging contractors of the world, leading the market with the most modern fleet of dredging equipment. During the last 10 years JDN expanded its fleet with 13 newly built units. Some of these new dredging vessels have been milestones in the industry. In 1992 the JFJ DE NUL, a trailing suction hopper dredge with a hopper capacity of 11.750 m3, the biggest at that time in the world, was commissioned and deployed at the construction of the century, as it was called at these times: The Chep Lap Kok Airport Platform in Hong Kong.

The largest added vessel is a trailing suction hopper dredge with a hopper capacity of 33.000 m3: the Vasco Da Gama. Today the vessel is foreseen to be extended to 44.000 m3 hopper hold, to become again the largest trailing hopper of the world. It is clear that these new vessels have added to the companies' growth thanks to their size and new technologies which were implemented. The size of these equipment was unthinkable 10 years ago. Large reclamation works in the Far East and Europe would not have been executed by dredgers without these mega dredgers. Today almost the whole world fleet of jumbo and mega dredgers, constructed over the last years is operating on large reclamation works in Singapore, Hong Kong, Korea and Taiwan. It would require too much time to talk about the technological developments which helped built these vessels.

The South American dredging market normally has no requirement for these large dredges, which have been built mainly for dredging sand at sea, transport it over considerable distances in open sea and pump it over several km into reclamation areas. South America, and Argentina in particular, with the relative shallow waterways and no need for large reclamation, will not see these mega dredgers deployed in the near future.

Actually the group has a still 5 dredges under construction, 2 sister vessels with a capacity of 11.300 m3, another 2 sister vessels with a 4.400 m3 hopper and one new cutter suction dredge, which will be again the most powerful of the world in its kind. These 5 dredges will come into operation at the end of this year, while the next 4 split hoppers are already ordered and should be delivered in 2005.

Another main development in the dredging technology is the evolution in alternative dredging methods for environmental sensitive projects. The need for environmentally acceptable solutions in dredging is something, which evolved all over the world, and will be more seen in the near future, also in South America and Argentina. Therefore I will give an overview of some new dredging methods developed by our company over the last years. Monitoring campaigns have demonstrated their efficiency and limitations.

As an environmentally conscious international company, Jan De Nul is involved in dredging projects around the world with strict requirements concerning removal and spreading of pollutants. A major policy of Jan De Nul is translated in a continuous strive to develop more efficient and environment friendlier dredging techniques.

5. Company and Environment

As environmental considerations continue to become more and more important throughout the world there are continuing calls to reduce the effects of dredging operations on the water column and surrounding marine environment. Dredging causes particulate suspension when certain soil types are disturbed and this can effect not only the balance in the water column, but also the sea bed environment following subsequent settlement of suspended particles. In particular whilst removing layers of contaminated or polluted silt for subsequent treatment processing, particulate suspension should be reduced to a minimum.

Jan De Nul Company recognises both the necessary stringent constraints now being placed on projects involving dredging works and the effect that dredging operations can, in some circumstances have on the marine environment.

6. Dredge types

At present two categories of dredges were equipped with special facilities enabling to work in accordance with strict environmental requirements.
In the next sections the performance of a trailing hopper dredge and a stationary dredge are discussed with special attention to the impact on turbidity.

What is turbidity ?
Turbidity is a measure for the reduction of the transparency of a liquid due to the presence of non dissolved particles.
A bundle of light beamed into a liquid will be attenuated when dissolved elements in the liquid cause a change of colour and will be dispersed if the liquid contains non dissolved particles.
Different approaches to measure the turbidity have been developed. Depending on the approach the turbidity will be expressed in different units. International norm ISO 7027 explains 4 methods to determine the water turbidity : 2 semi-quantitative and 2 quantitative methods.

Semi-quantitative method 1 : A clear graduated glass tube with a black mark on a white background at the end is used to evaluate the liquid transparency by measuring the height of the liquid (cm) when the mark fades
Semi-quantitative method 2 : A white round plate which is immersed into the water until it becomes hardly visible. The depth is measured to 1cm accurate when less then one meter and to 10 cm when more then one meter.
Quantitative method 1 : An optical sensor measures the intensity of the dispersed (backscatter) light with a cell, immersed in a fluid with non dissolved particles. The turbidity is given in nephelometric turbidity units (NTU).
Quantitative method 2 : An optical sensor measures the intensity of the attenuated light (transmissiometer) with a cell, immersed in a fluid with non dissolved particles. The turbidity is given in nephelometric attenuation turbidity units (NAU).
Different methods use different units and depending on the used calibration fluid different measuring units are adapted. The Jackson turbidity meter used to be the standard tool for turbidity measurement and Jackson turbidity units (JTU) have been the standard for a long time. At present optical sensors are calibrated using formazin calibration fluid and FTU (formazin turbidity units) have become the new standard. No general correlation between the different unit systems can be established.
Formazin is a chemical solution and is prepared as follows :
- dissolve 10 g hexamethylenetetramine in water and dilute to 100 ml
- dissolve 1g hydrazinesulphate (poisonous) in water and dilute to 100 ml
- mix 5ml from both dilutions and further dilute to 100 ml to obtain a 400 FTU solution

The suspended solids concentration is the dry weight of sediment devided by the weight of sample (expressed in ppm) or by the volume of sample in liters (expressed in mg/l).

<u>The terms turbidity and suspended solids concentration are similar but not equal.</u>

7. TSHD 'Cristoforo Colombo'

This modern dredge of Jan De Nul's versatile fleet combines following dredging techniques :

- standard dredging without overflow : dredging with one or two suction pipes until the overflow level is reached in the hopper
- standard dredging with overflow : continue loading the hopper barge with higher density while process water leaves the hopper by standard overflow
- low turbidity valve in the overflow funnel : an adjustable valve in the overflow funnel chokes the flow in such a way that no air is taken down with the suspension leaving the hopper
- 'green pipe' : the overflow suspension is pumped trough an additional pipe, mounted on top of the suction pipe, back to the suction head where it is used as process water

8. Low turbidity valve

When using the dredge technique with the low turbidity valve, without ‘green pipe’. An adjustable valve chokes the flow in such a way, that no air is taken down with process water leaving the hopper. The result is a density stream, causing a minimum of turbulence, taking the excessive material back to the sea bottom.
Without low turbidity valve (standard overflow), a big volume of air is taken with the overflow water due to the big fall height. Underneath the vessel a density stream of haevier particles moves down and at the same time an upward airstream occurs. These opposite actions cause a lot of turbulence with spreading of the plume as a result.

9. ‘Green pipe’

Using the ‘green pipe’ feature , a recycling pipe is mounted on the dredge pipe. When the overflow level is reached in the hopper, the overflow suspension is pumped through this recycling pipe , back to the suction head where it is used as process water. As positive result the overflow water does not fall through the complete watercolumn to the bottom.

10. Filling the hopper

Activating the ‘green pipe’ : the hopper is filled up to the overflow level.

11. The overflow funnel

Activating the ‘green pipe’ : the process water flows into the overflow funnel.

12. The second dredge pump

Activating the ‘green pipe’ : the process water flows into the second dredge pump.

13. The re-circulation pipe

Activating the ‘green pipe’ : the process water is pumped trough the re-circulation pipe.

14. The suction head

Activating the ‘green pipe’ : the process is pumped back to the suction head.

15. Suction head re-entry

Activating the ‘green pipe’ : the process water re-enters the suction head directly or trough the jet pipes.

16. Process water

Activating the 'green pipe' : the process water flows into the overflow funnel is re-circulated.

17. Additional filling

Activating the 'green pipe' : additional filling of the hopper is enabled.

18. Minimum turbidity

Activating the 'green pipe' : during additional filling of the hopper minimal turbidity is generated.

19. LTD 'Dirk Martens'

Focused on strict environmental performance criteria in mind a dredge with the following features was developed:

- able to remove thin layers of silt with high accuracy reducing the overdredged volume and the mixing of clean soil with slightly polluted silt
- dredge at in situ density for optimal utilisation of the barge capacity
- dredge in shallow areas
- minimise the mechanical disturbance to reduce the turbidity generation and the mobilisation of pollutants
- extended automation and monitoring of the dredging process

20. Low turbidity dredge head

To cope with these challenges Jan De Nul developed a special suction head : the so called 'Low Turbidity Dredge Head' (LTDH). The sweephead for LTD (low turbidity dredge) 'Dirk Martens' has been designed to dredge at maximum productivity and accuracy and with minimum disturbance to the environment.
The sweephead has two inlets and works without additional mechanical movements. A hydraulic valve in the head opens the inlet towards the dredging direction while the shape of the contact surfaces ensures optimal sediment transport. Process water is minimal, which means that the material is pumped at almost in situ density.
Additional sensors and instruments allow for better process monitoring and more accurate dredging.

21. TSHD ‘Cristoforo Colombo’ : turbidity plume

During dredge operations conducted with different dredging techniques, the performance related to the turbidity criterion was established.
Using the standard dredging technique as reference the following techniques were monitored :

- standard dredging without overflow
- standard dredging with overflow
- environmental valve in the overflow funnel
- ‘green pipe’

22. The dredging process

The turbidity generated during the dredge operations using the different dredging method was monitored starting from an empty hopper.

23. First phase of the dredge cycle

During the first fase of dredge cycle, independent of the adapted dredging technique, material is pumped into the hopper without overflow.
The suction head always causes some disturbance near the interface between dredged and non-dredged material and a small amount of solids is brought into suspension near the bottom.

24. Loading without overflow

The particles are brought in suspension at the suction head disperse in a plume close to the seabed and settle down again within a relative short time.

25. Additional loading with standard overflow

Once the overflow level is reached, with the overflow water, a big volume of air is taken due to the big fall height. Underneath the vessel a density stream of heavier particles moves down and at the same time an upward airstream occurs. These opposite actions cause a lot of turbulence with spreading of the plume as a result.

26. Plume generation when loading with standard overflow

While the dredge trails on the vessel’s propellers pass this area only seconds later. The energy of the revolving propellers spread the particles at high speed in all directions.
The turbidity plume stretches now from the surface to the seabed and settlement is as follows : the density stream of quasi unstirred and heavier particles and the slow settlement of stirred material and fine particles.

27. Additional loading with low turbidity valve

In contradiction with the standard cycle, almost no air is taken with the overflow water as a result of the choking effect of the environmental valve. Underneath the vessel the density stream is almost not disturbed and the overflow suspension sinks to the seabed.

28. Plume generation when loading with low turbidity valve

A small fraction, mainly fine particles, is caught in the turbulence around the vessel. This fraction is spread out when the vessel's propellers pass and settles slowly afterwards.

29. Additional loading with 'green pipe'

The overflow suspension is pumped back to the suction head where it is recycled almost integral as process water. The fraction leaving the suction head contains a suspension which is mixed during the dredge process by passing through suction pipe, dredge pump, hopper, discharge pump and discharge pipe and generates a turbidity increase near the suction head.

30. Plume generation when loading with 'green pipe'

Due to the mixing process the particles will stay longer in suspension compared to the particles brought in suspension during the cycle without overflow.

31. Turbidity plume dispersion comparison

The graph shows cross sections of the turbitity plume for each dredge technique at an interval of 5 minutes. High sediment concentrations are dark, low concertrations are light.

Comparing the plumes created with standard overflow and low turbidity valve :

- the plume width for the low turbidity valve is narrower
- the particles settle much faster from the upper section for the low turbidity valve

Comparing the 'green pipe' and no overflow cycles with these cycles:

- the turbidity stays close to the bottom and the plume never reaches the water surface

32. Dredge technique comparison

- When using the environmental valve in the hopper overflow the quantity of solids staying in suspension long enough to spread out through current effects is reduced to 41 percent of the quantity generated during the standard cycle.

- With the 'green pipe' cycle the quantity of solids in suspension is reduced to 21 percent compared to the standard cycle. Apart from this the generated plume is situated just above the seabed which reduces the settlement time considerably.

- Dredging without overflow reduces the generated turbidity to 13 percent of the quantity measured for the standard cycle. Everything happens very close to the seabed which further reduces the duration of the settlement process.

33. Background turbidity

The selection of the dredge technique to be adapted on a specific project will not only depend on turbidity-related performance.
Many ports are located near river estuaries where huge quantities of silt carried from upstream have settled. Exposed to hydro-meteorological forces, particles will be brought in suspension during periods of strong current or wave action and will settle down again during calm sea conditions.
The displayed example shows the tidal background turbidity at the cross entrance of the Port of Zeebruges, located near the Scheldt estuary. The suspended solids concentrations during periods of strong current raised to such a level that a different colour scale had to be used. Dark brown for the dredge induced turbidity plumes indicated 300 mg/l or more, for the background turbidity dark brown indicates concentrations higher than 1000 mg/l.
The graph on the right illustrates the contributing parameters even better. The brown line shows the background concentration of suspended solids on a time axis, the other lines show the impact of the different dredging methods.

34. Conclusions

- Plume generation relative to the plume generated during the dredge cycle with standard overflow is reduced to 41 % by using the low turbidity valve. Working with the 'green pipe' will generate 21 % and dredging without overflow will reduce the turbidity generation to 13 % compared to the standard dredging cycle.

- Application of alternative dredging techniques is not relevant if the additional turbidity generated during the dredging works is only a fraction of the background turbidity.

35. Operations with LTD ‘Dirk Martens’

To evaluate the performance of this dredging technique the following aspects were considered :

- generated turbidity
- secondary sources
- background turbidity

36. Generated turbidity

During the dredging operations with low turbidity dredge ‘Dirk Martens’ the turbidity increase at 100 m from the dredge location amounted to 16 mg/l average and 43 mg/l maximum. 150 m away from the dredge location these figures were respectively 11 and 31 mg/l. At 200 m from the dredge location the amounts further reduced to 6 and 23 mg/l.

37. Secondary sources

In shallow areas with a silty top layer on the bottom the suspended solids concentration increase caused by secondary sources (e.g. a manoeuvring vessel) easily exceeds 150 mg/l.

38. Background turbidity

In silty shallow port areas where current speeds remain low 10 to 50 mg/l suspended solids are measured for currents lower than 0.1 m/s, 70 to 150 mg/l for current speeds between 0.1 and 0.3 m/s.

39. Conclusions

With the development of the low turbidity head of ‘Dirk Martens’ the amount of particles brought into suspension during the actual dredging has been reduced to such a level that, especially in shallow areas, secondary sources and background variations generate more turbidity than the dredgehead.

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Specialised Alternative Dredging Methods

Environmental considerations become more and more important throughout the world.

As an environmentally conscious international company, a major policy of Jan De Nul n.v. is translated in a continuous strive to develop more efficiënt and environment friendlier dredging techniques.

Trailing hopper dredge :

- **low turbidity valve**
- **green pipe**

Stationary dredge :

- **low turbidity dredge head**

Multi - Functional Trailing Suction Hopper Dredge ‘Cristoforo Colombo’

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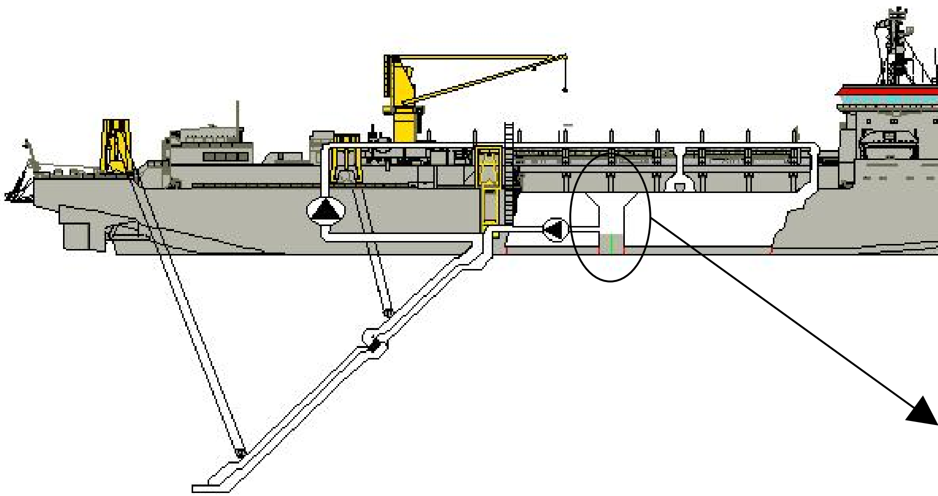
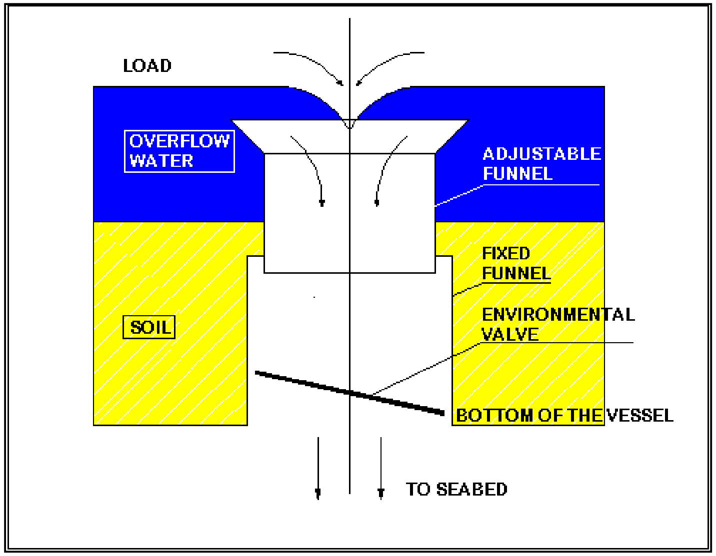
Features following dredging techniques :

- Standard dredging without overflow
- Standard dredging with overflow
- Low Turbidity Valve in overflow funnel
- Environmental dredging with ‘Green Pipe’

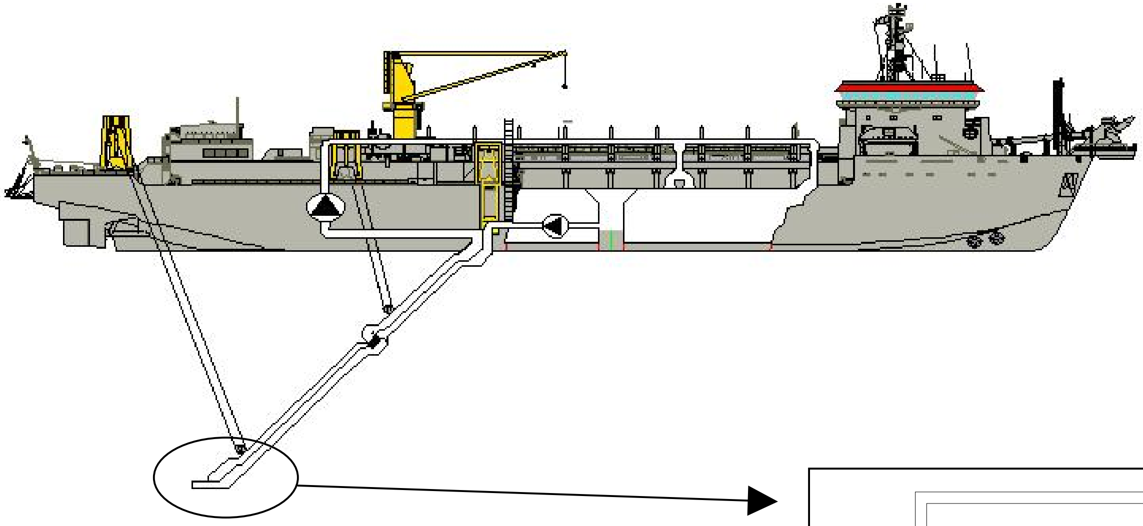
Low Turbidity Valve

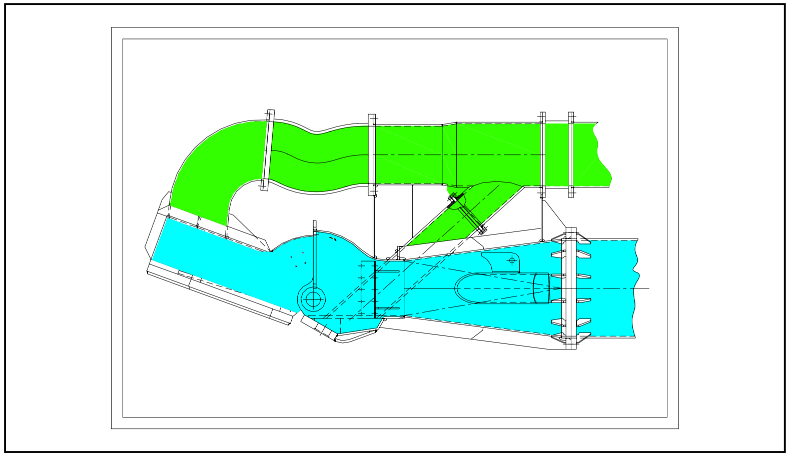




An adjustable valve in the overflow funnel chokes the flow in such a way that no air is taken down with the suspension leaving the hopper.

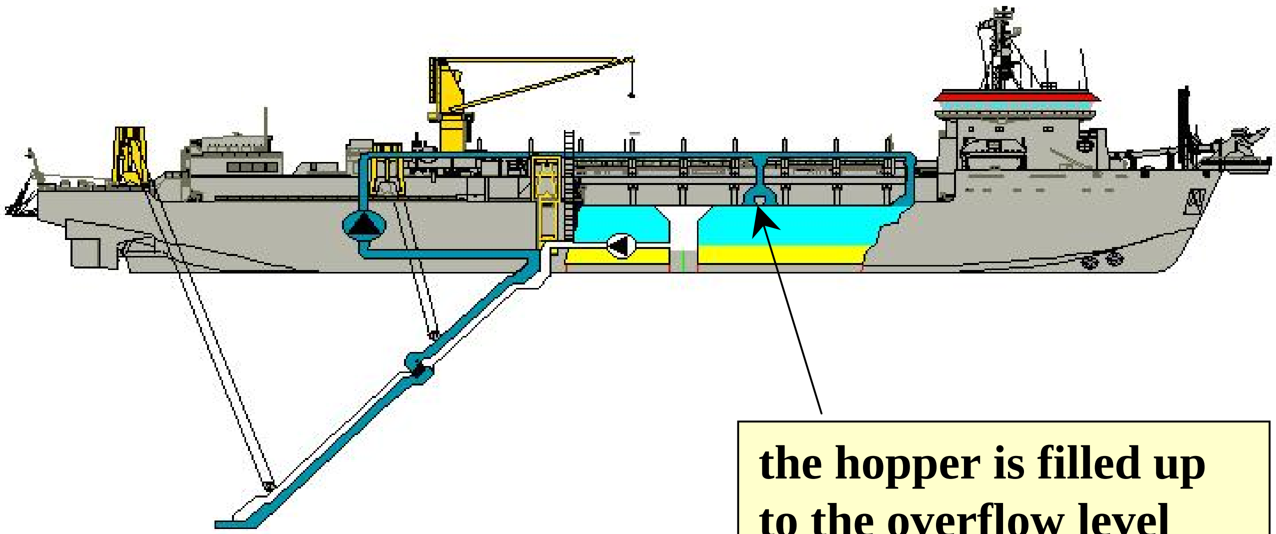
‘Green Pipe’





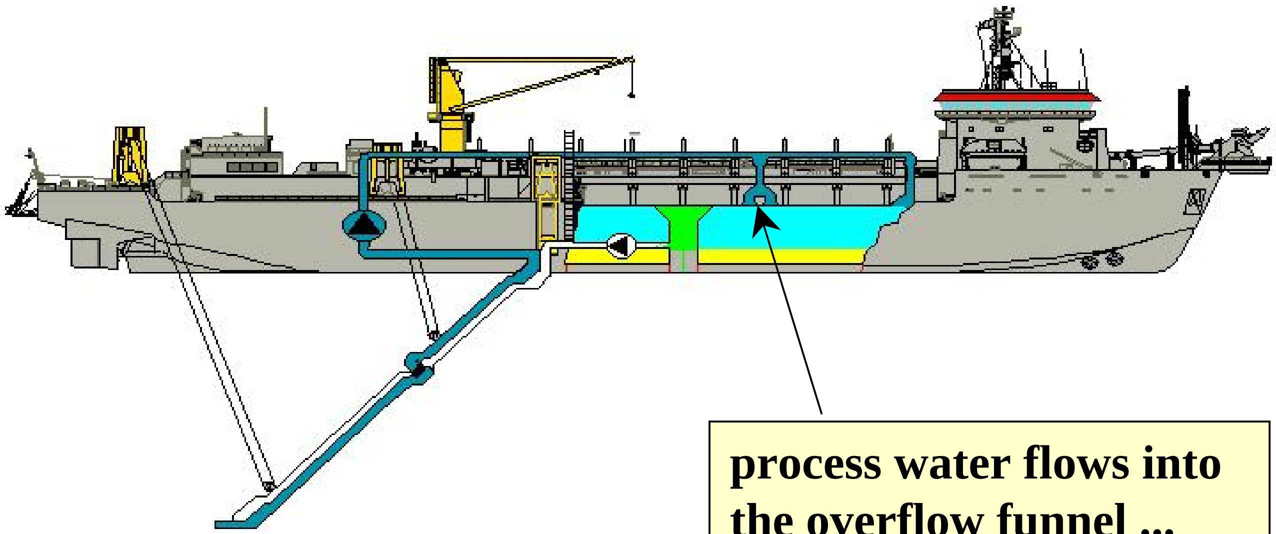
The overflow suspension is pumped trough an additional pipe, mounted on top of the suction pipe, back to the suction head where it is used as process water.

Activating the 'Green Pipe'



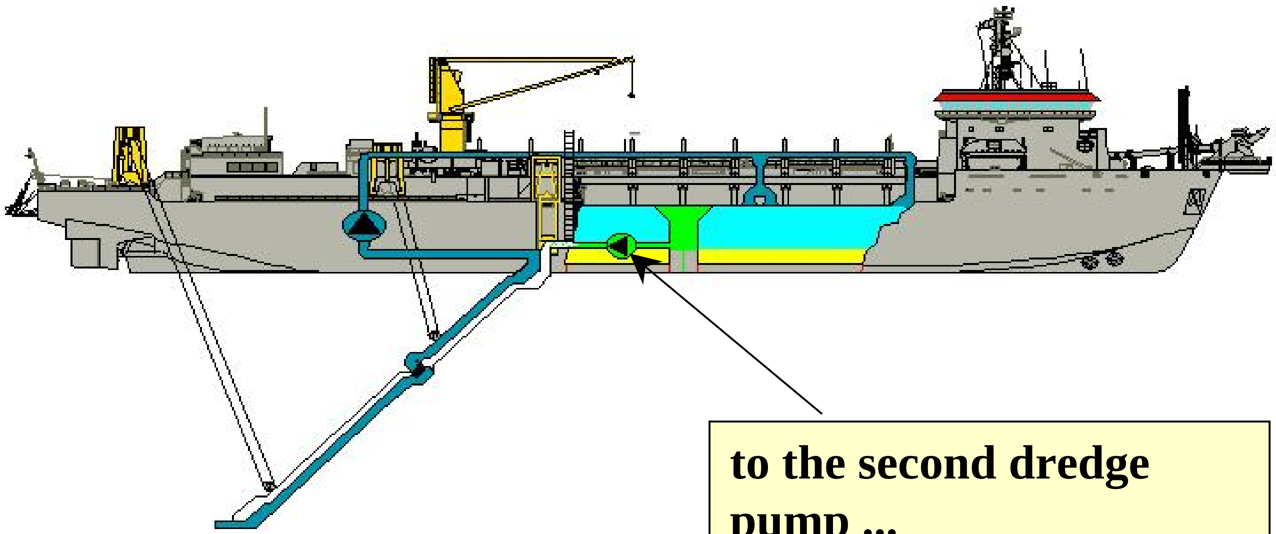
the hopper is filled up to the overflow level

Activating the ‘Green Pipe’



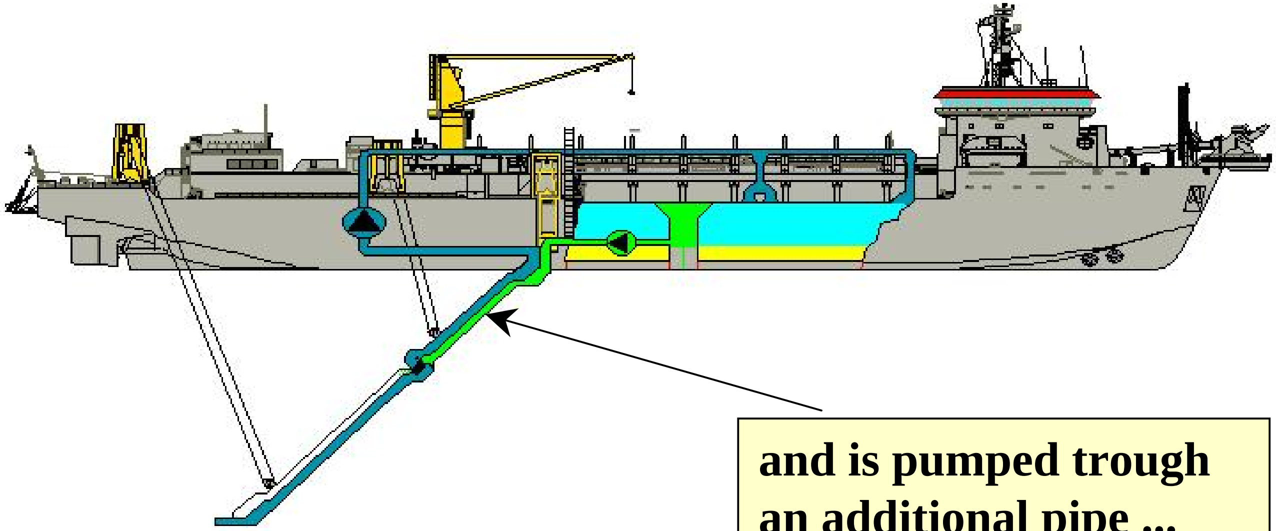
process water flows into the overflow funnel ...

Activating the 'Green Pipe'



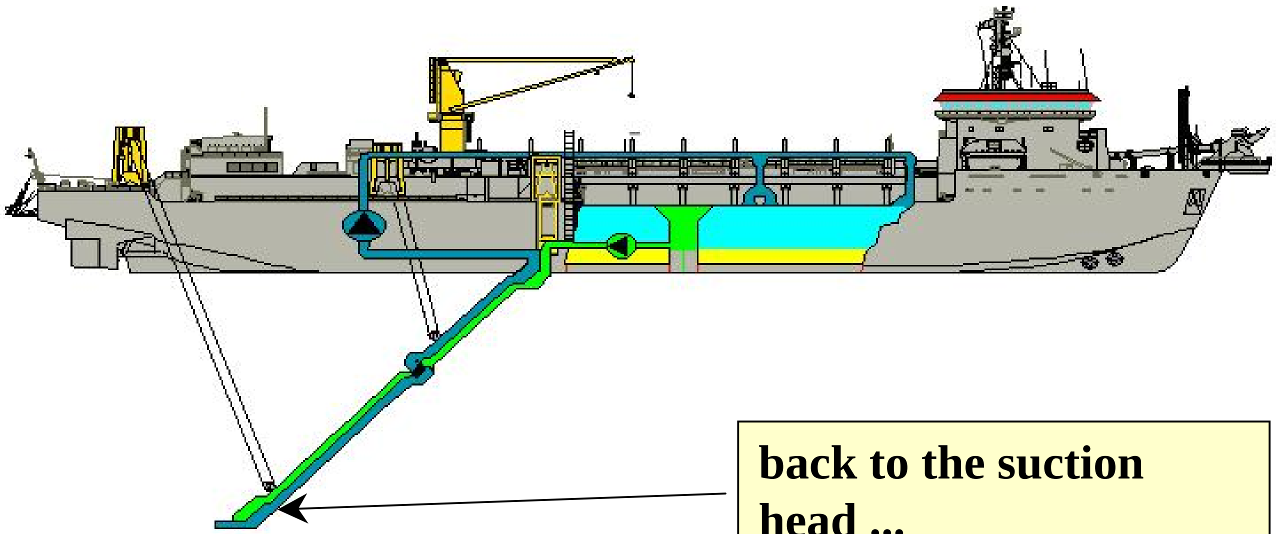
to the second dredge pump ...

Activating the ‘Green Pipe’



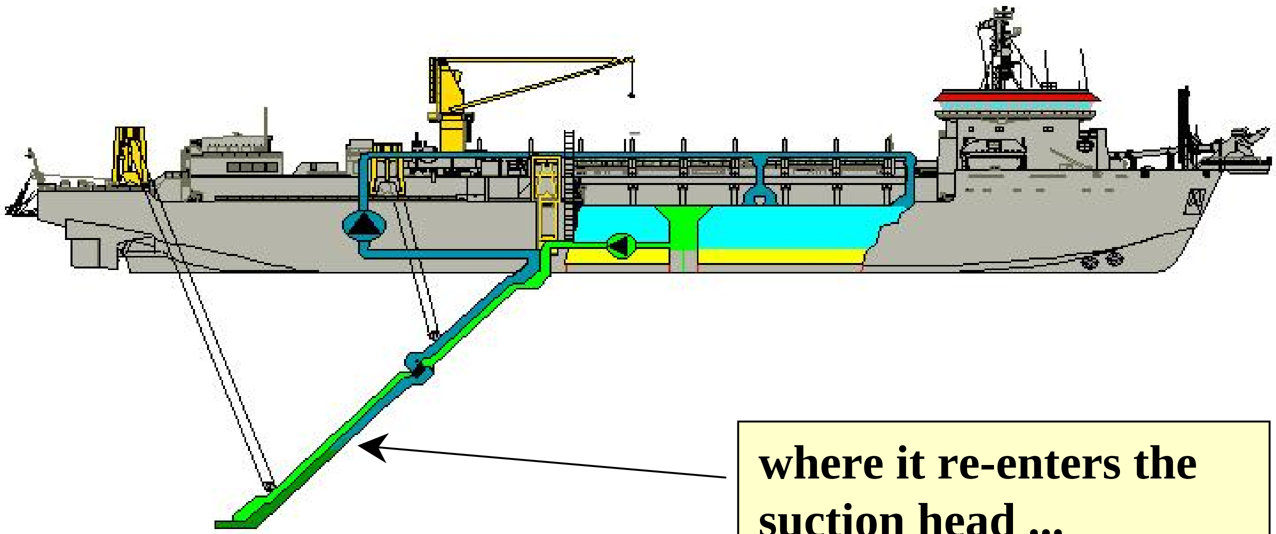
and is pumped trough an additional pipe ...

Activating the 'Green Pipe'



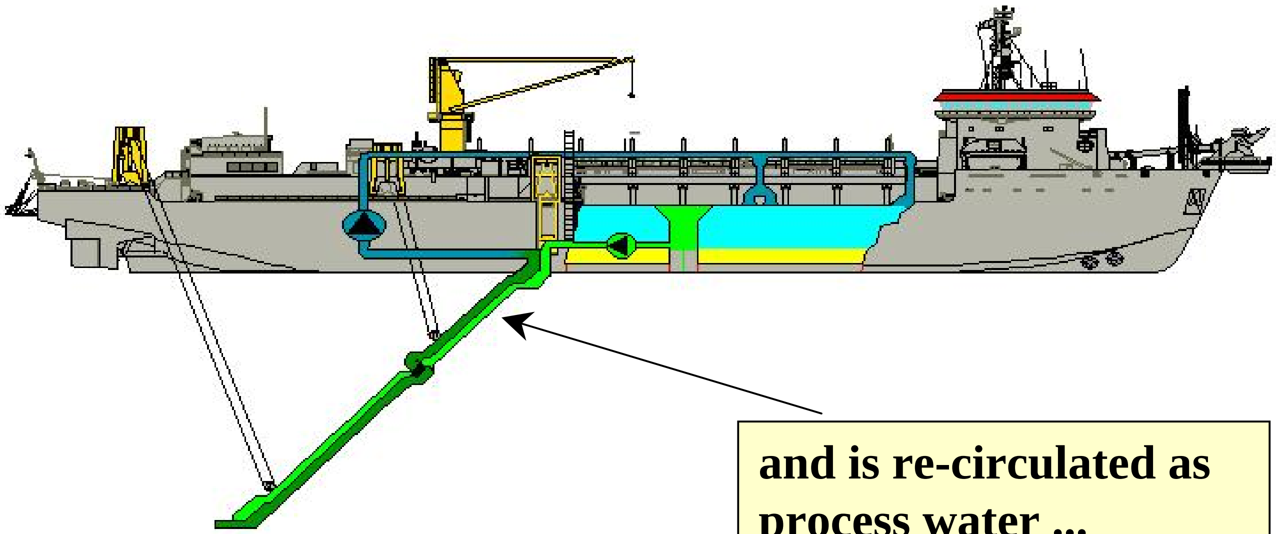
back to the suction head ...

Activating the 'Green Pipe'



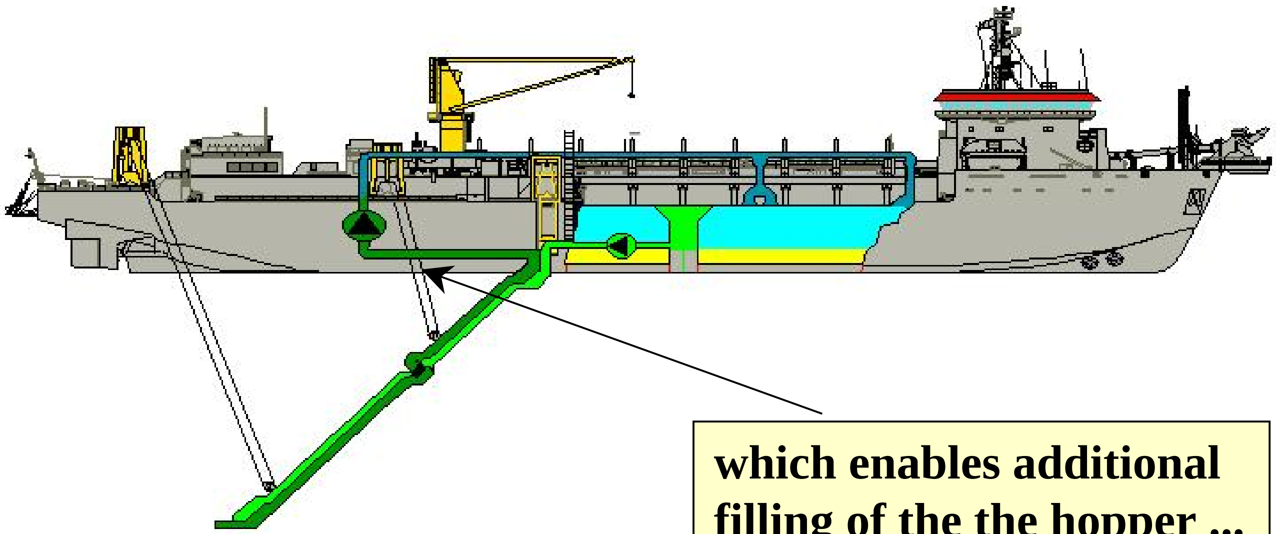
where it re-enters the suction head ...

Activating the ‘Green Pipe’



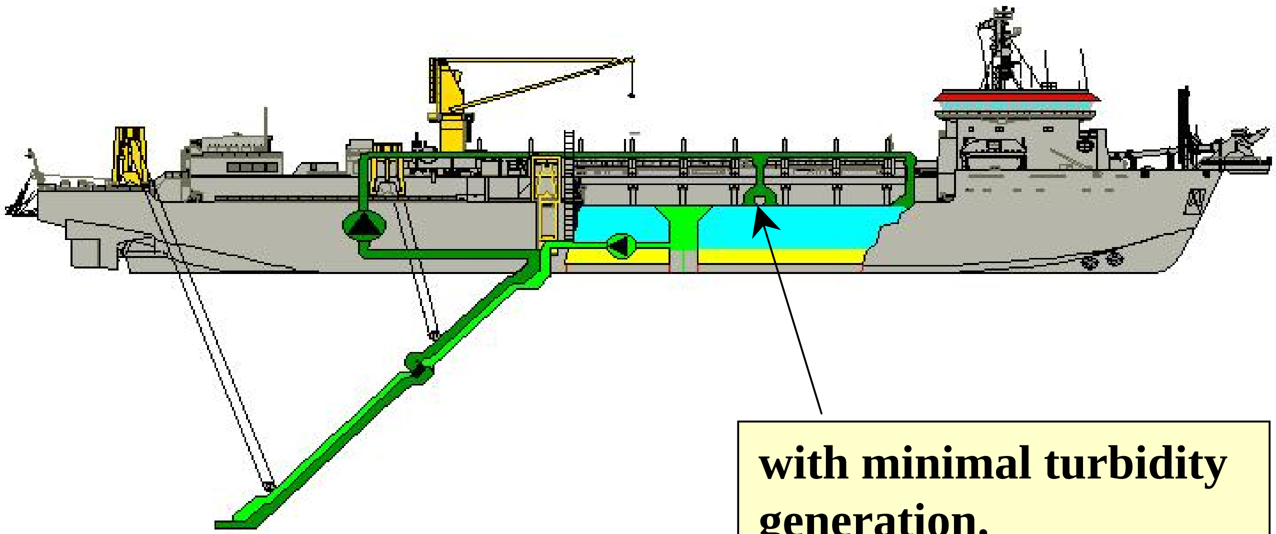
and is re-circulated as process water ...

Activating the ‘Green Pipe’



which enables additional filling of the the hopper ...

Activating the ‘Green Pipe’



with minimal turbidity generation.

Low Turbidity Dredge 'Dirk Martens'

Features :

- accurate removal of thin layers of silt
- dredge at in situ density
- dredge in shallow areas
- minimise the mechanical disturbance

‘Low Turbidity Dredge Head’

- two inlets
- a hydraulic valve opens the inlet towards the dredging direction
- the shape of the contact surfaces ensures optimal sediment transport

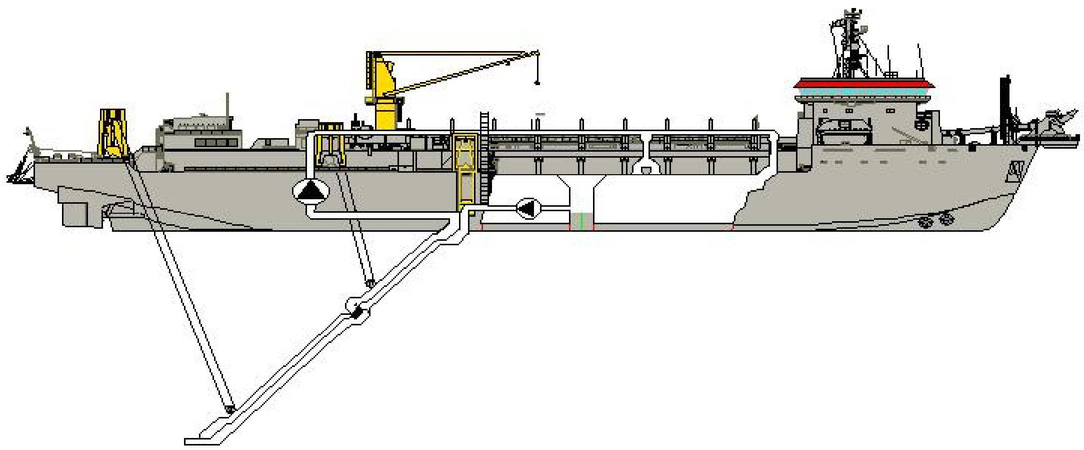
Turbidity plume generated during dredging operations with TSHD ‘Cristoforo Colombo’

Compared dredging techniques :

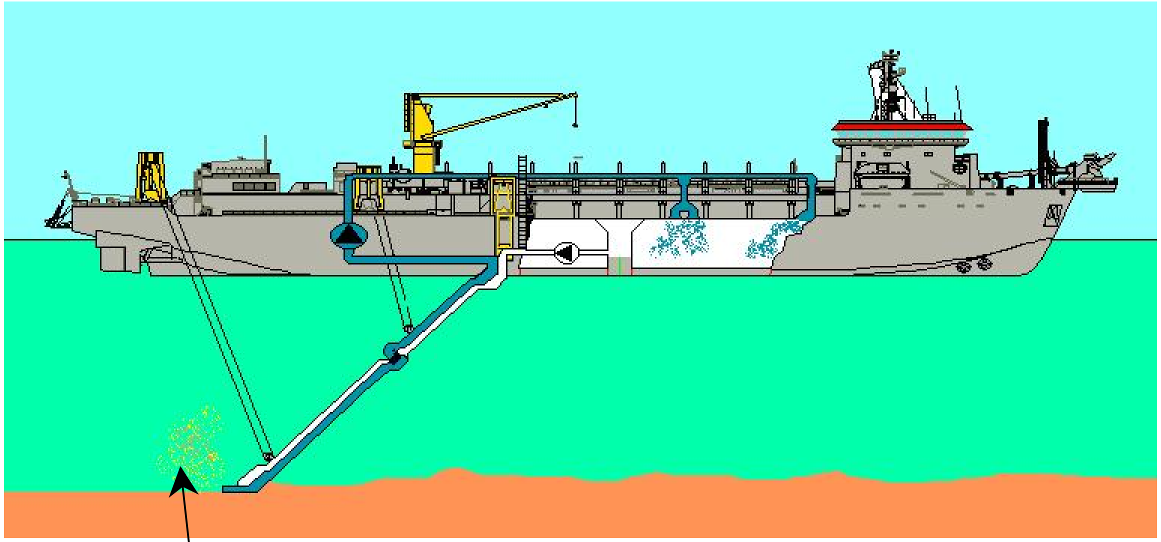
- Standard dredging without overflow
- Standard dredging with overflow
- Low Turbidity Valve in overflow funnel
- Environmental dredging with ‘Green Pipe’

The dredging process :

- commencing from an empty hopper

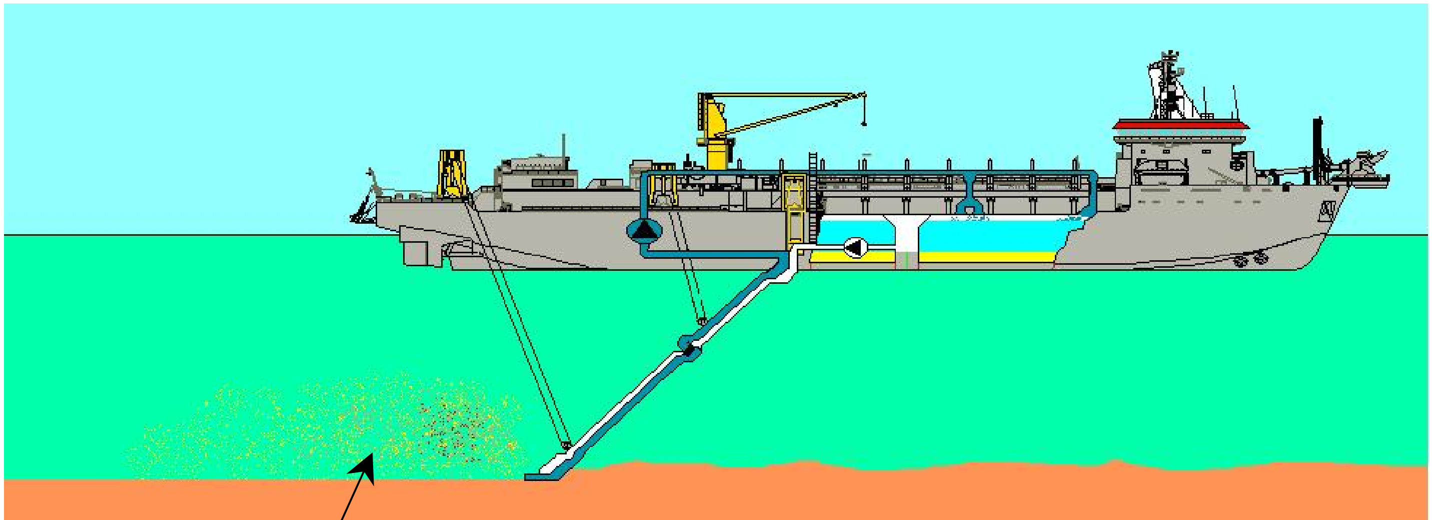


- dredged material is pumped into the hopper

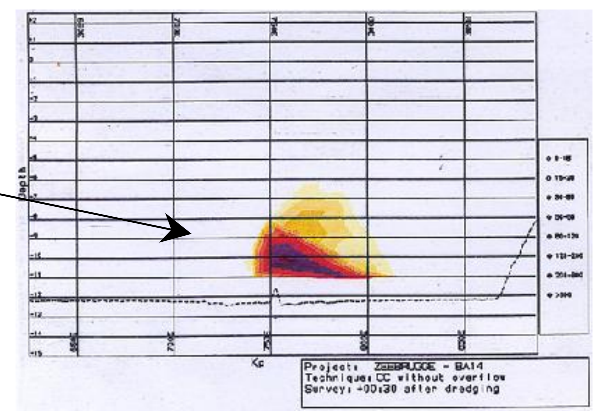


turbidity plume

- filling the hopper (loading without overflow)



turbidity plume



- additional loading with <u>standard overflow</u>

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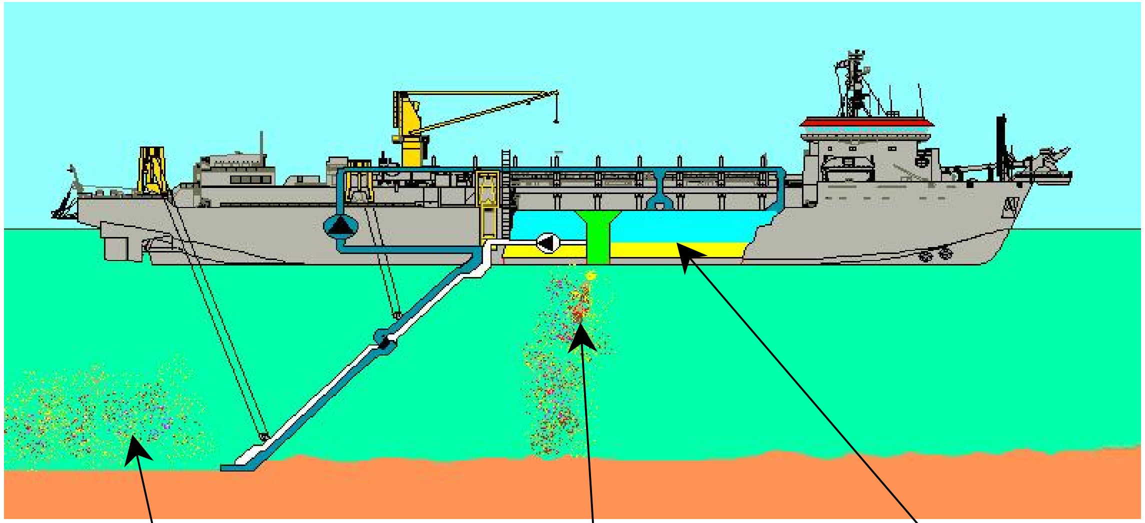
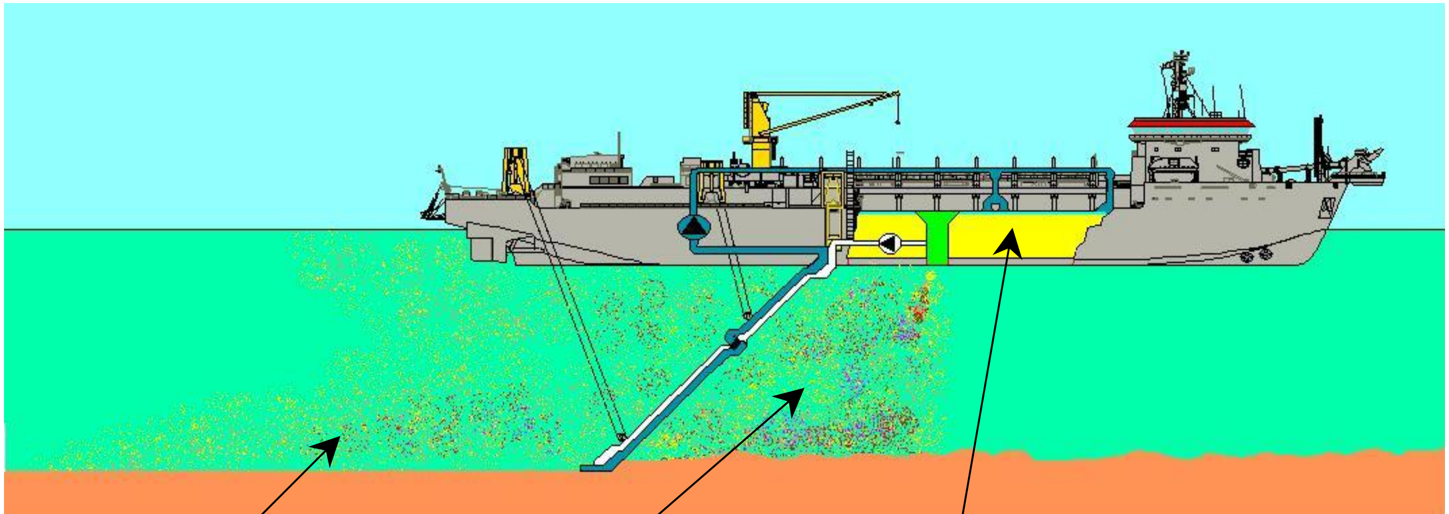


turbidity plume dredge head

turbidity plume overflow

continue loading

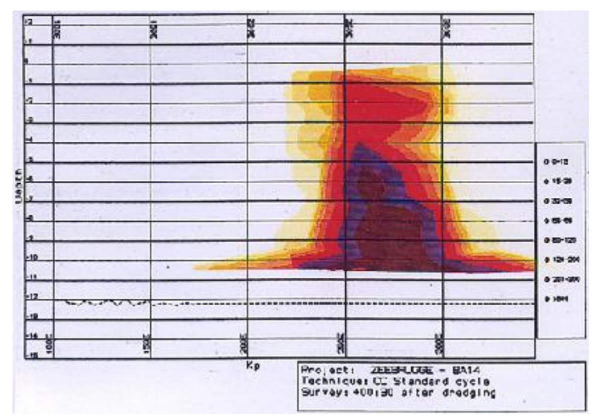
- plume generation while loading with standard overflow



turbidity plume dredge head

turbidity plume overflow

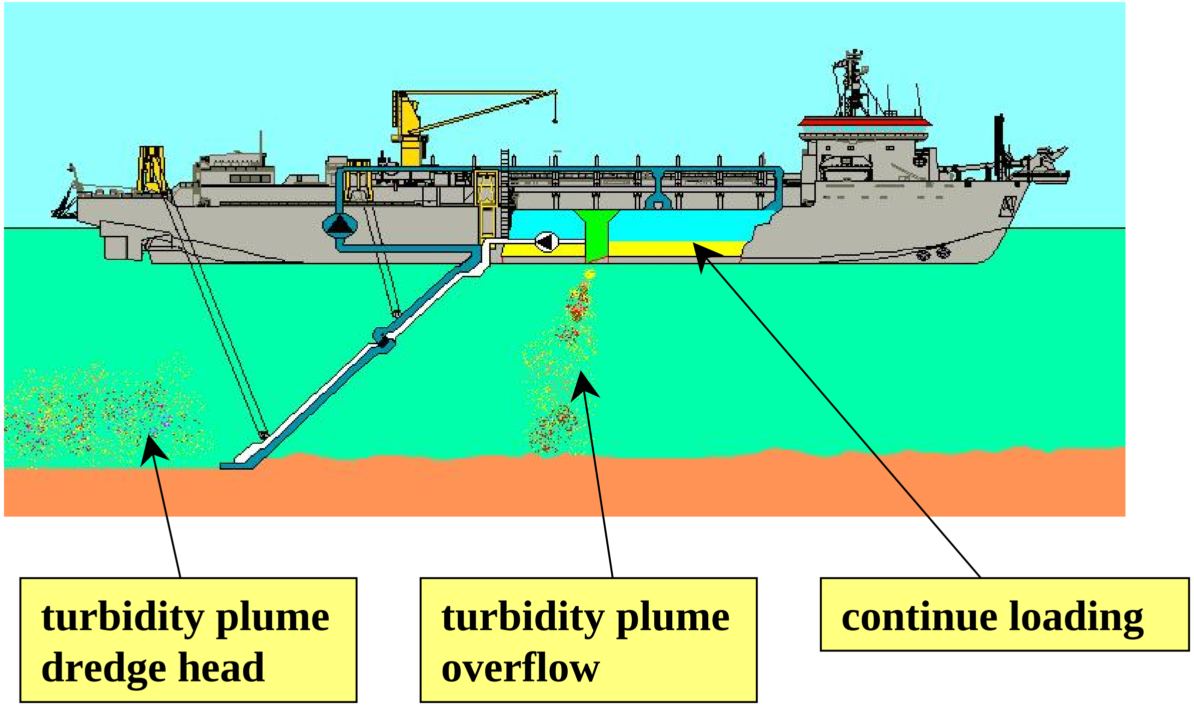
continue loading



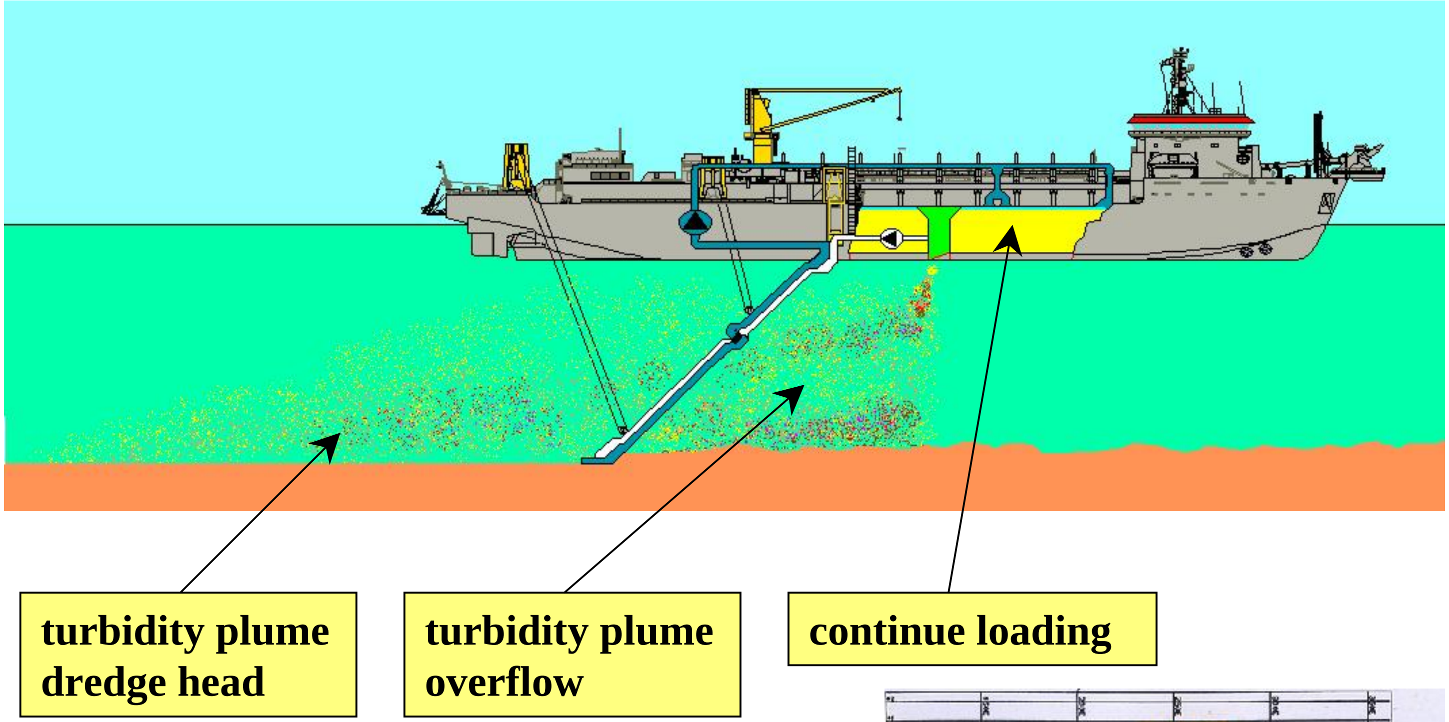
New parameters :

- upward airstream
- propeller impact

- additional loading with <u>low turbidity valve</u>

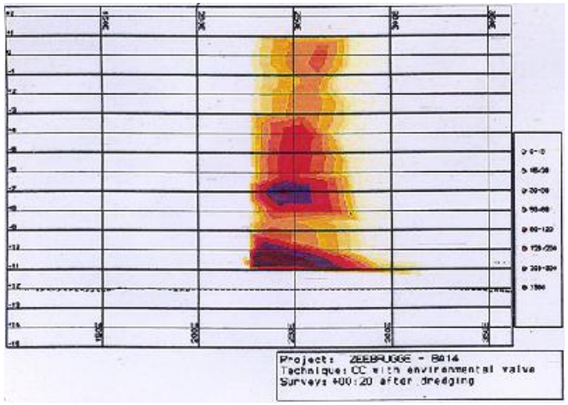


- plume generation while loading with <u>low turbidity valve</u>

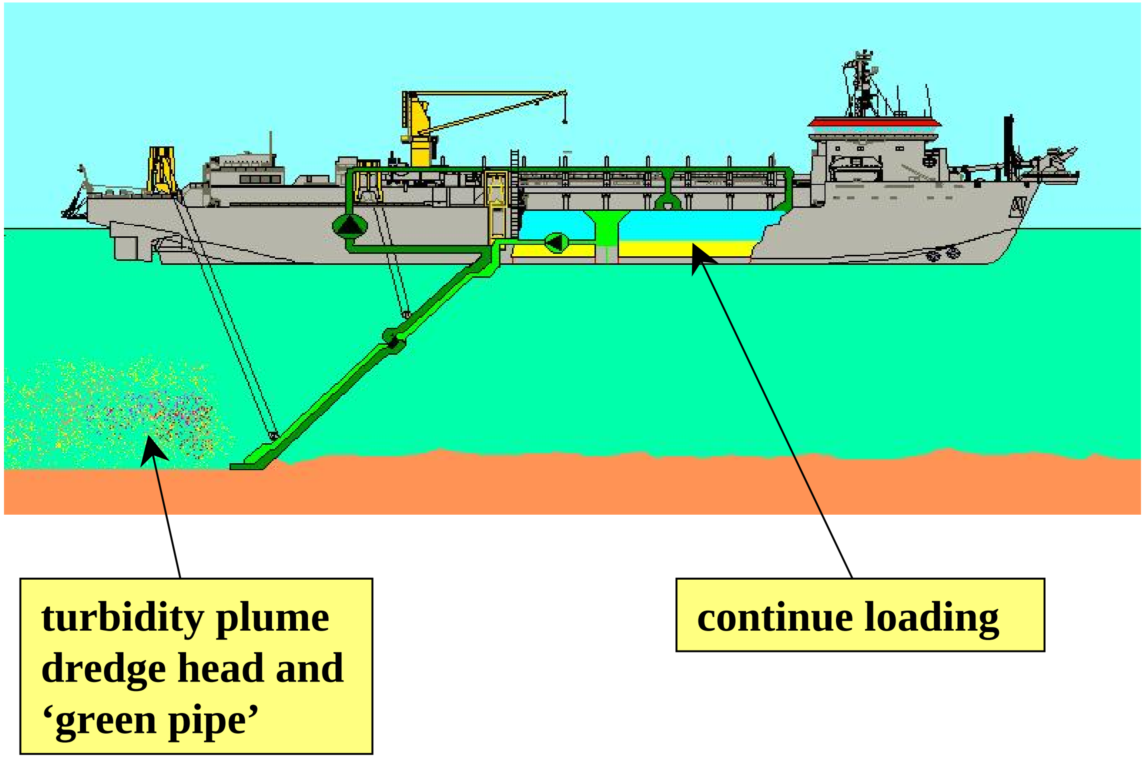


New parameters :

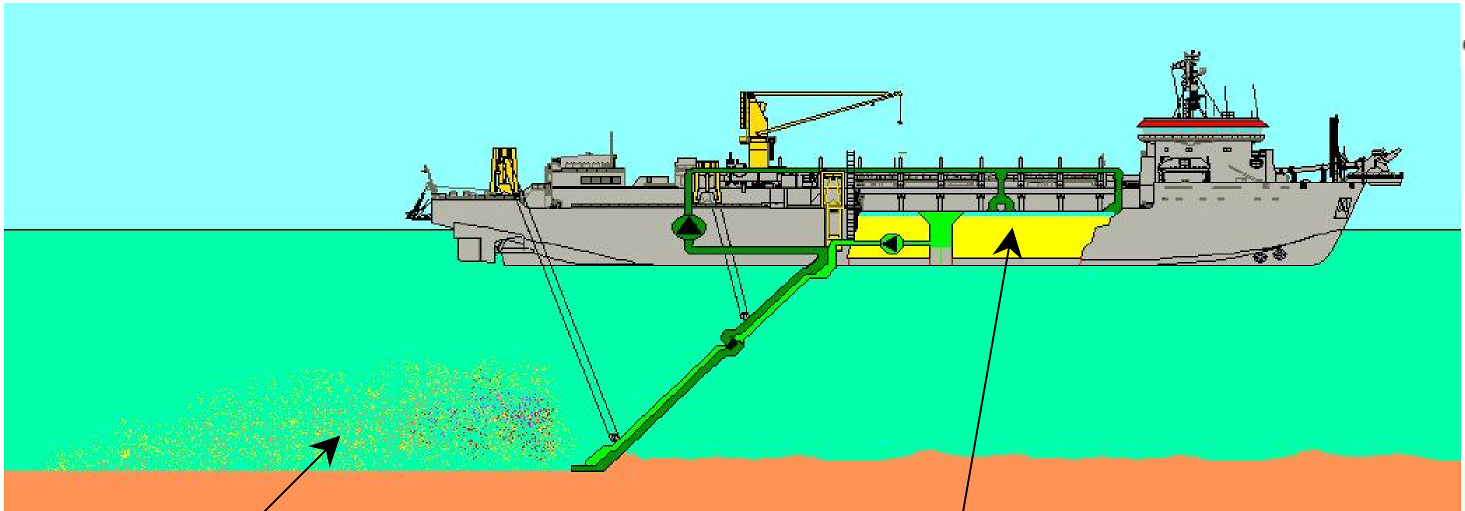
- density stream



- additional loading with <u>'green pipe'</u>



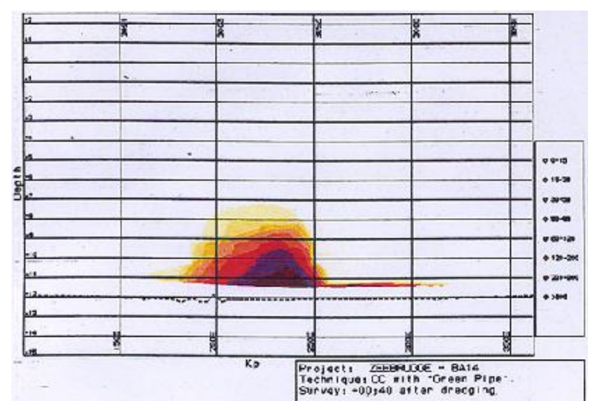
- plume generation while loading with <u>'green pipe'</u>



turbidity plume
dredge head and
'green pipe'

continue loading

New parameters :
- recirculation fluid



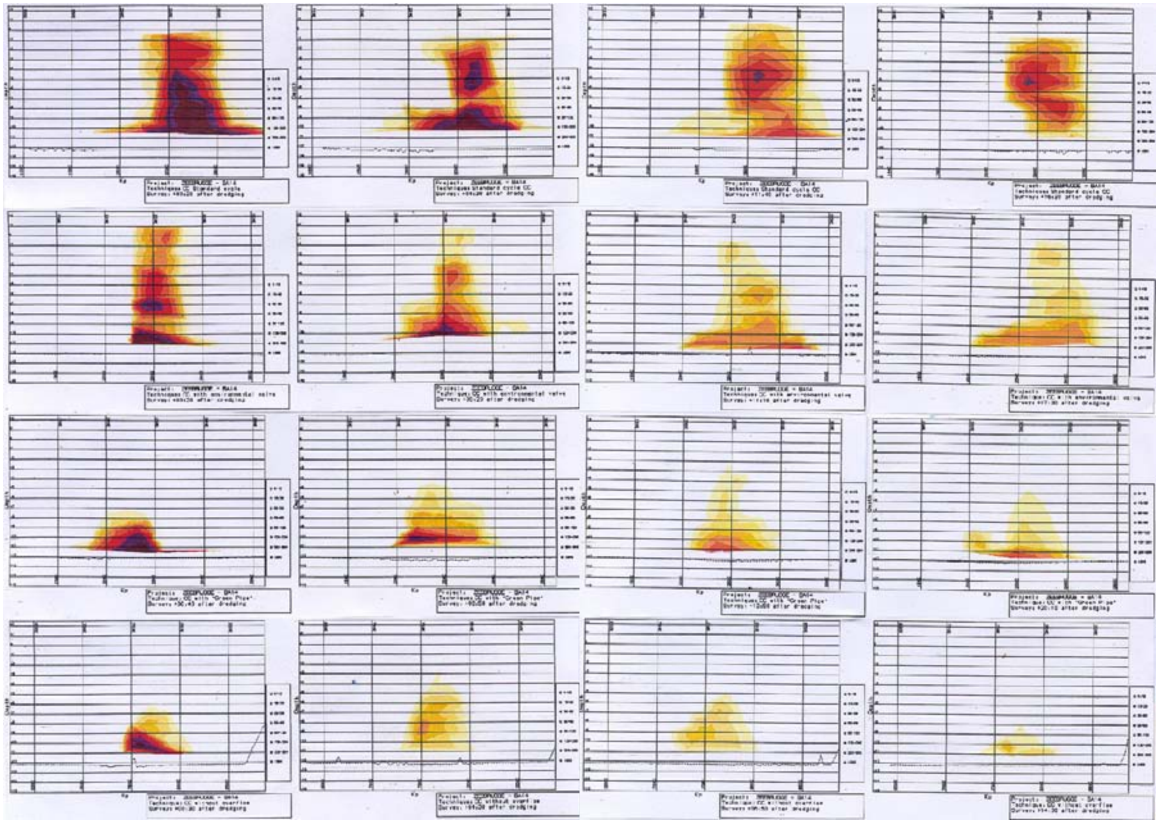
Comparison turbidity plume dispersion :

Standard overflow

Low turbidity valve

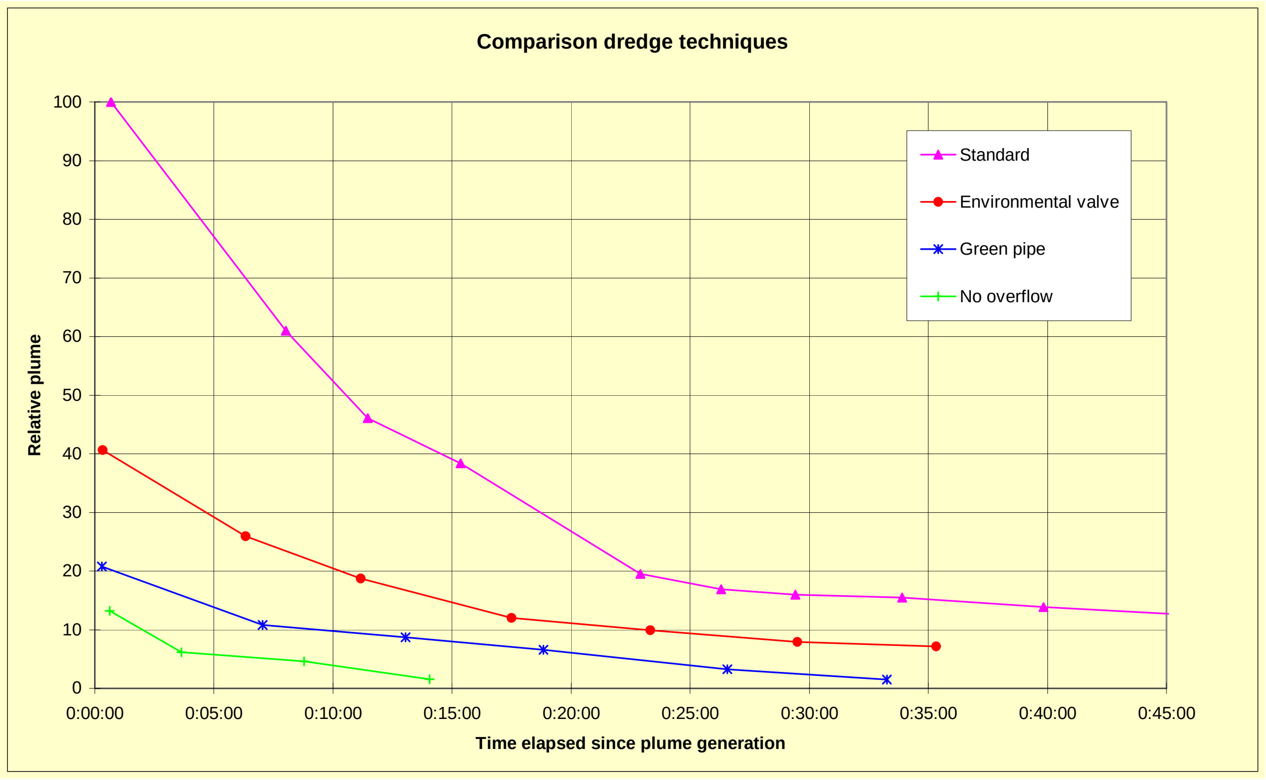
'Green pipe'

No overflow



Elapsed time : 00:30 05:00 10:00 15:00 min

Comparison dredge techniques :



Background turbidity :

HW - 4:00

HW - 3:00

HW - 2:00

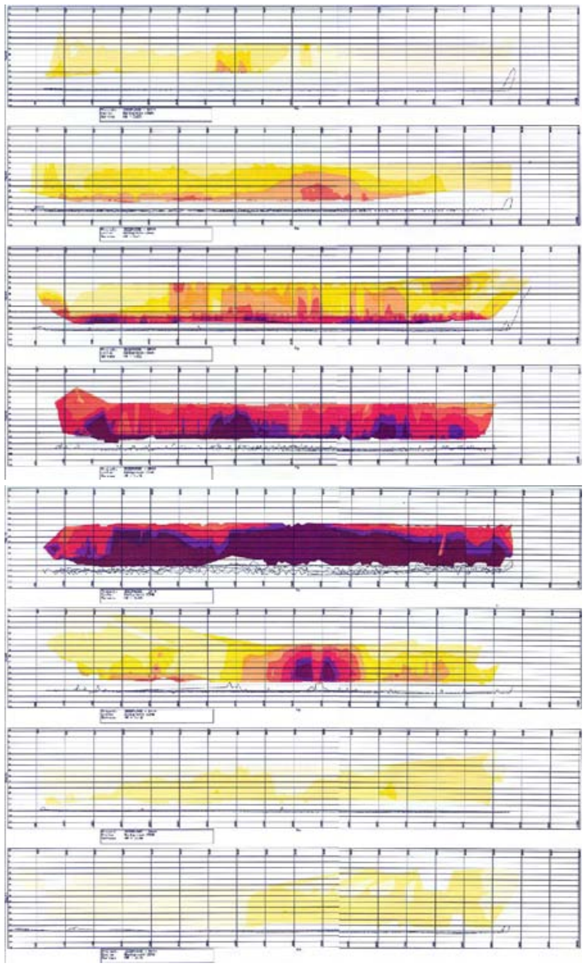
HW - 1:00

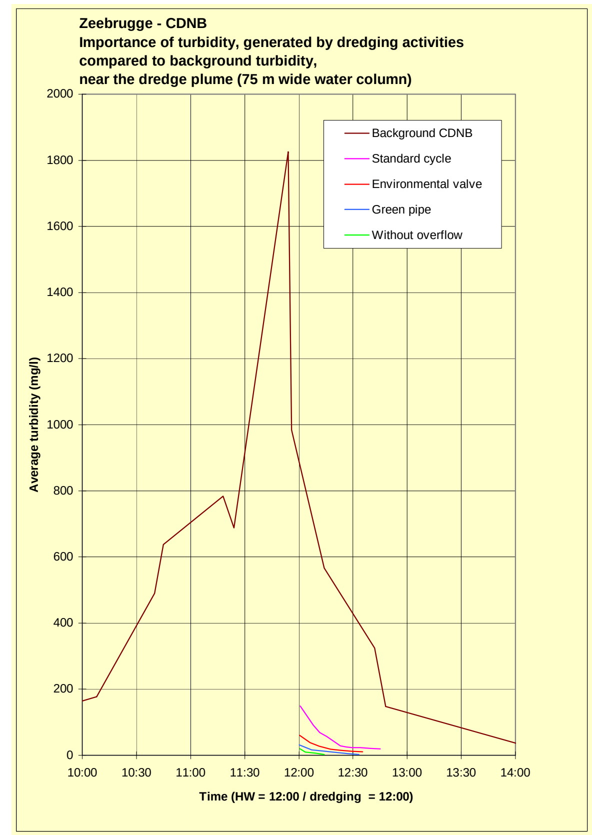
HW

HW + 1:00

HW + 2:00

HW + 3:00





Conclusions :

- **Plume generation relative to the plume generated during the dredge cycle with standard overflow :**

  - low turbitiy valve :   41 %
  - ‘green pipe’ : 21 %
  - without overflow : 13 %

- **Application of alternative dredging techniques is not relevant if the additional turbidity generated during the dredging works is only a fraction of the background turbidity .**

Turbidity plume generated during dredging operations with LTD 'Dirk Martens'

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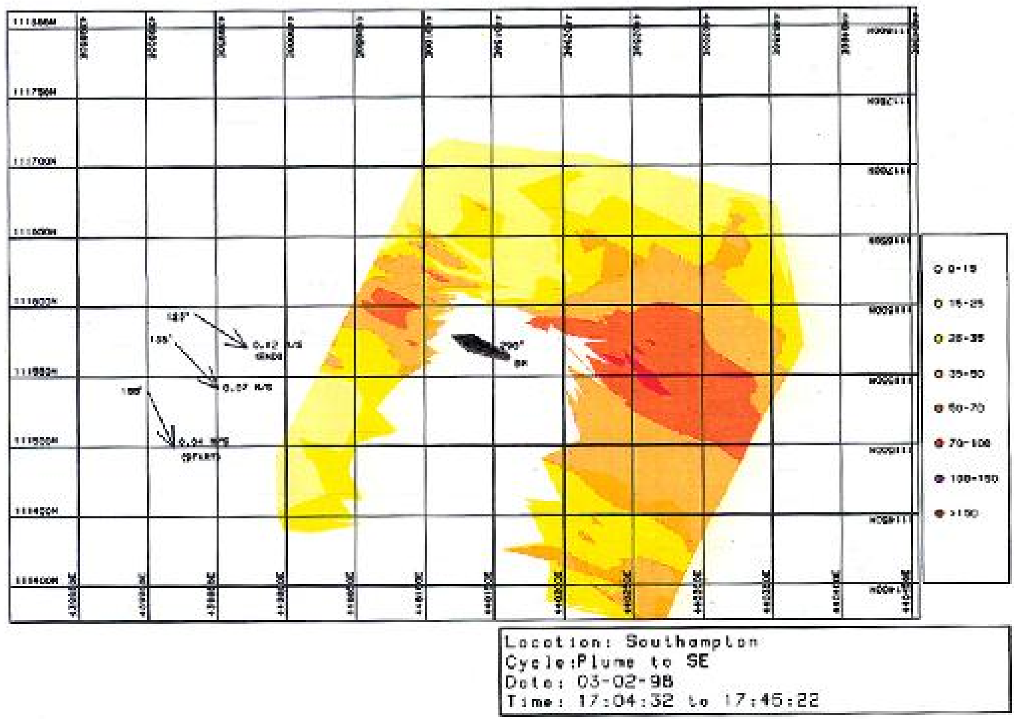
Performance evaluation aspects :

- Generated turbidity
- Secondary sources
- Background turbidity

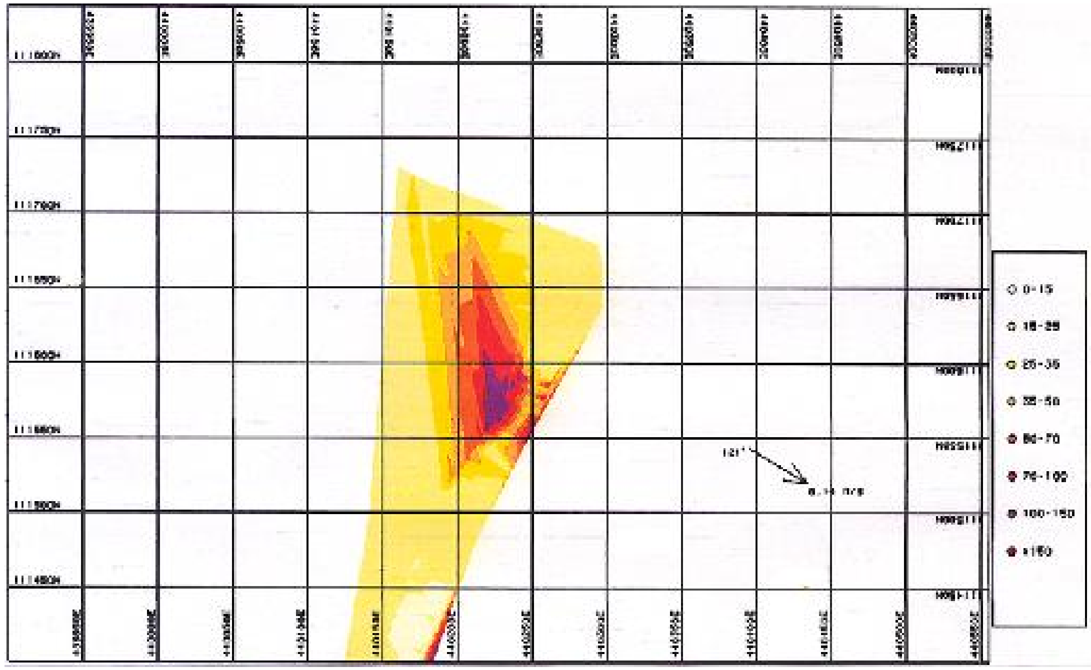
Generated turbidity :



Turbidity increase :

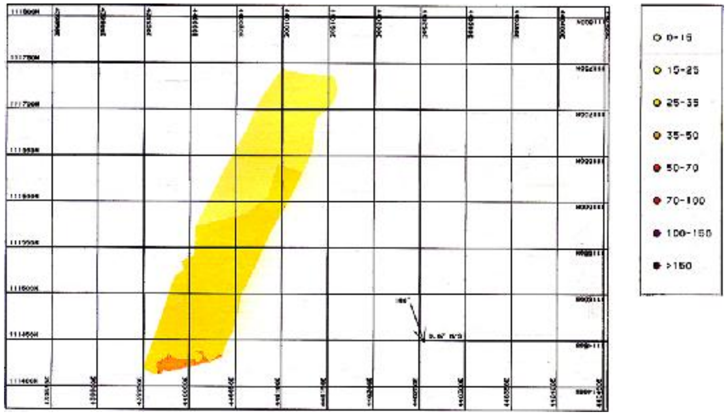
- **100 m from dredge location : average 16 mg/l - maximum 43 mg/l**
- **150 m from dredge location : average 11 mg/l - maximum 31 mg/l**
- **200 m from dredge location : average 6 mg/l - maximum 23 mg/l**

Secondary sources :

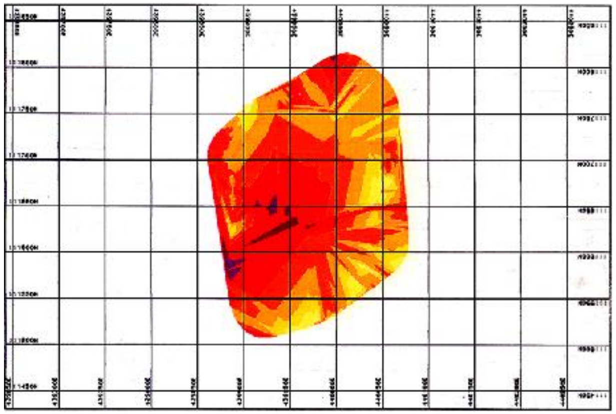


The turbidity increase caused by a manoeuvring vessel easily exceeds 150 mg/l.

Background turbidity :



10 - 50 mg/l during periods with low current speeds (< 0.1 m/s)



70 - 150 mg/l during periods with higher current speeds (0.1 - 0.3 m/s)

Conclusions :

With this dredging technique the amount of particles brought into suspension during the actual dredging has been reduced to such a level that, especially in shallow areas, secondary sources and background variations generate more turbidity then the dredgehead.

Appendix D

Workshop Details

- **Appendix D1** - Invite Letter To Attendees
- **Appendix D2** - List of Attendees
- **Appendix D3** - Workshop Agenda
- **Appendix D4** - Powerpoint Presentation Given At The Beginning Of The Workshop (See Enclosed CD)
- **Appendix D5** - Meeting Summary Notes By Jim Clausner, USACE

Appendix D1

Invite Letter
To Attendees

March 22, 2004

W.F. Baird & Associates Ltd.
2981 Yarmouth Greenway
Madison, WI 53711
Telephone: 608-273-0592
Fax: 608-273-2010

Baird

Re: MMS Contract 0103CT71516, Review of Existing & Emerging Environmentally Friendly Offshore Dredging Technologies

Dear Sir/Madam:

You are hereby invited to attend a workshop on the above noted project sponsored by MMS. Most of you will have already been informed of the workshop by Barry Drucker at MMS. The workshop will be held at the Days Hotel and Conference Center in Herndon, Virginia. We are planning sessions for the morning and afternoon of Thursday, April 1st and the morning of Friday, April 2nd. We will have time on Friday afternoon for further discussion if issues develop that need additional time. The hotel has set aside rooms for those attending from out of town. Reservations can be made by calling the hotel at 703-471-6700 and referencing the Baird conference. These reservations must be made by March 25th to take advantage of the conference rate ($109.00/day). The Hotel offers a complimentary 24-hour shuttle from Washington Dulles Airport.

Attached is a brief outline of the study with a tentative Workshop Agenda. We intend a full discussion on all agenda items but mostly focusing on Item 6, Item 7 and Item 8.

We look forward to your participation. Do not hesitate to contact us if you have any questions.

Sincerely,
W.F. Baird & Associates Ltd.

Rob Nairn, Ph.D., P.Eng.
Principal

File No. 10687

Appendix D2

List of Attendees

Name	Affiliation	Telephone	Email
Barry Drucker	MMS	703-787-1296	barry.drucker@mms.gov
Chris Spaur	USACE	410-962-6134	christopher.c.spaur@usace.army.mil
Tony Giordano	MMS	703-787-1283	anthony.giordano@mms.gov
Will Waskes	MMS	703-787-1287	will.waskes@mms.gov
Bill Hanson	GLDD	630-574-3469	whhanson@gldd.com
Bill Pagendarm	GLDD	630-574-2990	wfpagendarm@gldd.com
Nick Bray	Dredging Research, Ltd.	011 44 1483 860 731	nickbray@drl.com
Jim Clausner	USACE/ERDC	601-634-2009	James.E.Clausner@erde.usace.army.mil
Doug Clarke	USACE/ERDC	601-634-3770	Douglas.G.Clarke@erdc.usace.army.mil
Shawn Alam	MMS	703-787-1690	Shawn.Alam@mms.gov
Maureen Bornholdt	MMS	703-787-1300	maureen.bornholdt@mms.gov
Keith Good	MMS	703-787-1052	keith.good@mms.gov
Roger Amato	MMS	703-787-1282	roger.amato@mms.gov
Ancil Taylor	Bean Stuyvesant	504-587-8600	ataylor@efbean.com
Rob Nairn	Baird & Associates	905-845-5385	rnairn@baird.com
Tim Kenny	Baird & Associates	608-273-0592	tkenny@baird.com
Jacqui Michel	Research Planning, Inc.	(803) 256-7322 x 329	jmichel@researchplanning.com

Appendix D3

Workshop Agenda

WORKSHOP AGENDA
Review of Existing and Emerging Environmentally
Friendly Offshore Dredging Technologies
April 1st and 2nd, 2004

Sponsored by Minerals Management Service, US Dept of the Interior

W.F. Baird & Associates has been retained by the U.S. Department of the Interior, Minerals Management Service (MMS) to conduct studies relative to the mining of sand for beach nourishment and construction aggregates. The borrow areas are located on the Outer Continental Shelf (OCS) under Federal jurisdiction.

The United States Government, and specifically, the MMS, a bureau within the U.S. Department of the Interior, has jurisdiction over all mineral resources on the Federal OCS. The MMS has the authority to convey, on a noncompetitive basis, the rights to OCS sand, gravel, or shell resources for shore protection, beach or wetlands restoration projects, or for use in construction projects funded in whole or part or authorized by the Federal Government. MMS has provided Federal sand for beach nourishment projects in New Jersey, Maryland, Virginia, Florida, South Carolina, and Louisiana.

Offshore sand-dredging for beach nourishment projects employ hydraulic dredges almost exclusively and are normally either cutterhead or hopper dredges. The process may result in adverse effects on various components of the marine or coastal environment.

The offshore-dredging industry is constantly changing as the industry strives to make operations more efficient. New advances in offshore-dredging technology are leading to more environmentally-sensitive offshore operations. Researchers are actively increasing the knowledge base relative to physical processes involved in dredging procedures. Physical and mathematical modeling of these processes is being conducted with the aim to reduce the negative environmental aspects (biological and physical) associated with the offshore removal of sand. New dredging technologies being used overseas are contemplated for work on the OCS.

As the Federal agency responsible for regulation of OCS sand resources, the MMS must ensure that sand and gravel dredging operations conducted under its jurisdiction are conducted in a safe and environmentally-sound manner. This may, in some instances, entail the required use of particular dredging equipment or techniques. Thus, MMS must have sound knowledge of the most current dredging technologies available.

The objective of the study is to review and analyze dredging equipment and projects on a worldwide basis to identify both existing and emerging dredging technologies that aim to lessen or avoid potential adverse effects on the offshore biological and physical environment.

Contacts were made with Federal and State natural resources agency staff and others involved in research on the impacts of dredging, studies of the life history of special species of concern, and permit approvals to determine the direct and indirect impacts that are of greatest concern for dredging operations in the OCS. Recent MMS-sponsored reports and environmental assessments on dredging impacts in the OCS were also reviewed. This identification of the perceived environmental impacts of greatest concern will be used to evaluate the advances in dredging techniques and equipment to measure their success in reducing the degree of such impacts.

The prioritized list of perceived concerns from OCS dredging operations on marine biological and physical resources is shown below.

1. <u>Short-term and cumulative impacts from dredging that lead to loss or reduced stability of benthic habitats, including recolonization by an altered biological community</u>. All resource managers raised this concern. The greatest concern was in known benthic-associated fishery areas, such as the surf clam fishery off New Jersey and the shrimp fishery in the Gulf of Mexico. There was less concern in areas of general biological productivity or dynamic processes, such as in South Carolina.

2. <u>Injury and death of special species of concern (e.g., Sea Turtles) from being sucked into the draghead or cutterhead during dredging operations</u>. This concern was raised by every Federal agency with management responsibility for T&E species. Most agency staff thought the existing stipulations were effective, but even a single "take" was considered a significant impact.

3. <u>Changes in the substrate characteristics (grain size, dissolved oxygen, compaction and organic content) that lead to a reduction in benthic communities AND suitability of the area for future dredging</u>. This concern was identified in South Carolina where 3- to 40 meters of sediment was removed. The depressions persisted for many years and filled with fine-grained sediments.

4. <u>Changes in bathymetry that can alter the wave climate reaching the shore</u>. The importance of this concern varied by region. Where the OCS sand bodies were close to shore and/or shallow enough to influence the wave climate, there was high concern regarding the potential for increased shoreline erosion. The orientation, depth, and shape of the sand body and borrow areas should be considered in evaluating the impact of dredging on wave climate.

5. <u>Damage to hardbottom habitats: physical damage during dredging; burial by suspended sediment during dredging; and altered sediment processes that</u>

could bury hardbottom. This issue was of concern when dredging smaller sand bodies in between hardbottom habitat, even though these areas are supposed to be avoided.

6. Creation of depressions and furrows from removal of substrate. Though MMS has a “no pits” stipulation, there was still concern that furrows might interfere with bottom fishing. At least one responder thought that the furrows acted as recruitment sources, supporting the idea of leaving strips of undredged areas.

7. Short-term increased turbidity from cutterhead or draghead and overflow from hoppers on benthic species. Most responders assumed that OCS dredging occurred in sandy substrates, thus turbidity would be short-term and animals would avoid turbid areas. However, turbidity might be more of a concern in areas where a fine-grained overburden has to be removed to access the coarser sediment. This impact could also include burial by sedimentation from fallout of the plume.

8. Spatial and seasonal conflicts between dredging and commercial and recreational fisheries.

9. Potential to break an active or abandoned pipeline, resulting in a release of petroleum.

10. Collisions with marine mammals and Sea Turtles during vessel operations.

11. Damage to archaeological resources.

Our current study is focused on Atlantic and Gulf Coast sand borrow sites. The sites range from 5 kilometers to 20 kilometers offshore. The water depth at these sites varies from 5 meters to 25 meters deep. The material to be dredged for borrow is assumed to be sand with an average grain-size of 0.30 mm and less than 10% passing the 200 sieve. As a part of this study, we are reviewing the current scientific data to determine which of the perceived concerns enumerated above are real and need to be addressed.

We have distributed a survey to the Dredging Contractors in the United States and Europe, who mine sand from offshore borrow sites for aggregates and beach renourishment. We have also sent the survey to the Corps of Engineers Hopper Dredge Operations in Portland. The questions for the survey were based on the information developed during the literature review portion of the study. There are twenty-three questions in the survey meant to elicit comments relative to the perceived impacts enumerated above. The questions fall into the broad categories of plume related impacts, impacts to benthic habitats, dredge/marine mammal collisions and related questions. Please see attached list of questions. We anticipate receiving comments from the Contractors and Corps within the next week. Once the comments are received they will be summarized in preparation for the Workshop.

The Workshop is intended to provide a forum for the interested parties to review the data and opinions collected to date. It is hoped a discussion of the issues will provide a clear direction for the remainder of the study. The goal is to provide MMS with recommendations on the feasibility and performance of existing and emerging dredging technologies that reduce the adverse environmental impacts of dredging on the Outer Continental Shelf.

A tentative agenda for the Workshop follows. Once we have reviewed the Contractor survey results, we will allocate times to the agenda that reflect the relative interest in the different issues. There will be a full discussion of all agenda items with a focus on Items 6, 7, and 8.

AGENDA

1. Introduce background of the project and objectives

2. Review of Perceived Environmental Impacts of Dredging (US perspective)

3. Summary of Known Impacts Related to Offshore Dredging (US/UK/International perspective)

4. Current Efforts to Mitigate by Stipulation (US Perspective)

5. Review of Contractor's Survey (US, European and Worldwide)

6. Environmentally Friendly Technologies Related to Offshore Dredging (from Contractors Survey and Literature Survey)

7. Assessment of Effectiveness of New Technology for Offshore Work

8. Recommendations – Which technologies are feasible and effective, what is the cost implication of these, if any. Methods to implement promising technologies.

Appendix D4

Powerpoint Presentation Given
At The Beginning Of The Workshop

(See Enclosed CD)

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Review of Existing and Emerging Environmentally-Friendly Offshore Dredging Technologies

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Workshop to Develop Recommendations

April 1, 2004

Baird – RPI – DRL - MES

Workshop Outline

- Introduction to project and objectives 830 - 915
- Review perceived impacts 915 - 1000
- Literature survey and questionnaires 1015 - 1130
- Current efforts to mitigate by stipulation 1130 - 1215 + pm
- Appropriateness, effectiveness and practicality
- Recommendations and summary

Team Members and Workshop Participants

- Baird & Associates
- Research Planning, Inc.
- Dredging Research Ltd
- Marine Ecological Surveys
- MMS, USACE, dredging contractors and consultants

Goals and Objectives

- Evaluate dredging equipment and processes on a worldwide basis to identify existing and emerging technologies that aim to reduce or avoid potential adverse impacts on the offshore biological and physical environment
- Develop recommendations for an implementation strategy for promising equipment or approaches

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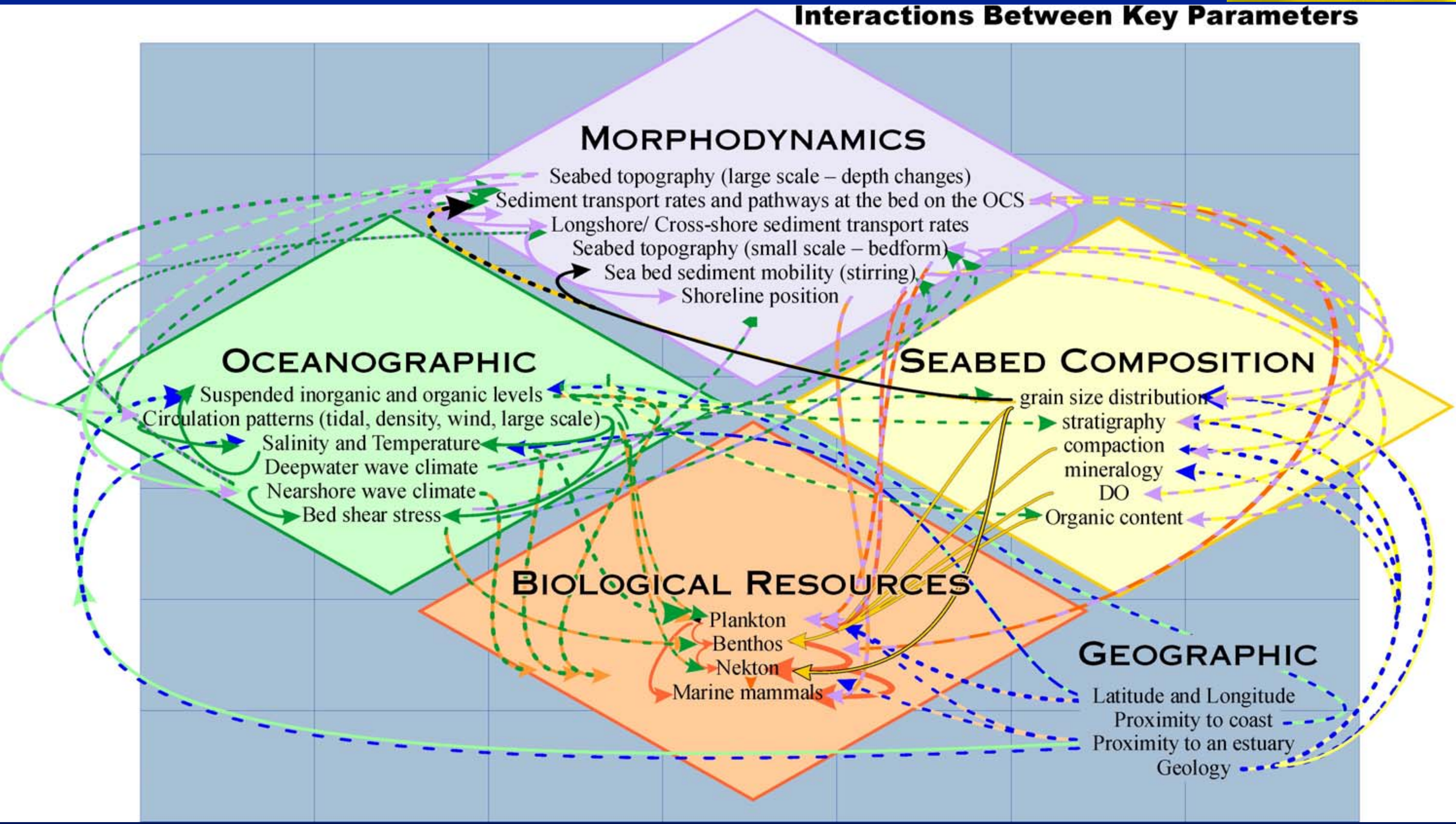
Understanding the Impacts

- UK/Worldwide and US state of understanding reviews
- Real vs. perceived is really a matter of sensitivity of receptor to impact
- Knowledge is rapidly developing on impacts (mostly through monitoring, also modeling)

Physical and Biological Environment



Physical and Biological Impacts

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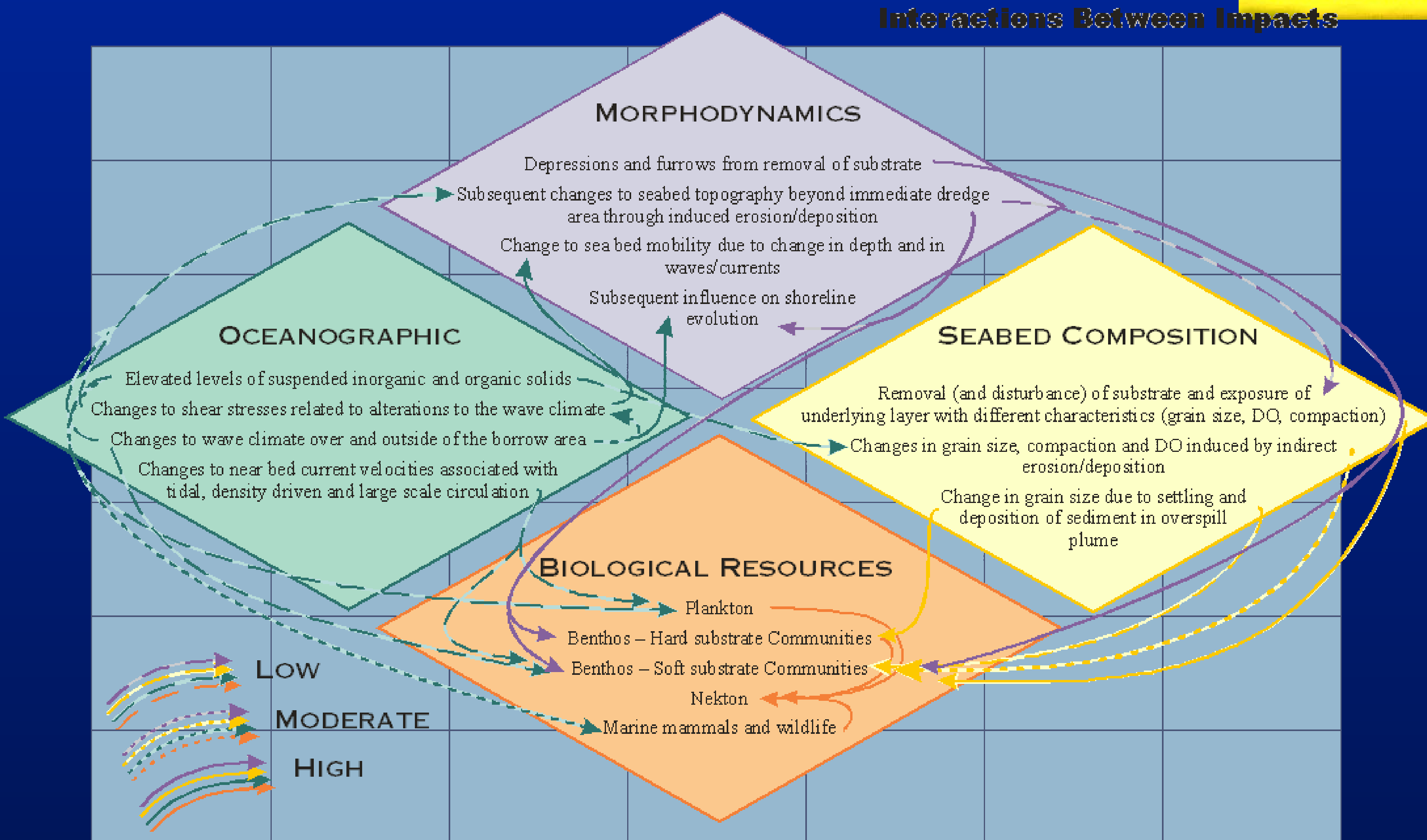

Environmentally-Friendly Technologies

- Literature surveys (scientific publications, industry periodicals, etc.) were completed in US and UK (latter with worldwide focus)
- Two questionnaires were issues, one from the US (MMS sponsored) and the other from UK (MIRO sponsored)

Stipulations Current and Future

- Review existing legislation, stipulations, guidelines and best practices, US and overseas
- The primary focus of current stipulations in the US are measures to protect turtles, mammals, pipelines and arch resources
- This project will provide recommendations to revise, refine, add

Evaluation of Possible Techniques

- Appropriateness, effectiveness and practicality
- Appropriate: consider sensitivity of the receptor to impact and relative improvement
- Effectiveness: how well does the proposed measure work?
- Practicality: feasibility of implementation, cost to the dredging process (capital and maintenance)

Summary and Recommendations

- Matrix of physical and biological impacts and related environmentally-friendly approaches
- Summary of appropriateness, effectiveness and practicality of each
- Propose guidelines and stipulations

Purpose of this Workshop

- Discussion of real vs. perceived issues
- Discussion of environmentally-friendly technologies and approaches
- Evaluation of appropriateness, effectiveness and practicality of existing and new technologies/approaches

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Framework for Evaluating Environmental Impacts from OSC Sand Dredging

1. KNOW impacts are small or recovery is quick – No action is necessary
2. KNOW impacts are not small or recovery is slow – Take actions to minimize impacts and speed recovery
3. UNCERTAIN if impacts are small or recovery is quick – Take actions, monitor results, revise actions

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PERCEIVED ENVIRONMENTAL IMPACTS FROM OCS DREDGING ON MARINE BIOLOGICAL AND PHYSICAL RESOURCES

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Impact # 1: Benthic Habitats

- Short-term and cumulative impacts from dredging that lead to reduced biological productivity of benthic communities

- All resource managers raised this concern. The greatest concern was in known benthic-associated fishery areas, such as the surf clam fishery off New Jersey and the shrimp fishery in the Gulf of Mexico. Less concern in areas of general biological productivity or dynamic processes.

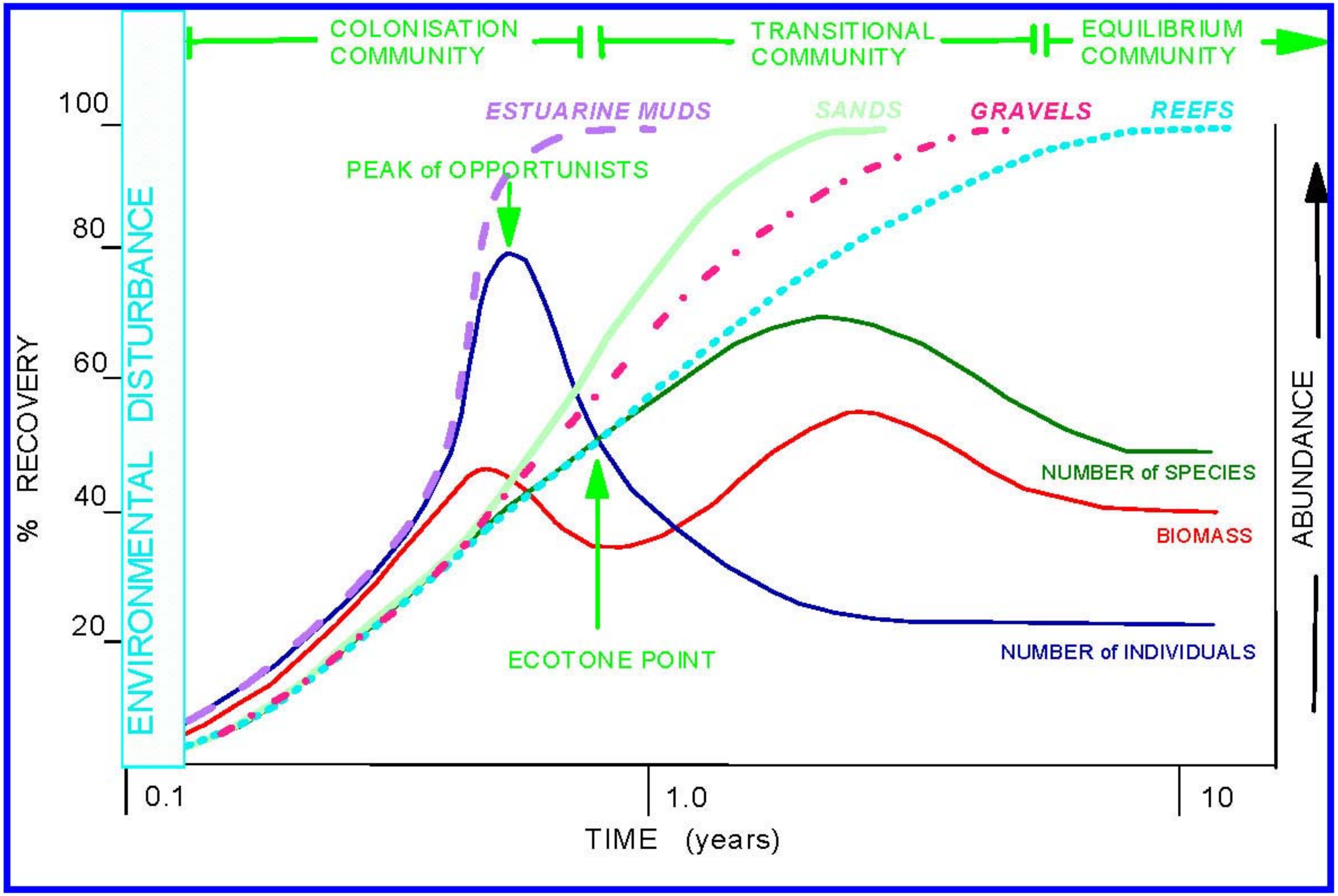

Figure 10. Schematic diagram showing the likely recolonisation rates for the benthic community of estuarine muds, sands, gravels and rocky reefs. Based on Newell *et al*, (1998).

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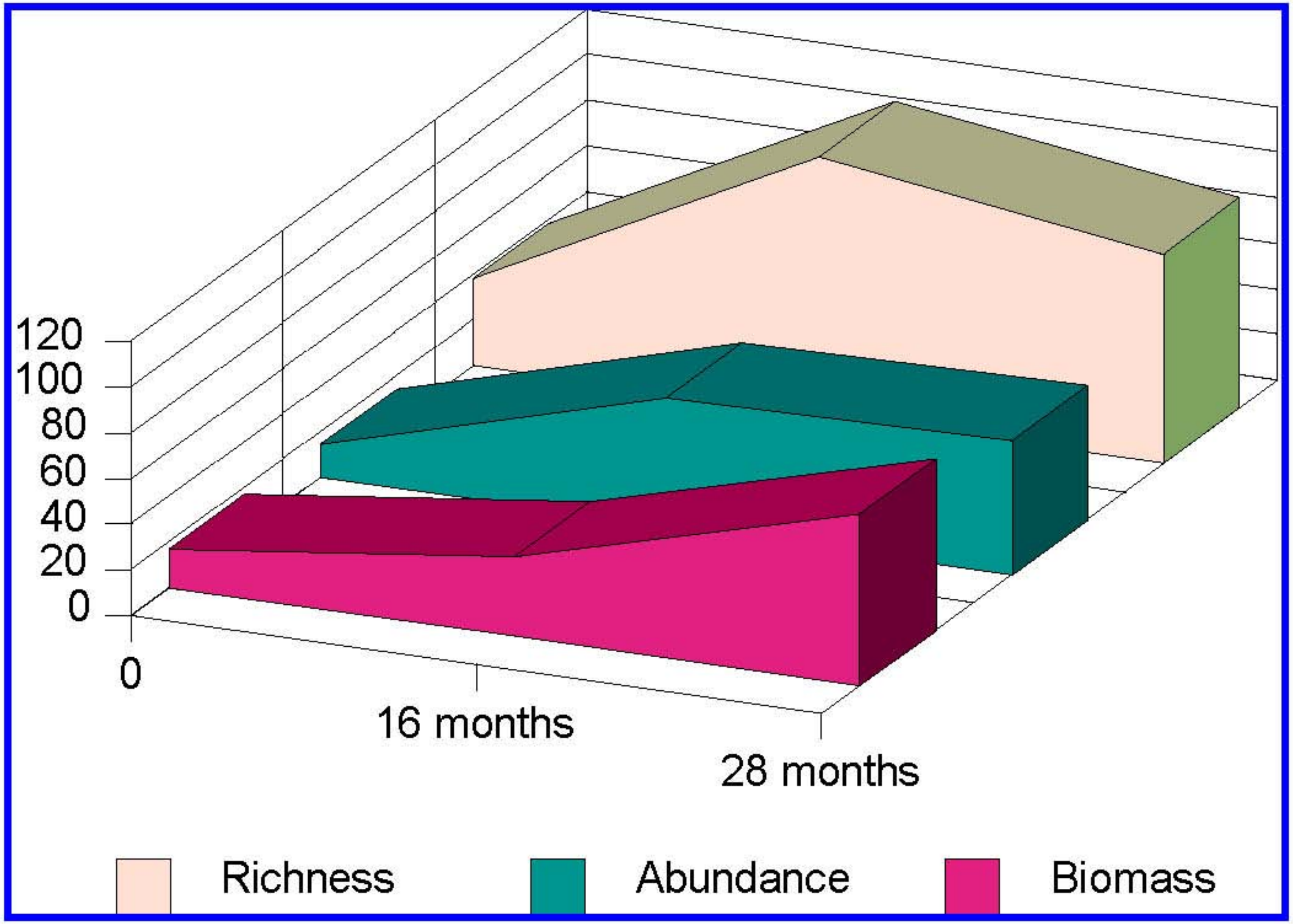


Figure 11. Diagram showing the percent recovery of species richness, abundance and biomass of benthic fauna following cessation of dredging at a site off Dieppe, France. Based on Desprez (2000).

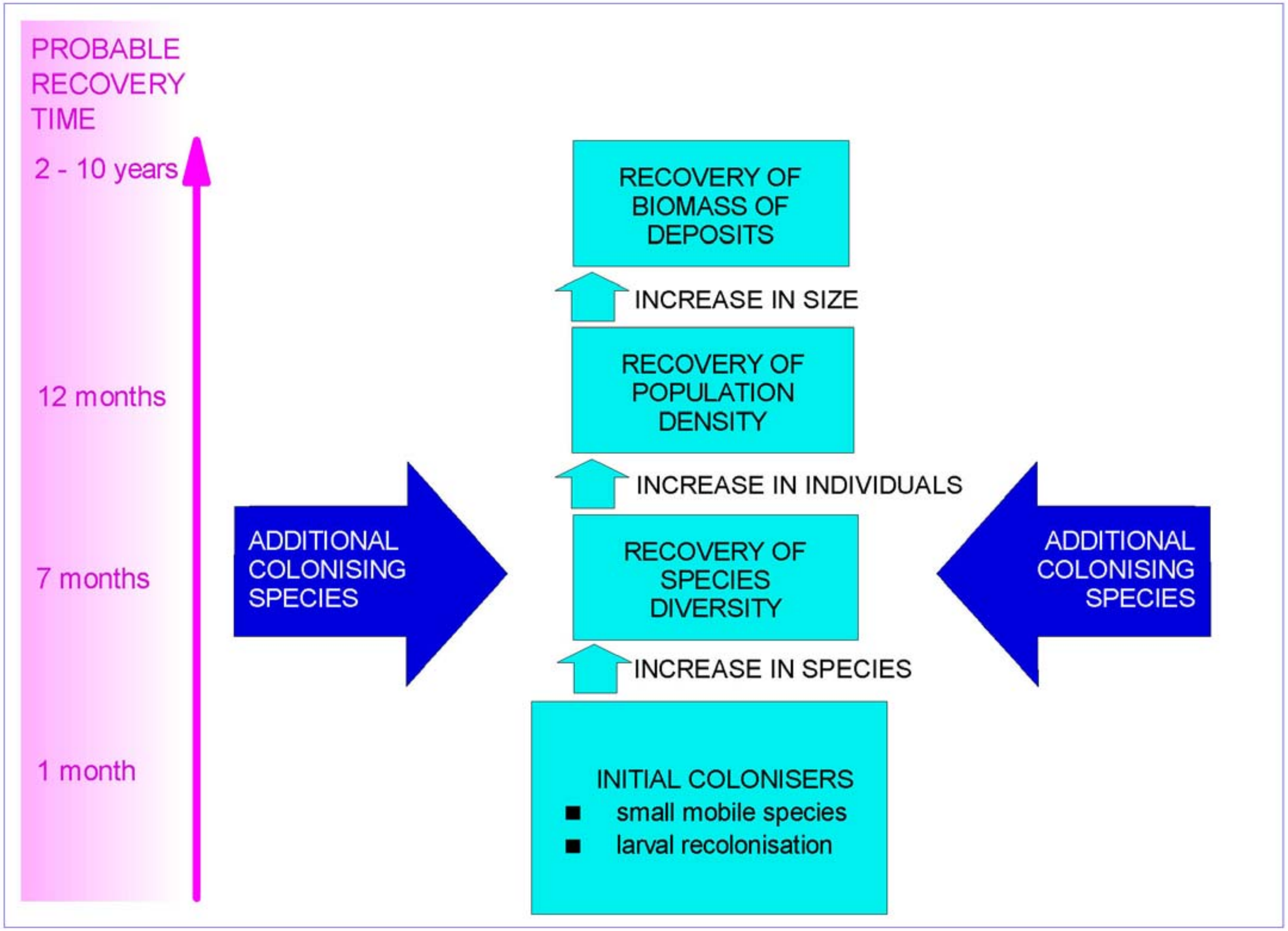


Figure 12. Generalised sequence showing the nature and rate of recolonisation of benthic macrofauna in coastal deposits following cessation of dredging. This sequence is applicable only to mobile sandy gravels. Note that the recovery of long-lived components of the community can take more that 10 years in stable coarse deposits. Based on Newell *et al*, 2001b; see also Hitchcock *et al*, 2002.

Impact # 2 : Sea Turtles

Loggerhead - Threatened

Green - Endangered populations in Florida; others are listed as Threatened

Leatherback - Endangered

Kemp's ridley - Endangered

Hawksbill - Endangered

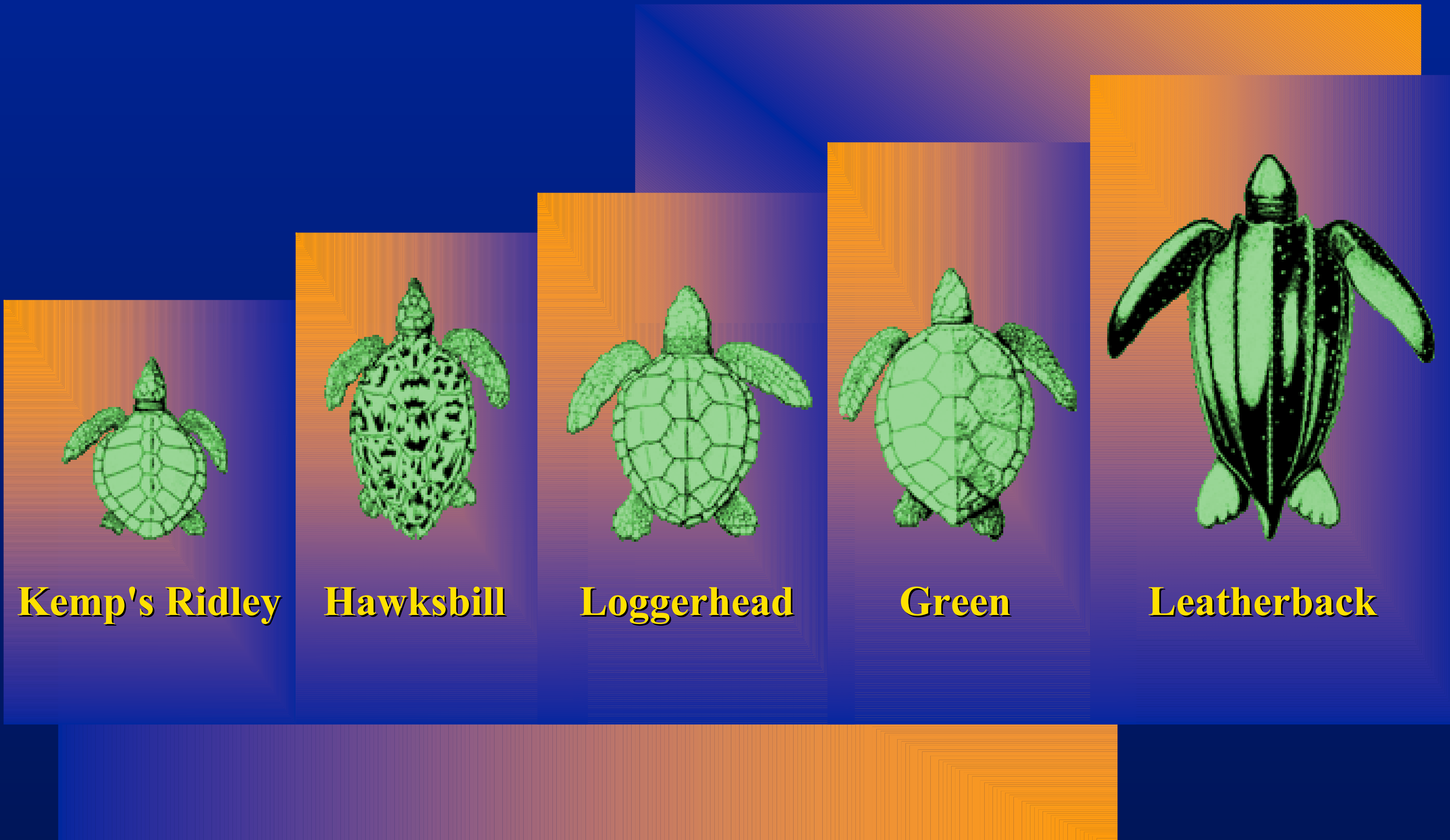
Green

Hawksbill

Leatherback

Loggerhead

Kemp’s ridley


Kemp's Ridley
Hawksbill
Loggerhead
Green
Leatherback

Impact # 2 Turtles: Documentation

Sea Turtle "Takes" 1995-2003 (Channel Dredging)

Galveston	31	
New Orleans	39	(most in MR-GO)
Mobile	0	(only required observers and screening in 2002)
Jacksonville	6	

NMFS: even with observers/deflectors/relocation, documented takes = 50% of actual

Impact # 2 Turtles: Documentation

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Sea Turtle "Takes" from Sand Dredging

Bouge Bank, NC	5	12/01-04/02
Bouge Bank, NC	1	2003
Myrtle Beach, SC	11	1997-99
Canaveral Shoals	1	2001

None reported in the Gulf of Mexico

Impact # 3: Changes in Substrate Characteristics

- Changes in the substrate characteristics (grain size, dissolved oxygen, compaction and organic content) that lead to a reduction in benthic communities and suitability of the area for future dredging.

- This concern was identified in South Carolina where 3-4 meters of sediment were removed. The depressions persisted for many years and filled with fine-grained sediments (van Dolah study).

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Impact # 4: Bathymetry Changes

- Changes in bathymetry that can alter the wave climate reaching the shore.

- The importance of this concern varied by region. Where the OCS sand bodies were close to shore and/or shallow enough to influence the wave climate, there was high concern about the potential for increased shoreline erosion.
- Modeling studies have been used to predict impacts; need to determine what changes are “significant”

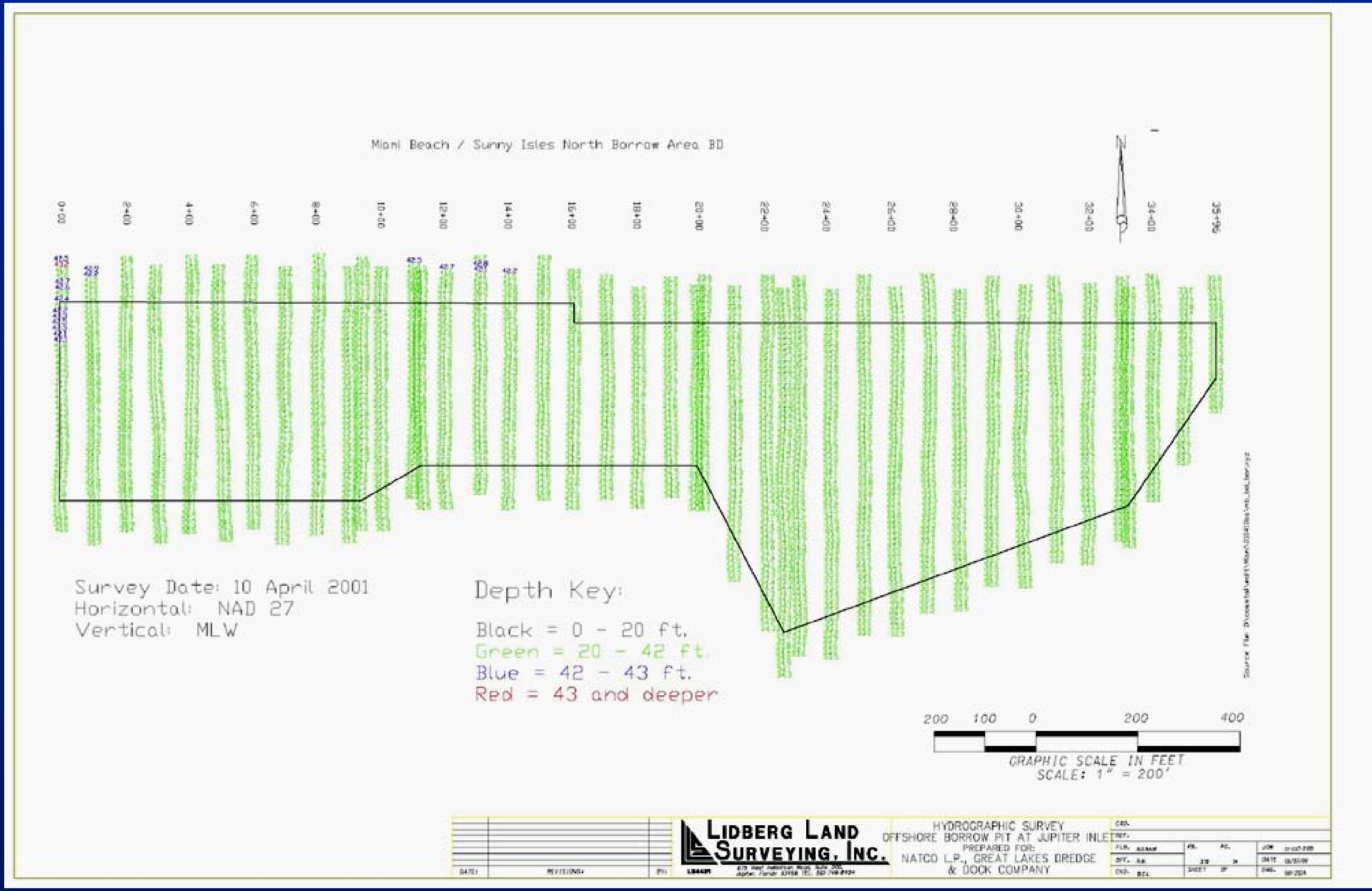
Impact # 5: Hardbottom Habitats

- Damage to hardbottom habitats: Physical damage to during dredging; burial by suspended sediment during dredging; and altered sediment processes that could bury hardbottom.

- Of concern when dredging sand in hardbottom habitat
  - Highest along the Florida coast
  - Growing awareness that hardbottom habitats are also common along the mid-Atlantic coast, though not likely in OCS sand borrow sites

Impact # 6: Depressions and Furrows

- Creation of depressions and furrows from removal of substrate that might interfere with bottom fisheries
  - Rate of infilling by sedimentation or slumping of the sides will be site-specific
  - No existing data on whether fisheries have actually been impacted



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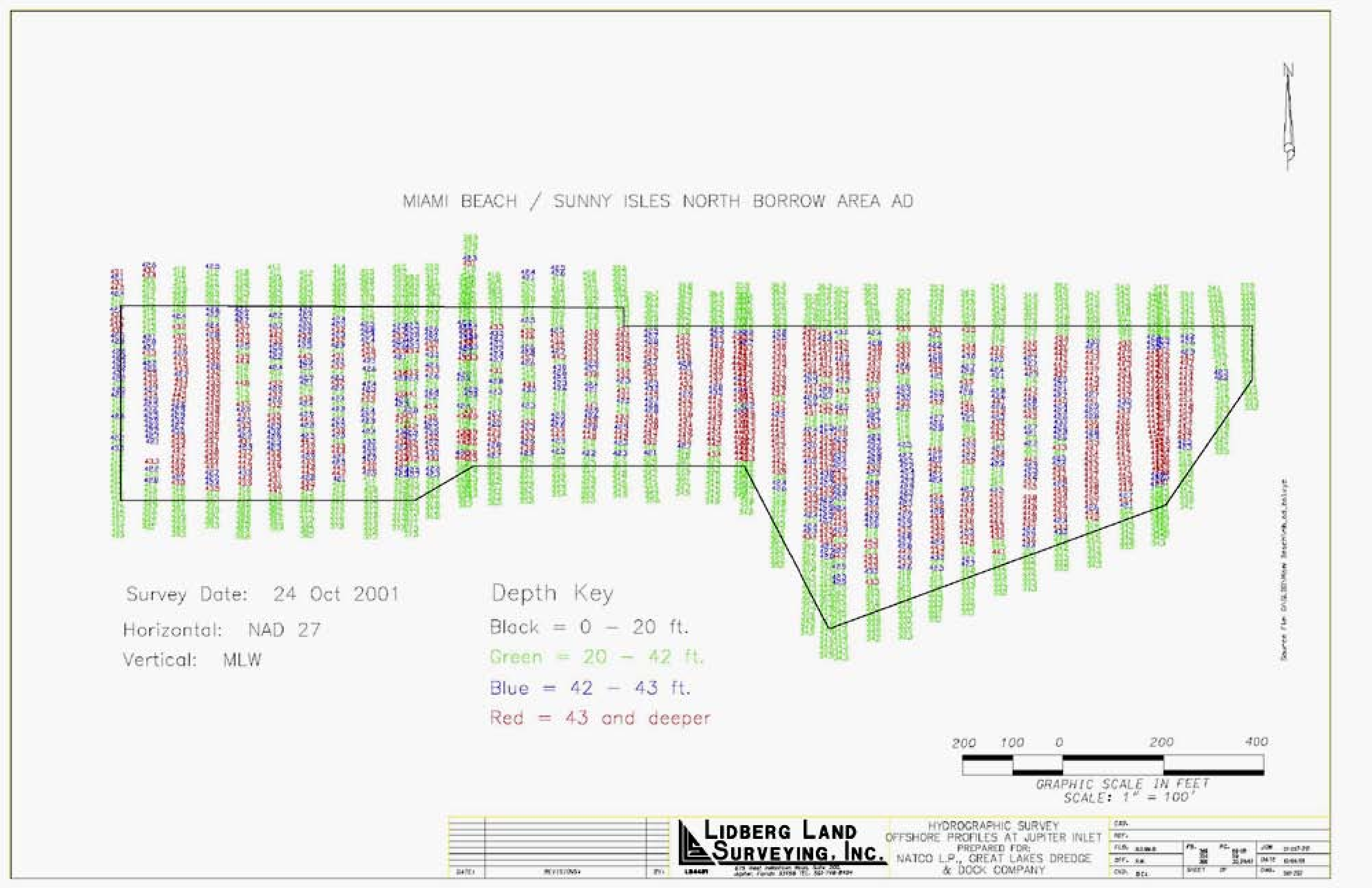

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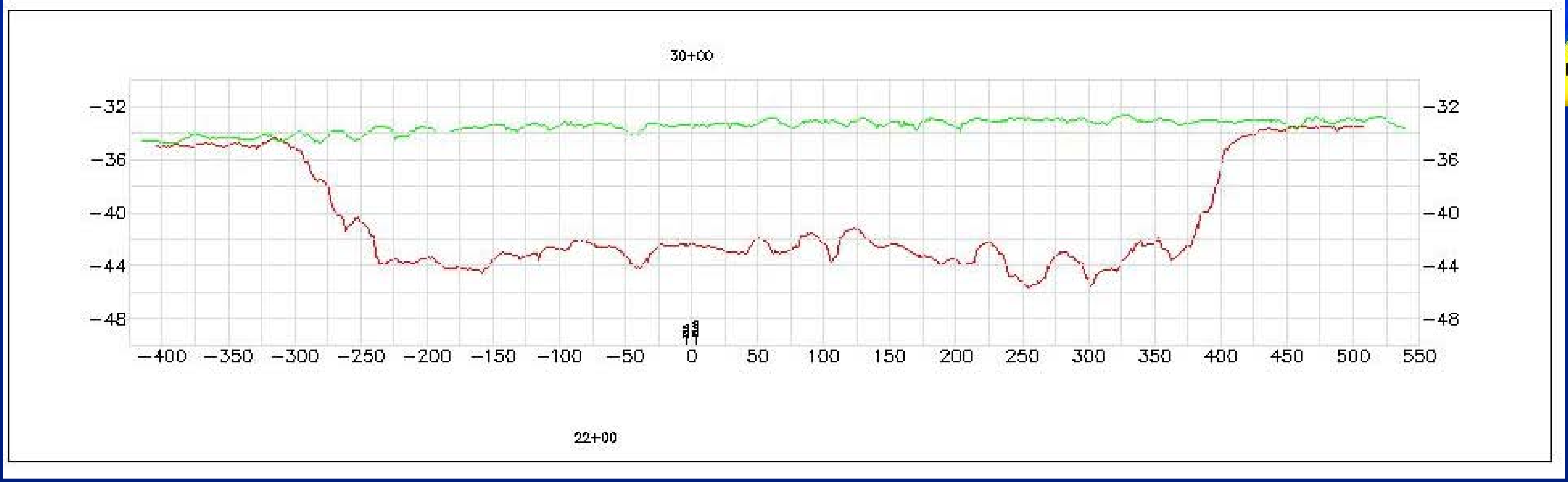
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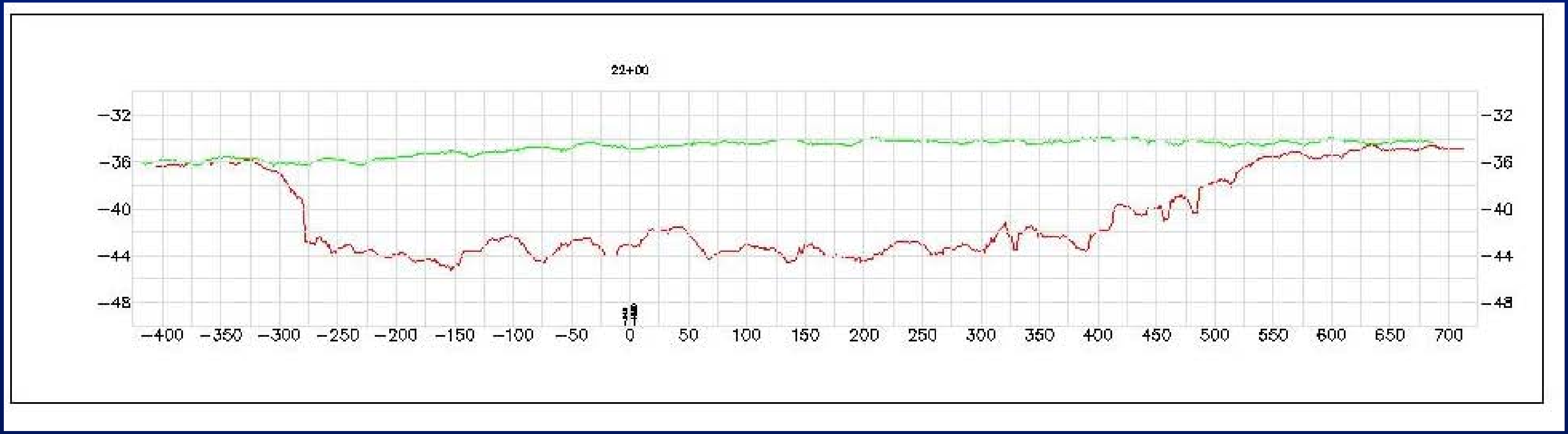
22+00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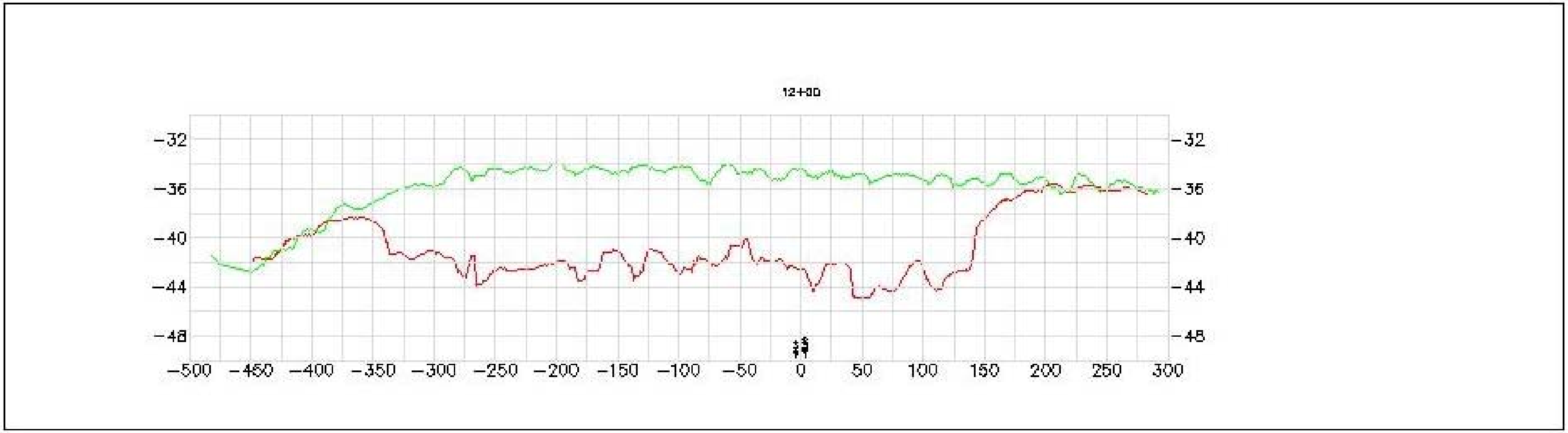

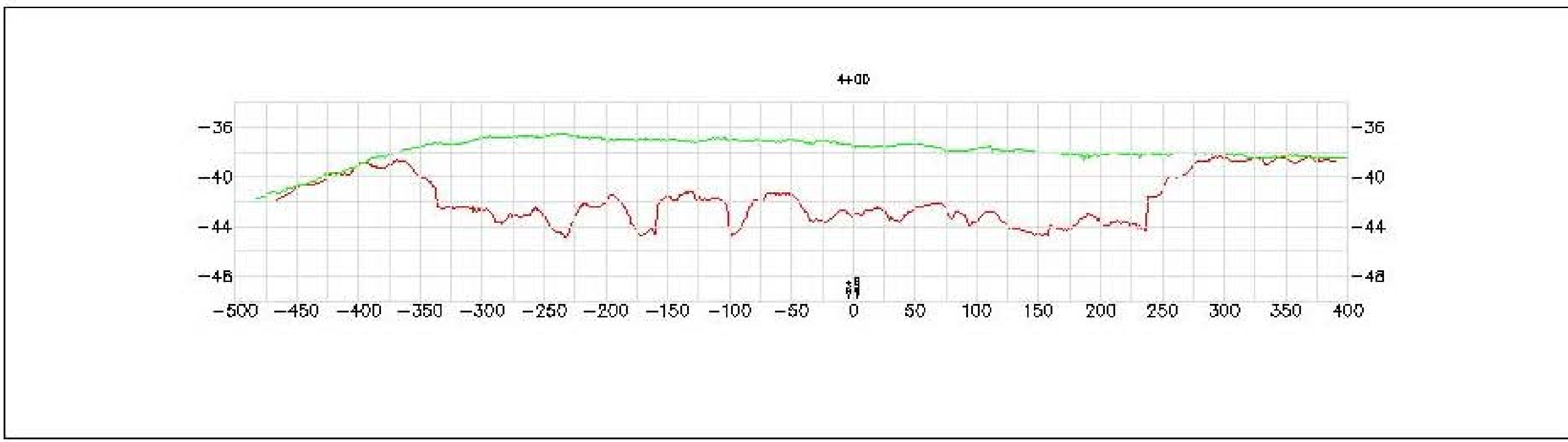

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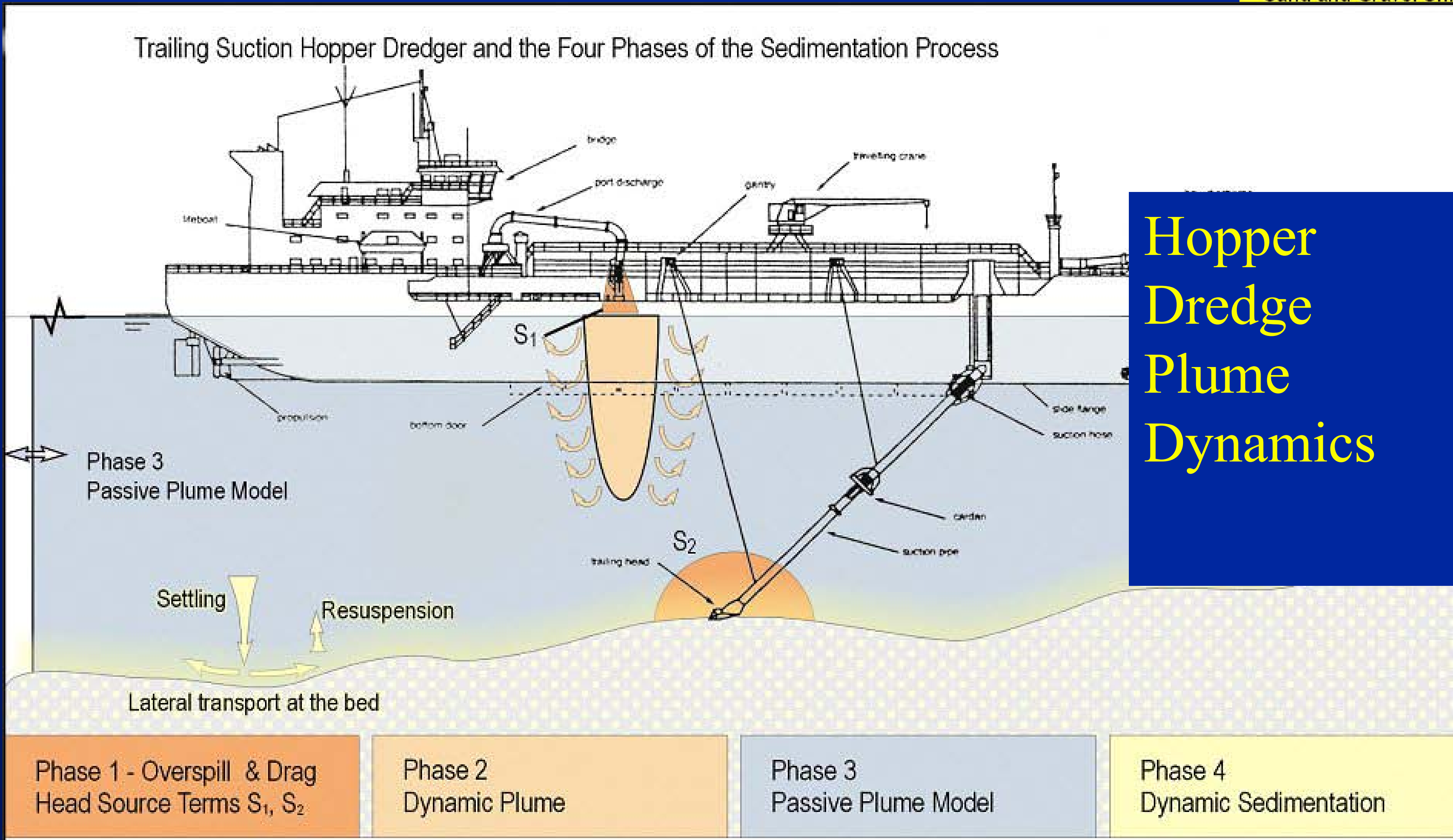
Impact # 7: Turbidity

- Short-term increased turbidity from cutterhead or draghead and overflow from hoppers on benthic species.

- Assume that OCS dredging occurs in sandy substrates, thus turbidity is short-term/avoidable. May be of concern where a fine-grained overburden has to be removed
- Extensive studies of sand and gravel sites in the UK

Hopper Dredge Plume Dynamics



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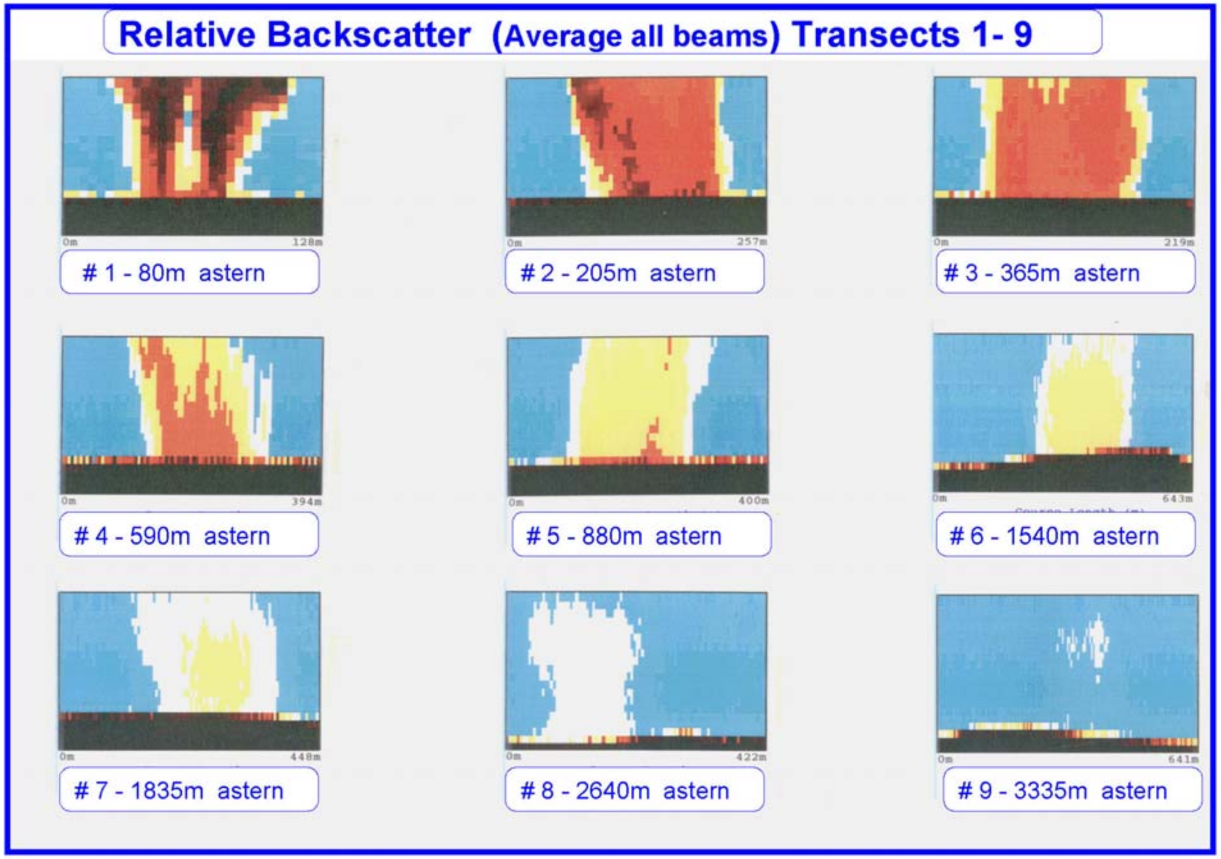

Figure 1. Acoustic Backscatter images across the plume at varying distances downstream of an anchor-dredger during loading of a screened cargo at Owers Bank off the south coast of UK. Based on Hitchcock & Drucker (1996). The black band at the seabed is a data corruption zone which precluded assessment of plume morphology at the sediment-water interface. The red signal indicates coarse sand-sized particles; the yellow signal indicates the settlement of silt; and the white signal is considered to represent organic flocculating material.

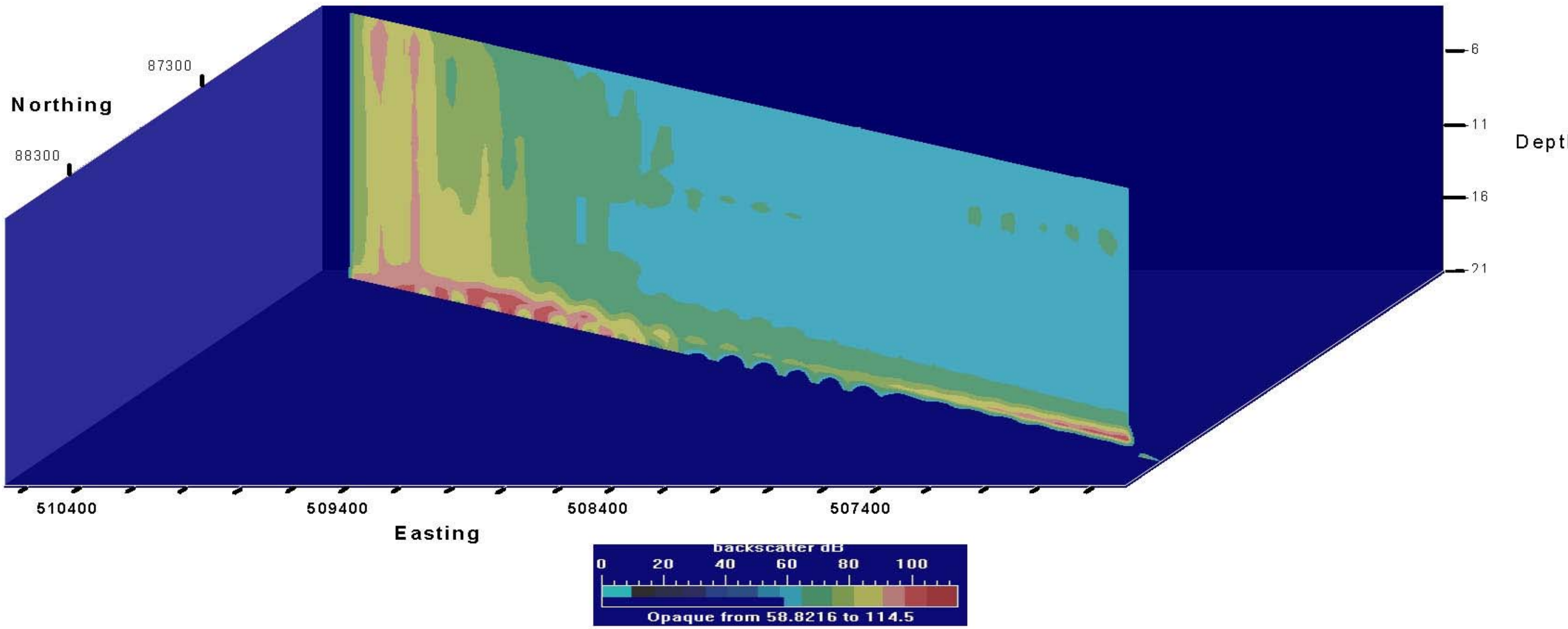

Figure 6. Longitudinal section of the Acoustic Backscatter profile from a dredger loading an "all-in" cargo at Owers Bank in 1995. Based on Hitchcock *et al*, (2002). The red side of the scale indicates high backscatter levels and the blue side of the scale indicates low backscatter levels.

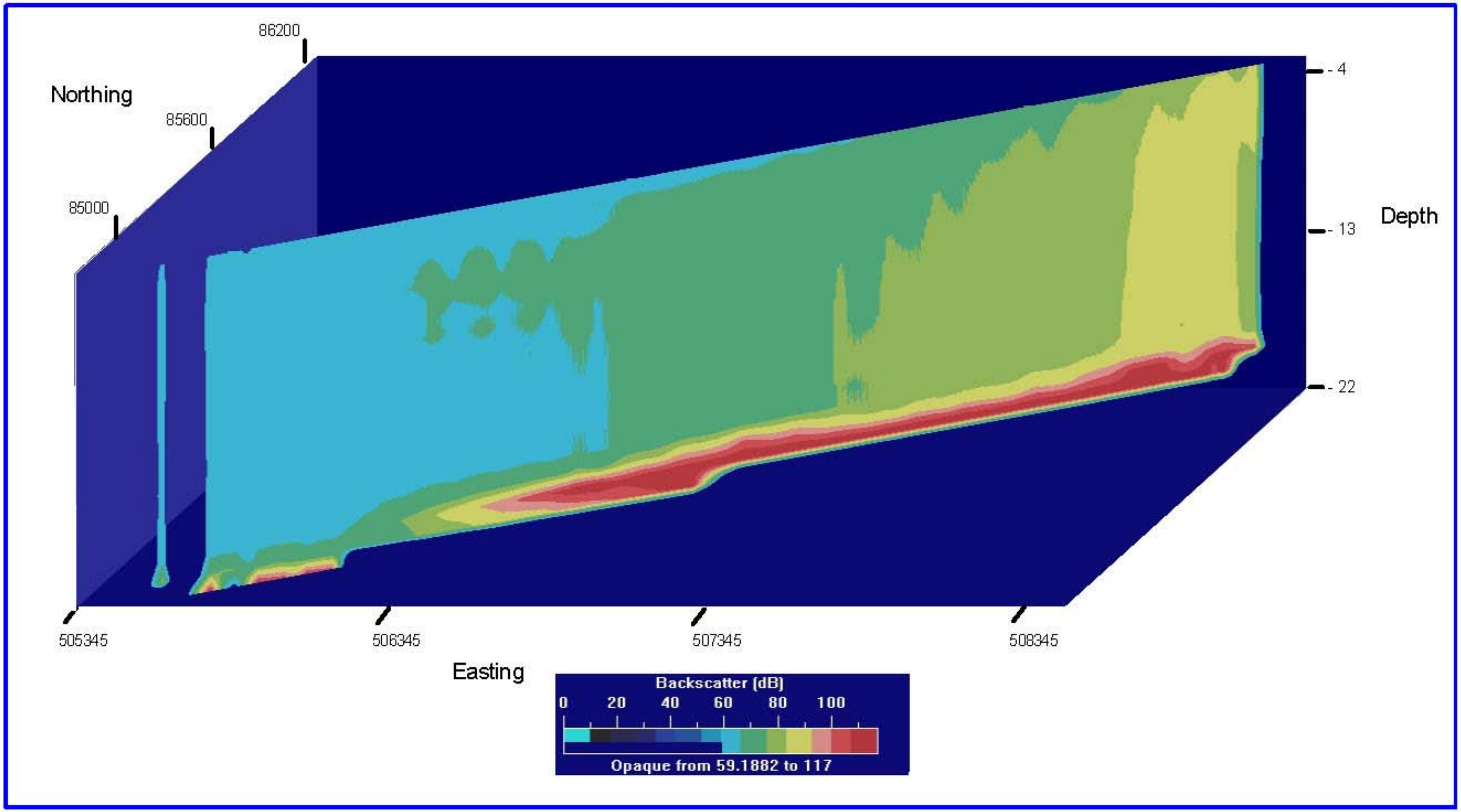

Figure 5. Longitudinal section of the sedimentation plume from a dredger loading a screened cargo at Owers Bank in 1995. Based on Acoustic Backscatter data from Hitchcock *et al*, (2002). The red side of the scale indicates high backscatter levels and the blue side of the scale indicates low backscatter levels.

Far Field Plume Impacts

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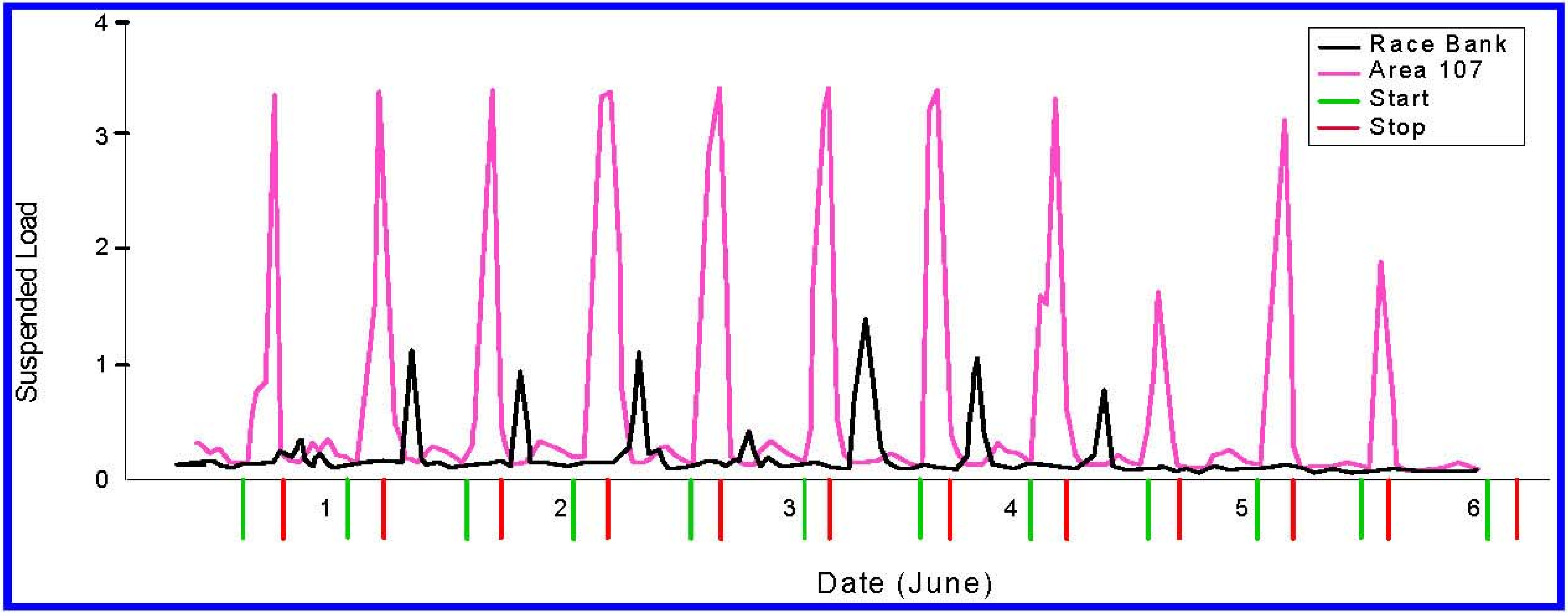

Figure 2. Mini-POD records showing suspended sediment spikes at dredge Area 107 (magenta) and at Race Bank (black) at a distance of 6.5 km from the dredge site in 1995. Redrawn after Dickson & Rees (1998).

Race Bank is 6.5 km from Area 107 Dredge Site
50 - 150 mg/l elevation 7% of time

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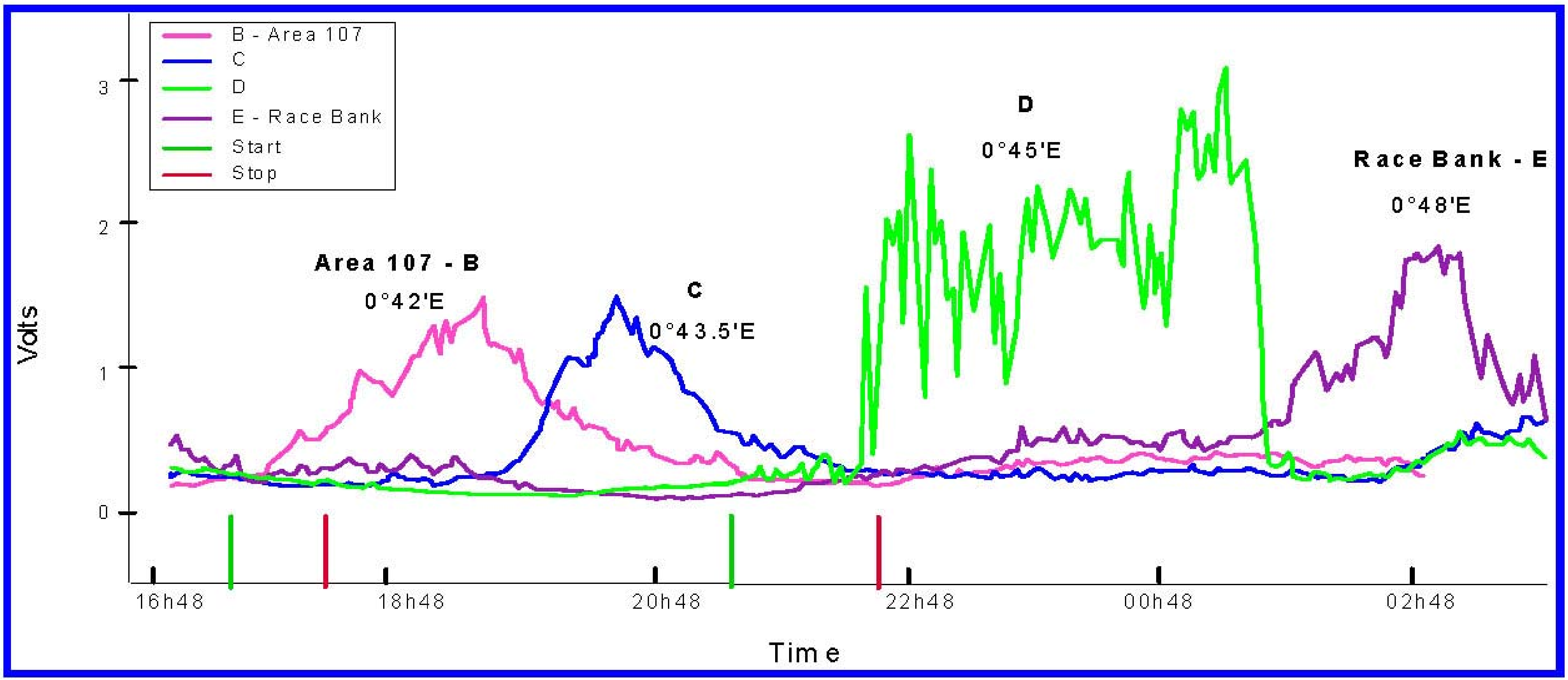


Figure 3. Traces from 4 Mini-PODs recording the passage of a benthic sediment plume from a site of dredging at Area 107 to Race Bank in June 1996. Redrawn after Dickson & Rees (1998).

Evidence of a Turbidity Current

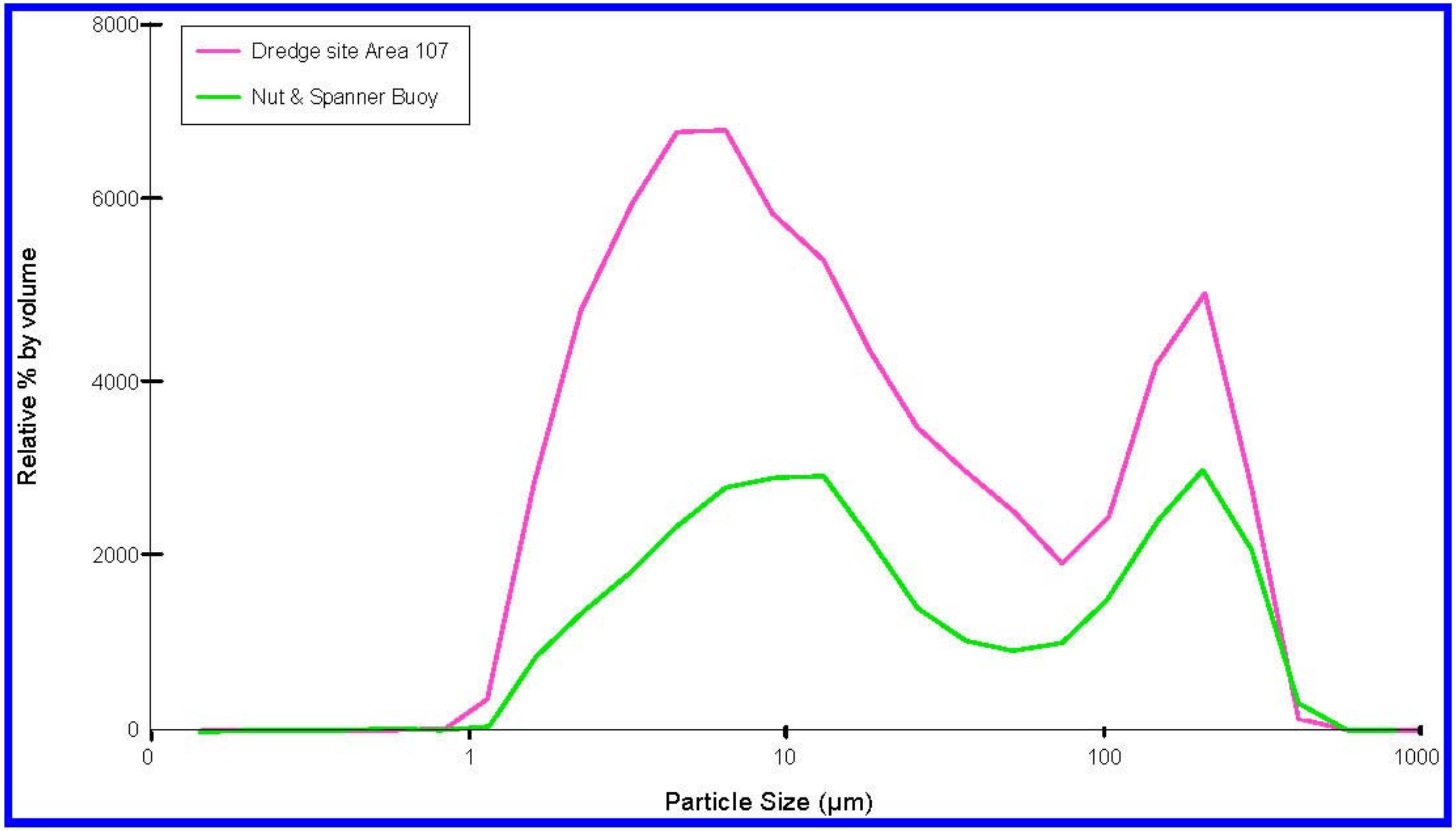
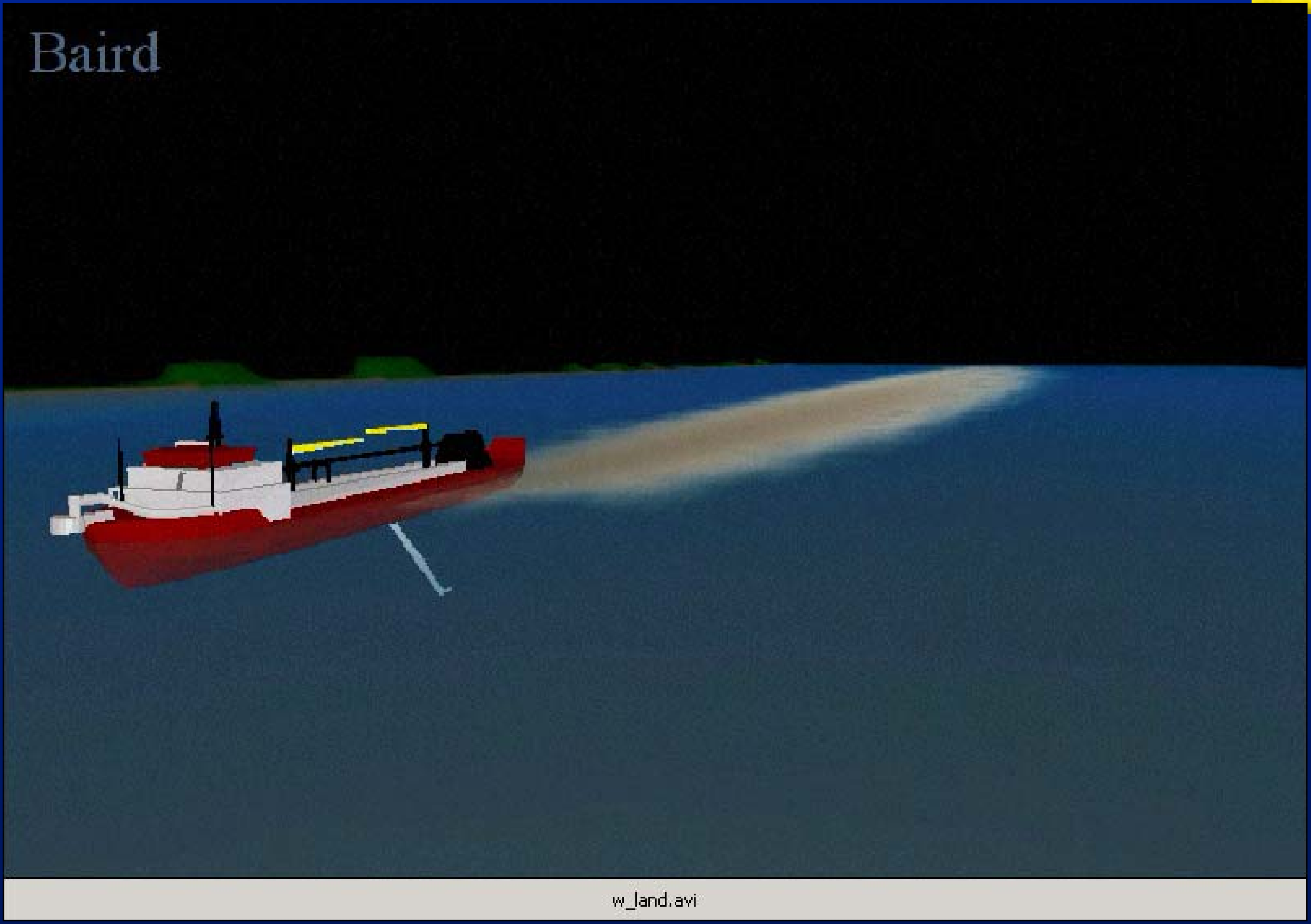


Figure 4. Relative Particle Size composition of the benthic boundary plume at the dredge site at Area 107, and at Nut & Spanner Buoy 8.5km to the south of the dredge site. Redrawn after Dickson & Rees (1998).

MMS Plume Model



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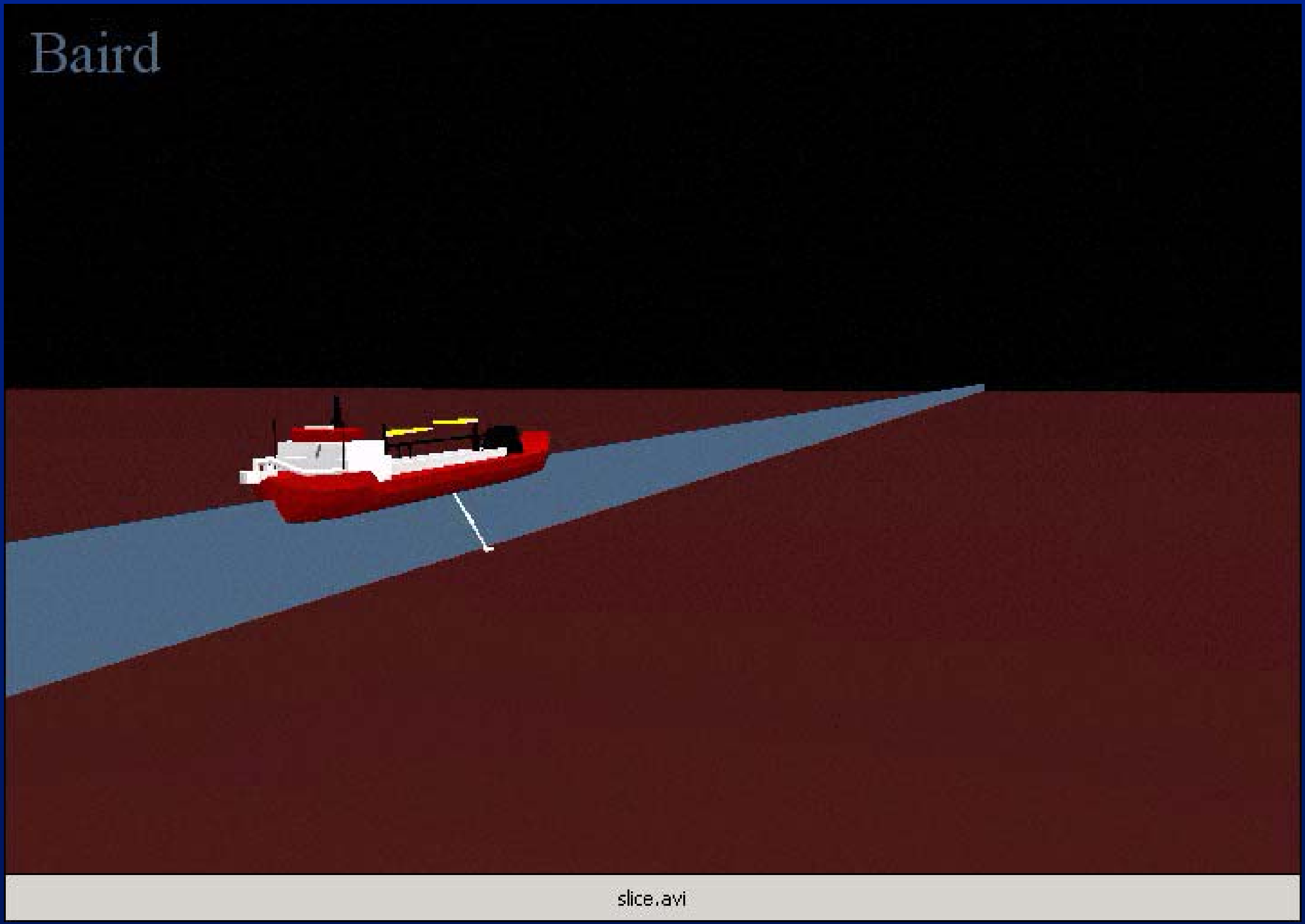
MMS Plume Model



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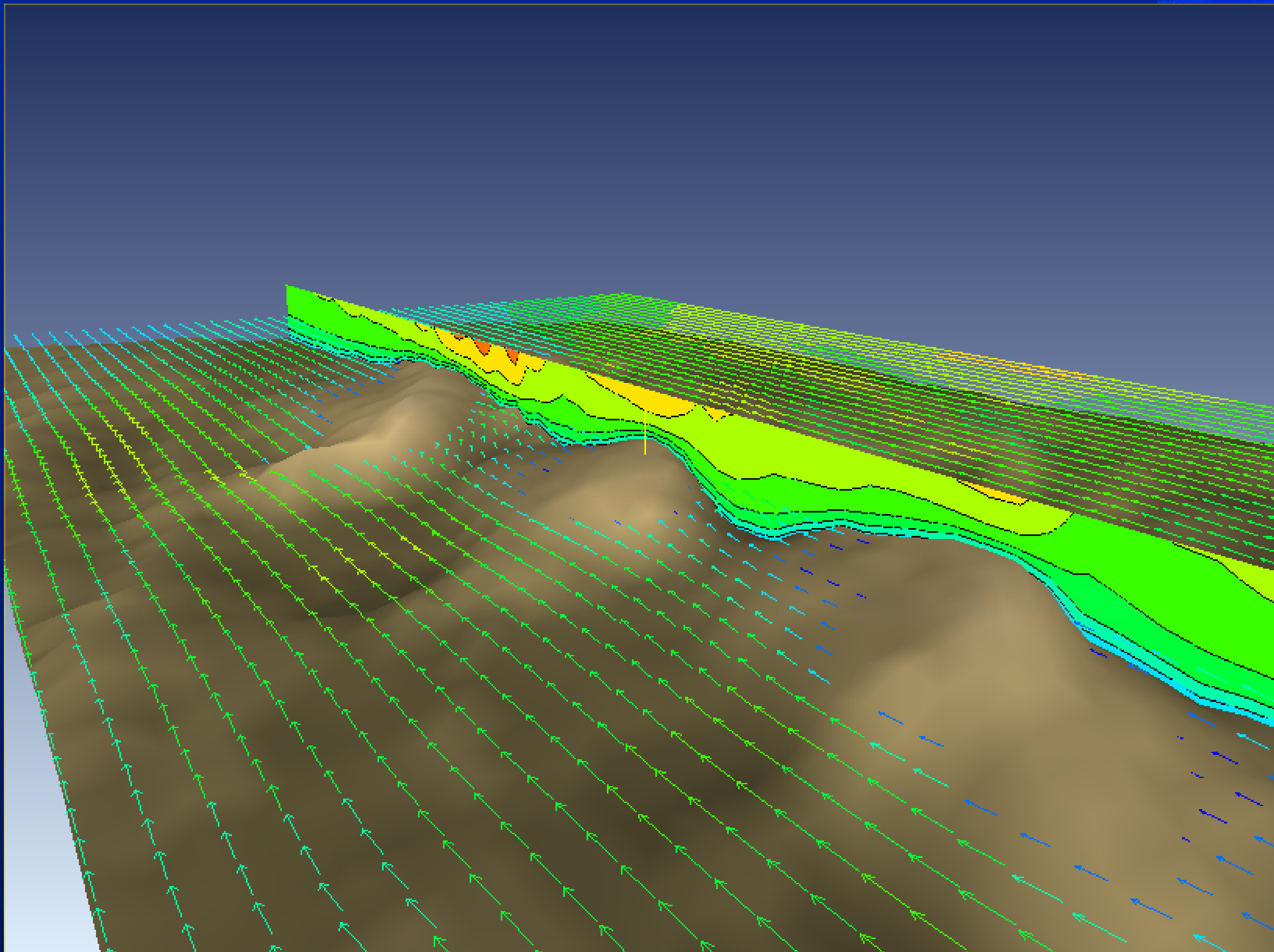
Gravel Unit



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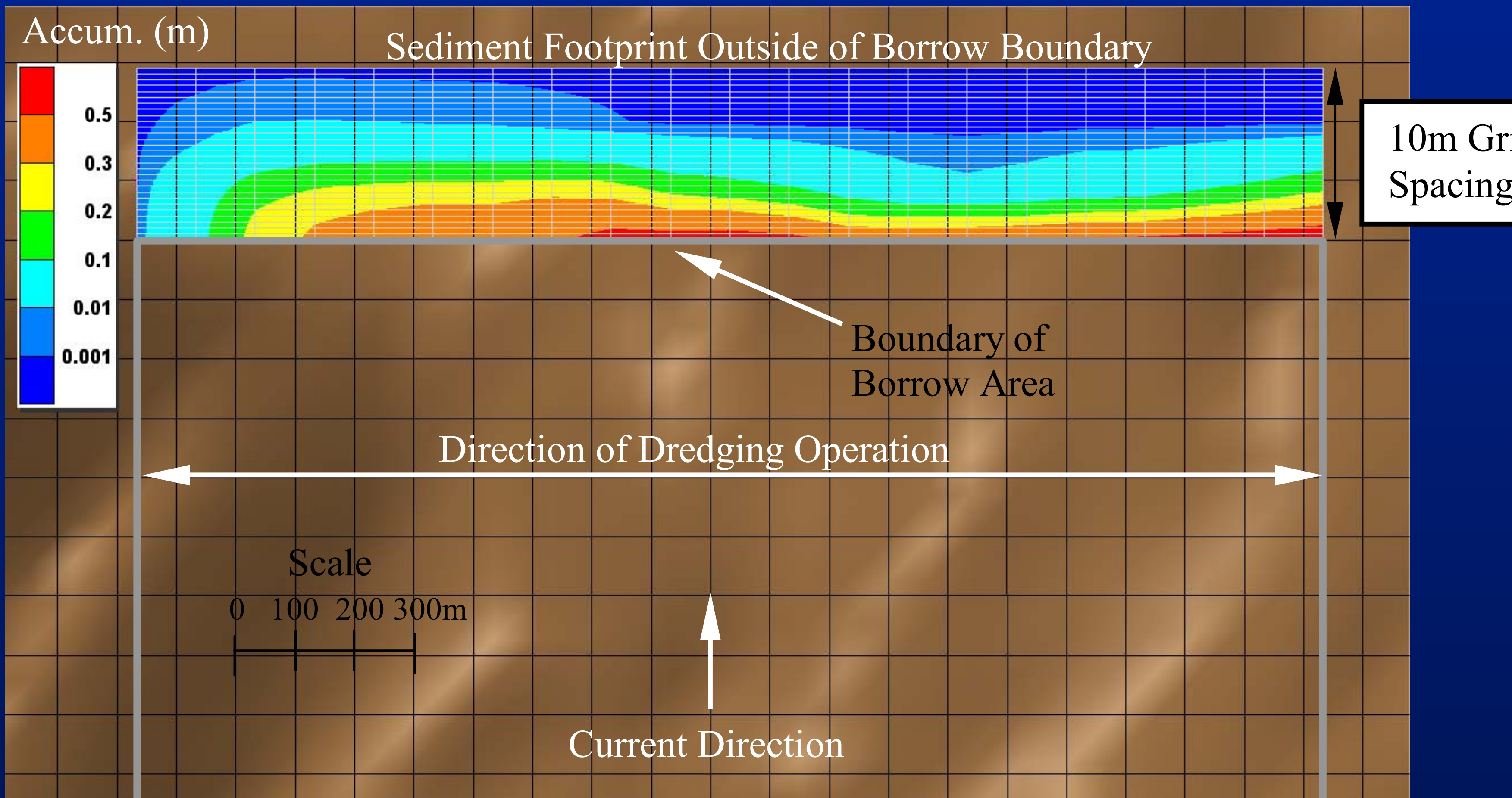
Plume Model Output



Turbidity – Quantity vs. Dispersion

- Total amount of overflow
- Extent of dispersion

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Turbidity and Sedimentation Impacts Conundrum

- Reduce dispersion - increase potential for dynamic plume and pancaking/turbidity current – far field influence
- Increase dispersion - larger plume – sedimentation is thinner, wider

Impact # 8: Dredging - Fishing

- Spatial and seasonal conflicts between dredging and commercial and recreational fisheries
  - No data on degree of significance
  - Could be prevented by coordination with fisheries groups and notifications during dredging

Impact # 9: Structural Damage to O & G

- <u>Potential to cause structural damage to oil and gas infrastructure by direct contact, soil de-stabilization, and erosion</u>
  - Great concern in the Gulf of Mexico
  - Planned MMS study to address this concern

Impact # 10: Mammal/Turtle Collisions

- Collisions with marine mammals and sea turtles during vessel operations

- Existing stipulations include (probably adequate):

  If operating in areas of known whale occurrences, observers are required. If whales are observed, avoid intentional approaches within 100 yd (500 yd right whales) and slow speeds to less than 4 knots.

  See stipulations for sea turtles.

Impact # 11: Archaeological Resources

- <u>Damage to archaeological resources</u>

  - Structural damage from direct contact
  - Soil de-stabilization leading to exposure, erosion
  - Burial (not a technical problem, but could reduce recreational access)

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OCS Study MMS 2004-005

http://www.mms.gov/sandandgravel/OtherGenericStudies.htm

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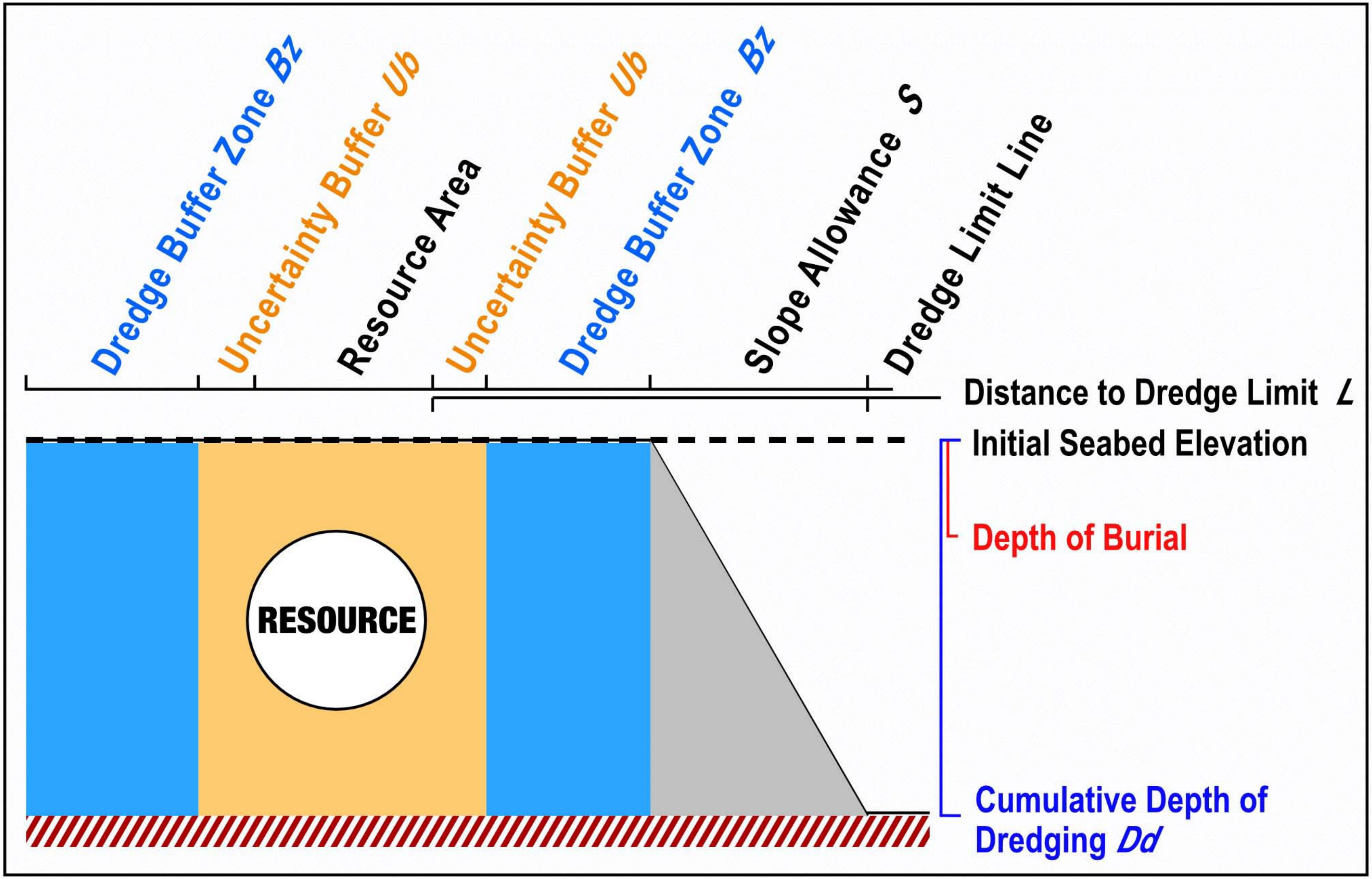
Archaeological Study Recommendations

1. Implement a GIS-based data management strategy
2. Refine and test baseline studies that define the potential archaeological resource base
3. Require state-of-the-art means of locating and identifying those resources

Archaeological Study Recommendations

4. Develop a scientific basis for buffer zones for resource protection, based on:
   - *Uncertainty in the resource location*
   - *Accuracy of dredge positioning*
   - *Ultimate stable slope*
   - *Prevention of full pedestals*

Unit


Dredge Buffer Zone Bz
Uncertainty Buffer Ub
Resource Area
Uncertainty Buffer Ub
Dredge Buffer Zone Bz
Slope Allowance S
Dredge Limit Line
Distance to Dredge Limit L
Initial Seabed Elevation
Depth of Burial
RESOURCE
Cumulative Depth of Dredging Dd

Guideline for Dredging to Prevent Pedestal Formation

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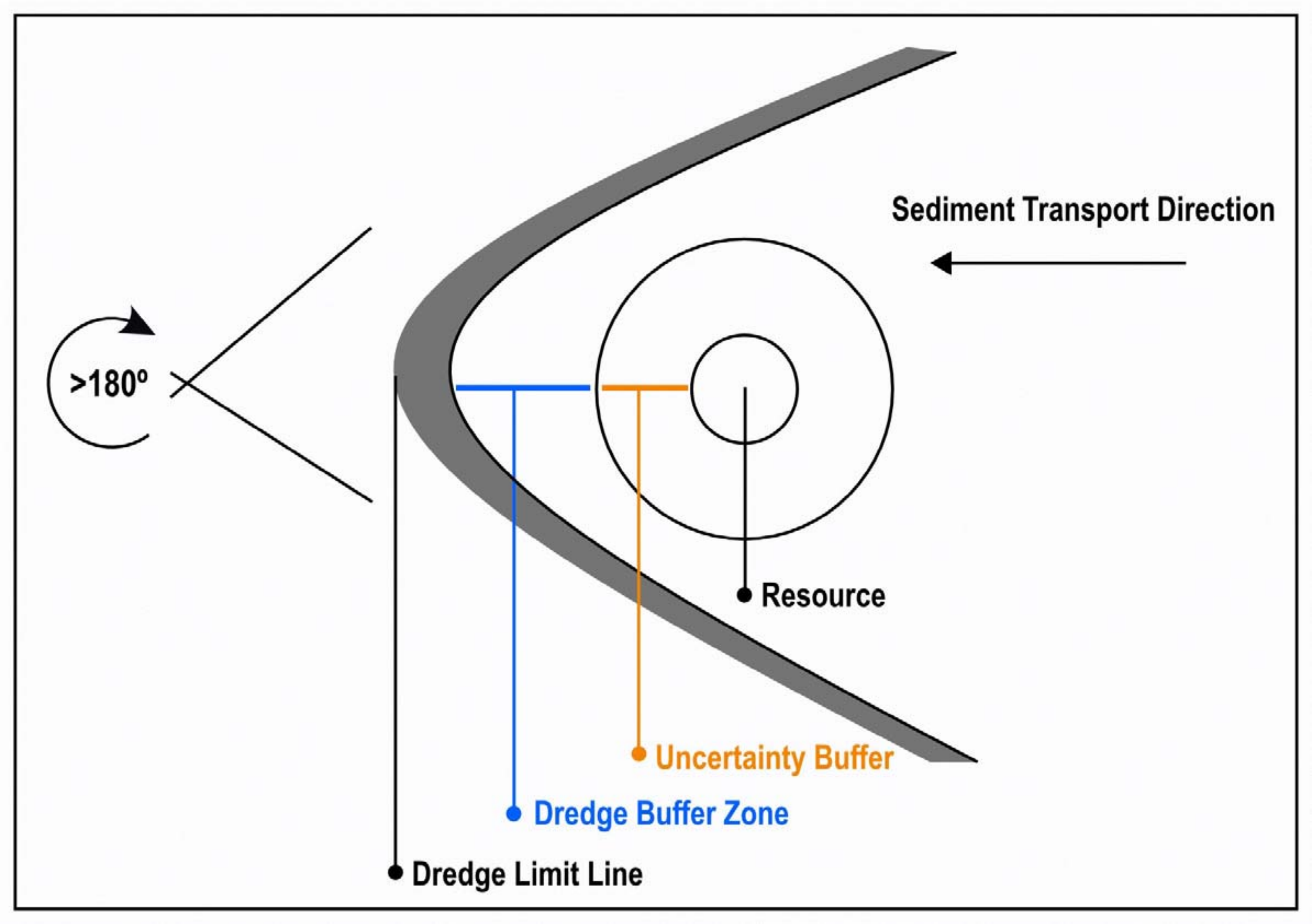

Archaeological Study Recommendations

5. Dredging operations
   - *Require DGPS positioning equipment and tracking software*
   - *Require plots of actual dredge tracks and buffer zones*

Archaeological Study Recommendations

6. Require monitoring during dredging (high-potential areas):
   - *Onboard monitor*
   - *Random monitoring of sediment pumped onto beaches*
   - *Test the relic landform hypothesis*
7. Post-dredging, document effectiveness of buffers and slope stability of borrow site

Impact # 12: EFH Impacts

- <u>Change in shoal shape that degrades fish habitat</u>
  - Limited data on potential degree of impact; greatest concern is cumulative, long-term impacts
  - Current MMS study to assess stability of shoals and potential impacts of dredging

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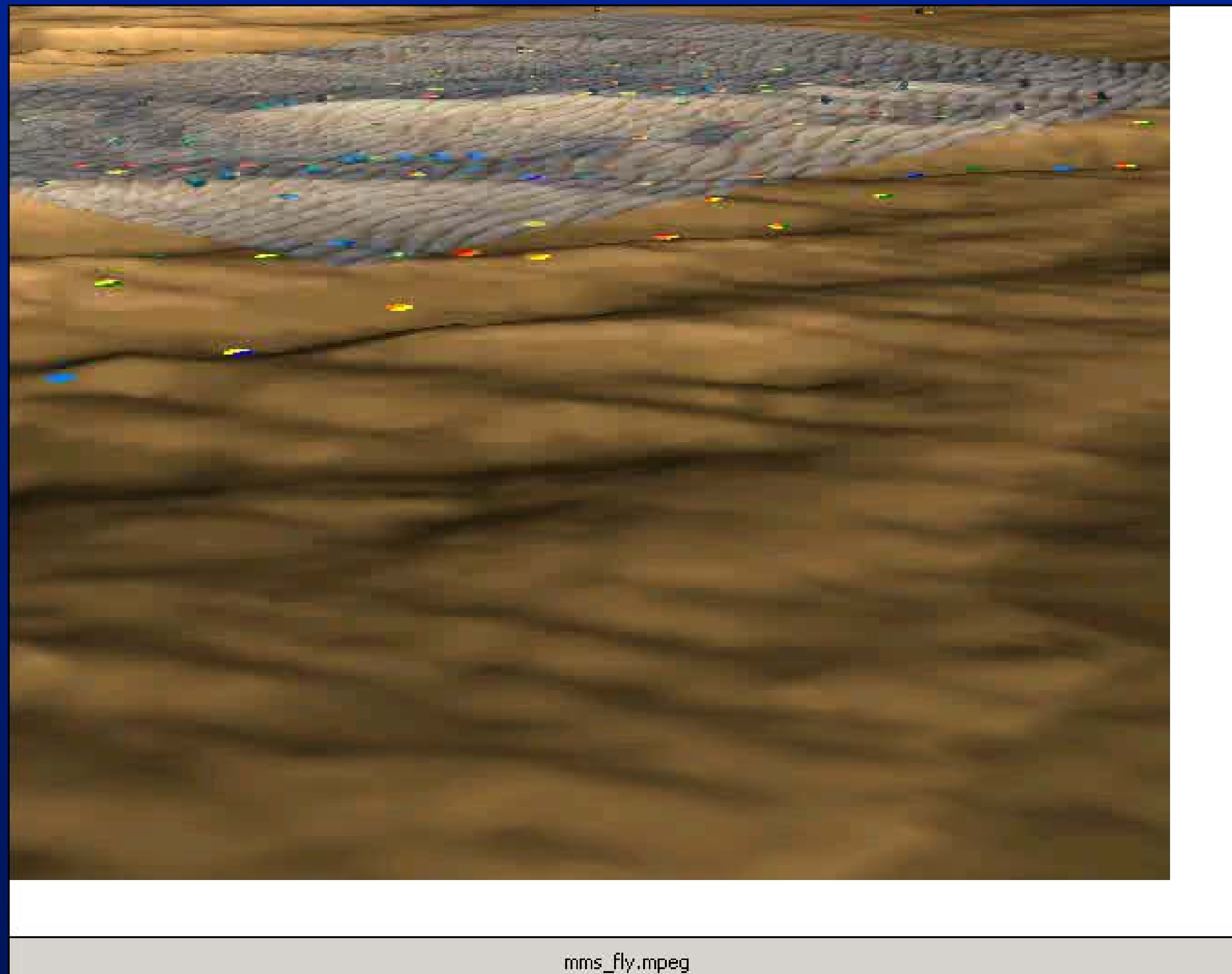
Unique Habitats Associated with Shoals



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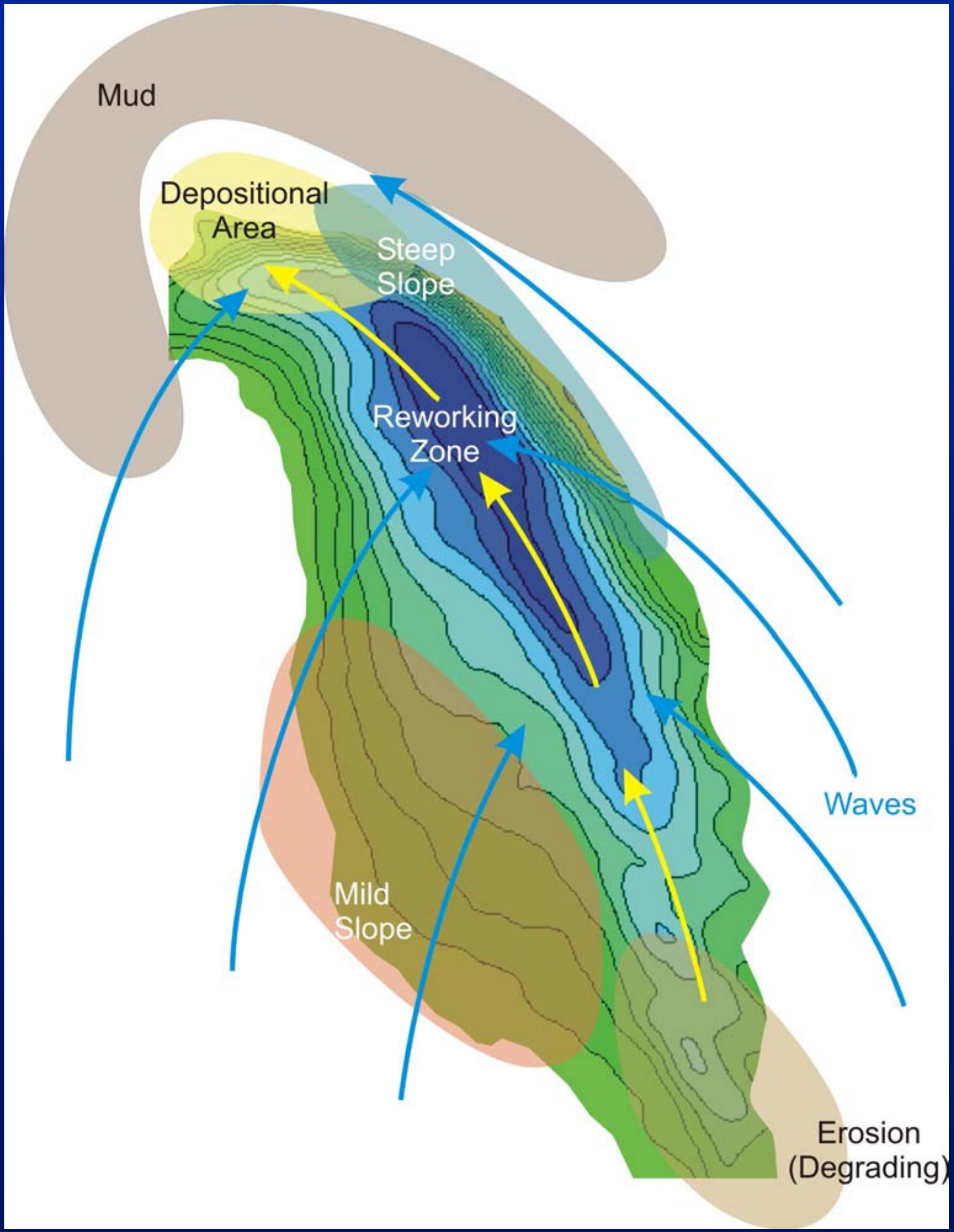
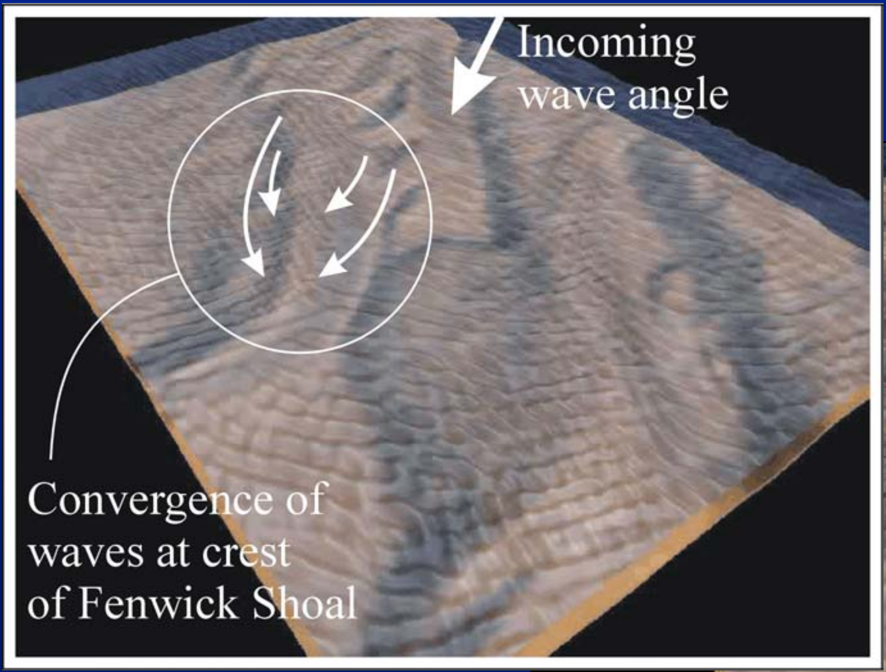
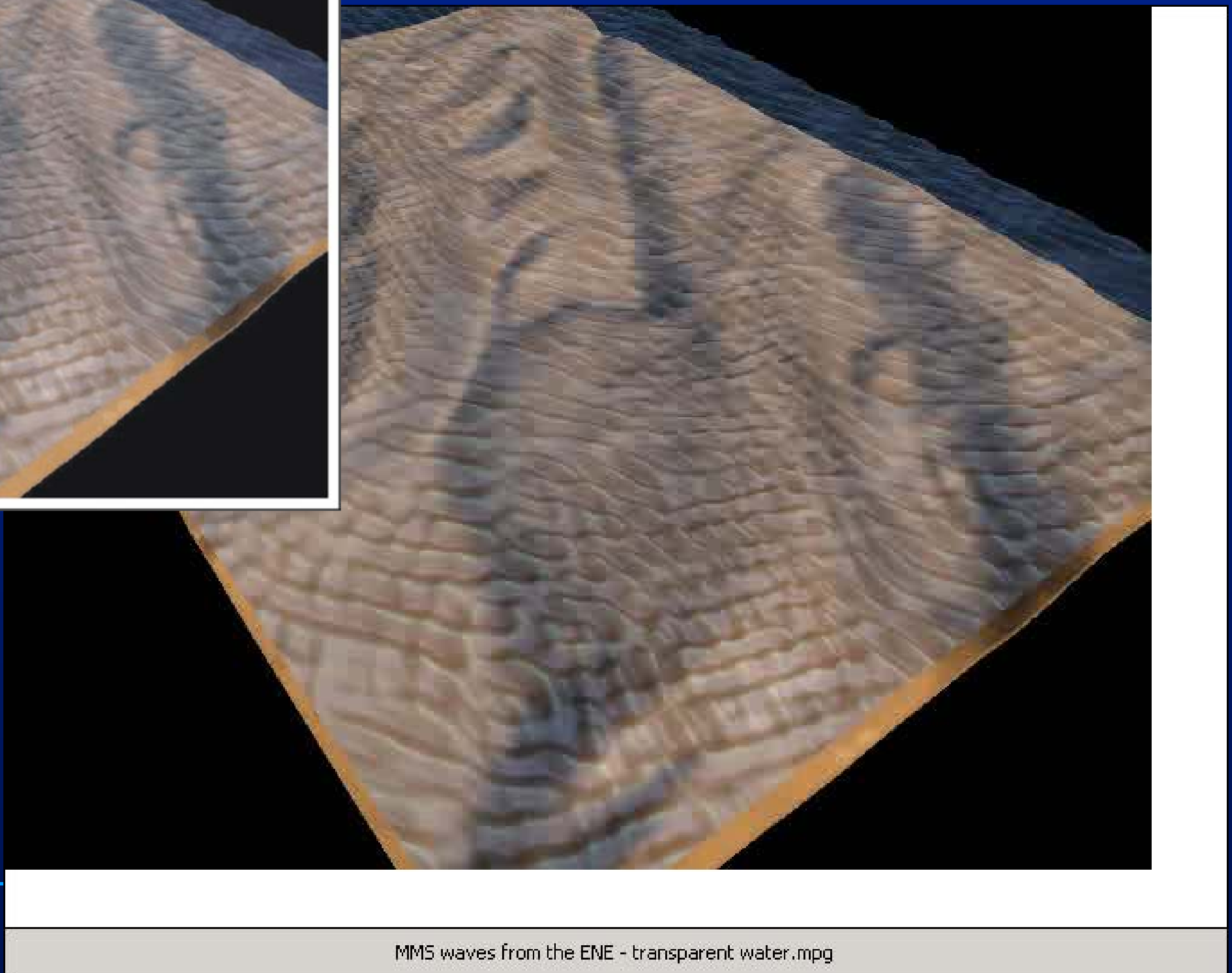
Ridges and Shoals – Technical Background



Ridges and Shoals – Technical Approach





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Literature Review

- TU Delft, Texas A&M, U Wisconsin, CISTI, British Library
- USACE DOER Program
- World Dredging, International Dredging Review, Terra et Aqua, Dredging and Port Construction

24	check	Assessment Of Short Term Environmental Impacts On Dredging In A Tropical Estuary	Cbalchand A.N and K. Rasheed	2000	Terra et Aqua number 79
25		Ocean Wave Attenuation Due To Soft Seafloor Sediments (Personal Interest)	Kraft L.M et al	1990	Marine geotechnology Vol 9 pp 227-242
26	check/se nd rob	An Approach To The Physics And Modeling Of Submarine Flowslides	Norem et al	1990	Marine Geotechnology Vol. 9 pp 93-111
27	check	Environmental Protection Spurs Dredging Technology	XXXXXX	1998	Sea technology, Vol 39 no 3 pg 45
28		Navigation In Marine Protected Areas: National And International Law	Spadi F	20000	Ocean development and international law
29	?	Environmental Considerations To Channel Dredging	Ghobrial F	1987	Coastal Zone 87 Vol1 pg 300
30	check	Biological Effects Of Marine Sand Mining And Fill Placement For Beach Replenishment: Lessons For Other Uses	Hurme A.K	1988	Marine mining Vol 7 pp 123-136
31	check	Fisheries Interests And Ocean Mining	Scarratt D.J	1987	Marine mining Vol 6 pp 141- 147
32	check	A Process For Setting, Managing And Monitoring Environmental Windows For Dredging Projects	NRC US	2002	Transportation research board special report; 262
33	x	Engineering Design And Environmental Assessment Of Dredged Material Overflow From Hydraulically Filled Hopper Barges In	USACE WES	1990	USACE report D-90-4
34	x	Ecological evaluation of a beach nourishment project at hallandale, FL, Volume I evaluation of fish populations adjacent to barrow	USACE CERC	1980	CERC report MR No. 80-1
35	si	A Common Sense Plan For Prevention Of Overflows: Applicable To All Rivers With Sandy Channels	Shaughnessy M	------------	------------------------
36		**Need To Get**			
37	?	Practical Criteria To Assess Dredging Methods On Environmental Aspects	Arts T	1993	CEDA Dredging days, no 8 pg 1
38	1	Modern Dredging Methods And Their Environmental Aspects	Van Drimelen N.J and Loevendine N.J	1988	CEDA Dredging days, no 7 pg 1
39	**yes**	Environmental Impact Of Water Injection Dredging	Verweij, JF, Winterwerp, JC	1999	CEDA Dredging days pg 175
40	1	Environmental Dredging Technology In Close Cooperation With Local Partner Shipyards	Pflug J. and Ohlig, F	2000	Int Conf/ Exhibition on Inland water transport and Dredging, no 10, pg 1
41	x	Environmental Impact Assessment Of Dredging Project In The Yagtze Estuary	Zhou Q.Y.	2001	Dredging for prosperity: Achieving social and economic benefits: World dredging congress and exhibition / WODA Vol 1 no 8 pg 1
42	3	Numerical Simulation Of The Sedimentation Process In A Trailing Suction Hopper Dredge	Van Rhee C	2001	Dredging for prosperity: Achieving social and economic benefits: World dredging congress and exhibition / WODA Vol 2 no 6 pg 1
43	3	SSFATE (Suspended Sediment Fate), A Model Of Sediment Movement From Dredging Operations	Anderson E etal	2001	Dredging for prosperity: Achieving social and economic benefits: World dredging congress and exhibition / WODA Vol 2 no 14 pg 1
44	**yes**	One Mans View Of Dredging Equipment 2020	Greener, G.E.	1994	Dredging and dredged material disposal/Placement, Vol1 pg 683
45	**yes**	Dredging And The Environment	Van Diepen H et al	1993	Bulletin de PIANC, Vol 167 no 80 pg 29
46	3	The Environment Friendly IHC Cutter	-------------	1992	Ports and dredging No. 139 pg 12
47	**yes**	Environmental Dredging: New Techniques From Europe And The US	-------------	1995	Port Engineering Management, Vol 13 no 2 pg 6
48	**yes**	Environmental Friendly Dredging Techniques In The Netherlands	-------------	1997	Port Engineering management, Vol 15, no 2, pg 24
49	**yes**	Sedimentation Engineering Techniques For Environmentally-Friendly Dredging	Kirby R	1994	Underwater Technology, Vol 20, no 2, pg 16

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		Literature Review - Environmentally Friendly Dredging Technology					
		Mineral Management Service 2004					
		Title	Authors	date	Source	Micrpphische	status
2	si	Proceedings Of The National Workshop On Methods To Minimize Dredging Impacts On Sea Turtles	Dickerson Dena.D & Nelson David A.	1988	USACE report EL-90-5, USAED, Jacksonville FL	AD-A218 990	Abs
3	?	Sand Waves; Engineering Considerations And Dredging Techniques	Alexander Michael P	1990	USACE report HL-90-17, USACE Washington DC		Abs
4	x	Benthic Community Response To Dredging Borrow Pits, Panama City Beach, Florida	Saloman Carl H et al	1982	USACE report MR 82-3, Coastal engineering research center Kingman building, Fort Belvoir, VA 22060	D103.42/8:82-3	Abs
5	x	The Ecological Impact Of Beach Nourishment With Dredged Materials On The Intertidal Zone At Bouge Banks, NC	Francis J Reilly and Vincent J Bells	1983	USACE report MR 83-3 , Coastal engineering research center Kingman building, Fort Belvoir, VA 22060		Abs
6	beach	Tylers beach, Virginia, dredged material plume monitoring project 27 Sep to 4 Oct 1991	Michelle M Thevenot et al	1992	USACE report DRP-92-7, WES	D103.24/2:DRP-92-7	Abs
7	x	Seasonal Restrictions On Dredging: An Approach Toward Issue Resolution	Mark W La Salle	1992	USACE report D-92-1, Environmental laboratory WES	D103-24/2; D-92-1	Abs
8	si	A Framework For Assessing The Need For Seasonal Restrictions On Dredging And Disposal Operations	Mark W La Salle et al	1991	USACE report D-91-1, Environmental Laboratory WES and New England district	D103.24/2:D-91	Abs
9	si	Effectiveness Of Sea Turtle Deflecting Hopper Dredge Draghead In Port Canaveral Entrance Channel, FL	David A Nelson and Deborah J. Shafer	1996	USACE report D-96-3, WES EEDP (Environmental Effects of Dredging Programs)	D103.24/4:D-96-3	Abs
10	x	Effects Of Dredging And Disposal On Aquatic Organisms	Nina D Hirsch et al	1978	USACE report DS-78-5, US Army Washington DC		
11	x	Environmental Effects Of Dredging	----------------------	1983	---------------------	D103.24/16 (stacks 3rd floor Wendt)	
12	rob	Patterns Of Succession In Benthic Infaunal Communities Following Dredging And Dredged Material Disposal In Monterey	John S Oliver	1977	USACE D-77-27		
13	si	Natural Gas Pipeline Rupture And Fire During Dredging Of Tiger Pass, Louisiana	NTSB	1996	National Transportation Safety board report NSTB/PAR-98/01/SUM		
14	x	The Marine San And Gravel Dredging Industry Of The United Kingdom	Uren M.J	1988	Marine mining, Vol 7 pp 69-88		Full
15	quick	Seabed Sand Mining In Japan	Tsurusaki K. et al	1988	Marine mining, Vol 7 pp 49-67		
16	si	Effects Of Marine Mining Dredge Spoils On Eggs And Larvae Of A Commercially Important Species Of Fish, The Mahimahi	Jokiel P.L	1989	Marine mining, Vol 8 pp 303-315		
17	si	The Red Sea Pilot Project: Lessons For Future Ocean Mining	Amann H.	1989	Marine Mining, Vol 8 pp 1-22		
18	si	Liquefaction In The Coastal Environment: An Analysis Of Case Histories	Chaney R C	1991	Marine Geotechnology Vol 10 pp 343-370		
19	check	Impact on the Environment of turbidity caused by dredging	Pennekamp J G S and M.P Quaak	1990	Terra et Aqua Number 42		
20	x	Assessment Of Offshore Sand And Gravel For Dredging	Selby I and Ooms K	1996	Terra et aqua Number 64		
21	si	Turbidity Caused By Dredging; Viewed In Perspective	Pennekamp J G S et al	1996	Terra et Aqua number 64		
22	rob has	Effects Of Dredging And Dumping On The Marine Environment Of Hong Kong	Evans N. C.	1994	Terra et Aqua number 57		
23	si	Dispersion In The Marine Environment Of Turbidity Generated Overflow	Bonetto E	1995	Terra et Aqua number 58		

50	x	Marine Aggregate Dredging In The UK: A Review	Singleton G.H.	2001	Underwater technology, vol 25, no1 pg 3
51	3	Assessment Of The Impact On Seafloor Features In INDEX Area	Sharma R	2000	Marine Georesources and Geotechnology, Vol 18, no 3 pg 237
52	x	Protecting Manatees During Blasting	Roeder D.A	1984	World dredging, Vol 20, No. 6 pg 20
53	**yes**	Overview Of Dredging International's Environmental Operations		1995	World dredging mining and construction, Vol 31 no. 8 pg 8
54	**yes**	Innovations In Dredging Technology: Equipment, Operations, And Management	Francisques, NR et al	2000	Proc. Western dredging association Twentieth Technical conference…Texas A&M dredging seminar pg 3
55	3	Reflections Made By The Dredging Industry	Boer, P	1999	Proc. Oresund Link Dredging and Reclamation Conference: Challenges, solutions and lessons on environmental control, project management, construction
56	**yes**	The Future Challenges Of Environmental Dredging	Romagnoli, R et al	1998	WODCON: World Dredging Congress on Dredging into the 21st Century/ WEDA, Vol 2 pg 651
57	**yes**	Generation And Decay Of Sediment Plumes From Sand Dredging Overflow	Ooms, K and Postma , GM	1995	World dredging congress Vol 2 pg 877
58	**yes**	Environmental Effects Of Dredging, The United States Experience	Herbich J.B.	1985	Dock and harbour authority, Vol 66 no 771 pg 55
59	**yes**	Investigation Of Benthic And Surface Plumes Associated With Marine Aggregates Mining In The UK	Hitchcock D.R and Drucker B.R.	1996	Oceanology International Vol 2 pg 221
60		Automated inspection tool "silent inspector" undergoes field testing	James Rosati	1999	Dredging research Vol2 No1
61		Inovations in dredging technology: Equipment, Operations and management	McLellan N.T and Hopman R.J.	2000	USACE ERDC TR-DOER-5
62		Environmental aspects of dredging, Machines Methods and Mitigation		1998	IADC /CEDA
63	yes	Bibliography of Selected References to US Marine Sand & Gravel	S. Jeffress Williams	2003	U.S. Geological Survey
64	yes	Sand Transport and Morphology of Offshore Sand Mining SAND PIT		Jun-01	
65	yes	National Practices and Regulation in the Extraction of Sand & Gravel			
66	yes	Research Brief: Environmebtal Effects of Near Shore Placement of Dredged Material	D.G. Clarke et al	Nov-01	U.S. ERDC
67	yes	A Process For Setting, Managing And Monitoring Environmental Windows For Dredging Projects			
68		Review of current state of knowledge of the impacts of marine aggregate extraction - a U.K. perspective	Boyd,S.E. et al.	Feb. 2002	EMSAGG Conference Feb. 2003 Delft University
69		Assessing the impact of sand extraction on shore stability: project for a methodological framework	Cayocca, F.	Feb. 2002	EMSAGG Conference Feb. 2003 Delft University
70		Aspects of sediment disturbance associated with Marine Aggregate Dredging	Hitchcock D.R	1997	University of Wales
71		Legislative and environmental development in the Netherlands	Stolk, A	Feb. 2002	EMSAGG Conference Feb. 2003 Delft University
72		Section 5 & 6 MIRO Recommendation for Best Practice	From Nick Bray		Minerals Industry Research Organization
73		Research on Hopper settlement using large-scale modeling	S.C. Ooijens, et al		MTI Holland
74		Hopper Overflow System			Training Institute for Dredging

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Sand and Gravel Unit

Literature Review – Technologies and Approaches

- Hopper settlement and overflow (design modifications)
- Draft Best Practices – mitigation and monitoring (Mineral Industry Research Organization)
- Innovations in dredging equipment - technology

Literature Review – Technologies and Approaches

- Machines, Methods and Mitigation
- Endangered Species Biological Opinion 7
- SANDPIT – EC research initiative

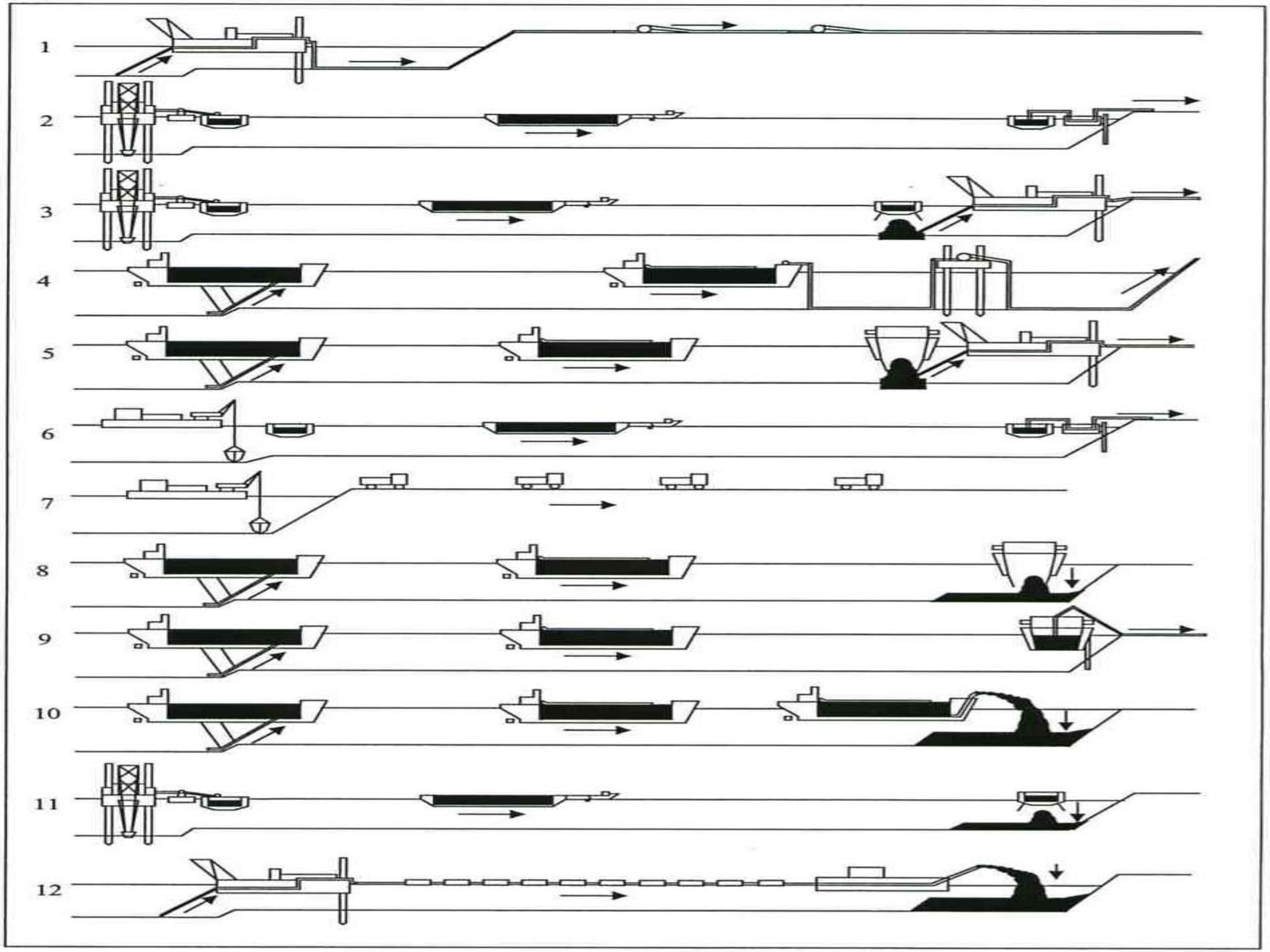

Figure 10. Beach nourishment scenarios using different dredging equipment combinations.

Draghead with turtle deflector

Questionnaires

- Two questionnaires MIRO and MMS sponsored
- Bean, Great Lakes, Manson, Weeks, USACE (Portland District), Westminster (Boskalis), Dredging International, van Oord, Jan de Nul, Rhode Nielsen, BMAPA

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
1.	What percent of material overflows the hopper while digging sandy, low-silt content material, assuming a 10 km sailing distance to pump ashore?	We have not conducted an exhaustive study of this because it is not generally required. In dredging sand for beach projects or for other uses it is usually desirable to have a coarser product than a finer product. Therefore, unless there are restrictions regarding overflow, loading typically continues until the dredge obtains an economic load measured in displacement of the vessel. If silt or very fine-grained sands are part of the materials being dredged a considerable quantity may overflow. We have not conducted specific studies of this although I would suggest that the Corps of Engineers or others have studied or modeled these items over the years for various purposes. In rule of thumb type thought it is very difficult when loading sand to the ships maximum tonnage to retain more than a few % of particles smaller than the 200 sieve (ie. .076mm). Sands with grain sizes between .076mm and 1.50mm are not well retained in a hopper. As the grain size increases they become more easily retained. Sands in the range of 1.50 - 2.00mm become increasing retained within the hopper and above 2.00 mm I believe that most are retained. Other factors impacting overflow losses are loading concentration, flow rate, method of loading, hopper size, hopper layout / configuration. On a beach project in San Diego with a 3600 cy hopper dredge we experienced retention rates of between 16 and 100%. The majority of loads retained between 40 and 65% of the quantity discharged into the hopper. The average retention percentages and grain size distributions were as follows: Retention / D15mm / D50mm / D85mm 90% / .3 / .56 / .9 60% / na / .2 / na 31 / na / .09 / na	The percentage of material overflowed is the result of many different factors, the most important of which is the % fines (i.e. silts and clays) in the material being dredged. The other factors that come into play are the overall grain size distribution, the overflowing method (overflow type and location) and the duration of overflowing. The greater the sailing distance the longer the overflowing duration in order to achieve an economic load. The % overflow increases with increasing overflow duration.	Unable to answer with any accuracy due to a lack of information provided. Overflow losses are a function of several variables. The terms "sandy" and "low-silt content" is used to describe the material. A grain-size distribution curve is needed to determine both the grain size and the percentage of fines that are to be expected in a representative sample. Sand is classified as having a grain size between .06mm and 2mm. Obviously, the higher the concentration of fines, the greater the losses will be. Additionally, it is impossible to determine the percentage of silts from the information provided without a grain-size distribution curve, although, one could expect that most if not all of the silts will be lost via overflow. Sailing distance noted in the question has no bearing on overflow losses expected.	Material less than 200 μm will be lost in the overflow as the dredge loads.	The amount of fines overflowing during the hopper loading process depend on grain size distribution of the incoming material, the method of overflowing (function of vessel design and of operational settings) and especially of duration of overflowing (in order to obtain an economic load). The amount of overflow is not dependent on sailing distances.	Very little. Any silt overflowing during sailing is not dependent on the sailing distance, probably more dependent on prevailing sea condition.	Little or none. Sandy material becomes a "dry load" (No spillage to dump)

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Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		With respect to sailing distances, generally, the greater the distance the longer the vessel will overflow attempting to achieve its maximum load. 10 kms is a relatively short distance and therefore the vessel may depart the borrow site with somewhat less than a full load. I have attached a research paper from MTI Holland on overflow losses. Please reference <u>*04-06 Research on Hopper Settlement*</u>						
2.	Can a hopper dredge mine sand from below a 1-meter silt overburden without removing the overburden? Does this result in significantly increased material overflow and consequently an increase in turbidity?	Depending on the nature of the silt it may not be necessary to strip an area of silt before dredging the sand below it as the drag heads will penetrate through some of the silt. However it is likely that in dredging an area over time that the silt will eventually pass through the pumps and be returned as overflow. Where this silt settles will depend on currents and sea conditions in the area. Much of it may settle back very close to where it was originally dredged and may even be dredged and overflowed many times during subsequent dredge passes through the same area. Turbidity will be related to the volume of silt overflowing. If overflow occurs near the surface it will be more visible than if it overflows at a lower elevation such as through overflows which discharge beneath the hull. However since hopper dredges normally dredge when underway to avoid potholing, the ships propulsion propellers may tend to spread the turbidity out even making it more visible at the surface. Air entrained in overflow water columns may also tend to bring turbidity to the surface increasing its visibility.	This is possible but generally leads to a significant increase in the turbidity created during dredging as part of the overburden material is sucked in during the dredging process. In addition the characteristics of the silts must be such (very soft and low density) that the dragheads be able to penetrate the overburden by means of its own weight. Yes, as explained above, some overburden will get mixed into the mixture leading to more fines being overflowed. These additional fines will lead to more hindered settling and a higher percentage of fine sands being overflowed.	A hopper dredge is not suited to remove material below a layer of silt without removing the overburden first. If the overburden must be removed first, any overflow of material will create increased turbidity.	It is likely to increase turbidity by entraining the silt along with sand as dragheads work by erosion.	In principle, yes, depending on silt properties. Whether this is an effective operation, in relation to environment and to quality of the load, is doubtful. Turbidity would most likely increase.	No. For aggregate dredging purposes we would not entertain exploitation without having first removed the overburden. Consequently we would not normally choose an area with an overburden for exploitation.	No.
3.	In mining sand with a low-silt content, with a turbidity requirement not to exceed 29 NTUs above background, is it necessary to take special	It can require measures to meet a 29 NTU standard. Generally the only very successful means is to restrict overflow time. This can result in reducing the load size dredged. This	This is highly dependent upon the exact location and timing of the turbidity sampling relative to the working area and dredge. In low-silt material the settling	Again, the percentage of silt encountered will greatly affect the turbidity created during dredging operations. One special measure which could be	For 29 NTU, with a low silt material, no special precautions are necessary.	Depends on where measurements are taken, at what distance from the (moving) dredge, relative to current, both velocity and	No experience of dredging in open sea conditions with such an imposition.	No, but probably depends on the dilution zone 150 – 200 feet.

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
	measures to meet this maximum turbidity requirement?	can have severe economic effect on a project. Properties such as color of silt and other items may also have significant effect on measurement of turbidity. In near shore borrow areas, the background NTU level is highly influenced by wind and current conditions on a day-to-day basis. Our understanding of the 29 NTU standard is that it came originally from State of Florida Statutes for industrial discharges. What science the 29 NTU standard was originally based on I do not know. I am also unaware of any studies that indicate that 29 NTU's is a significant level in affecting species at an offshore dredging site. It may be that levels significantly higher within a limited area or over a short duration may have little effect on organisms.	of the fines is generally quick enough to remain within turbidity requirements.	implemented to reduce, to the point of not exceeding turbidity is to reduce time overflowing. A second measure would be to eliminate overflowing entirely. A third measure would be to recycle overflow water into the drag arm jet system.		direction. If silt content is low, sand is mainly quartz, and fines are not lime, 29 NTU should in general not be a problem.		
4.	What measures do you employ to minimize turbidity?	Typically turbidity at offshore borrow areas has not been a big problem. Primarily the borrow areas utilized have been picked because they are known to contain primarily clean sand with low silt or clay content. Since the primary uses of the borrowed materials have been for beach nourishment and for construction aggregates, sites have been chosen which have quality materials. Also in an offshore environment the dispersal zone for turbidity is large enough that mixing occurs rapidly. Dredging in more confined areas such as channels, very near shore or in bays and rivers can be more problematic. Dredging near known reef areas or near highly sensitive environmental areas has increased immensely. In recent years we have performed several projects in the Dade County, Florida area where the borrow sites were in close proximity of reefs. The Department of Environmental Regulation Miami (DERM) has closely monitored impacts to the reefs during dredging and has worked with contractors to modify dredging	By far the most effective is to reduce the overflowing time if necessary to nil. This reduces or eliminates the turbidity produced by the pumping process but costs can as much as double due to reduced loads. There also exist various 'limited overflow' systems which modify the dredging process in such a way that the dimensions and characteristics of any turbidity plume are reduced.	Reduction of time pumping material past overflow or elimination of time pumping past overflow are two measures that will minimize turbidity.	Limit overflow as necessary, depending on permit conditions.	Assumed this question relates to hopper dredges: limitation of overflow, or ultimately allowing no-overflow at all, is most effective, but leads to significant cost increases (add 50 to 100%). Application of 'green overflow' systems does not reduce the amount of material brought in suspension, but modifies the way the fines are released in the environment in such a way that turbidity plumes are considerably reduced, both in dimension, dispersion and content.	We would employ unlocked overflow.	Anti turbidity valves, restricted overflow.

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Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		techniques as needed to minimize impacts. This has included limiting work in certain areas of the borrow site periodically, reducing overflow time when necessary, and even changing the boundaries of the borrow site as actual conditions require.						
5.	If you use measures such as recycling overflow water back to the draghead, is there a reduction in dredging production?	We have not recycled overflow water back to the drag head because it has not been necessary to meet the needs to date. The costs of equipping or retrofitting a dredge to recycle all the excess water would be very expensive. For example if a dredge loads approximately 30% solids, you would have to have a system which must recycle as much as 70% of its flow back to the drag head. This would take an additional piping and pumping system not much smaller than the existing dredge pump loading equipment. It might be accomplished without a large loss of pump production, there would be a huge Capital cost in equipping the dredge and significantly higher wear and maintenance costs for the equipment. Additionally the weight of the additional equipment would reduce the tonnage available for the Cargo and therefore reduce the load size causing an increase in the number of loads to complete a project. The maintenance and wear to the additional equipment would also add somewhat to downtime for the dredge thereby also negatively impacting the production. There were several foreign vessels built in the late 90's, equipped with recycling systems. However, recent US and Foreign new builds have not included this equipment on the vessels.	By recycling part of the overflow water the volume of suspended sediments discharged is reduced as part of them are recirculated. This won't affect productions in sands but will lead to increased costs due to the wear and tear of these components involved in the recirculation.	Typically no, however, there is an increase in wear to the jet water systems.	It is impractical to recycle all overflow back to dragheads. It will result in silt being recirculated and could increase turbidity over a smaller area.	In principle re-cycling of overflow to the draghead will not influence dredging productions in sand.	We do not use such measures. They would significantly increase energy requirements and time on the dredge area.	N/A
6.	Have you completed research on passive and dynamic plume processes associated with overflow and is this information publicly available?	We have not conducted research. We have provided turbidity sampling results to the owner of a project. However I know that the Corps engineering station (WES) in Vicksburg has done studies and some research on hopper overflow and Turbidity. This information should all	Studies such as these mentioned are generally carried out by large research institutes that develop the theoretical models and then turn to leading dredging firms such as Bean Stuyvesant for the collecting of field measurements.	The Norfolk District COE in conjunction with VIMS (Virginia Institute of Marine Sciences) did an extensive research project on this subject in 1988 at the deepening of the York Spit Channel project.	Have not done any research.	Some studies have been undertaken by research institutes. The mathematical part of the subject is normally covered by these institutes themselves; the practical part of the study, field measurements around	No.	No.

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Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		be available. DERM may have some specific information on the projects, which they have monitored which they would be willing to share.	A good outline of this type of studies can be found in the Report CIRIA C547 'Scoping the assessment of sediment plumes arising from dredging'.			dredging and disposal project is often made on instruction of and in co-operation with dredging contractors. Most of this information is published, the best overview is given in the CIRIA C547 Report, "Scoping the assessment of sediment plumes arising from dredging".		
7.	Do wind, wave, and/or current forces offshore determine the direction the dredge works? What are the consequences of dredging perpendicular to the current in order to influence the shape and dispersion of the dredge plume? Do you have any data to demonstrate the direction and rate of deposition of material discharged by the dredger during dredging operations?	Yes, typically it is best to dredge stemming the current and seas. The ship is much more easily controlled in this manner. If dredging broadside to heavy seas the ships will roll causing difficulty in maintaining bottom contact with the drag heads as they are dropped and snatched off the bottom with each roll of the ship. The ship's hull also tends to ride over the down current drag head and away from the up current drag head. This forces the drag tender to continuously raise each head and reset it on the seabed, which impacts loading production. It is much more difficult to maintain a course if seas, current, or swells are effecting the ship from abeam direction. We have worked in such conditions with difficulty and at times have been unable to continue dredging operations when we certainly could have if the borrow site layout was conducive to stemming currents, seas or winds. We do not possess any data showing the direction and rate of deposition of the overflow plume. However, the WES or DERM may possess such information.	Wind and wave conditions only determine the dredging direction when they reach borderline magnitudes. At this point the captains orient their dredgers parallel to the wave directions in order to avoid excessive rolling of the vessel. If strong currents are also encountered a compromise is reached that leads to minimum rolling while avoiding damage to the suction pipes. Dredging perpendicular to a current requires the vessel to sail at an angle to the dredging direction. The greater the current the greater the angle. This can lead to the dragheads slipping under the vessel with the consequent increased risk of damage to the equipment. Though there have been a number of attempts to model this process, to the best of our knowledge there is no hard data on this subject. This is in great part due to the considerable difficulties involved in tracking and recording an ever expanding plume with suspended solids barely above background levels.	All three elements (wind, wave and current) have an impact on a hopper dredges ability to maneuver and maintain position while dredging. As such, the dredge will often dredge in different orientations to the winds, waves, and currents, as conditions (both physical and environmental) will allow. A consequence of dredging perpendicular to the current is the vessels possible restricted ability to maneuver and stay on course during dredging operations depending upon the speed of the current encountered. Yes but only some bathymetry, change of which may be attributable to other factors.	The dredge typically works against current or sea conditions. Perpendicular approach requires the dredge to "crab" which can lessen production by 10 – 20 %.	Hopper dredging is preferably executed parallel to the current and with head or tail waves. This will not always be possible if current and wave directions are different. Depending on dominance by one or the other optimal working directions are defined. Depending on the force of the current when working perpendicular to the current, the risk exists that the dredge is pushed over the draghead, which might lead to damage to the vessel of the dredging system, if not properly managed by accurate manoeuvring. Our company does not have any data other than some theoretical modelling studies. The direction of material dispersion might be derived from visual plume observations. The relatively limited quantity "spilled" during dredging and the way this material is dispersed make it practically impossible to monitor deposition within the accuracy of state-of-the-art survey systems. Also the dynamic behavior of the seabed makes these assessments virtually impossible. Theoretical sediment plume	The influence of wind, wave and current are to an extent linked to characteristics of the vessel itself. The direction the dredger works is normally determined by geological factors. We would not choose to work perpendicular to the currents but the determining factor is the geology. Yes but only some bathymetry, change of which may be attributable to other factors.	Yes. Depends on sea state. The angle of dredging is determined by shiphandling concerns.

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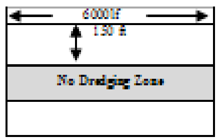
Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		be available. DERM may have some specific information on the projects, which they have monitored which they would be willing to share.	A good outline of this type of studies can be found in the Report CIRIA C547 'Scoping the assessment of sediment plumes arising from dredging'.			dredging and disposal project is often made on instruction of and in co-operation with dredging contractors. Most of this information is published, the best overview is given in the CIRIA C547 Report, "Scoping the assessment of sediment plumes arising from dredging".		
7.	Do wind, wave, and/or current forces offshore determine the direction the dredge works? What are the consequences of dredging perpendicular to the current in order to influence the shape and dispersion of the dredge plume? Do you have any data to demonstrate the direction and rate of deposition of material discharged by the dredger during dredging operations?	Yes, typically it is best to dredge stemming the current and seas. The ship is much more easily controlled in this manner. If dredging broadside to heavy seas the ships will roll causing difficulty in maintaining bottom contact with the drag heads as they are dropped and snatched off the bottom with each roll of the ship. The ship's hull also tends to set over the down current drag head and away from the up current drag head. This forces the drag tender to continuously raise each head and reset it on the seabed, which impacts loading production. It is much more difficult to maintain a course if seas, current, or swells are effecting the ship from abeam direction. We have worked in such conditions with difficulty and at times have been unable to continue dredging operations when we certainly could have if the borrow site layout was conducive to stemming currents, seas or winds. We do not possess any data showing the direction and rate of deposition of the overflow plume. However, the WES or DERM may possess such information.	Wind and wave conditions only determine the dredging direction when they reach borderline magnitudes. At this point the captains orient their dredgers parallel to the wave directions in order to avoid excessive rolling of the vessel. If strong currents are also encountered a compromise is reached that leads to minimum rolling while avoiding damage to the suction pipes. Dredging perpendicular to a current requires the vessel to sail at an angle to the dredging direction. The greater the current the greater the angle. This can lead to the dredgehead slipping under the vessel with the consequent increased risk of damage to the equipment. Though there have been a number of attempts to model this process, to the best of our knowledge there is no hard data on this subject. This is in great part due to the considerable difficulties involved in tracking and recording an ever expanding plume with suspended solids barely above background levels.	All three elements (wind, wave and current) have an impact on a hopper dredges ability to maneuver and maintain position while dredging. As such, the dredge will often dredge in different orientations to the winds, waves, and currents, as conditions (both physical and environmental) will allow. A consequence of dredging perpendicular to the current is the vessels possible restricted ability to maneuver and stay on course during dredging operations depending upon the speed of the current encountered. Yes but only some bathymetry, change of which may be attributable to other factors.	The dredge typically works against current or sea conditions. Perpendicular approach requires the dredge to "crab" which can lessen production by 10 – 20 %.	Hopper dredging is preferably executed parallel to the current and with head or tail waves. This will not always be possible if current and wave directions are different. Depending on dominance by one or the other optimal working directions are defined. Depending on the force of the current when working perpendicular to the current, the risk exists that the dredge is pushed over the draghead, which might lead to damage to the vessel of the dredging system, if not properly managed by accurate manoeuvring. Our company does not have any data other than some theoretical modelling studies. The direction of material dispersion might be derived from visual plume observations. The relatively limited quantity "spilled" during dredging and the way this material is dispersed make it practically impossible to monitor deposition within the accuracy of state-of-the-art survey systems. Also the dynamic behavior of the seabed makes these assessments virtually impossible. Theoretical sediment plume	The influence of wind, wave and current are to an extent linked to characteristics of the vessel itself. The direction the dredger works is normally determined by geological factors. We would not choose to work perpendicular to the currents but the determining factor is the geology. Yes but only some bathymetry, change of which may be attributable to other factors.	Yes. Depends on sea state. The angle of dredging is determined by high-sounding concerns.

5

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Boskalis Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		accomplished safely. Waiting for calmer seas to safely place, repair or move an offshore pipeline can cause weeks of delay to a project.						
18.	Does your dredge have a system to reduce pressure/flow at the draghead when the draghead is off the bottom? How does it work?	When the drag head is raised off the bottom as can be evidenced by the seating of the swell compensator ram, the drag tender manually reduces the dredge pump speed. Raising the drag head off the seabed is typically not a problem in borrow sites since there is generally plenty of material to dredge above the specified maximum depth, if one is stipulated. In channel dredging where a grade elevation must be achieved and the contractor is not paid for excess dredging, drags do occasionally hang off above the seabed.	In the event that the draghead comes off the bottom we have various technical solutions that would apply. One possibility is to redirect the flow so that it doesn't come through the draghead. Another more attractive possibility is to stop the flow completely. Both these solutions would require relatively minor adjustments to the equipment. None the less, the effectiveness of a reduced flow in reducing turtle takes is questionable. The system determines if the draghead is off the bottom by means of sensors on the draghead and swell compensation system. The flow is then interrupted by use of valves or the pump control.	No such system exists on our dredges.	No	Yes, the so called swell compensator. A hydraulic buffer system keeps a constant tension on the draghead wire. As soon as the draghead loses contact with the bed, either through a depression in the bed or by an upward move (wave induced) of the dredge, the head hangs with a higher weight in the wire, causing the swell compensator to veer out an additional length of wire, until the draghead is in contact with the bed again, at the pre-set pressure. If the distance between bed and vessel is reduced, by bed elevation or wave trough, the wire could come slack, which again is prevented by the swell compensator paying in some wire length.	No.	Pump is stopped.
19.	How effective are observers and trawling to reducing turtle takes?	There is no relation between observers and the number of turtle takes. Observers may occasionally see turtles on the surface, but turtle takes occur on the seabed. Observers inspect the drag heads, inflow and outflow screens and document / identify any takes. We believe trawling can be an effective method to reduce the number of turtle takes. Great Lakes was involved on an emergency contract in Canaveral where trawling was performed by 2 vessels on a 24 hour/ day basis for 3 days prior to the start of dredging and in front of the vessel during dredging operations. Canaveral is one of the most populated turtle areas and no turtles were taken during the dredging operations	The only contribution of 'observers' is to inspect the turtle cages at the hopper inflows for any evidence of a take. In addition, if turtles are spotted at the surface you may draw the conclusion that there is a high density of turtles in the vicinity. This often triggers the requirement for turtle trawling. Trawling follows special guidelines (e.g. net type and size) and often lead to the capture of turtles in the general area which reduces the density of turtles in the vicinity of the dredging though by no means does it eliminate the risk of turtle takes.	Observers have not proven to reduce turtle takes. Trawling has proven to be effective in some instances.	Trawling when working in a channel seems to help. Observers just record results.	This is not an issue in UK waters.	Not understood.	N/A Trawling is not effective. Turtles will swim back to nesting ground. That is what they do!
	Additional Questions							

17

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		projects. Requiring overflow to be discharged beneath the bottom of the hull will reduce turbidity in the upper water column. Some systems can be employed at a cost to reduce the amount of air that is entrained in the overflow. This reduction of air that helps lift some of the turbidity to the surface will further lessen turbidity in the upper water column, although commensurately it may increase the turbidity in the lower water column as the sediments will be spread throughout a lower volume of seawater. This system is called an anti-turbidity valve. Re-circulation of water back to the drag head may also have an impact in reducing the visible turbidity in the upper water column. However the particles that cause the turbidity still are not retained in the hopper and eventually are returned to the sea. Typically multiple dredging passes are made in a borrow site and these particles will be moved around within the area regardless of what technique is employed. While it may reduce visible turbidity at the surface, it may cause increased turbidity concentration in the lower water column or at the sea floor. I have attached a paper from MTI Holland on overflow systems. Please reference 04.09 Overflow Design.						
9.	What are your views on requiring overflow to be discharged below the hull?	This is the normal practice within the industry except where the goal is to deliberately agitate material in order to have currents carry the material away. For example at the Mississippi River Southwest Pass, the Corps deliberately uses agitation dredging and requires that overflow occurs at or near the water surface.	This is a simple and effective way of reducing turbidity by reducing the settling distance and settling time of any sediments released through the overflow. All Bean Stuyvesant hoppers are equipped accordingly.	Unsure if this question means discharging at the drag head or at the bottom of a thru hull overflow system (as opposed to a water surface overflow system).	It's not a problem.	This is a standard feature on most of our hopper dredges. It contributes to the reduction of dispersion of suspended overflow material, and it improves the direct visual aspects	See 4. Above	This is our standard practice.
	Question Impacts to Benthic Habitats							

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
10.	If there is a stipulation in the specifications that required that only 70% of a borrow area can be used and the unused portion cannot be on the boundaries, what would be the most efficient use of the area? What is the minimum width cut that a hopper can dig efficiently? The reason for this proposed stipulation is that the benthic community will recolonize faster if the area is dredged with intermittent non-dredged areas. Do you have any comparative data to show whether dredging in strips to leave recolonizing adults in the dredge site enhances recovery rates compared with sites where all the surface deposits are removed?	In general, borrow sites of approximately 6000 feet in length are ideal. They allow the hopper dredge to trail at 2kts, making one pass in each direction to obtain a full load. If only 70% of the site could be utilized, a 'no-dredge' zone in the middle of the area would be preferred, as shown in the following drawing.  The minimum width of the dredging lanes should be 150 feet. This will allow positioning of both drag heads within the dredge area at all times and eliminate any 1-arm dredging. We do not have any data with respect to the effect of strip dredging on recolonizing adults. However, WES and DERM may have such information.	It would be viable to define dredging areas interspaced with non-dredging areas so long as the work areas have the necessary characteristics not to limit the standard dredging process. To this end each dredging area should be roughly rectangular with its long axis aligned parallel to the predominant currents and a minimum width of 300 ft at the maximum dredging depth. Ideally this area should also be at least 3000 ft long. An area less than 300 ft wide (at the maximum dredging depth) would lead to reduced productions due to increased manoeuvring as well as leading to an inefficient removal of all the available sands. The reason for this proposed stipulation is that the benthic community will recolonize faster if the area is dredged with intermittent non-dredged areas. It is our understanding that there is currently a study being carried out in Europe under the name 'Sandpit' that addresses this issue. The Dutch Rijkswaterstaat-NL has also looked into this and a conference was held on the issue in 2003 (see EMSAGG 2003 conference).	There is not enough information to answer this question. What is the total surface area (length and width) that "70%" would be used. There is an enormous difference between using 70% of a borrow area that is 500' X 5,000' and 70% of a borrow area that is 5,000 X 50,000'. The minimum width that a dredge can dig efficiently is dependent on wind, wave, and current, but in general, a hopper dredge of 300' length and 55' width can dredge efficiently in a cut width of 300 – 500 feet. We have no data for the final question on this item.	The best way to work a site would be in rectangular strips, typically 300-600' wide by 5,000-6,000' lengths. No data is available from Manson.	A division of the borrow area into dredging zones and no-dredging zones is feasible. This can be achieved by allowing for relatively long dredging zones, parallel to the main current direction, of sufficient width and allowed dredging depth. A dredging zone should minimally be some 200 m wide at the bottom of the cut, with no-dredging zones of some 100 m at bed level, slope distances to be defined as function of cut depth and slope angle. A dredging width less than 100 m might reduce operational freedom for a larger type hopper dredge. The question is whether it is environmentally more attractive to take a thin layer off a large area, or to affect a smaller area only by dredging deeper for a thicker layer. This topic is presently being studied under a European Research program 'Sandpit' (check the website with that name). Side research at national level is known to be executed by CEFAS-UK and by Rijkswaterstaat-NL. Also much of this information is in the public domain. A useful overview is given in the proceedings of the EMSAGG 2003 conference. Wherever possible we try to minimize the area impacted by dredging. This can include the adoption of strip zoning. However, we do not have any site specific monitoring information on recolonization.	We would normally anticipate dredging in lanes. Current practice is that the footprint of dredging should be less than 10 sq km. No but we are advised that this would tend to promote recolonisation.	Dr. Nairn: Can be done with Dynamic Position Dredging (cost $ high)
11.	Are you aware of any damage to hard bottoms caused by	There have certainly been cases, although the technology of monitoring	Beyond the damages caused by one of our competitors in the	No. When pumping silty borrow material directly from a	Unknown.	We are not aware of any damage to hard seabed	No.	No.

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
	dredging including covering by sediment? If yes, was a buffer or exclusion zone applied and was it sufficient?	has improved dramatically over the years. I cited earlier the projects in Dade County Florida. These were Corps projects that were closely monitored by DERM. Partnering between the Corps, DERM and the Contractor has been very successful at minimizing impacts. The borrow areas were first established with designated buffer distances from hard bottoms and then these buffers were modified as necessary during the project in order to account for actual conditions encountered.	very sensitive habitats of south Florida we are unaware of any additional impacts arising from dredging operations. In the case of Florida we do not recall if buffer zones were used. None the less, it is evident that due to the heavy activity taking place in the dredging area and the nature of the dredging process there is always a high probability of encountering noticeable side effects in the contiguous areas. As a result, based on the specific characteristics of each situation, buffer zones should be defined where limited impact of dredging is acceptable.	borrow site, the concern is greater, however on such projects we have never seen it occur		caused by dredging.		
12.	Are your dredges capable of tracking and recording the position of each draghead? Have you done tracking relative to a buffer zone? Would you have a problem providing this information to the regulatory agencies?	Yes, tracking and recording of positional information is standard operating procedure for our TSHD operations. Great Lakes' TSHD fleet is equipped with real-time monitoring electronics and positioning software enabling us to effectively position our dredges at all times. Because the systems incorporate project control criteria and real-time dredge orientation our operational staff can efficiently plan and manage of precise dredging operations. Each of our TSHD's uses a combination of the following electronic equipment for dredge position monitoring. • Navigation / Guidance System. - Compaq Workstation with Great Lakes' Hopper Positioning Software. • DGPS Receiver. - Trimble Navigation 4000 GPS receiver (or like) using RTCM corrections from US Coast Guard Beacon Transmitter or site specific Reference Stations. • Electronic Water Level Receiver. - Valeport VTM710 or Hazen HTG 3000. • Heading Sensor. - Sperry Marine MK-37VT Gyro Compass or like. • Drag Head Depth Sensors. -	Yes, all our bigger dredgers are equipped with this capability. It is often the situation that we must track the draghead position relative to a known feature or area, be that a buffer zone, shipwreck or submerged pipeline. No problem, this is pretty much standard procedure. In addition the USACE often uses a 'silent inspector system' to track this kind of information independently of our own systems.	Yes, the dredge guidance system and Silent Inspector System is capable of tracking and recording the position (X,Y) and elevation (Z) of each drag head. Drag head and vessel tracking has been performed on every project for several years. Information can be provided up request.	We typically track and record position of dredge, draghead, and other parameters and furnish info to COE on almost every project.	Some of our dredgers have the facility and can track the draghead relative to buffer zones or other features. As far as we are aware this information is not normally required for UK projects. However, the position and status of any dredger is required when operating within Crown Estate marine aggregate dredging licences within UK waters. The Crown Estate holds this data.	Yes but only with a special installation.	Yes. Would not provide directly to agencies. Reports through PM or COR.

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		Various sensors used to obtain depth readings can include: differential pressure electronic devices on the drag head and gimbal, angle measurement devices, and hull mounted vessel draft / pressure sensors. Great Lakes' hopper positioning system provides real-time displays of the dredge and contoured channel plans for reference by the dredge operators. Dredge sensor information such as DGPS information, heading, drag head depth, tide, pump production information, etc, is compiled for the system through several interfaces and Program Logic Controllers (PLC). In addition, relevant dredge data, such as dredge and drag head coordinates, is displayed and may be stored at user-specified intervals. **<u>See Figure 1 Attached.</u>** Examples of the type data stored include: Load No., Date mm/dd/yy: 1/27/98, Time 24hr hh:mm:ss, Northing of GPS Ant., Easting of GPS Ant., Port Drag Head Depth, Stbd Drag Head Depth, Fwd. Draft, Aft Draft, Port Density, Stbd Density, Port Velocity, Stbd Velocity, Port Pump RPM, Stbd Pump RPM, Tide Ft., Gyro, Speed, Port Gimbal Depth, Stbd Gimbal Depth, Easting of Bow, Northing of Bow, Easting of Port Drag Head, Northing of Port Drag Head, Easting of Stbd Drag Head, Northing of Stbd Drag Head. At user-defined intervals the data is written to the hard drive of the positioning systems computer in comma separated form. For example: 135, 12/19/03, 00:00:15, 171929.66, 929651.55, -36.3, -36.8, 18.9, 20.3, 1.00, 1.00, 0.00, 0.00, 218, 200, 5.76, 152.2, 6.92, 15.7, 16.3, 171874.00, 929815.30, 172078.80, 929759.80, 172121.50, 929829.10						

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Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		Dredge operations staff utilizes these track data files to pinpoint where the dredge has traveled throughout the previous days operations. As shown in Figure 2, the dredge's draghead locations and depth is compiled into a track plot indicating the dredge area limits, project stationing, etc. To the question "Have you done tracking relative to a buffer zone?" Yes our TSHD positioning / tracking systems track relative to any user defined zone provided the "buffer zone" means some area calling for special dredging or non-dredging areas. Lastly, to the question "Would you have a problem providing this information to the regulatory agencies?" No, we would not. The process of providing information to regulatory agencies is standard practice on every project administered by the U.S. Army Corps of Engineers. As you may know, a majority of our domestic operations are for the Corps so such a requirements is expected. **See Figure 2 Attached.**						
13.	When offshore sand dredging is completed for a beach project, what does the bottom look like? Are there draghead tracks, (width and depth?) throughout the area? Are the tracks parallel or crossing? Can you provide examples to us of high resolution mapping of pre- and post-dredging seabed conditions for offshore dredging with TSHD?	I have attached before and after dredging plan view maps and cross section overlays of the Miami Beach / Sunny Isles North Borrow Area taken in late 2001 and summer of 2002. The cross sections clearly show drag head tracks and multiple pass trenches. These tracks / trenches are typically 10 to 20 feet wide and 3 to 4 feet deep. **See Miami Beach Survey Data attached.**	After offshore dredging in sands the bottom is generally somewhat more uneven than before dredging. The average roughness (i.e. difference between the highest and lowest spots in an area) will depend on the original layer thickness to be removed and the characteristics of the borrow area (length, width, currents) A high quality survey would allow individual tracks to be recognized though currents and wave action would steadily smoothen the bottom until it is difficult to distinguish from the surface encountered before dredging. As mentioned previously, a narrow borrow area will lead to parallel tracks and a higher roughness.	Unsure what the bottom looks like at completion of the project.	Offshore borrow areas will have tracks. The size and condition will depend on dimensions off the borrow pit and how the vessel works.	If you could take a direct look, you would be able to recognize the tracks of the latest series of trails. Depending on morphologic activity, smoothing of the area will occur sooner or later. The direction of the tracks will be mainly parallel, refer to question 10. But depending on contract requirements additional effort might be made to deliver a flat bed. This is normally applied in dredging for navigational purposes, but is not standard procedure in sand mining. It would be possible against some additional cost. As a matter of course we collect pre and post dredge data although this is generally	This is as much a question of geology, prevailing currents etc. as it is of operations. Normally the dredger would follow parallel tracks.	Yes. We have the tracks on the bridge display (see Essayons Bridge)

Baird – RPI – DRL - MES

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Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
			Though rarely done in borrow area, this roughness can be reduced at the cost of diminished production. That information can be provided to you separately as it will entail very large files.			commercially confidential.		
14.	When mining sand off shore, is the dredge tended by a survey boat?	Normally, there is a survey boat utilized. Most project owners require at least before project and after project surveys. Contractors typically will survey for their own purposes in managing the resource. This vessel is typically employed on a 12hour/day basis	The availability of a survey boat will generally depend on the contract specifications and the necessary level of follow up. The regularity of the surveys may vary between twice daily or only the before and after dredging surveys.	A Survey/Crew boat is assigned to each dredge during all projects.	Yes a survey boat is used.	Within UK waters there is generally no stipulation for a dredge to be tended by a survey boat when winning sand or aggregate.	No.	Our launch is our survey boat.
15.	Other than turtles, has your dredge ever been in a collision with a marine mammal? Do marine mammals have a tendency to swim near an operating dredge?	We have never noted any collisions with marine mammals, nor am I aware of any collisions between a hopper dredge and a marine mammal in the United States. I did hear several years ago that a dredge off of South Africa collided with a whale, and there certainly are documented collisions of ships with Marine mammals. However there is quite a difference between an ocean going ship sailing at 20-30 knots and most hopper dredges that typically attain maximum speeds of 10-15 knots. It should be noted turtle takes occur from contact with the dredge drag head at or near the sea floor not due to contact from the hull of a sailing dredge. We recently saw a permit that restricted dredge sailing speed when turtles were in the area. When checking with the permit agency we were told that they didn't request the restriction or think that it was necessary but that it had been in the proposed application. Such a restriction put in by an uninformed person can have a huge impact on a project. We have not noted that marine mammals are attracted to dredges.	To the best of our knowledge this has never happened. In order to reduce this risk we generally employ biological observers to carry out a constant lookout for such fauna in the area of operation and if any are spotted we modify our operations to minimize the risk of collision. Based on experience the only mammals with a tendency to swim near a dredge are dolphins and seals. The former tend to escort sailing ships of any kind and the latter are known for their curiosity and tendency to sunbath on floating lines and auxiliary equipment.	No incidents with other marine mammals. In Ft. Pierce, Manatees have been seen in the vicinity of the dredge while it was dredging and transiting to/from the dig area.	No, Not in our experience.	No, this is not an issue in UK waters.	No.	No.
16.	When appropriate, does your dredge use a dragheadd designed to reduce the probability of entraining sea turtles? Is this use mandated by the	The following is the Corp turtle exclusion device specification from our present dredging project in Kings Bay Georgia. Hopper Dredge Operation:	Yes. In most cases. Yes, in many cases it does.	When mandated by contractual requirements, the dredges drag heads are outfitted with NMFS designed and approved TED's (Turtle Excluder Devices). The use of TED's does reduce	We use draghead deflectors on most projects. The best change would be to allow the deflector to float on the bottom.	No, this is not an issue in UK waters.	No special measures employed.	This is an East Coast problem. No. No Sea Turtles on Pacific

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Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
	Owner? Does the use of these draghead, reduce the productivity of the dredge? Is the modified draghead, effective? Do you have any recommended changes to the design of the turtle deflector? Do you have any recommendations on operating techniques to avoid entraining turtles during offshore dredging operations?	(1) The Contractor shall operate the hopper dredge to minimize the possibility of taking sea turtles and to comply with the requirements stated in the Incidental Take Statement provided by the National Marine Fisheries Service in their Biological Opinion. (2) The turtle deflector device and inflow screens shall be maintained in operational condition for the entire dredging operation. (3) When initiating dredging, suction through the drag heads shall be allowed just long enough to prime the pumps, then the drag heads must be placed firmly on the bottom. When lifting the drag heads from the bottom, suction through the drag heads shall be allowed just long enough to clear the lines, and then must cease. Pumping water through the drag heads shall cease while maneuvering or during travel to/from the disposal area. (Information Only Note: Optimal suction pipe densities and velocities occur when the deflector is operated properly. If the required dredging section includes compacted fine sands or stiff clays, a properly configured arrangement of teeth may enhance dredge efficiency, which reduces total dredging hours, and "turtle takes." The operation of a drag head with teeth must be monitored for each dredged section to insure that excessive material is not forced into the suction line. When excess high-density material enters the suction line, suction velocities drop to extremely low levels causing conditions for plugging of the suction pipe. Dredge operators should configure and operate their equipment to eliminate all low level suction velocities. Pipe plugging in the past was easily corrected, when low suction velocities occurred, by raising the drag head off the bottom until the suction velocities increased to an appropriate level. Pipe plugging cannot be corrected by raising the drag head off the bottom. Arrangements of teeth and/or the reconfiguration of teeth should be made during the dredging	Though no hard evidence is yet available, all signs indicate a greatly reduced incidence of sea turtle takes, It might be questioned if this is due to the effectiveness of the design or a drop in turtle density but anecdotal evidence suggests a slight increase in turtle numbers. No, none at this time though we have made some practical modifications to reduce wear and tear. Our present operating procedures for eliminating takes apply equally well to inshore and offshore activities.	productivity. Uncertain if the TED is or is not effective as it is designed. No recommendations on changes to design or operating techniques.				Coast.

Baird – RPI – DRL - MES

MMS

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Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		process to optimize the suction velocities.) (4) Raising the drag head off the bottom to increase suction velocities is not acceptable. The primary adjustment for providing additional mixing water to the suction line should be through water ports. To insure that suction velocities do not drop below appropriate levels, the Contractor's personnel shall monitor production meters throughout the job and adjust primarily the number and opening sizes of water ports. Water port openings on top of the drag head or on raised stand pipes above the drag head shall be screened before they are utilized on the dredging project. If a dredge section includes sandy shoals on one end of a tract line and mud sediments on the other end of the tract line, the Contractor shall adjust the equipment to eliminate drag head pick-ups to clear the suction line. (5) Near the completion of each payment section, the Contractor shall perform sufficient surveys to accurately depict those portions of the acceptance section requiring cleanup. The Contractor shall keep the drag head buried a minimum of 6 inches in the sediment at all times. Although the overdepth prism is [unclear] the required dredging prism, the Contractor shall achieve the required primarily removing the material from the allowable overdepth prism. (6) During turning operations the pumps must either be shut off or reduced in speed to the point where no suction velocity or vacuum exists. (7) These operational procedures are intended to stress the importance of balancing the suction pipe densities and velocities in order to keep from taking sea turtles. The Contractor shall develop a written operational plan to minimize turtle takes and submit it as part of the Environmental Protection Plan. (8) The Contractor must comply with all requirements of this specification						

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		and the Contractor's accepted Environmental Protection Plan. The contents of this specification and the Contractor's Environmental Protection Plan shall be shared with all applicable crew members of the hopper dredge. The use to TED's is mandated by the Owner and dredging permit. The use of TED's negatively impacts the productivity of the dredge. The leading edge of the TED is held a minimum of 6 inches in the seabed and in effect plows sand away from the drag head visor. Occasionally, the TED will plow into the seabed, burying the drag and slowing the vessel. When shell or gravel is encountered, the inflow screens plug up and have caused hopper deck piping plugs. There is no hard data on the effectiveness of TED's. There is no way of knowing what the number of takes would be if TED's were not employed. Operating a hopper dredge with one drag head TED equipped and one head unequipped has not been tested. The only testing we are aware of was done by Scripps Institute and involved the use of concrete turtles. Our recommendation would be to conduct dredging operations during the low turtle population season. We typically only encounter turtles in near shore borrow areas or shipping channels and do not have many problems when working in offshore borrow sites. *Please reference attached TED Operational checklist*						
17.	What effect do the seasonal requirements restricting dredging due to the proximity of turtles have on the overall annual dredging schedule?	The seasonal effects have had a very large impact on the hopper dredging industry. Currently there are seasonal restrictions enforced by the US Army Corps on their projects in the South Atlantic area. For maintenance and new work channel dredging it effects the Harbors from North Carolina south	The use of seasonal restrictions, either due to turtles or other factors, lead to a disproportionate volume of the total annual dredging work being restricted to a limited time period. As a result of this there is a lack of dredging	Seasonal requirements increase the costs four services some years, and some years it does not.	It bunches some of the work.	This is not an issue in UK waters.	If such should apply the implications are on shore installations where additional storage and buffer capacity would be required.	N/A

Baird – RPI – DRL - MES

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
	Do you have any information on the rates of recovery of biological resources at your sites following cessation of dredging?		many different factors and are very variable in their results. The European studies mentioned in the answer to question 10 showed recovery periods that ranged between a few months and a few years.			rates.		
23.	Do you have any comments, general or specific, regarding dredging equipment and procedures and the reduction of adverse impacts on the environment?	While special precautions are obviously necessary when working in proximity of highly sensitive resources, these need to be addressed on a project specific basis. Often mandating restrictions and procedures is unnecessary and based on "feel good" perceptions rather than scientific need or practicality. We should be cautious about over regulating a situation where the benefits are not well founded.	It is essential that all parties involved pool their knowledge in an open discussion to achieve a balanced result that best achieves the interests of all. This process is also essential in building the mutual trust and understanding that will ensure the successful solution of any hurdles that might arise. Our company recognizes the adverse impacts that dredging might have. Every effort is made to minimize the impacts. Mitigation might include seasonal restrictions, minimization of impacted area and developing site specific procedures just to name a few. It is in the interest of all to define a feasible methodology that allows often critical projects to proceed without delay.	We have dredged +/- 30,000,000 cubic yards of sand from offshore borrow areas for beach nourishment in the past 10 years. We have damaged (1) utility cable, taken 0 turtles from borrow areas and have not damaged the environment or archeological resources to the best of our knowledge.	A typical hopper dredge operation in clean sand is probably the least disruptive to the environment.	Our company recognizes the adverse impacts that dredging might have. Every effort is taken to minimize the impacts and mitigation might include seasonal restrictions, minimization of impacted area and developing site specific procedures.	See 4. Above.	For the most part routine maintenance dredging occurs in regularly impacted navigation channels, so benthic communities are transient in nature. Disposal site issues are the main focus of our coordination with agencies, with the exception of entrainment of salmonid. This is avoided by turning off pumps when dragheads are more than 3' above bottom.

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Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		through the East Coast of Florida. The allowable operating windows in these areas run from December through March with some of the Ports restricted to Dec15-February. There is also movement to extend these restrictions to Virginia on the North and into the Gulf of Mexico. This concentrates dredging requirements in these areas to a short winter time period. This if coupled with a considerable amount of new work, heavy dredging needs on the Mississippi River which sometimes occur during this period, or with other heavy demand elsewhere can occasionally cause a short term demand for bigger dredges which strains capacity. However, during the remainder of the year there can be serious overcapacity with a lot of idle plant. During the past few years there was overcapacity and considerable idle plant even during this time period however. Of more concern to contractors is that with such tight contract periods there is often little or no flexibility in scheduling equipment. If a dredge unexpectedly has a significant problem requiring repair they can be hard pressed to meet the schedules. With windows it no longer is a matter of being a few days late and perhaps having some penalties, there can be a risk that the project won't be completed. As regards maintenance and deepening work, there is an effect that these winter months are the worst weather months. This can moderately lower time efficiencies somewhat and make surveying to monitor projects more problematic. However, if and when, beach projects are restricted to this window these effects are much more severe because the laying and moving of pipeline offshore and connecting to offshore pumpout connections requires much better sea conditions to be	capacity (i.e. equipment) during part of the year leading to higher prices and, sometimes insufficient capacity to complete all projects. This is in the interests of neither the clients nor the contractors, both of whom would benefit from a reduced overlap in the seasonal restrictions of different regions.					

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
20.	What has been your experience dredging in a fishing ground? Has any fishermen or commercial fishing company complained about any aspect of the dredging process? Did you modify your operation to accommodate the fishermen?	We have conducted hopper-dredging operations near identified fishing grounds. The majority of problems involve contact with nets or traps within the dredging area or the disposal route. In some cases, the disposal route was modified to avoid concentrations of nets / traps. The Portland Corp District has investigated the impact of dredging on the commercial crabbing industry in several West Coast Ports.	Designated dredging areas are always very clear-cut and it is very rare that permission be given to operate in a designated fishing ground. In such an event it would be the responsibility of the authorities to communicate to the fishermen that such a permission had been given and to deal with any conflicts of interest that might arise from it. Fishermen, despite a lack of evidence, often feel threatened if dredging is carried out in or close to their fishing grounds. Contrary to these complaints, the release of additional nutrients into the water column often attracts shoals of small fish and game fish leading to an improvement in the local sports fishing. In some cases small changes have been made to the operating methods in order to resolve a potential conflict with fishermen. The responsibility for any additional costs arising from these was determined from the contract. Our company takes a pro-active stance with the fishing industry. Any conflict of interest is usually resolved prior to the issue of any permission to dredge and mitigation measures adopted where appropriate. Fishing liaison officers are often employed at particularly sensitive sites.	No experience dredging in a fishing ground. Have experienced isolated encounters with crag pots, lobster traps, and fishnets in the North East area, which has resulted in complaints from commercial fishermen who claimed to have lost equipment due to our operations.	No real problem as most work is done in navigation channels.	Our company takes a pro-active stance with the fishing industry. Any conflict of interest is usually resolved prior to the issue of any permission to dredge and mitigation measures adopted where appropriate. Fishing liaison officers are often employed at particularly sensitive sites.	This is an on-going feature of operations. Normally dealt with by consultation pre license and regular dialogue.	Disposal impacts are more important than dredging impacts to our agencies.
21.	What measures do you, the dredge operator, take to insure that the dredge does not damage underwater pipelines and cables, or archaeological resources?	As shown in previous examples, our TSHD positioning displays provide real-time dredge orientation at all times. Using this system, operations staff can integrate pipeline locations, archaeological resources, cables, etc., into the heads up displays such that the dredge operator can avoid such hazards. In Figure 3, a screen shot of our positioning system displays, the	Assuming that accurate of such obstacles are known with some accuracy, The coordinates of each obstacle, assuming that they are known with some accuracy, are used as a basis for defining a no-dredging zone which is input into the onboard computer system. The dimensions of this zone are	With respect to pipelines or cables, we make every effort to contact the owners of them and request detailed location and elevation information. We also ask them to mark the location of their utilities (sometimes marked with buoys, etc) and give them the option of placing their own representative on board to	Notify owners and obtain information on locations that cross the work area.	We make every effort to ensure that all known positions of cables and pipelines are highlighted in our navigation package and appropriate safety zones are adopted. Safety zones of 500m either side of cables and pipelines are industry standards within the UK	Such services would normally be identified on the charts and track computer with the operation of security zones normally 500 m either side of a pipeline.	Not an issue in Fed nav. Channels. Pre-Con-Solve all these questions.

Question Number	Question Plume Related	Great Lakes Dredge & Dock	Bean Stuyvesant	Weeks Marine	Manson	Westminster	Dredge International	USACE
		area highlighted in BLACK is an avoidance area. In this instance it is for shallow depths that could ground the ship but the same application is indicative to any predefined caution area or obstruction. **See Attached Figure.** As a precautionary measure, some projects warrant hydrographic survey investigation prior to dredging activities to determine the locations of underwater obstructions. Such surveys are supported with a compliment of equipment that could include Cesium Magnetometers, side scan sonar, cable tracking devices, or high resolution multibeam / swath bathymetry systems. In most US government contracts, such underwater pipelines and cables, or archeological resources are previously located. Once the underwater obstruction locations are verified, operations staff integrates the information into the dredges positioning systems for dredge operator reference throughout dredging activities. Further, project meetings are held prior to dredging activities to discuss the plan for avoiding such obstructions.	adapted to the local operating conditions to include sufficient safety margin, both in horizontal and/or vertical direction. This no-dredging zone then shows up on the operator's screen and in certain cases activates a proximity alarm signal. Depending on the level of automation the dredhead will be hoisted automatically if coming within the safety zone. The dimensions of these safety zones are based on risk and will generally be in the order of 50m – 100m in the proximity of cables or pipelines.	within our operations while dredging eve near in the vicinity of their property. Should the pipeline or cable crossing be shown on the contract drawings, or the owner provide sufficient location information (X, Y, Z), that data is used to plot the utility on the dredge guidance screen so both the operator navigating the vessel and the drag tender operating the dredging gear can visually see where the utility is located. Typically, the customer (COE, State, or Private) will give us written direction to dredge over the utility, lift the dredging gear while navigating over the utility while dredging, or avoid the area completely where the utility is located (buffer zone provided). Archaeological resources typically are noted on the contract drawing with an avoidance buffer zone placed around it. These noted areas are also put on the navigation screen and are avoided.		aggregate dredging industry.		
22.	Some operating companies have a policy of dredging localized zones to exhaustion before moving to further zones within the dredge area. This assists management of the resource, but it also helps to minimize occupation of seabed and allow maximum time for recovery of seabed resources. Does your company have a policy of zoned dredging, and what are your reasons for dredging policy? Do you have any information that documents the impact of your dredging operations on marine organisms in specific dredge sites?	Our standard operating procedure is to dredge in specified lanes. In this way we can move the dredge to an adjacent lane while surveys and volume computations are run to check progress and output in the initial dredging lane. This procedure is also beneficial during clean up dredging and helps limit over dredging. We do not have any information in house on the impacts of lane dredging on marine organisms. WES and DERM have conducted extensive monitoring studies of impacts to marine organisms and rates of recovery in borrow areas and should be contacted.	Our company does not have a firm policy on this subject. Dredging strategies are project specific and aim to achieve the best possible economic and environmental situation. The collection of such information is normally done by the project client independently of the dredging contractor. In addition these studies often extend well beyond the completion of dredging making it difficult to follow up on. As mentioned above, the results of these studies are not always easy to come by, depend on	We have no "policy" regarding zone dredging as you note. Given a borrow area to dredge, we follow the contract specifications which typically give directions for material removal. Should no directions be given, we typically seek to find areas of the borrow area which have the best production and dredge that area to exhaustion before moving on to less productive areas of the borrow area. No additional information available regarding additional questions listed.	Our work plans are typically dictated by the owner as to what areas we work. All info concerning biological resources would be accomplished by the permitting agency.	The development of new UK marine aggregate licences is largely guided by the policies identified in MMG1 2002 (Marine Minerals Guidance Note 1). This document offers guidance on best practice which includes the adoption of zones as a means of reducing environmental impacts in addition to the exhaustion of resources before moving zones. All companies now work with MMG1. No. We do not have site specific information on recovery	Yes, this is specifically targeted to reduce dredging footprint and mitigate effects on surroundings. No but this is likely to be the subject of future monitoring. No.	No.

Questions To Dredging Contractors and Responses

Plume Related Impacts

Much of the perceived concerns were due to the plume resulting from hopper overflow and the bottom agitation at the draghead.

Plume Related Impacts

1. What percent of material overflows the hopper while digging sandy, low-silt content material, assuming a 10 km sailing distance to pump ashore?

- All sediment below 200 sieve (0.07 mm) is not retained, some losses 0.07 to 0.2 mm depending on loading rate and hopper design (our estimates: 7 to 17% overflow)

Plume Related Impacts

2. Can a hopper dredge mine sand from below a 1 m silt overburden without removing the overburden? Does this result in significantly increased material overflow and consequently an increase in turbidity?

- Depends on the density of the overlying silt

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3. In mining sand with a low-silt content, with a turbidity requirement not to exceed 29 NTUs (about 50 mg/l) above background, is it necessary to take special measures to meet this maximum turbidity requirement?

- Depends on silt content and where it is measured (among other factors influencing overflow)
- Not generally used by MMS

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Sand and Gravel Unit

Plume Related Impacts

4. What measures do you employ to minimize turbidity?

- Turbidity in offshore borrow areas has not been a problem (borrow areas generally feature clean sand)

5. If you use measures such as recycling overflow water back to the draghead, is there a reduction in dredging production?

- Requires dredge refit, would increase cost, reduce carrying capacity and increase maintenance
- Most recently built dredges (US and Europe) do not have this feature

Plume Related Impacts

6. Have you completed research on passive and dynamic plume processes associated with overflow and is this information publicly available?

- No, but referred to CIRIA publication C547 and Norfolk USACE and VIMS did research study at York Spit Channel

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7. Do wind, wave, and/or current forces offshore determine the direction the dredge works? What are the consequences of dredging perpendicular to the current in order to influence the shape and dispersion of the dredge plume? Do you have any data to demonstrate the direction and rate of deposition of material discharged by the dredger during dredging operations?

- Best when headed into current and/or parallel to wave direction
- Problem with down-current drag arm pushing under the hull, also need to continually raise drag head – problem with turtles
- Pre/post dredging surveys (insufficient resolution)

Plume Related Impacts

8. Given a mandate to reduce turbidity, what are the most cost effective ways of accomplishing the reduction? We understand this is a question of degree. Please explain the consequences.

- Responded turbidity has not been a problem to the extent that would require special measures
- If necessary, could reduce overflow by partially loading (after 10 min of 60 min loading period – 1/6 load) – US multi-purpose TSHDs
- Aggregate dredges in UK use lower loading rate with lower loss rate (longer loading = $$)

9. What are your views on requiring overflow to be discharged below the hull?

- All respondents indicated this was standard practice in the industry

Impacts to Benthic Habitats

Considerable concern was expressed relative to the loss of benthic community. Re-colonization rates are being studied, as are changes in substrate characteristics such as grain size, dissolved oxygen, etc. It has been suggested that dredging in patterns may speed the re-colonization rate by leaving “refuge” areas (that have undisturbed sediment characteristics and undisturbed benthic communities).

Impacts to Benthic Habitats

10. If there is a stipulation in the specifications that required that only 70% of a borrow area can be used and the unused portion cannot be on the boundaries, what would be the most efficient use of the area?

What is the minimum width cut that a hopper can dig efficiently? The reason for this proposed stipulation is that the benthic community will recolonize faster if the area is dredged with intermittent non-dredged areas.

Do you have any comparative data to show whether dredging in strips to leave recolonizing adults in the dredge site enhances recovery rates compared with sites where all the surface deposits are removed?

Plume Related Impacts

- Ideal borrow area dimensions to leave refuge areas are (assuming 3,000 cy hopper, distance drag arms is about 75 ft):
  - *Length: 5000 to 6000 ft (one turn only - preferred)*
  - *Minimum Lane Width: 250 to 600 ft*
  - *These should be considered in determining plan of borrow area and design of refuge zones*
  - *One respondent indicated refuge strips should be 100 m wide at the top*
  - *Several referred to the SANDPIT study*

Impacts to Benthic Habitats

11. Are you aware of any damage to hard bottoms caused by dredging including covering by sediment? If yes, was a buffer or exclusion zone applied and was it sufficient?

- There have been some instances, but real-time monitoring of turbidity and sedimentation have reduced impact considerably (DERM)

12. Are your dredges capable of tracking and recording the position of each draghead? Have you done tracking relative to a buffer zone? Would you have a problem providing this information to the regulatory agencies?

- All dredges in the US have this capability and would provide information

13. When offshore sand dredging is completed for a beach project, what does the bottom look like? Are there draghead tracks, (width and depth?) throughout the area? Are the tracks parallel or crossing? Can you provide examples to us of high resolution mapping of pre- and post-dredging seabed conditions for offshore dredging with TSHD?

- GLDD provided survey of tracks, typical track is 10 to 20 ft wide and 3 to 4 ft deep
- Bed will naturally smooth with time

14. When mining sand off shore, is the dredge tended by a survey boat?

- Yes

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Sea Turtles

There is an ongoing concern with marine mammal/dredge collisions and entrainment of Sea Turtles.

15. Other than turtles, has your dredge ever been in a collision with a marine mammal? Do marine mammals have a tendency to swim near an operating dredge?

- No contact reported with any other mammals

Sea Turtles

16. When appropriate, does your dredge use a draghead designed to reduce the probability of entraining sea turtles? Is this use mandated by the Owner? Does the use of these dragheads reduce the productivity of the dredge? Is the modified draghead effective? Do you have any recommended changes to the design of the turtle deflector? Do you have any recommendations on operating techniques to avoid entraining turtles during offshore dredging operations?

- All use Turtle Deflectors, may reduce productivity (but not a strong opinion), small changes have been made to address wear & tear

17. What effect do the seasonal requirements restricting dredging due to the proximity of turtles have on the overall annual dredging schedule?

- Large impact on inshore hopper dredge industry – but not yet an influence on offshore dredging

Sea Turtles

18. Does you dredge have a system to reduce pressure/flow at the draghead when the draghead is off the bottom? How does it work?

- One possibility to redirect flow so it does not come through draghead or stop flow completely (more restrictive than the current stipulation)

19. How effective are observers and trawling to reduce turtle takes?

- Observers document turtle takes but do not directly influence reduction of takes
- Trawling may be helpful in some circumstances but does not eliminate risk
- ERDC – perceived as effective under moderate turtle abundances in channels

20. What has been your experience dredging in a fishing ground? Has any fisherman or commercial fishing company complained about any aspect of the dredging process? Did you modify your operation to accommodate the fisherman?

- There are some problems with fishermen but these can be addressed through coordination (pre-construction meeting) and notification

Additional Questions

21. What measures do you, the dredge operator, take to insure that the dredge does not damage underwater pipelines and cables, or archaeological resources?

- Structures and buffers show up on navigation displays (MMS requires infrastructure is accurately located by the lessee)

Additional Questions

22. Some operating companies have a policy of dredging localized zones to exhaustion before moving to further zones within the dredge area. This assists management of the resource, but it also helps to minimize occupation of seabed and allow maximum time for recovery of seabed resources.

- Does your company have a policy of zoned dredging, and what are your reasons for dredging policy?
- Do you have any information that documents the impact of your dredging operations on marine organisms in specific dredge sites?
- Do you have any information on the rates of recovery of biological resources at your sites following cessation of dredging?

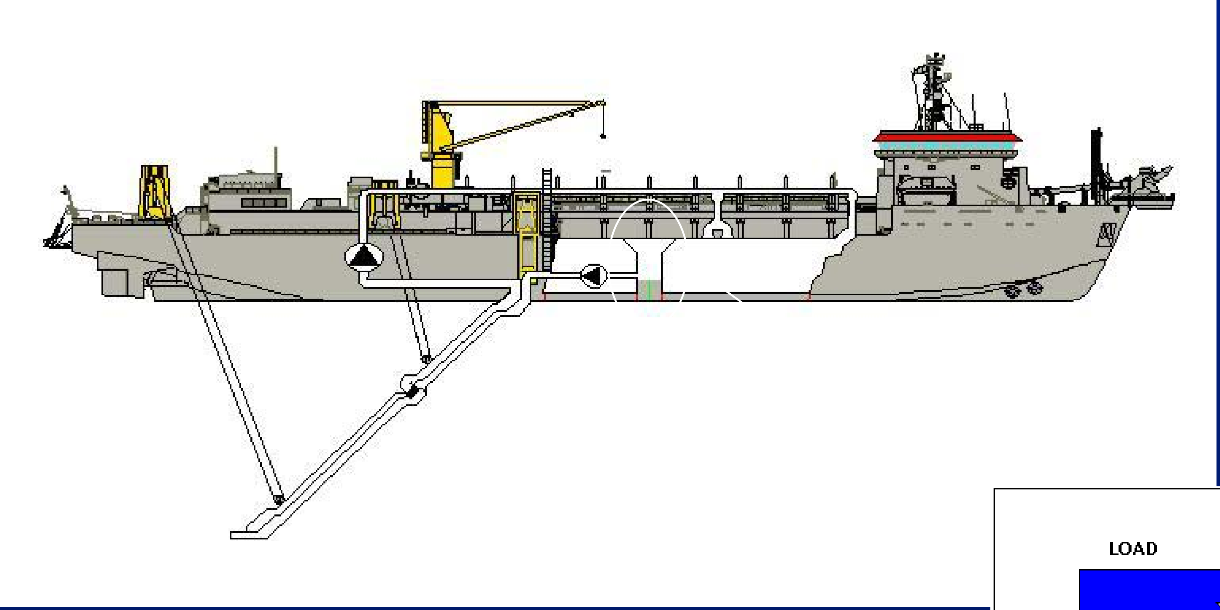
Additional Questions

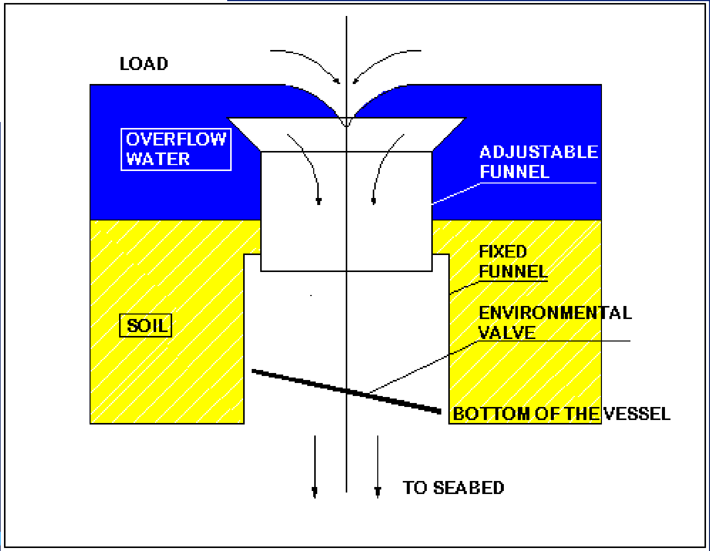
- Some companies dredge in lanes
- Another responded they follow specifications
- If no specification the contractor digs the best material first
- No direct information on recovery
- Latest in UK: recently there is conflicting opinion on whether to dredge low intensity or high intensity (exhaustive – historically thought to be the best approach)

23. Do you have any comments, general or specific, regarding dredging equipment and procedures and the reduction of adverse impacts on the environment?

- Regulations and guidelines should be based on scientific need and practicality
- One respondent indicated no turtles taken in 50,000,000 cy of offshore dredged sand for beach nourishment in the last ten years

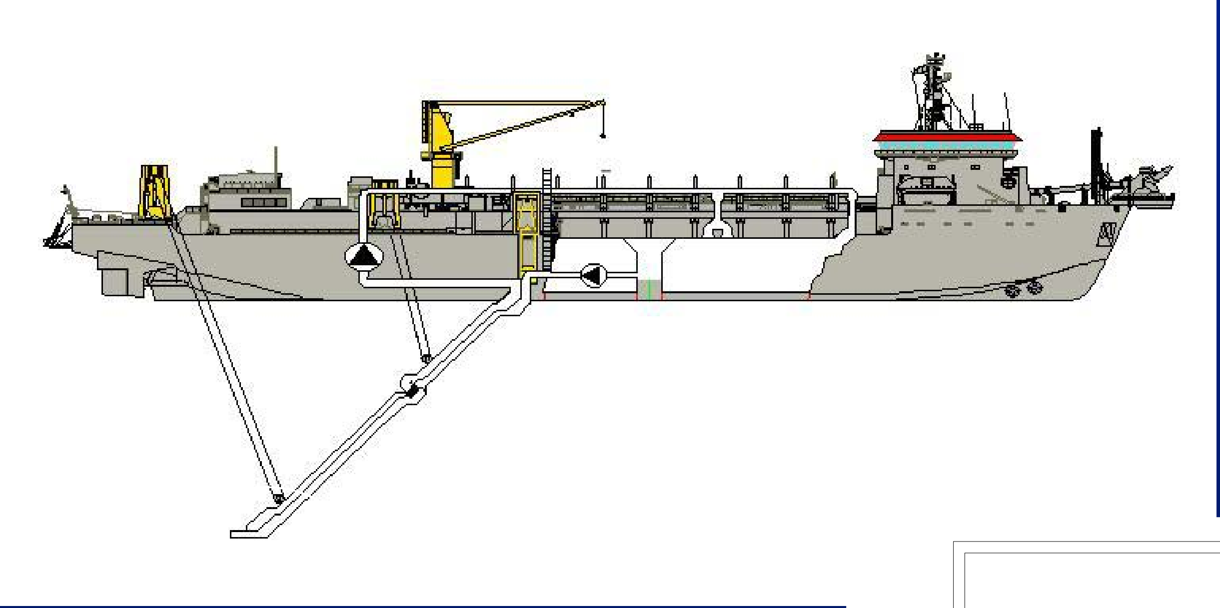
Low Turbidity Valve



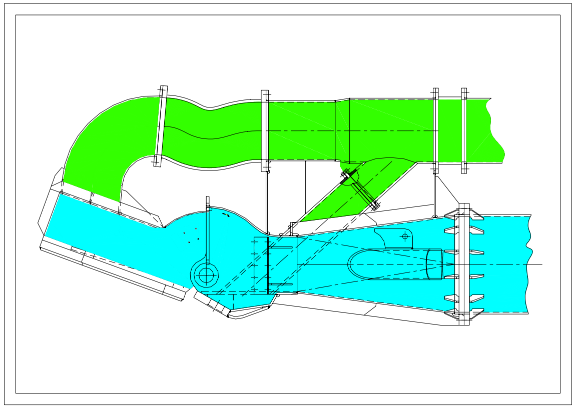


An adjustable valve in the overflow funnel chokes the flow in such a way that no air is taken down with the suspension leaving the hopper.

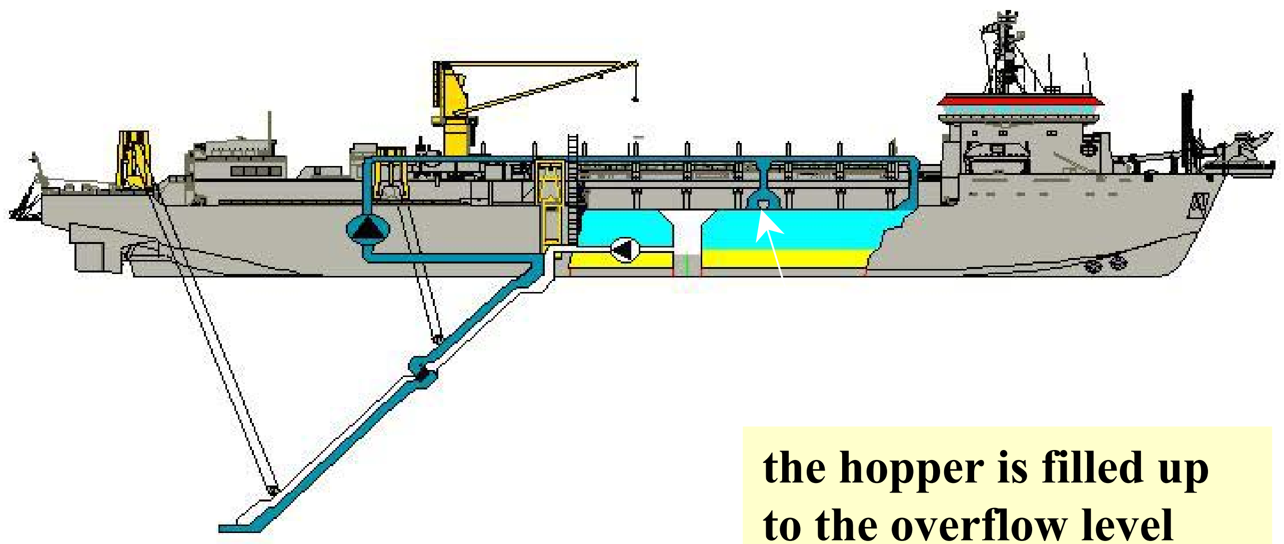
'Green Pipe'



The overflow suspension is pumped through an additional pipe, mounted on top of the suction pipe, back to the suction head where it is used as process water.

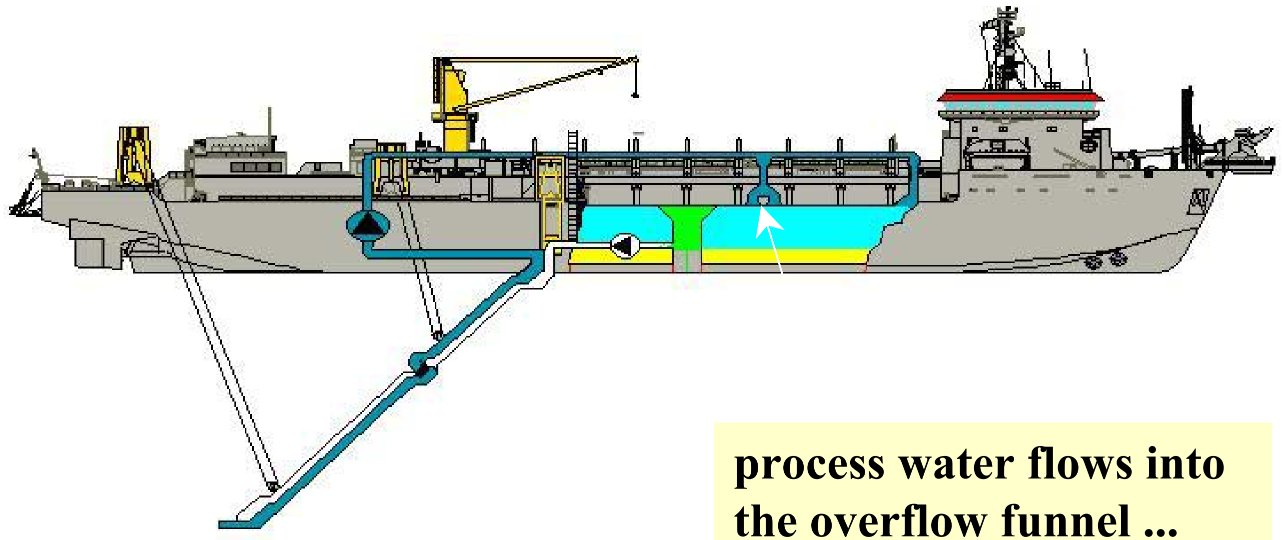


Activating the 'Green Pipe'



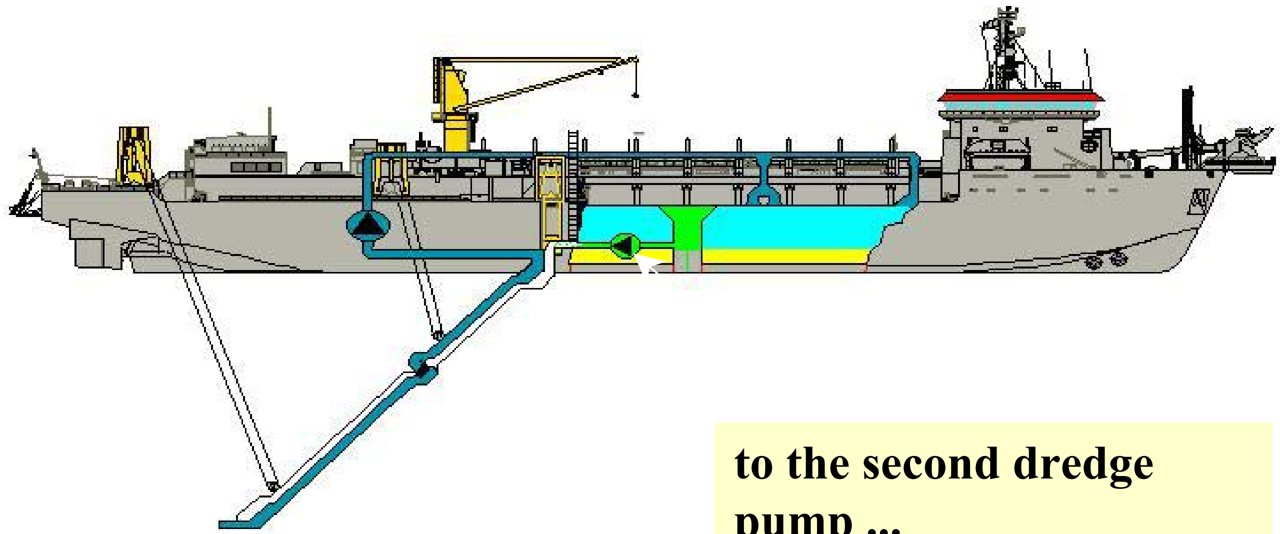
the hopper is filled up
to the overflow level

Activating the 'Green Pipe'



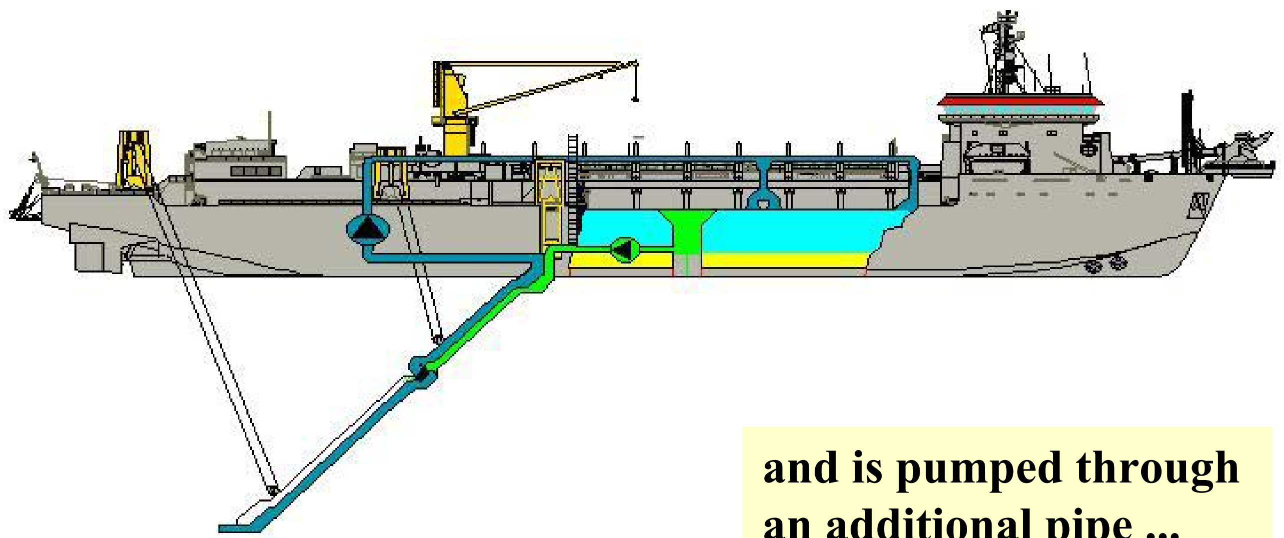
process water flows into the overflow funnel ...

Activating the 'Green Pipe'



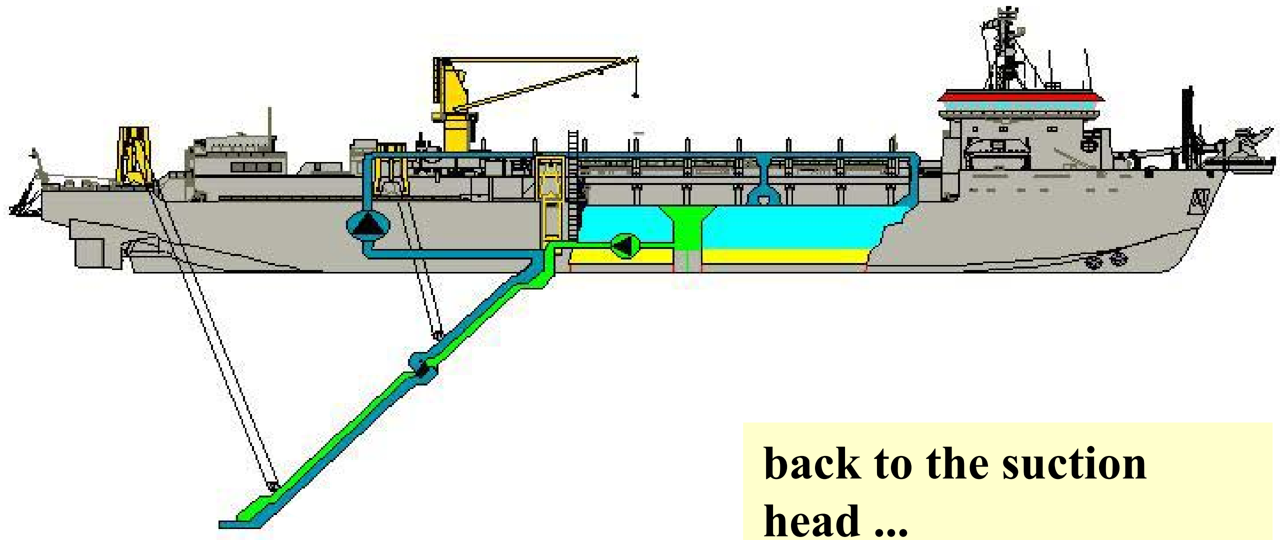
to the second dredge pump ...

Activating the ‘Green Pipe’



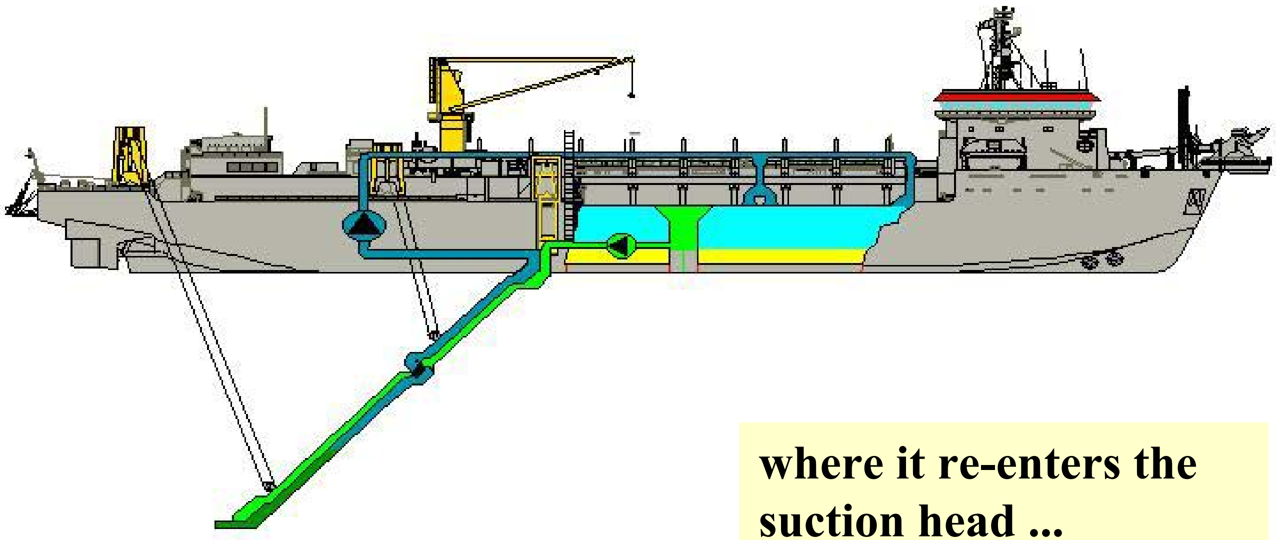
and is pumped through an additional pipe ...

Activating the ‘Green Pipe’



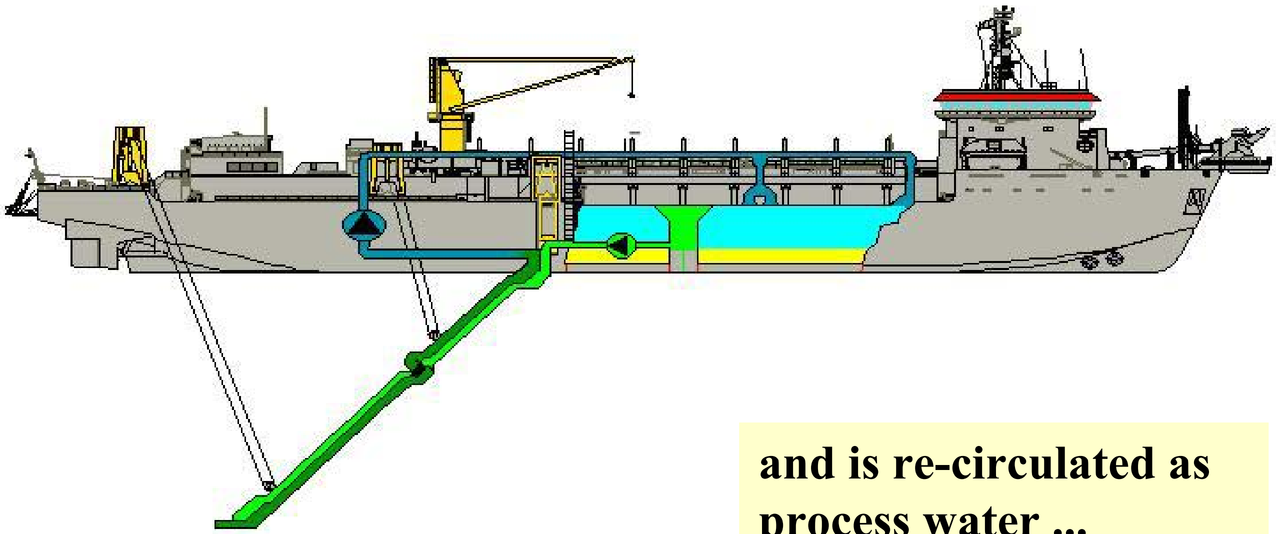
back to the suction head ...

Activating the 'Green Pipe'



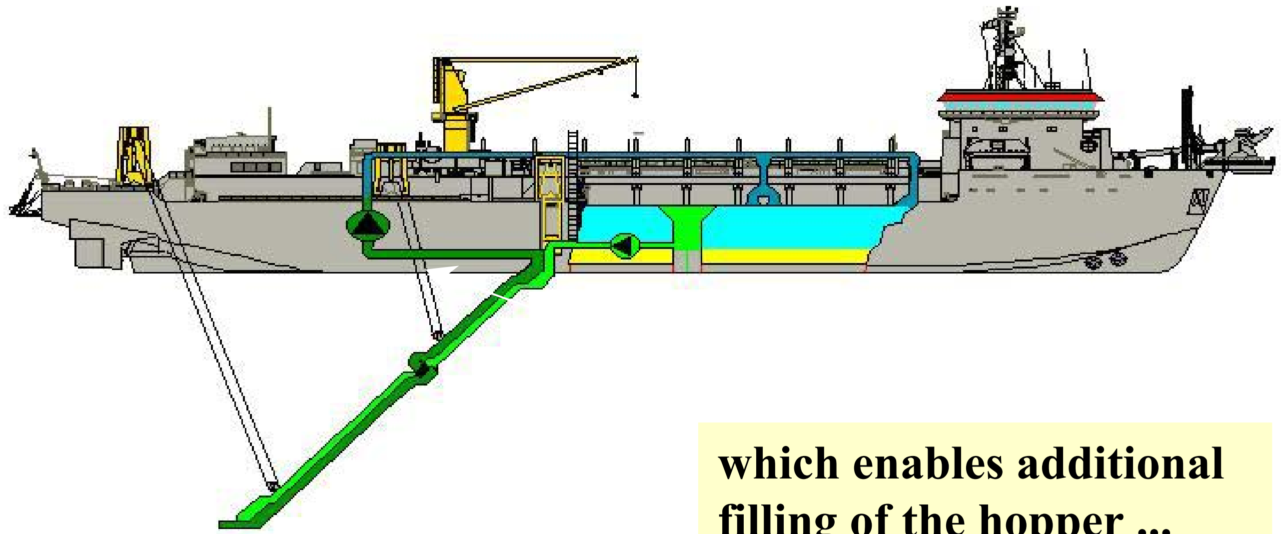
where it re-enters the suction head ...

Activating the 'Green Pipe'



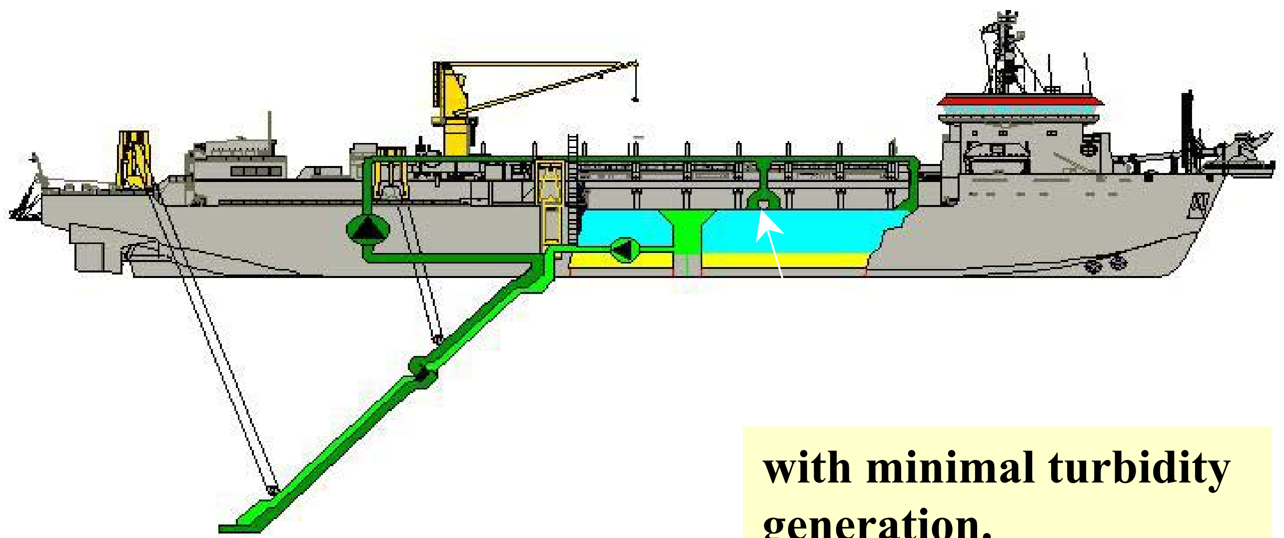
and is re-circulated as process water ...

Activating the 'Green Pipe'



which enables additional filling of the hopper ...

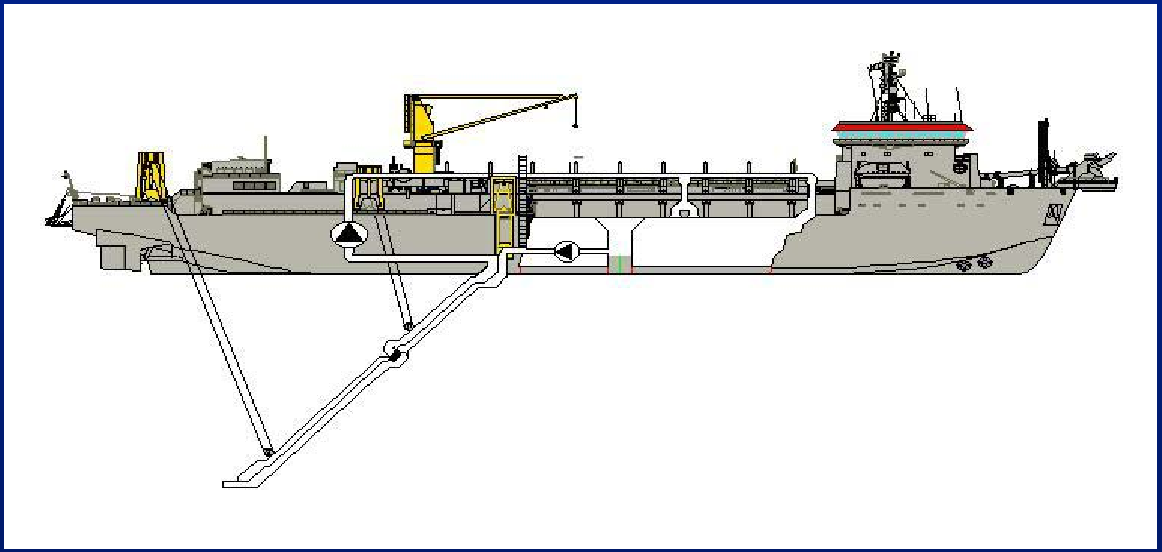
Activating the ‘Green Pipe’



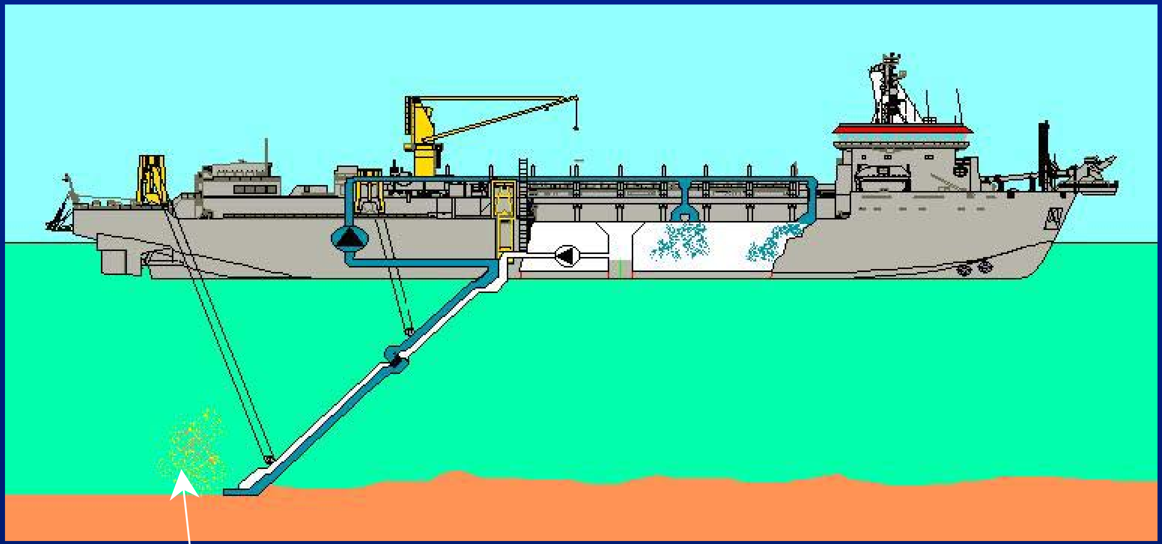
with minimal turbidity generation.

The dredging process:

- commencing from an empty hopper

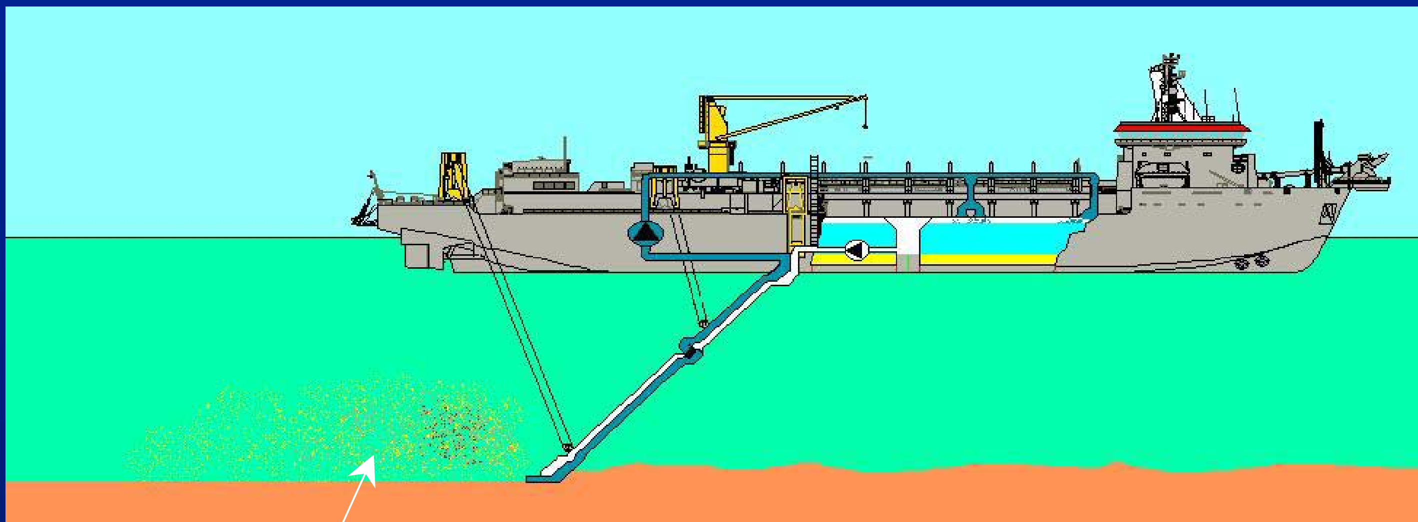


- dredged material is pumped into the hopper

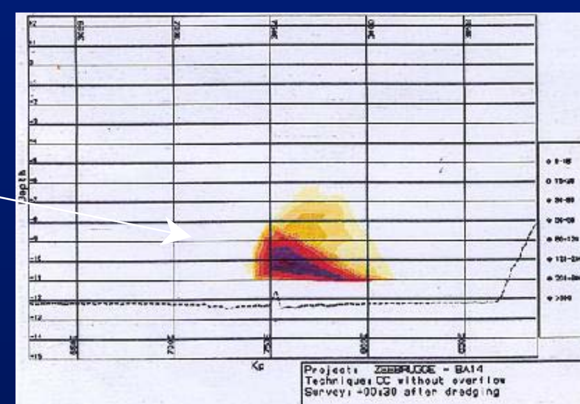


turbidity plume

- filling the hopper (loading <u>without overflow</u>)



turbidity plume



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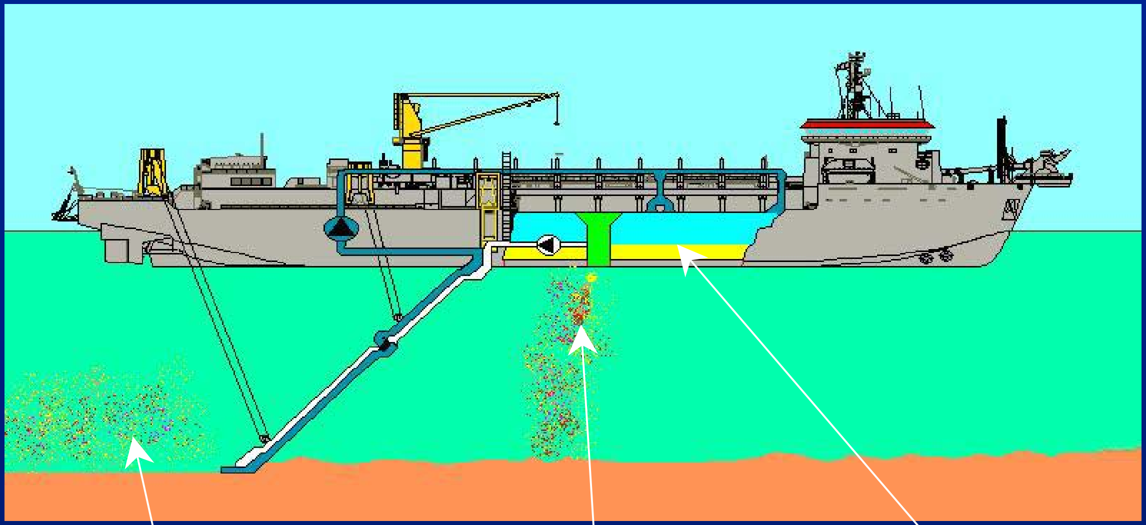
- additional loading with <u>standard overflow</u>

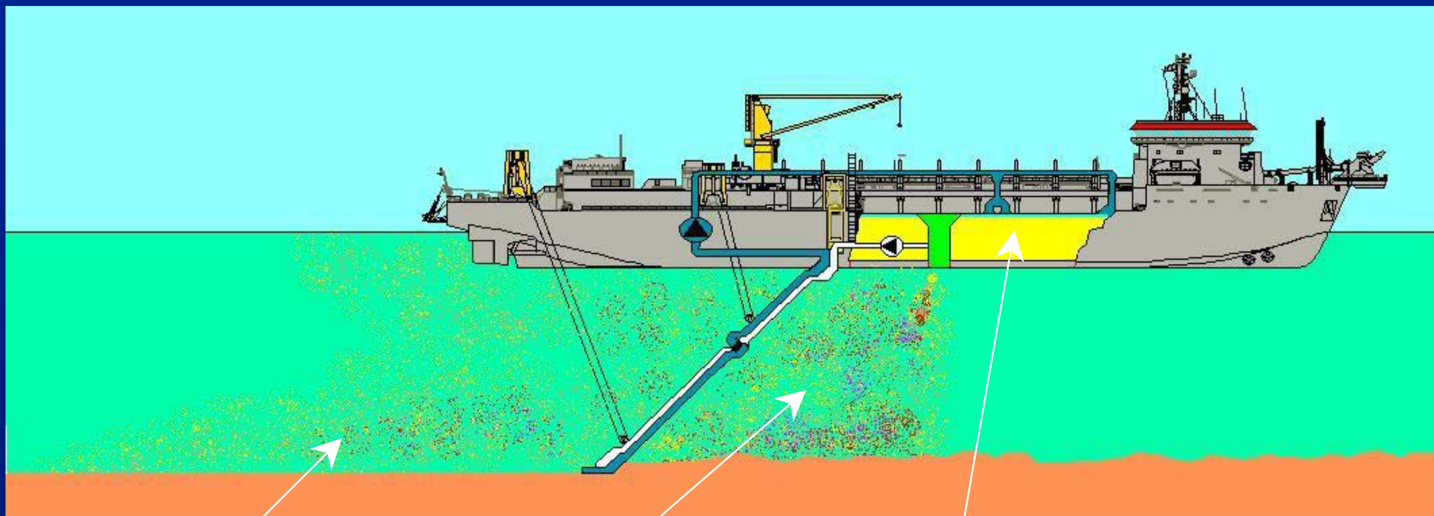


turbidity plume dredge head

turbidity plume overflow

continue loading

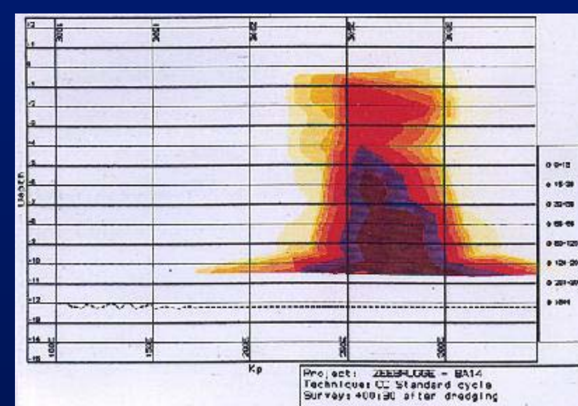
- plume generation while loading with <u>standard overflow</u>



turbidity plume dredge head

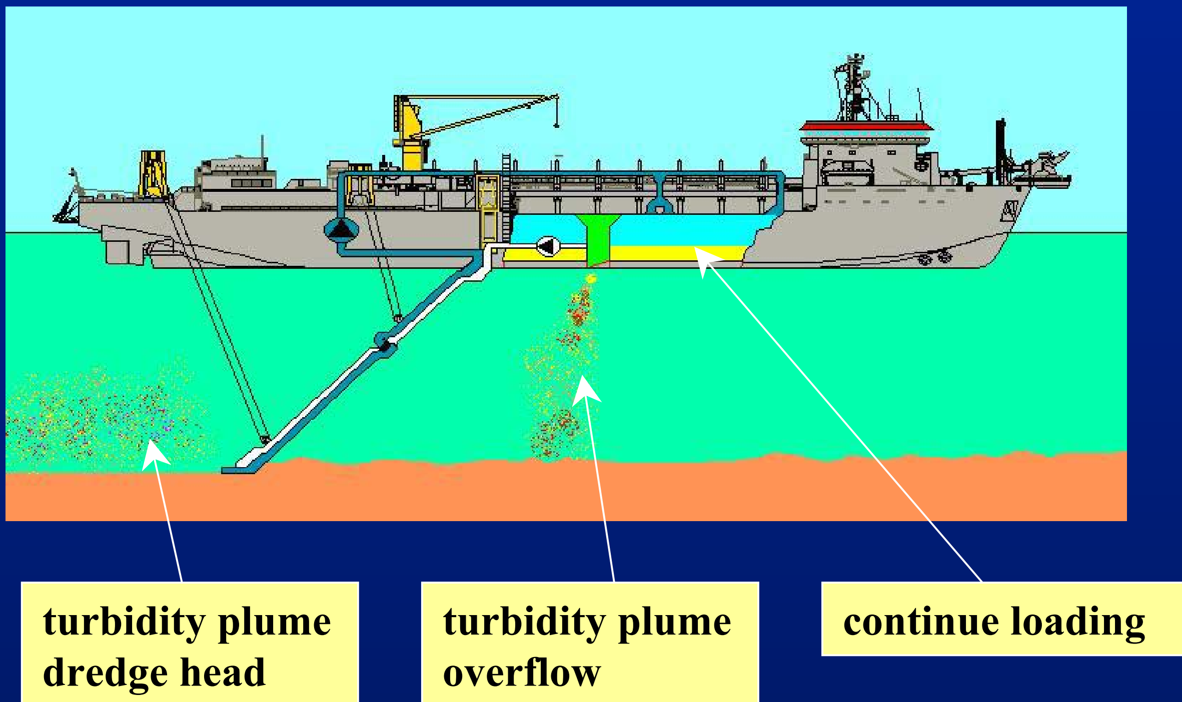
turbidity plume overflow

continue loading

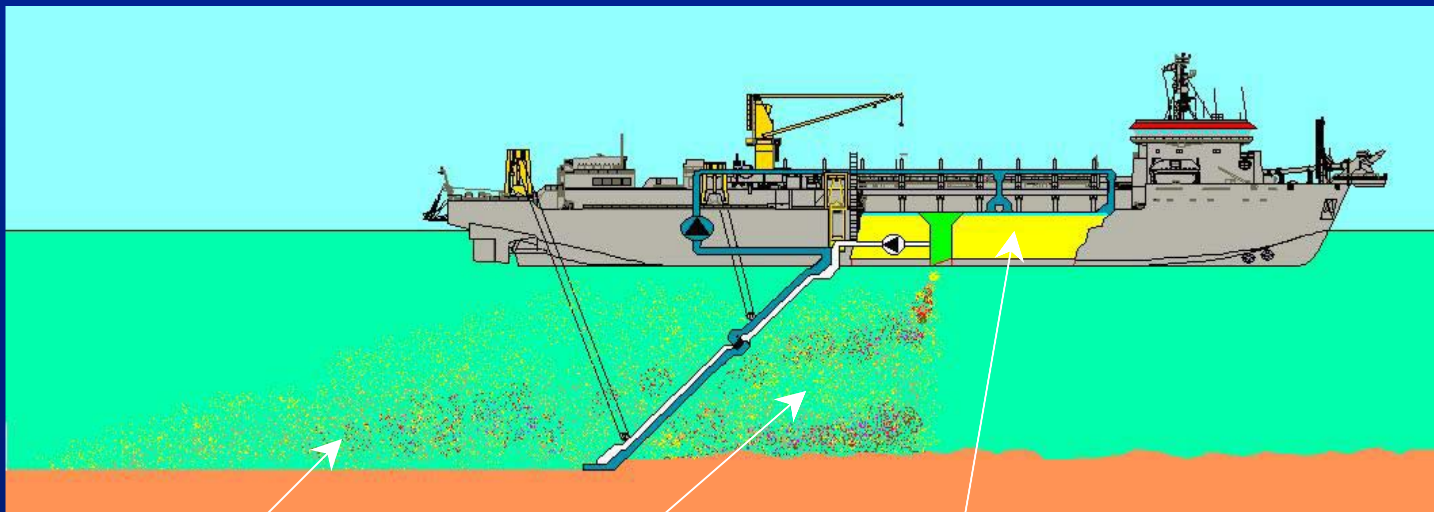


New parameters:
- upward airstream
- propeller impact

- additional loading with <u>low turbidity valve</u>



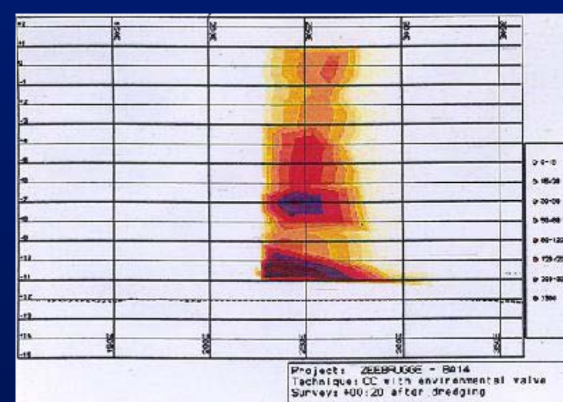
- plume generation while loading with low turbidity valve



turbidity plume dredge head

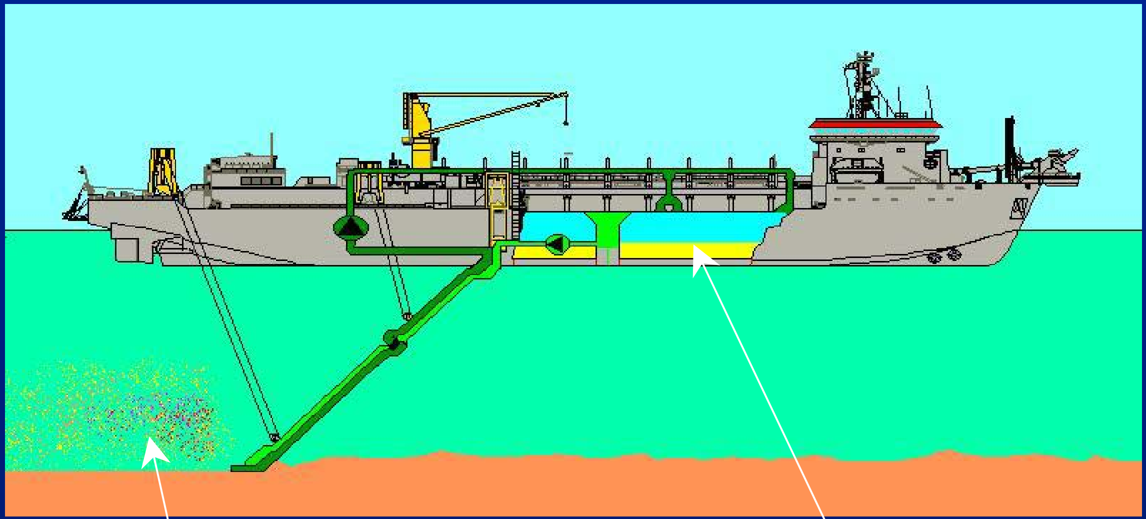
turbidity plume overflow

continue loading



New parameters :
- density stream

- additional loading with ‘green pipe’



turbidity plume dredge head and ‘green pipe’

continue loading

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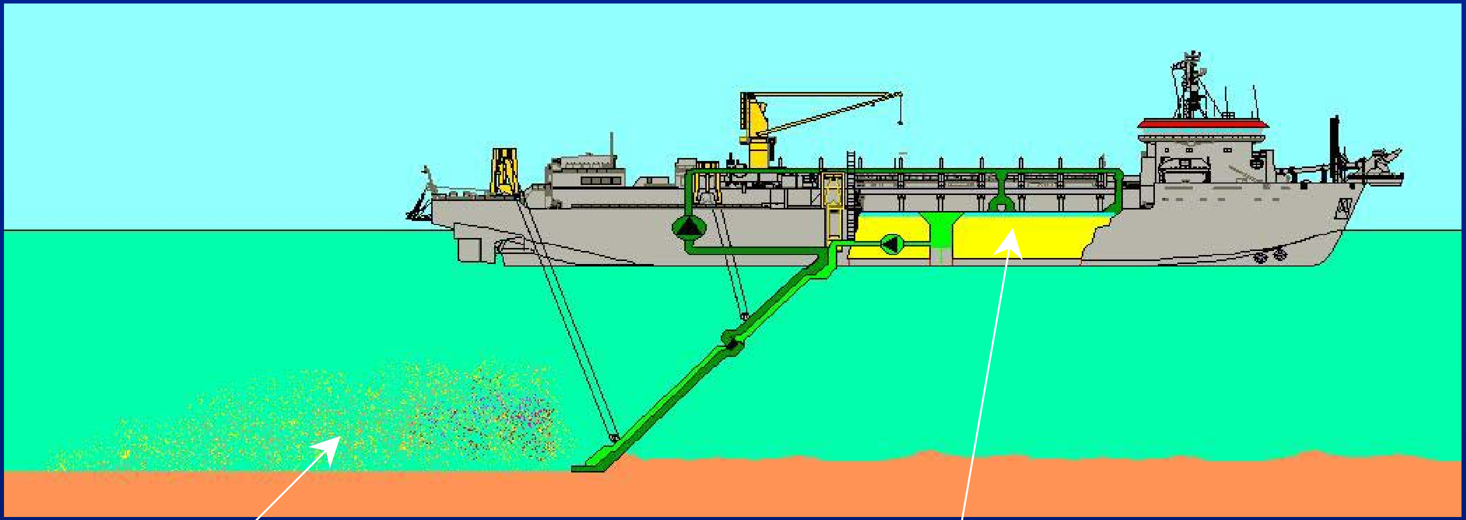
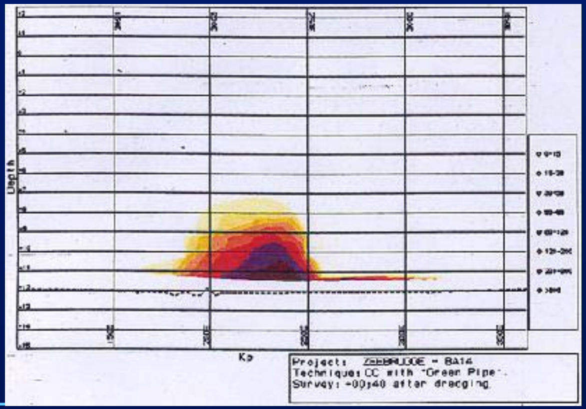
- plume generation while loading with 'green pipe'



turbidity plume dredge head and 'green pipe'

continue loading

New parameters:
- recirculation fluid



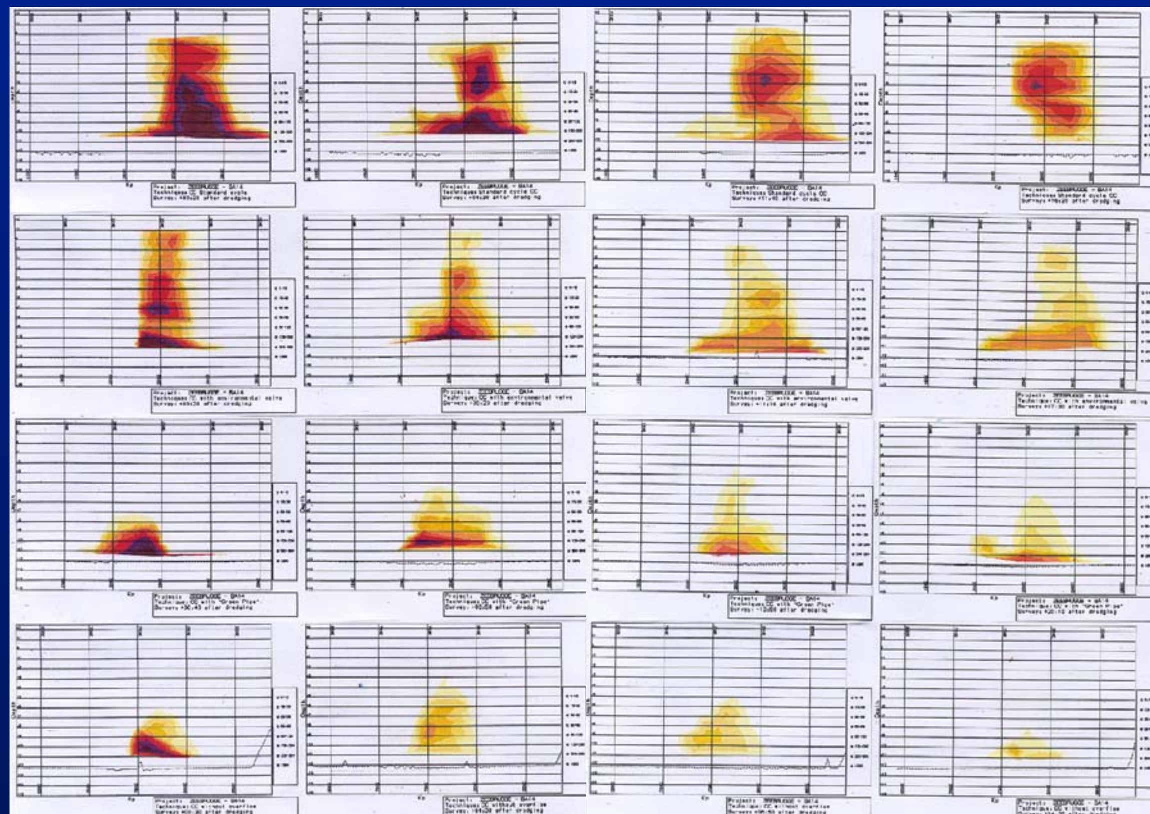
Comparison of turbidity plume dispersion:

Standard overflow →

Low turbidity valve →

'Green pipe' →

No overflow →



Elapsed time: 00:30 05:00 10:00 15:00 min

Comparison dredge techniques:

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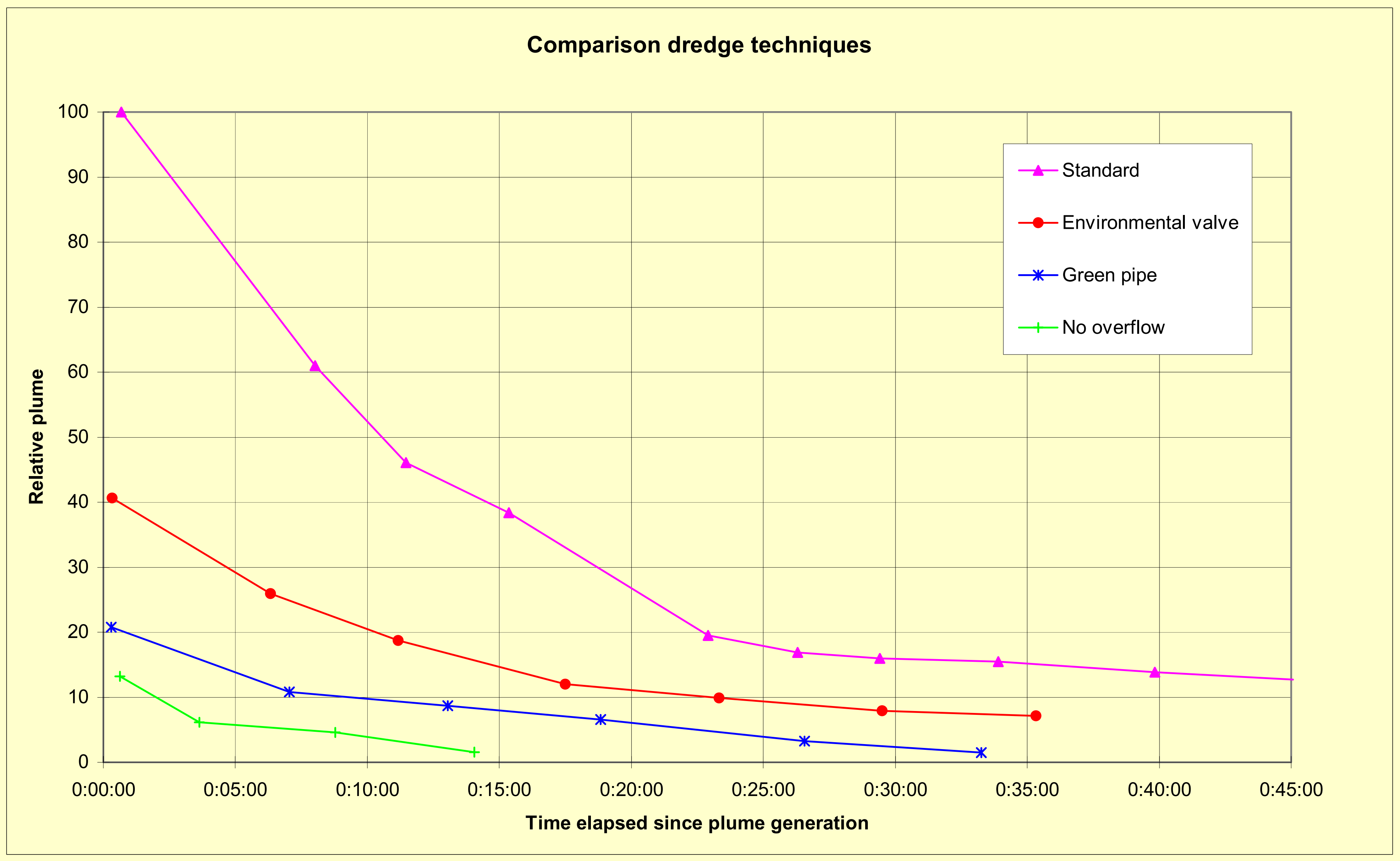


Background turbidity:

HW - 4:00

HW - 3:00

HW - 2:00

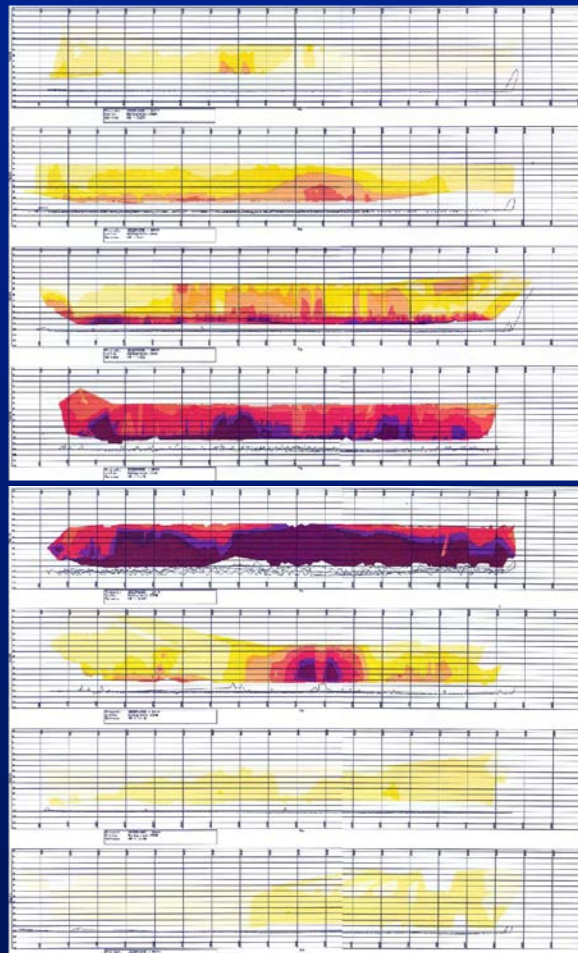
HW - 1:00

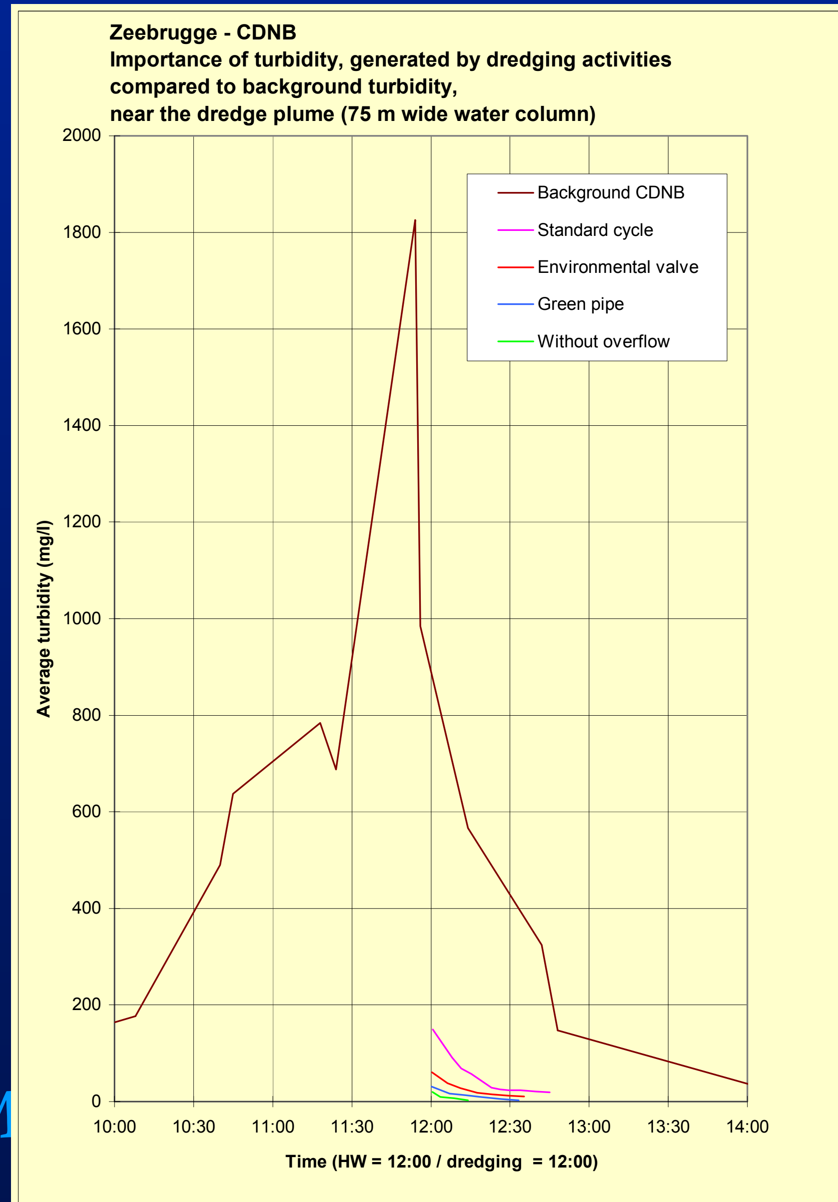
HW

HW + 1:00

HW + 2:00

HW + 3:00





Baird – RPI – DRL - M

Conclusions:

• Plume generation relative to the plume generated during the dredge cycle with standard overflow:

- low turbidity valve: 41 %
- 'green pipe': 21 %
- without overflow: 13 %

• Application of alternative dredging techniques is not relevant if the additional turbidity generated during the dredging works is only a fraction of the background turbidity

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CURRENT AND POTENTIAL EFFORTS TO MITIGATE BY STIPULATIONS

(US Perspective)

Impact # 1: Benthic Habitats

- Possible stipulations:
  - *Leave strips of undredged areas to act as recruitment sources*
    - Refuge areas within dredging site
    - Exclusion zones to be avoided, identified during pre-dredging studies

Impact #2: Turtles

- Existing stipulations include:

  a. Presence of trained observer(s) 50-100% of the time who follow specific protocols.

  b. Use of state-of –the-art a rigid sea turtle deflector.

  c. Keep the draghead on the bottom except:

  1) when the dredge is not in a pumping operation and the suction pumps are turned completely off,

  2) when the dredge is being re-oriented to the next dredge line during borrow activities, and

  3) the vessel's safety is at risk

Impact #2: Turtles

- Existing stipulations include:

  d. Dredge equipped with inflow screening baskets (variable mesh sizes) to better monitor the intake and overflow of the dredged materials for sea turtles and their remains.

  Screens sample 50-100% of the overflow area and should be installed at the applicable area.

Impact #2: Turtles

- Existing stipulations include:

e. Assessment/relocation trawling to further assess/reduce the potential for incidental take during dredging.

There are many details on:

- Trawl tow time

- Trawl speed

- Handling and relocation of captured turtles

- Ancillary data collection for turtle research

Impact #2 Turtles

- Existing stipulations include:

f. Minimal lighting on dredges and pump out barges within 3 nm of nesting beaches

- to reduce disorientation of females and hatchlings

g. Seasonal windows when dredging is allowed:

- In the GOM, hopper dredging shall be completed between December 1 and March 31, when sea turtle abundance is lowest throughout Gulf coastal waters

NOTE: no windows for OCS dredging

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Impact # 3: Changes in Substrate Characteristics

- Changes in the substrate characteristics (grain size, dissolved oxygen, compaction and organic content) that lead to a reduction in benthic communities and suitability of the area for future dredging.

- Possible stipulations include:
  - *In sandy substrates, specify maximum dredging depths*
  - *Modeling studies to predict rate of infilling to acceptable depths*

Impact # 5: Hardbottom Habitats

- Damage to hardbottom habitats: Physical damage to during dredging; burial by suspended sediment during dredging; and altered sediment processes that could bury hardbottom.

- Existing stipulations include:
  - *buffers of 60-120 m (but driven by turbidity concerns)*

Impact # 6: Pits

- Creation of depressions and furrows from removal of substrate.
- Existing stipulations include:
  - *To assure that deep pits and furrows are not created, conduct post-dredging hydrographic surveys*
  - *Slopes are not to exceed 2:1*

Impact # 7: Turbidity

- Short-term increased turbidity from cutterhead or draghead and overflow from hoppers on benthic species

- Existing stipulations include:

  Turbidity > 29 NTUs beyond 150 m. If monitoring shows turbidity exceedences, dredging activities shall cease immediately and not resume until corrective measures have been taken and turbidity has returned to acceptable levels.

Impact # 7: Turbidity

- May be more of a perception problem for OSC sand borrow sites
- What is the footprint for sand overflow plumes?
- There are mitigation measures to reduce overflow but are they necessary for OSC sand borrow sites?
- See data from UK studies

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Impact # 12: EFH Impacts

- <u>Change in shoal shape that degrades fish habitat</u>

Existing stipulations include:

- *Detailed bathymetric surveys prior to dredging, immediately following dredging, and 5 years later to determine the amount of recovery at the site*
- *Surficial sediments be removed from shoal flanks, if practicable. Avoid shoal crest and adjacent troughs, which are generally more productive biologically*