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Marine Environment Monitoring Group
(formerly Marine Pollution Monitoring Management Group (MPMMG))

The Group Co-ordinating Sea Disposal Monitoring

Final Report of
The Dredging and Dredged Material Disposal Monitoring Task Team

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CONTENTS Page

FOREWORD

The Group Co-ordinating Sea Disposal Monitoring (GCSDM), a sub group of the Marine Pollution Monitoring Management Group (MPMMG)*, was set up in 1987 in order to co-ordinate the monitoring work carried out at sewage-sludge disposal sites. To help achieve its aims, the GCSDM established a number of specialist Task Teams to review the existing procedures used for the monitoring of sewage sludge disposal sites and to derive sediment quality criteria which could be employed to ensure that such waste disposal does not cause undesirable effects. In 1992, the Group's remit was extended to include a similar review of dredged material disposal sites.

Since then a series of outputs covering various aspects of disposal and monitoring activity have been provided by GCSDM and each of the task teams. The reports have been published by CEFAS in the Aquatic Environment Monitoring Report series and are available from CEFAS, Lowestoft or may be downloaded from the CEFAS web site (www.cefas.co.uk/publications).

The Dredged Material Monitoring Task Team draws on expertise from Government Agency, Industry and Academia to provide this comprehensive manual of protocols for monitoring dredging and disposal sites to ensure that impact on the environment by dredging requirements is minimised. It is a welcome addition to the series of guidance documents.

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* *With effect from 1 June 2003 the Group was re-named Marine Environment Monitoring Group (MEMG)*

EXECUTIVE SUMMARY

Dredging and the marine disposal of dredged material are activities essential to the marine shipping industry of the United Kingdom. Without adequate depths within our harbours, shipping and trade would be severely restricted. It is recognised that both the dredging activity and the disposal of dredged material in the sea have the potential to cause long-term environmental impacts, possibly affecting marine life, the fishing industry and other legitimate users of the sea, and that careful management of the activity is needed to minimise potential harm. Monitoring forms an important part of that management activity, checking that the impact is as predicted, that harm to the marine environment has been avoided, feeding back information into future assessment processes, and providing reassurance to other legitimate uses and users of the sea.

Since the 1980s concern about the quality of dredged material, and in particular the presence of contaminants such as PAHs, PCBs and TBT, has resulted in controls being placed on sea disposal operations. The quality aspects of dredged material disposal, at least in terms of current understanding of pollutant effect and loading are now addressed by screening, and by excluding the most contaminated dredged materials. Concern remains regarding the physical impact of dredged material disposal and the presence of undetected contaminants. The impact of the dredging operation itself, which may not be covered by the licensing procedure, must also be taken into consideration when reviewing the wider environmental implications of the activity.

Monitoring may have serious resource implications. Therefore, before embarking on a monitoring programme there must be a clear understanding by all concerned of both the objectives and benefits. Not every dredging and disposal activity will have a significant near or far field impact. It is important that the monitoring programme is proportional to the problem and linked to an assessment of the effects.

This report discusses both the near field and far field effects of dredging and disposal on the biology, physics and chemistry of the water column and seabed. The methods that may be used for monitoring are then outlined. The objectives to be met and the derivation of generic hypotheses are also discussed. In developing a monitoring protocol for marine dredging and disposal, the report first considers the need for monitoring in terms of the potential adverse effects of the activity and the consequent value of the monitoring. Using a flow chart and structured tables, this report offers guidance to those proposing, for example, dredging or disposal, and also to statutory bodies regarding targeting the monitoring effort. Tables included in this report outline the perceived effects of the activities and the potential repercussions on the uses and users of the marine environment.

The report provides generic examples to encompass a cross-section of potential operations and a number of recent case studies of monitoring dredged material disposal operations. Finally the report makes some recommendations for monitoring practice and suggests what action should be taken by regulatory authorities to ensure the development of effective monitoring programs.

THE MONITORING REQUIREMENT FOR MARINE DREDGING OPERATIONS AND DREDGED MATERIAL MARINE DISPOSAL SITES

1. INTRODUCTION

1.1 Background

In 1992, the work of the Group Co-ordinating Sea Disposal Monitoring (GCSDM) was extended to include the disposal in the marine environment of dredged material. With increasing interest in marine dredged material disposal it was considered valuable to examine the various monitoring issues that could be associated with this activity. This view resulted in the Group establishing, in 1993, a Task Team to report on the monitoring of dredged material at the point of disposal in the sea. Following the discussions of the Task Team, it was later agreed that the remit be extended to include monitoring at the dredging site.

The disposal of dredged material in the sea is a very different activity from the sewage sludge dumping which formed the initial interest of GCSDM. Dredged material disposal sites are much more numerous than the sewage sludge sites - 177 of the former being used at least once since 1990 in UK waters contrasting to just 13 sewage sludge sites. The quantities involved in dredged material disposal are also much greater. Around 40 million wet tonnes of dredged material are relocated annually in licensed sites in UK waters. This tonnage is about four to five times the average sewage sludge weight in the last years in which its disposal was permitted (up to 1998).

There is a generally increased awareness about the environmental consequences of dredging. As several major estuary port channels are in or adjacent to Natura 2000 sites designated under the EU Habitats and Species Directive and the Wild Birds Directive, it has become still more important that strategies for monitoring are formalised.

At the signing of the Bergen Declaration, 20–21 March, 2002 (Anon, In Prep.) at the 5th North Sea Conference, there was an acknowledgement that all human activities that affect the North Sea need to be managed in a way that conserves the biological diversity of the sea and ensures sustainable development. The Declaration outlines an ecosystem approach to management through developing integrated Ecological Quality Objectives (EcoQOs). The aim is that EcoQOS will be used as a tool for setting operational environmental objectives towards specific management and serving as an indicator for the ecosystem health. As such they may be used as an additional assessment and monitoring tool both for areas that are to be dredged and for sea disposal sites.

1.2 Dredging

Dredging, under the remit of the Task Team, can be conveniently divided into capital dredging and maintenance dredging. These activities are most usually associated with port and harbour operations, but may also arise from construction activity. Ports and harbours undertaking dredging for navigation can range from major cargo handling ports through individual berths to small fishing berths and marinas. Dredging specifically to obtain marine aggregates was excluded from the Task Team's remit, as the licensing of this is dealt with by other procedures. However, it was recognised that there are similarities with marine aggregate extraction in the dredging equipment used and the environmental effects needing to be monitored.

Maintenance dredging is the periodic removal of material, typically sand, silt and gravel deposited by nature through river flow, tidal currents or wave action in areas previously dredged. Some estuarine ports have engaged in various forms of maintenance dredging continuously for nearly 200 years to the extent that the dredgers are a familiar and accepted part of the local activities. In recent years however, there has been a tendency for small to medium sized ports to dredge intermittently under contract instead of relying on their own vessel. In some locations maintenance dredging need only be undertaken once every five or ten years, in others on two or three occasions every year. In a few of the UK's major ports maintenance dredging is virtually continuous throughout the year.

Capital dredging is the initial deepening of an area such as a channel, harbour or berthing facility, but can also include excavation of underwater trenches for cables, pipelines, tunnels and other civil engineering works. Because capital dredging is the first deepening of an area, any type of geotechnical material can be encountered. Thus rock and boulder clay is not unknown as well as the more common soft clay, sand and silt.

A major port with a diversity of customers may need to carry out a capital project every few years to accommodate changes in the patterns of trade and growth in the sizes of vessels to be accommodated. By contrast, the excavation of a trench for an outfall pipe or the construction of an oil-rig construction yard may involve an isolated and sometimes large operation in a previously undisturbed area.

Both capital and maintenance dredging may be undertaken by any of the different types of dredger.

The most common types in use today are the bucket ladder, grab, backhoe, cutter suction and trailer suction. The first three of these remove material mechanically by means of a grab or bucket whereas; suction dredgers transport the material as a suspension via pipeline. Because of the often variable nature of the material found in capital dredging, dredgers used for this type of work tend to be larger and more powerful than those employed for maintenance dredging. The clearance of silt and sand accumulations from the corners of harbour and dock entrances is sometimes achieved by bringing it into suspension and making use of water currents to carry it away. In other places, towed equipment is used to drag or flatten out the local deposit. Methods such as plough dredging and other agitation dredging activities such as water injection dredging, fall outside the scope of FEPA (see Section 1.5). However, in some cases, other legislation can control such dredging activities and hence be used to assess the potential impacts, for example, with the introduction of the Water Framework Directive, water body quality issues are to be addressed. Under this Directive, aspects of water, sediment and biota quality are to be considered in order that waters can be maintained or restored to high ecological quality.

Mechanical type dredgers normally load the dredged material into barges or hoppers for transport to the disposal area although some self-propelled grab hopper dredgers do exist. The barges may be towed by tugs or be self-propelled and discharge either through bottom opening doors or by splitting. Trailer suction hopper dredgers both load and transport the dredged material. For sea disposal they normally discharge through bottom doors or valves, although a few split trailers are in operation, and occasionally trailers discharge by pumping at the sea disposal site. The type of plant employed and the way it is operated will significantly influence the nature and dispersal characteristics of the dredged material being re-located. In turn this will influence the potential for environmental degradation around the receiving area and the requirements for monitoring.

1.3 Marine disposal

Marine disposal of dredged material has been commonplace since the advent of the steam dredger at the end of the eighteenth century. This form of disposal increased rapidly from the mid-nineteenth century with the introduction of the first self-propelled bottom dumping hopper barges. Disposal sites were first selected for convenience in terms of proximity to the area of dredging activity together with a location considered to be deep enough such that any accumulated deposit would not interfere with navigation. Thus ‘dredged spoil disposal grounds’ became established at the seaward part of almost every port and harbour. In time, Admiralty Charts became appropriately annotated. Later, under the flood and Environmental Protection Act, 1985, additional sites were designated for disposal of dredged material taking into account the potential environmental impact of their use, and some of the earlier sites were closed.

The frequency of use of a dredged material disposal site can vary greatly from place to place around the UK coast. The disposal site for a small fishing harbour or marina may receive maintenance dredging on an annual or bi-annual basis, consisting of a few thousand tonnes of marine sand moved into the harbour area from the adjoining seabed by winter storms. In contrast, the disposal ground for a group of estuarine ports may receive many millions of tonnes of low density silt placed in the disposal ground on three or four occasions each day for most days of the year. Part of this sediment quantity may be of marine origin, but much will have been derived from land or intra-estuarine sources such as the continual remobilisation of fine material by the dredging activity itself, or even navigational activity. The dredged sediment may also be a mixture of material from different sources and as such may posses varying characteristics from one year to another and over short distances.

In the year 2000, 10 UK sea disposal sites received in excess of 1 million wet tonnes of dredged material. 24 received between 100,000 and 1 million wet tonnes and 40 between 10,000 and 100,000 wet tonnes. Some 21, however, received less than 10,000 wet tonnes in that year. While a relatively small number of sites accounted for a large proportion of the UK’s dredged material disposal in 2000, at least 95 sites had some material deposited in them. A number of the sites received material from several different dredging areas.

It should be recognised that not all dredged material is disposed of at sea, and that significant tonnage’s are placed ashore in lagoons, land claim areas and landfill sites. On shore placement may be used for infilling development land, for coast protection and disposal when the deposit is contaminated with hazardous materials or simply for operational convenience. There is increasing use of dredged material for environmental benefit, for example in mudflat or salt marsh regeneration for nature conservation and coast protection benefits. A practice encouraged by the regulators. Non-marine disposal was not included in the remit of this report except in so far as the over-wash from bunded impoundment’s returns to the sea. Different legislation covers non-marine disposal and there may well be quite different concerns and monitoring requirements. Similarly non-marine dredging activity is not included in this report.

1.4 Potential impact of dredging and disposal in the aquatic environment

Both dredging and disposal of marine sediment can affect the water column features, the physical and chemical nature of the seabed, and the seabed biota, in both the short-term or long-term. The potential impacts could be manifest in the following:

- A deterioration in the overall health/quality of the marine ecosystem;
- A reduction in the socio-economic aspects of the sea including fishery and amenity interests;
- An interference with the legitimate uses (i.e. those legally permitted) of the sea, such as recreation and navigational aspects;
- A reduction in the aesthetic qualities associated with the area.

The impacts associated with these activities require both near-field and far-field consideration.

1.5 Marine disposal regulation

The disposal of dredged material in UK waters is licensed under Part 2 of the Food and Environment Protection Act 1985 (FEPA). This Act controls deposits in the sea below the mean high water springs in order to protect human health, the marine environment and legitimate uses of the sea. In assessing whether a licence should be issued, the respective licensing authorities for England and Wales (Department for Environment, Fisheries and Rural Affairs), for Scotland (Fisheries Research Services on the behalf of The Scottish Executive, Environment and Rural Affairs Department) and for Northern Ireland (The Department of the Environment Northern Ireland) will take account of the principles of the various international conventions on marine disposal, particularly the London Convention of 1972 (LC72) and the OSPAR Convention. These conventions and their associated guidelines take into account the presence of any contaminants within the sediment and whether some alternative beneficial use is possible. In many cases retention of the material within the coastal or estuarial circulation system is a major consideration in determining whether marine disposal is acceptable, and which disposal site should be selected.

In addition to this, other European Directives such as the Environmental Impact Assessment Directive (97/11/EEC), Habitats and Species Directive (92/43/EEC), the Wild Birds Directive (79/409/EEC), the Strategic Environmental Assessment Directive (85/337/EEC) and the Water Framework Directive (2000/60/EC) are taken into consideration by the appropriate licensing authority. If dredging or disposal is likely to affect the conservation value of a European site, the licensing authority must ensure that an Appropriate Assessment is carried out.

In locations where dredging is not specifically authorised under a local harbour act, dredging and dredging disposal has to be approved by the Department for Transport under the Coast Protection Act 1949, and, sections of the Merchant Shipping Act. When considering applications for approval, the Department may wish to enforce the requirements of Statutory Instrument No 424, Harbours, Docks, Piers and Ferries - The Harbour Works (Assessment of Environmental Effects No 2) Regulations 1989. A requirement for monitoring may then follow.

The majority of applications under FEPA relate to disposal from regular dredging activity within long established ports, at which considerable experience has been accumulated by both the regulatory agencies and the port authorities. This information includes sediment quality characteristics of the areas involved and the impacts of dredging and disposal on the surrounding marine environment. Many of the disposal sites around the UK coast for which FEPA approval is sought have been long established and in regular use for a number of years. Conditions at the site therefore reflect the steady inflow of material. In such cases, the disposal and its environmental impact have frequently been accepted as a normal part of the activity of a port.

The assessment of an application for a new disposal site, for a site which has not been in use for some years, or for a site where some major change in usage is proposed, usually requires additional study. In these situations, the proposed disposal site has not experienced or had recent experience of an input of dredged material. Possibly the material to be deposited may be quite different in characteristics from the naturally occurring sediment or the material previously deposited. The response of the site and its various forms of marine life to the deposit and the effects of potential movement of the material away from the site to other areas will then require detailed study. In addition, the disposal activity, clearly visible, may in itself generate concern about the environment from an audience who are neither familiar with the activity nor are likely to benefit from it.

1.6 Monitoring

While extensive studies of the proposed dredging and dredged material disposal sites may be undertaken as part of the approval process, not all licences issued under FEPA carry a requirement to monitor the marine disposal of dredged material. The requirement for monitoring is determined by the Licensing Authority on a case specific basis. One of the major problems with dredged sediment quality in the past has been contamination by tributyl tin (TBT). The current status is that application is banned on hulls of ships <25 m. By 2004 there will be a complete ban on its application on all ships and by 2008 there will be a ban on the presence of TBT on ship hulls. However, there exists a legacy of contamination within harbour sediments and as such this material is required to undergo assessment if its presence is suspected. Replacements to TBT are in use and as such require review on their potential effects on the aquatic system.

Specific licence conditions relating to disposal monitoring are most likely to be imposed in situations where concern exists about possible dispersal of dredged material to sensitive areas or where the disposal site itself has potential sensitivity. The required monitoring may be undertaken by the licensing authority or it may be the responsibility of the licence holder. Where the licensing authority undertakes a programme of monitoring to assist in the assessment of licence applications, costs can be recovered through the licensing process.

Monitoring of the dredging operation itself, in terms of possible environmental impact is not a matter addressed by FEPA. There is, however, the possibility of a regulatory interest in dredging through other legislation, however, and the possibility of the imposition of a requirement for monitoring at the dredging site. For example, some areas of dredging activity are covered by specific legislation, mainly via the mechanism of local harbour acts. Such local legislation often allows the relevant conservancy authority to impose monitoring requirements if it considers that monitoring of a dredging operation is required.

1.7 The Task Team rationale

The Terms of Reference of the Task Team on Dredged Material Disposal Monitoring as originally constituted are as follows:

- To propose guidelines for the methods to be used for monitoring such areas;

- to propose standards by which the meeting of objectives can be assessed taking due account of the nature of the receiving area and the different types of dredged material likely to be involved;

- to advise on situations where monitoring may or may not be required and as appropriate suggest minimum frequencies of monitoring for the assessment of compliance with the defined objectives and standards;

- to review the impact of dredged material disposal against the objectives set by GCSDM for the quality of areas used for dredged material disposal (these objectives are listed in Table 1.1).

Following the initial work of the Task Team, the Terms of Reference were expanded to include the site of dredging activity in addition to the marine disposal site. The Task Team recognised when considering potential environmental effects, that the environmental impact of works to relocate marine deposits cannot be easily separated into the excavation and disposal parts of a scheme and that consideration of the whole of the operation from dredging through to disposal is required.

Membership of the Task Team was intended to include those who might apply for licences to dredge and dispose of material in the marine environment as well as those who have experience of marine environmental impact assessment, monitoring procedures and practices.

1.8 Team philosophy

The members of the Task Team were conscious of the potential for increased concern about the disposal of dredged material in the sea from environmental groups, the media, the public and politicians. In several industrialised countries this concern is very real, and on occasions has manifested itself in public protest and the introduction of significant constraints on navigational dredging activity.

Table 1.1. Environmental Quality Objectives as derived by GCSDM (from MAFF, 1989)

Use	Objective
Amenity	Maintenance of environmental quality, so as to prevent public nuisance arising from aesthetic problems and interference with other legitimate users of the sea
Commercial harvesting of fish and shellfish for public consumption	Maintenance of environmental quality, such that commercial marine fish and shellfish quality shall be acceptable for human consumption, as determined by fisheries legislation e.g. the Shellfish Hygiene Directive and Shellfish Waters Directive
Protection of commercial species	Preservation of the general well-being of commercially-exploited species
General ecosystem conservation	Maintenance of environmental quality to prevent deterioration of aquatic life and dependent non-aquatic organisms within the existing ecosystem of the area
Preservation of the natural environment	Impacts shall be restricted to the designated disposal zone, areas outside of which shall be non-impacted reflecting the quality of the adjacent estuarine or marine environment

The Task Team was equally aware that marine disposal of dredged material was in many cases not only the best practicable environmental option (BPEO) but also the only economically realistic one. Unlike the situation of sewage sludge, the cessation of marine disposal of dredged material could not be envisaged in any practical or economic way.

Nevertheless, the Task Team took the view that there was a need for greater understanding of the impact of dredging activity and dredged material disposal on the marine environment and other marine related activities in order to minimise any potential impacts. Understanding of the processes occurring at such sites would be assisted by the information obtained from monitoring of sites. The extent to which dredged material disposal sites met any defined Environmental Quality Objectives (EQOs) also required monitoring. However, as monitoring can be expensive, it is possible in some areas of dredging activity and at some dredged material disposal sites that a blanket requirement to undertake a monitoring programme, using prescriptive standards or procedures could place an unacceptable cost burden on the licence holder. Conversely it was recognised that monitoring is frequently required to ensure environmental protection and that monitoring can be carried out in a cost effective manner if properly designed and targeted.

In endeavouring to meet the Terms of Reference, the Task Team took the view that a first step was the development of a transparent mechanism to determine in a logical and reasoned way whether a requirement for monitoring of dredging activity or of a dredged material disposal ground should be part of a licence award. This was considered to be very important in order to avoid the imposition of monitoring requirements which might not only be expensive to meet but also, in reality, be of limited scientific or practical value.

The development of a general protocol for monitoring then followed, together with detailed consideration of methodologies and techniques.

2. MONITORING RATIONALE, CONDITIONS AND PROPOSED PROTOCOL

2.1 Potential Impacts of dredging and dredged-material disposal on the aquatic environment

The nature of the actual, potential or perceived effects of dredging and dredged-material disposal will in turn dictate the nature of the monitoring required. This section discusses the potential effects of these activities as well as the rationale, conditions and proposed protocol for monitoring to detect those effects.

The potential effects of dredging and dredged material disposal can be regarded as a set of bottom-up causes and primary effects, in which the physical system (both in the water column and on the bed) is altered and which in turn affect the health of the biological system. The eventual effects on the biological system and its uses by Man can be regarded as a set of top-down responses, e.g. the effects on the higher levels of the ecological system (such as fishes, seabirds and marine mammals) as well as on fisheries and conservation objectives (Elliott *et al*., 1998). Our knowledge of these effects and the linkages between the different responses can be regarded as a conceptual model which, by the nature of the system and the potential changes to dredging and marine disposal, is naturally complex (Figure 2.1 and Figure 2.2, taken and adapted from Elliott & Hemingway, 2002).

Dredging will alter the bed topography and bathymetry which in turn will remove the bed organisms and it substratum as well as changing the overall hydrodynamic regime of the area. The structure and functioning of those bed sediments and the overlying hydrographic regime (water currents, tidal circulation, etc.) will be intimately linked to the structure and functioning of the bed biological community, principally the invertebrates (Elliott *et al*, 1998). In turn this will influence the fishes and, in nearshore areas, the birds feeding on those invertebrates. The second major effect of dredging will be the resuspension of the bottom sediments and its effects on water turbidity and the liberation of any materials contained and sequestered within the sediments. The release of those materials into the water column will then have the potential for a biological effect. In turn, all of these effects has the potential to influence the fisheries and nature conservation value of the area (Figure 2.1).

The disposal of dredged material will similarly have the potential to affect the water column, the bed conditions and their biota (Figure 2.2). Reductions in water clarity through an increased turbidity will in turn affect the primary production by the phytoplankton. The release of any materials contained within the dredged material, either as the water soluble fraction or the release of particulate materials may be the result of the changed chemical environment, i.e. anoxic fine sediments liberated into the oxygenated water column will cause the release of pollutants previously sequestered due to the anoxic chemical conditions. Similarly, any organic matter in the sediment will create a water column oxygen demand. The deposited sediment will change the nature of the bed sediment, if it is of a different particle size and it can have a smothering effect on the bed community as well as bringing new organisms to an area. Both of these features will affect the structure of the bed community and in turn the demersal and benthic fishes feeding on that bed community.

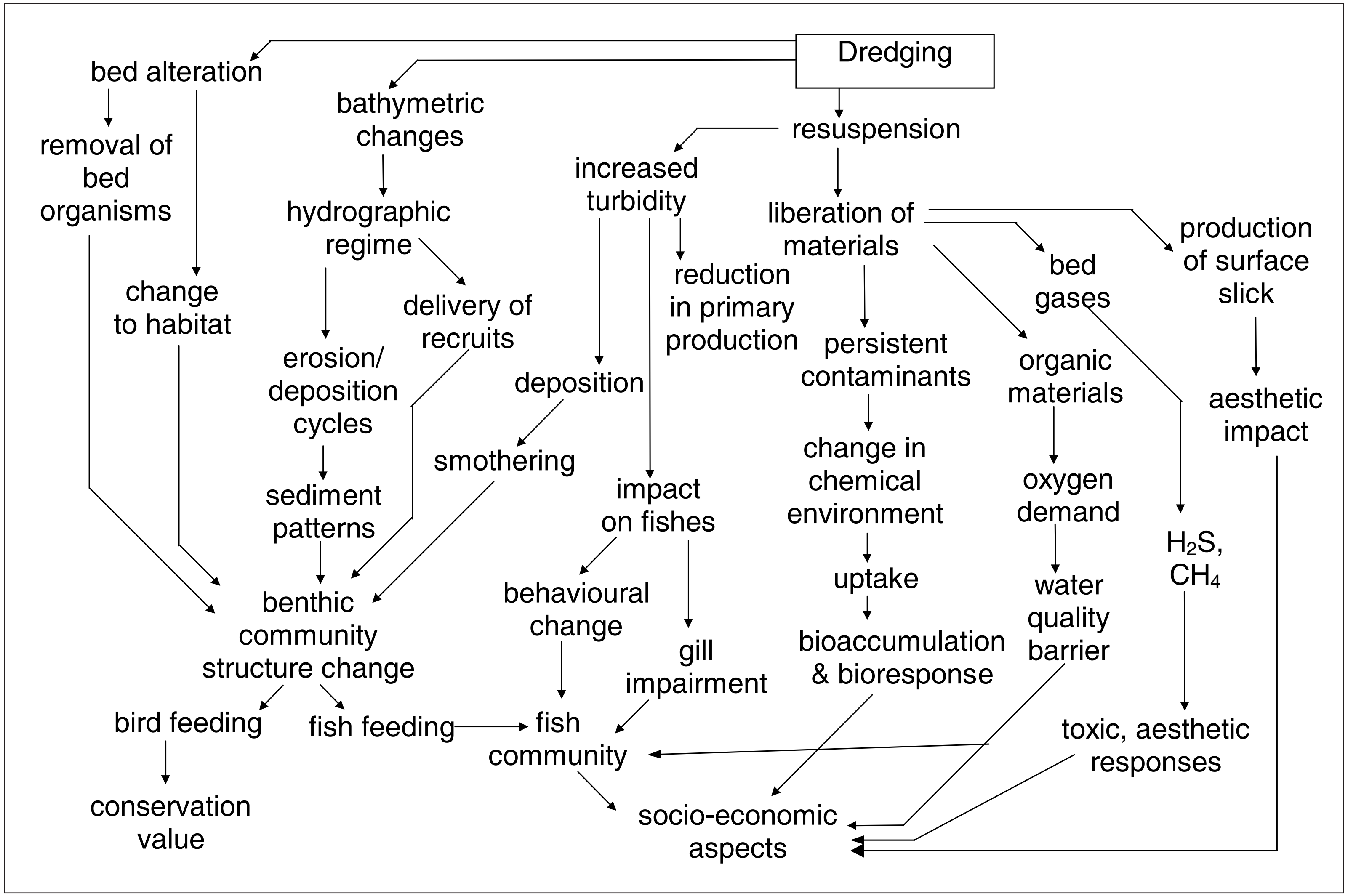

Figure 2.1. The potential environmental impacts of marine dredging - a conceptual model (from Elliott & Hemingway, 2002).

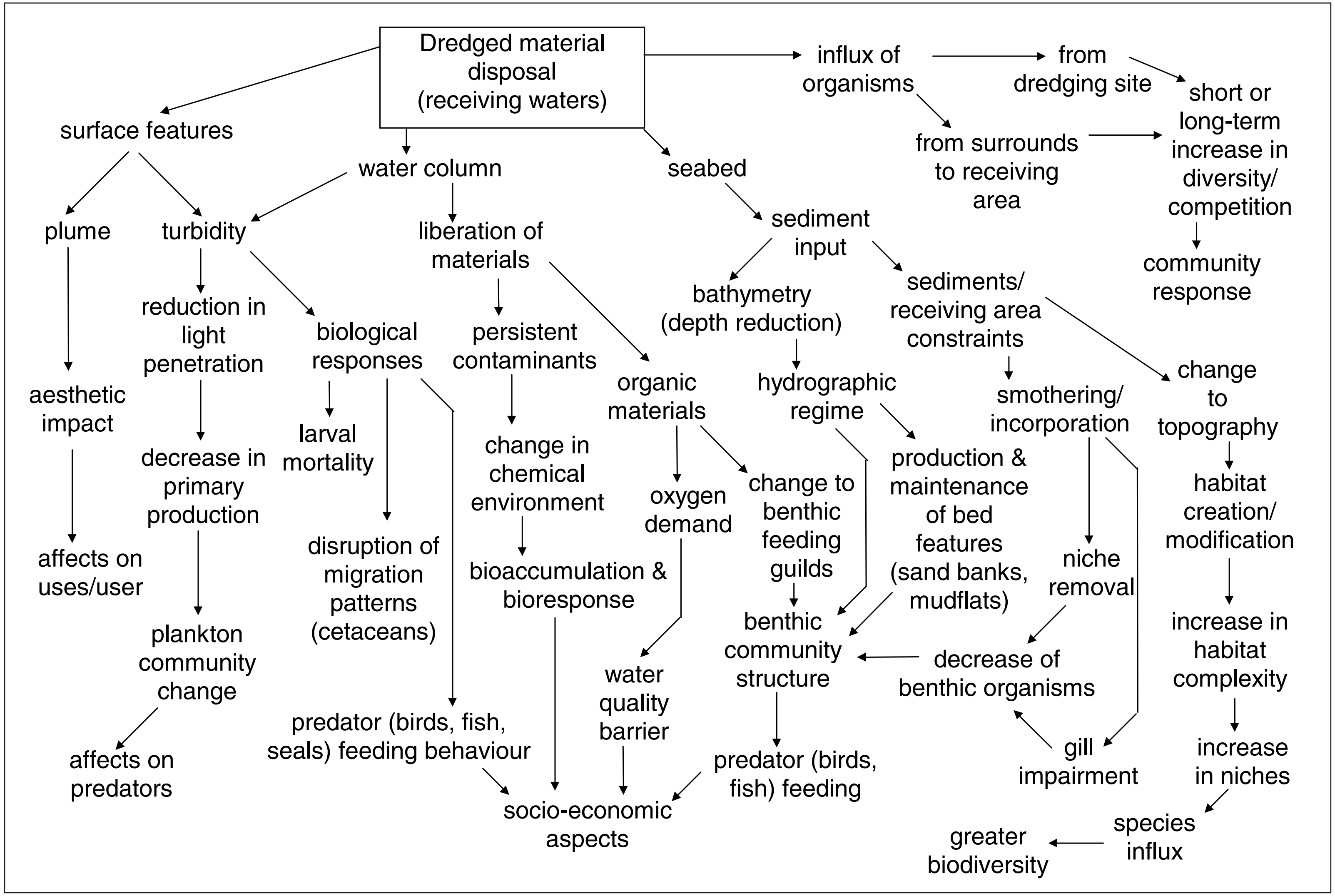

Figure 2.2. The potential environmental impacts of marine dredged material disposal - a conceptual model (adapted from Elliott & Hemingway, 2002)

Whereas most of the above impacts of dredging and dredged material disposal relate to the ecological system, the resultant impacts on the uses and users of the marine environment are often of greater prominence and more public concern. These include the actual or perceived effects on socio-economic aspects such as fisheries, and aesthetic aspects including recreation and tourism. Similarly, the perceived or actual effects on the conservation importance of an area will be of concern, especially where the habitats and species within and adjacent to the dredging and disposal areas are of importance.

2.2 Monitoring rationale

Monitoring of the marine environment may encompass all biological, chemical and physical components. Usually the purpose of monitoring is to demonstrate compliance with licence conditions and/or verify the impact assessment. It is important that the scale and thus the cost of any monitoring programme should relate to the extent of the perceived problem, and that the components for monitoring relate to the cause for concern. For example, possible problems in the water column due to dredging activity or dredged material disposal require the monitoring of the physical and biological characteristics of the water column. Similarly the ability of the disposal area to receive the dredged material without degradation of the seabed will depend to a large extent on the following factors:

- Similarity/dissimilarity between the substratum and the nature of the material being disposed;
- Hydrodynamic regime at the disposal site;
- Existing conditions at the disposal site (nature of the seabed);
- Volume of material to be deposited;
- Method and frequency of disposal operations.

The extent of monitoring and thus the methods to be used, will depend on that ability to receive the material. Because of this, the degree of effect, if any, at the dredging and disposal areas are site and operation specific and therefore the design of any monitoring programme is also both site and case specific. However, a generic approach can be given which summarises the predominant rationale. This is shown in Table 2.1.

The data collected and evaluations made in determining whether monitoring is required (Section 3) form the basis for the case-specific monitoring. The extent of the monitoring will be dependent on an evaluation giving the scale of the perceived concern and the amount of information known about the specific area and surroundings. The statement of monitoring requirements derived at the end of the evaluation process forms the framework for the monitoring tasks and methodology.

Monitoring in relation to the disposal of dredged material is defined in the London Convention Dredged Material Assessment Framework Guidelines as:

I. Measurements of compliance with permit requirements, (compliance monitoring);
II. Measurements of the condition and changes in condition of the receiving area to assess [the adequacy of (sic)] the Impact Hypothesis upon which the issue of a disposal permit was approved (validation or surveillance monitoring).

Monitoring of the activity at the dredging site may also be undertaken for these two distinct purposes and both or either types of monitoring may be necessary depending upon the circumstances. Compliance monitoring at the dredging site can be related to permit

Table 2.1. Generic guidelines for monitoring dredging areas and dredged material disposal sites

1. Overall Aim	To ensure that there is no unacceptable loss of quality or deterioration to the health of the system in its structure or functioning nor hindrance to the uses and users of an area.
2. LDC and OSPARCOM Guidelines Adopted	Demonstration of compliance with permit conditions and that changes in the condition of the receiving area are within those predicted in the Impact Hypotheses.
3. Objectives Defined	Environmental and Ecological Quality Objectives (EQO and EcoQO) will be defined as Null Hypotheses and incorporated into Generic Indicators of Favourable Conditions at each site.
4. Standards Adopted	Any available and accepted Environmental and Ecological Quality Standards (EQS/EcoQS) for waters and sediments will be adopted for use in the monitoring.
5. Monitoring Strategy	The BACI (Before-After Control Impact) pairing strategy will be used in the design of the monitoring programme: (a) to compare change within the area with a nearby similar area, (b) to compare any change with a baseline (pre-operation situation).
6. Action Point and Feedback Monitoring	If monitoring suggests unacceptable environmental damage then the operation should be terminated pending further assessments. If monitoring shows un-anticipated effects, such evidence should act as a trigger for further investigation.
7. Audit of Monitoring	The methods used are subject to Best Available Practice and AQC/QA (Analytical Quality Control/Quality Assurance) and that the scoping document and reports produced are independently peer reviewed.

requirements but is more often related to contractual obligations. By definition, compliance monitoring requires testing against pre-agreed standards or objectives in which the standards, again by definition, are numerical and quantitative. Surveillance monitoring on the other hand requires only that established conditions are checked for alteration on a spatial or temporal basis.

The determination of effect depends on an adequate knowledge of baseline conditions. Where little background information exists prior to the dredging or disposal operation for an area or particular habitat, surveillance type surveys may be required to determine any underlying trends and the variability in the natural environment. Such information is required to formulate the impact hypothesis (or hypotheses), and to provide a baseline against which the impact can later be measured. Any change is not necessarily synonymous with the term impact as the significance of any change always requires to be determined. Statistical significance in a particular parameter, given sufficient representative samples, can be defined. However the overall significance of the effect on the biology and/or the environment is more difficult to establish.

2.3 Dredging and disposal monitoring: impact hypotheses

As proposed by the LC72 Guidelines (London Convention 1996), one or more impact hypotheses should form the basis for defining post-operational monitoring. Impact hypotheses can also be used to define monitoring during the dredging operation. Consequently, a suitable monitoring programme should be designed around an impact hypothesis from which the following questions should be answered:

- What testable hypothesis can be derived from the impact hypothesis?
- What measurements (type, location, frequency, and performance requirements) are needed to test the hypothesis?
- How should the data be managed and interpreted?

From the statement of monitoring requirements, a hypothesis can be derived which can be tested in order to demonstrate compliance with any relevant Environmental or Ecological Quality Objectives and Standards (Elliott, 1996) or that any changes are within those predicted and accepted by the licensing authority. In some cases, monitoring may be required for some parameters where insufficient data exists in order to predict potential effects with greater confidence. In this way, a precautionary approach can be adopted whereby the operations are monitored and practices reviewed.

The impact hypothesis should be defined and then monitoring carried out to test the hypothesis. The hypothesis can be defined as being related to the operation, to the health of the marine ecosystem or to the impact on other uses and users as indicated in Table 2.2.

The type, amount and extent of monitoring will depend on the formulation of the hypothesis. The monitoring may either be in the water column, on the seabed or in both. It may be physical, chemical or biological in origin and it may be near the point of disposal or at specific locations beyond the deposit area. In reality most monitoring will be required to cover several elements of potential concern, each having separate questions to be answered or hypotheses to be tested. The sequence in which the monitoring of those elements is carried out, however, provides for an efficient and effective monitoring strategy.

Having decided on the features to be monitored and the types of monitoring, it will then be straightforward to indicate the methods to be used during the monitoring. It is emphasised that in order to provide valid and appropriate data, the proposed methods of collection of the relevant data and the form of analysis must include appropriate analytical quality control/quality assurance. The methods to be employed during the monitoring are discussed in Section 4.

Table 2.2. Examples of types of impact hypothesis

Type of Hypothesis	Example
Operational	Does the extent of dispersion from the dredge or deposit location exceed that which has been predicted? Can the disposal site receive the required amounts?
Environmental health	Has the ability of the seabed to support fish been degraded? Do suspended solid levels exceed critical levels for fish? Do the changes degrade the overall health/quality of the system in its structure and functioning?
Effect on Users/Uses	Does the depth of accumulation cause concern for navigation?

2.4 Monitoring - methodological considerations

Decisions on the type of measurements required and the methodology to be employed involve many factors. Each of these will require to be addressed on a site and operation specific basis as outlined in Table 2.3. With careful consideration of these topics, a site specific programme can be derived which can monitor a dredging operation and safeguard environmental quality and/or existing usage of the area. Any sampling should of course be designed to ensure that effects detected are attributable to the dredging or disposal and not to natural or unexplained variability. The design requires consideration of the number, frequency, size and location of samples and of the requirements of the statistical analysis of the produced data.

The time taken for the monitoring is especially important when results are required for reactive or feedback monitoring and a rapid response to protect the environment from degradation. In such circumstances rapid but possibly less rigorous survey design and sampling techniques may be required. As an illustration, seabed nature may be determined by side-scan sonar or the biological community analysis may be undertaken only to genus rather than to the more detailed species level (MAFF, 1994). Equally it is advised that consideration is given to the degree of precision appropriate to the prevailing circumstances. For example, although physico-chemical measurements are required to support ecological monitoring, where it is biological effects that give rise to most concern, the expenditure of effort in obtaining precision in the physico-chemical measures should be appropriate to the ecological situation.

I. Sequence of monitoring

Monitoring strategies require a logical progression otherwise there is the danger of them being inefficient and therefore not cost effective. It is possible to monitor synoptically all features of the system. This process has been described as ‘helicopter. While this produces a large amount of information which is perhaps valuable in the wider framework, it does not lead to cost effective answering of particular questions. For example, the monitoring strategy given by Rees *et al.* (1990) can be modified for dredging and dredged material disposal areas (see below).

Much of the information required to define an effective dredge monitoring strategy may already be available from the licensing process or any environmental impact assessment. A desk study is therefore required initially to collate existing data, especially on the wider fields of impact. If insufficient data are available then a baseline survey may be needed. At the same time numerical modelling and associated hydrographic studies may be necessary to assist in predicting the movement of material. After generating the impact hypothesis, the locations at which an effect is predicted may need to be subjected to a more detailed substratum study to give the nature of the bed material especially in relation to that which is to be deposited. Once the physical changes are understood then the biological repercussions can be determined because of the intimate relationship between the variables.

Table 2.3. Monitoring considerations

Factor	Explanation
Sequence	The order in which any monitoring and associated studies are carried out, including the need for any baseline survey prior to the dredging and disposal operation
Generic indicators	The indicators of favourable physico-chemical and biological conditions at the dredging and disposal areas
Pre-survey information	The presence of information through a desk-study which may increase the efficiency of the monitoring
Practicality	The methods and that equipment which are available and practical in the area of concern is available
Temporal basis	The time-scale and period within which measurements should be taken, the duration of impact and the frequency of sampling
Spatial basis	The spatial area(s) to be monitored, the arrangement of sampling sites and the extent of predicted effect
Detection of effect	The ability to determine any effect above background variability
Significance of effect	The significance of any change detected in the parameter being measured (significance may be in statistical or biological terms)

The preferred sequence can be summarised:

⇒ Carry out desk study

⇒ Apply modelling

⇒ Describe the hydrography

⇒ Define the impact hypotheses

⇒ Define monitoring stations

⇒ Define appropriate methodology, techniques and sampling design for each monitoring station

⇒ Assessment sequence

Seabed	Water Column
1. Physical aspects	1. Physical
2. Chemical aspects	2. Chemistry
3. Biology	3. Biology

⇒ Assess the areas' macrobiota (fishes, birds, sea mammals)

The homogeneity/heterogeneity of the area of potential concern will dictate the extent (number of samples and area covered) of the monitoring analyses. However, despite the above preferred sequence, as it is generally more cost-effective to take physical, chemical and biological seabed samples concurrently, it may be necessary to sample all areas for the complete suite but then to be selective about their analysis depending on the results of the physical analyses or an initial assessment of the benthic biotopes found. Concerns may relate solely to physical effects and in such cases it may be unnecessary to monitor for and then proceed to a chemical or biological assessment. Once the seabed biota has been characterised and the likely impact of dredging or disposal determined then it can be decided whether the successive impact on water column macrobiota (e.g. the fishes feeding on the seabed organisms) requires study. In turn, if the water column is most likely to be impacted, then its nature requires to be characterised before a decision can be reached on which part of the water column biota needs to be studied.

The strategy should continue to emphasise that the sequence and type of monitoring should depend on the main reason for that monitoring. If the main concern is over depth changes which may impact on navigation, for example, then monitoring must concentrate on these. On the other hand, if protection of a healthy local marine environment is of primary concern then the biological and associated physical features of that environment require to be determined.

Both spatial and temporal monitoring require to be undertaken rigorously in order to identify the significant natural and anthropogenic changes. In most cases there will be insufficient data to determine the range of natural variability for a particular parameter in the area of concern. Taking the spatial and temporal designs, the 'BACI' station pairing survey design can be adopted. This design requires a pairing of samples either **B**efore and **A**fter the operation is carried out, or at a **C**ontrol site against an **I**mpact site (Schmitt & Osenberg, 1996).

II. Generic physico-chemical, biological and socio-economic indicators of environmental attributes and impact

Once the hypotheses to be tested have been set it is necessary to determine the natural variability of the indicators which require to be monitored in the areas of concern. To determine the well-being and maintenance of an area, and its structure and functioning in relation to the physico-chemical regime, one approach is to indicate as many features as possible, even if minor, as a check list. This approach is relatively easy to implement but requires both expertise and a priority list. The Task Team has produced tables of indicators, Table 2.4 and Table 2.5, to assist in the process and the use of few attributes makes the scheme as generic as possible. The over-riding influence of the physical environment dictates that it would more cost-effective to study the changes in those features rather than in the biology, which, because of the effort required, might not be studied in detail. The selection of indicators is made on a case by case basis from available field survey data and/or a literature review and desk study.

The parameters to be assessed can be divided into physical and chemical attributes which could cause habitat disruption, and secondary parameters, the biological attributes, which reflect the consequences of change. The most appropriate evaluation considerations for each general indicator are given in Table 2.4 and Table 2.5. The biological attributes to be used include important features which describe community structure and functioning. While some changes within the immediate dredging and disposal sites may be accepted, outside of the sites' boundaries or defined zones of impact, the considerations detailed below will apply.

Table 2.4. Indicators of physico-chemical environmental impacts and evaluation considerations at dredging areas and dredged material disposal grounds, outside area of accepted impact

Indicator	Features
Area	The expected size of the habitat
Substratum	The underlying nature of the bed material: the maintenance of baseline thickness, stability characteristics and particle size composition within natural fluctuations.
Depth and Tidal Elevation	Indicating no significant change to either the coverage by water for subtidal habitats or the extent to which intertidal habitats are exposed at Low Water.
Water Characteristics	The maintenance of underlying water chemistry, including salinity, temperature and nutrient regime.
Hydrophysical Regime	The summation of tidal, wind-induced and residual current baseline conditions, which influence the bed nature and the delivery of food and dispersive stages to an area.
Habitat Mosaic	The maintenance and an indication of the complexity of the environment created by the physical attributes and thus leading to biological complexity.

Table 2.5. Indicators of biological and socio-economic environmental impacts and evaluation considerations at dredging areas and dredged material disposal grounds, outside the area of accepted impact

Indicator	Features
Community Structure	The maintenance of the net result of taxa and individuals supported, the diversity of the area and, where necessary, the zonation as expected, given the environmental conditions and hydrographic regime.
Biotopes	The number and mixture of representative biological-environment entities
Species	The maintenance of the presence and viability of important species, especially those considered rare and fragile and included in any site notification, and the dominant species in terms of functioning and support of predators or as predators. The rare species could decline if their niche is removed, the area decreases or the supplying population declines.
Community Functioning	Ensure the habitat continues to support important predator populations such as birds and fishes as an indication of the overall health of the system.
Uses/Users	Ensure no unmanageable hindrance to other uses and users of the area, including no deterioration in aesthetic qualities of the area.

III. Practicality in the area of concern

When choosing a method of monitoring which is to be consistent with the objectives, consideration of the practicality of the method is required in the specific area of concern. This will involve a review of the predominant sea state, depths, tidal characteristics, waves, flow environment and bed characteristics. For example, in areas where there are invariably high energy sea states, ‘background noise’ and aeration may mean that acoustic methods for monitoring the water column may not produce the resolution required to determine any changes from normal conditions. Similarly, a dredger may be able to work in sea conditions, which will restrict or prevent the deployment of the monitoring vessel and/or equipment. In such cases, different methods and techniques will be required. In sampling the seabed, efficient and relevant samplers are needed to ensure representative samples are collected. For example, if accumulation of fines in a gravelly area is the concern, a suitable bottom sampler would be required (see Section 4).

Any proposed monitoring programme must be realistic in relation to the size of the individual project, but it is also the case that a large dredging/disposal project will not necessarily require more monitoring than a smaller one. The dredged material type and quality and the sensitivity of the specific environment will be the primary determinants for the levels of monitoring required. The need to target the monitoring requirement and the local availability of the equipment and skilled personnel, and the practicality of use, are also important considerations. As such, the over-riding aim is to produce a site-specific, cost-effective and efficient monitoring protocol.

IV. Temporal basis of monitoring

The requirement for continuous monitoring of a dredging activity, or monitoring of every load of material discharged from a hopper, will be dependent on the homogeneity or heterogeneity of the material. In most cases, sustained monitoring is neither necessary nor practical. At each site the specific concerns and predictions for the duration of the impact will influence the overall monitoring timescale. Thus the period of measurement and the duration of any monitoring programme needs to be flexible.

Compliance monitoring of a dredging operation, for example, must take account of variations in the dredging activity due to restrictions, natural and imposed, as well as breakdown and bad weather delays. It is also important that a review/feedback procedure is incorporated into the programme to allow the monitoring to be curtailed or reduced should no effects of concern be recorded.

If monitoring is to be effective in controlling possible harm to the environment by dredging or disposal, then it is imperative that the methods employed are capable of producing analysed results quickly and when required, both qualitatively and quantitatively. With real-time feedback to the dredging project the results can then be used to minimise any further problems by determining possible new working practices, implementing other specific mitigation procedures, or even stopping the work.

The relevance of either a Before/After pairing of monitored stations or a Before/During/After monitoring strategy depends on the duration of the dredging and disposal campaign. With either strategy, testing for change at the site should be accompanied by similar monitoring at a control or reference site to take account of natural changes in the environmental conditions. The Before/After pairing strategy works best either where the campaign period is short or where the repeat monitoring can be undertaken at similar times of year. However, depending upon the timescale of the dredging operation, monitoring of daily, seasonal or annual variations may ideally be required, or the use of a time series which takes account of extreme conditions such as storm events.

V. Spatial basis of monitoring

The spatial extent of monitoring is governed by the location of near and far field areas and the degree of potential concern with respect to movement in both the short and long terms. Disturbance by the grab, bucket or draghead and overflowing of the hopper at the dredging site may create short term, immediate effects. Conversely, possible erosion and subsequent movement of the deposited material might continue or even not occur until many months after disposal has finished; this may even be delayed until seasonal weather conditions mobilise and redistribute the deposit.

If areas of concern lie within the predicted dispersal path from, for example, hopper overflowing, tracking of the resultant plume (e.g. by electronic/acoustic devices), tracers or spot sampling over a pre-defined grid will confirm or allay concerns. For areas away from the immediate extent of the plume, longer term monitoring may be required to establish any detrimental trends. This may involve repeated bathymetric surveys over an area or across specific cross-sections, or bed sampling with subsequent analysis. Again, the form of the concern will determine the range of analyses required.

The monitoring strategy will require one or more Control (or Reference) - Impact pairing(s) of stations in order to detect possible changes due to the dredging and/or disposal activity. The Control (Reference) sites should have a hydrodynamic, sedimentological and biological environment similar to the impact site but be unaffected by the dredging or disposal works being monitored. A regular grid of sampling stations implies no prior indication of impact areas whereas circular patterns, with sites arranged around a central impact area, or a hexagonal pattern, again surrounding a central area, may be required to detect impacts which may occur in any direction. With greater information regarding the potential dispersal of disturbed or deposited material, then either a transect of stations can be monitored, to indicate a gradient of effect, or the control sites may be arranged in the relevant direction. In both cases the number of measurement sites can be reduced.

VI. Level of detection

When deciding on a monitoring technique, the size and frequency of the dredging operation also needs to be considered with respect to the relevance and magnitude of any changes expected. For example, if smothering of the seabed away from the immediate disposal area is the concern, but the volume of material to be deposited is small, then it is unlikely that small changes in the bathymetry would be accurately detected by the use of an echosounder. If the level of significance is then defined as being less than the limits of echosounder detection, the true significant extent of change is unlikely to be able to be detected using this technique. In such a situation a direct means of measuring biological change would be more appropriate. However, it should be noted that although the biological characteristics can be precisely measured, e.g. as the primary community variables of abundance and species richness, small and subtle changes in these characteristics are neither likely to be detected nor be attributable to the dredging or disposal operation.

All field and laboratory techniques and instruments are subject to some tolerance limitation and experimental error and therefore, where possible, realistic detection levels should thus be established for the methods and equipment to be used. It should be remembered that the aim of any monitoring is to separate this natural and experimental/analytical variability (termed 'noise') from the required 'signal', i.e. the degree of impact caused by the operation. Hence monitoring is required to be sufficiently rigorous to determine the signal to noise ratio. Any changes recorded during the monitoring process must be assessed against this background of natural, experimental and analytical variability to determine the significance. Despite such an aim, field variability is inherently large. This is especially so for the biological features but also applies to the physico-chemical ones. That variability and its causes are often not adequately understood or explained, and thus an underestimation of this variability may lead to inappropriate monitoring.

VII. Levels of significance

If the monitoring is to succeed in preventing any unforeseen problems with respect to the specific areas of concern, realistic levels of significance should be established for the parameters being monitored. When these levels are approached or breached, mitigation measures, including possible cessation of operations, can then be instigated or reviewed to prevent significant change occurring. This process is termed feedback monitoring. For most parameters, these significance levels will be site specific and for biological parameters they will also vary according to the natural cycles.

All set levels of significance must take into account any existing relevant Environmental and Ecological Quality Objectives (EQO/EcoQO). They must also compliment the relevant available standards (EQS) while being aware of natural variability. The classical and long-adopted pollution control strategy implies detection of the breaching of defined action levels as standards, which in turn implies that action will be taken. However, while there are accepted standards for chemical and some microbiological determinands in the water column, as given in EU Directives, there are none for physical parameters and few for sediments. Although biological community standards have been proposed (MAFF, 1993), these were derived for the action of a well-defined stressor - sewage sludge - and are not necessarily applicable for sedimentary perturbations caused by dredging and dredged-material disposal. There are no accepted standards for use in the dredging and dredged-material disposal monitoring discussed here and the Task-team concluded that further work is required to define such standards (SOAEFD, 1996).

One of the most common problems caused by the dredging and disposal processes is the smothering of the seabed by sediment. A realistic value of the depth of smothering which would be significant to the bed fauna needs to be established for the particular site. This is likely to vary between faunal types, and with the rate and frequency of input of material. While material of a given type disposed into a similar area may allow the biota to recover easily, greater differences between the disposed material and the sediment in the receiving area will produce greater biological effects.

Similarly, erosion and deposition cycles related to tidal and seasonal patterns occur in many areas, especially estuaries. These variations further increase the difficulty of detecting effects. They may also either mask effects or mean that effects will be unlikely where dredging or disposal-induced sediment movement is minor in relation to natural sediment movement. As soft-sediment seabed levels are naturally variable in a high energy coastal or estuarial environment, changes are likely to occur due to cyclical changes such as tidal range and perhaps more significantly by intermittent severe storms. Any changes attributable to dredging or disposal must therefore be in excess of this natural change to be significant. The large scale variability of the natural system, especially in estuaries, thus gives a guide to the levels of change which the environment can withstand without what is regarded as a long term detrimental effect.

The difficulty in setting precise standards for the biological and physical parameters combined with the large scale inherent variability in the system, dictate that the significance of change cannot easily be quantified. While statistical significance can be detected (given an adequate replication of samples) between the Before/After and/or Control/Impact site pairings, the result may be meaningless in terms of the health of the marine environment. Because of this difficulty, the significance of change in physical or biological terms may have to be that which is identified by the competent marine scientist.

2.5 Conclusions

The large number of UK dredging and dredged material marine disposal sites in variable hydrodynamic environments, each with possibly different bed characteristics and varying natural background conditions, make the derivation of numerical standards for the evaluation of monitoring of dredging and dredged material disposal difficult. If relevant EQSs have been derived for the particular dredging/disposal operations these should be used, but it is believed that all sites must be considered on their own merits, taking due account of the overall Environmental Quality Objective (EQO).

3. PROCEDURE FOR DETERMINING MONITORING REQUIREMENT

3.1 Introduction

While dredging and disposal of dredged material are vital for the maintenance and development of ports and waterways, it is essential to ensure that these activities do not result in unacceptable environmental degradation. Monitoring of the activities has a major role to play in obtaining such assurance. It provides validation of the assessment of the environmental impact of the activity (the impact hypothesis) and information to assist in the assessment of any future proposals for dredging or disposal. It can produce data for discussion with third parties who may be concerned about the activities. However monitoring can be both difficult and expensive. It is essential that careful targeting is achieved to ensure that the data collected are relevant and of real value.

The procedure developed by the Task Team for the determination of monitoring requirements makes use of information relating to the dredging activity, the material to be disposed, the method of disposal and the characteristics of both the dredging and disposal sites. Potential far field effects, *i.e.* effects at sites outside the immediate dredging or disposal site are considered. Based on the factual information, a series of objective and subjective judgements can be made.

It is considered important by both the GCSDM and the Task Team that the procedure is transparent. This has been achieved by the development of a series of tables into which information is entered. The tables standardise the data collection and evaluation process. They also assist in identifying information not available, and which may need to be found at some later stage. It is recognised that the more information available the better informed any decision will be, but it is not intended that all tables should be fully completed before a decision is taken.

The collection of data is followed by an evaluation of the various data types and inter-comparison between data sets. A scoring system has not been used but instead the procedure allows informed decision at the different stages.

The procedure defined here is essentially that used by a licensing authority in deciding whether to grant a permit, and the conditions, including monitoring conditions, that should be imposed. The procedure is set out here to provide an approach which is clear to all those involved in the activity or concerned about its consequences, recognising too that it may be useful in those situations where such statutory controls are not in force.

3.2 Methodology

A flow diagram has been prepared to assist users in completing the tables (Figure 1, overleaf). In this diagram, both evaluation step sequence and the text table references are denoted. Following from the flow diagram is a description of each of the tables explaining their rationale and purpose. The tables are generic in that they can be used equally well to assess the monitoring requirements of both the dredging activity and the disposal operation.

Table 1 sets out information about the dredging and disposal activities and the material characteristics, in order to indicate the source of any potential problems. Most of the data required to complete Table 1 are likely to have been made available during the initial licensing assessment process. Information is required about the physical, chemical and biological characterisation of the material and the dredging/ disposal operation.

3.2.1 Identification of sites likely to be impacted

Near-Field sites:
Table 2 identifies the characteristics of the dredging and disposal sites. These areas, together with areas in the immediate vicinity are termed near-field sites. The features, uses and users of the disposal (or dredging) site are recorded in Table 3.

Far -Field Sites:
The dredging activity and any resulting disturbance and/or the deposited material have the potential to affect areas beyond the dredging and disposal sites. These areas are termed far-field. The potential for sediment movement is evaluated by consideration of the characteristics of the dredged material (Table 1) and of the dispersive nature of the disposal site (derived from Table 2). These areas are termed far-field.

The assessment requires knowledge of the way the disturbed or deposited sediments are likely to move under the prevailing hydrodynamic conditions in the dredging and disposal sites. Movement of the material will depend upon the sediment characteristics, the method of dredging and disposal, and the rate and frequency of dredging and disposal, as well as the wave and current patterns and the water depth. Modelling results or field tracer data can aid the process.

If all the available data indicate the near field sites are retentive, evaluation of the far field locations is not required. However, should the data suggest a potential for dispersion then the likely area(s) to be affected by the dispersion should be identified.

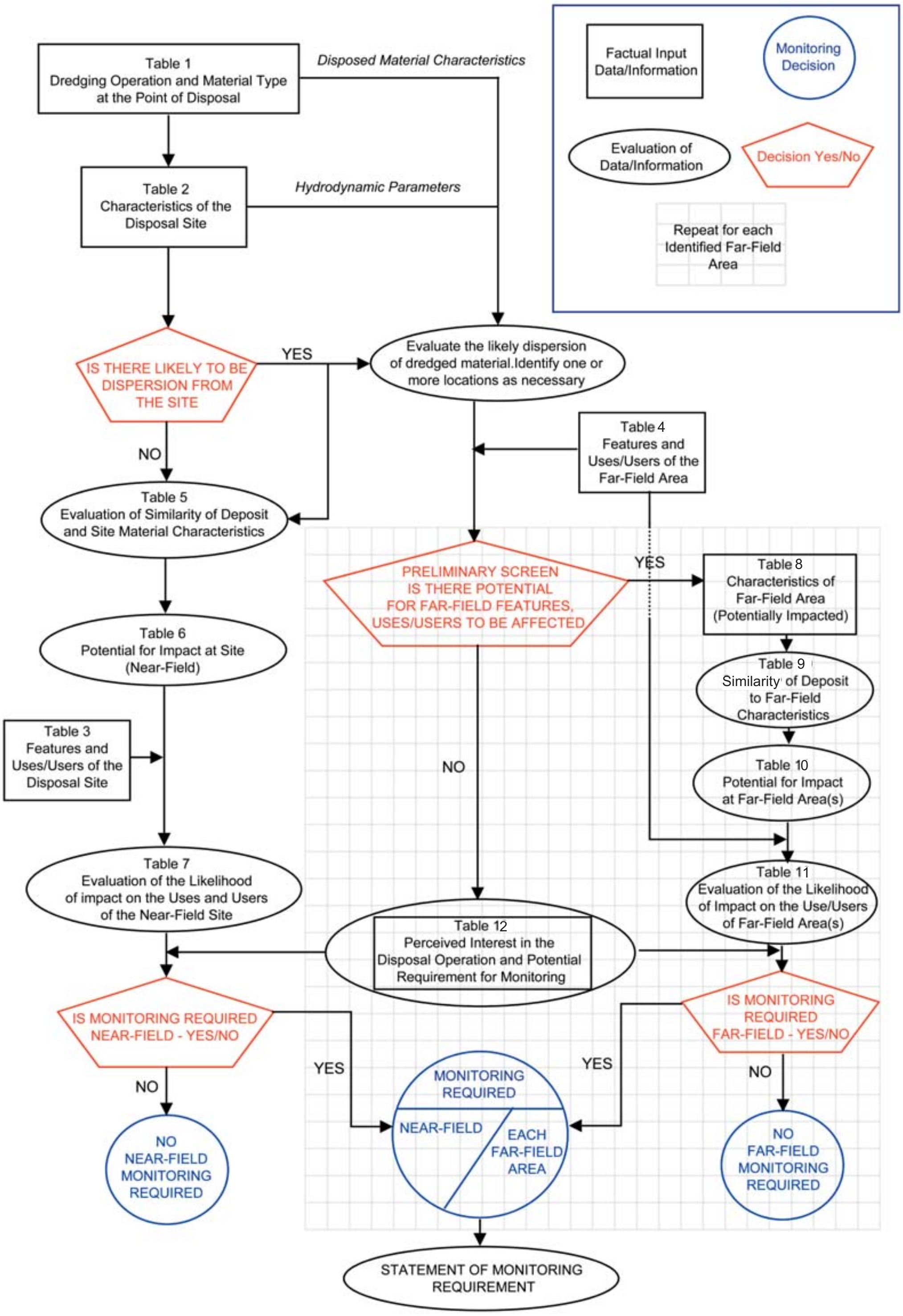

Figure 1. Procedure to determine monitoring requirements for dredging operations and the disposal of dredge material at sea

Once the likely area(s) of potential impact have been identified, the site(s) should be cross referenced against features, uses and users of each area as recorded in Table 4. A preliminary screen is then required. This allows a judgement on which of the areas, if any, will be affected by the dispersal of the sediment. Only those areas where there is a realistic potential for the existing uses and users of the area to be affected need be fully characterised by completing one or more examples of Table 8.

3.2.2 Impact evaluation

Consideration of the interactions which may occur between the site characteristics and the characteristics of the material to be disturbed or deposited are needed to determine the potential for concern at the near and far field sites. For example, if the material to be deposited is a small quantity of non-contaminated sediment similar in physical, chemical and biological terms to the seabed material at the deposit site, then the potential for concern may be low. Conversely, the deposition of mildly contaminated silt on a gravel covered sea-bed is likely to have a greater potential for concern. The results of the assessments are entered in Table 5 and Table 9 for the near and far field sites respectively.

Table 6 and Table 10 record the level of potential impact on the physical, chemical, biological and aesthetic attributes of the water column and bottom at each site. This is achieved by revisiting the initial tables, and making judgements in respect to the impact on each attribute, as applicable. This process will identify which of the attributes are of greatest potential concern.

The effects on the other uses and users of the near and far field sites are evaluated by using the information in Table 3, together with that in Table 6 to complete Table 7. Similarly the effects at the far-field site(s) are evaluated using the information in Table 4, together with that in Table 10 to complete Table 11.

For example, a high potential for biological impact on the water column will have no significant effect on gas/oil pipeline activity, but would have a high likelihood of impact on mariculture and fisheries exploitation activities.

At the conclusion of this part of the analysis, the main area(s) of interest and concern will have been identified together with an indication of the level of concern. Impact hypotheses can now be derived for which a monitoring programme can be designed to validate.

3.2.3 Requirement for monitoring

The extent and nature of the monitoring requirement derives primarily from the potential for environmental impact, i.e. the sensitivity of the activity, but it is also important to take into account the perceived interest in the activity by a variety of stakeholders, and the reasons monitoring might be required.

Table 12 is used to record perceived interest in the dredging and disposal activity.

From Table 12 it can be seen that there is a wide range of reasons for monitoring. Each of these may result in a different monitoring requirement. Nevertheless the monitoring rationale outlined in Section 2 should be the basis for the programme.

Table 1. Dredging operation and material type at the point of disposal

Dredging and Disposal Operation		**Characteristics** (add qualitative comment/qualitative assessment where possible; give units and references (published/unpublished material) as necessary) (if information not known at present time, use nk)		
Feature	**Characteristic**	**Material 1**	**Material 2**	**Material 3**
1. Dredging Reason	1.1. Operation type (capital, maintenance)			
	1.2. Total Quantity to be Disposed (t, m^3) and *in situ* density.			
2. Dredging Method	2.1. Type (*e.g.* mechanical, hydraulic)			
3. Disposal Method	3.1. Duration of Campaign (d/m/y)			
	3.2. Quantity per Disposal Operation (t, m^3)			
	3.3. Method of Delivery (add rate if known or time taken; $m^3\ s^{-1}$, slow, fast)			
	3.4. Frequency (number of loads per day)			
	3.5. Interval Between Campaigns (*e.g.* quarterly)			
	3.6. Operational constraints (*e.g.* tidal working)			
4. Dredged Material Type at Point of Disposal	4.1. Type (*e.g.* particle size: including grain size, coarse to fine nature, sorting)			
	4.2. Type (mineralogy)			
	4.3. Cohesiveness (*e.g.* solid/cohesive, fluid); Bulk density in hopper			
	4.4. Homogeneity			
	4.5. Organic content (*e.g.* high, low, organically enriched)			
	4.6. Chemical quality (*e.g.* clean, contaminated)			
	4.7. Biological quality (toxicity/bioassay: *e.g.* no effect, toxic)			
	4.8. Overall description of quality			

Table 2. Characteristics of the dredge/disposal site

Dredging or Disposal Site Features/Component		**Description and Quantitative Information** (if not known, use nk)
1. Site	1.1. Location (attach copy of chart)	
	1.2. Shape of site (attach copy of chart)	
	1.3. Size of site (km^2)	
	1.4. Distance and Direction from land (km, from MHWS)	
	1.5. Water Body Type (*e.g.* estuary, coast, open sea)	
2. Site History	2.1. Previous Disposal Operation (Material Type, duration of use, method of disposal, quantity disposed, frequency of use)	
3. Water column, Physical characteristics	3.1. Depth (CD, m)	
	3.2. Wave-climate (strength; estimation of maximum height, average wave conditions) (data obtained from Admiralty Chart);	
	3.3. Prevailing strength and direction of wind and wind-driven currents	
	3.4. Tidal Currents (tidal stream, direction, maximum speed; distance and direction of tidal excursion) (data obtained from Admiralty Chart)	
	3.5. Seabed characteristics	
	3.6. Other Information	
4. Water quality	4.1. Turbidity (*e.g.* NTU, mg l^{-1}, Secchi disk depth)	
	4.2. Chemical characteristics (*e.g.* salinity, DO)	
	4.3. Chemical characteristics (contaminants)	
	4.4. Biological characteristics	
5. Seabed characteristics	5.1. Type (*e.g.* rock, gravel)	
	5.2. Homogeneity	
	5.3. Bedform Activity (sediment transport)	
	5.4. Chemical quality (contamination, organic enrichment, Redox activity)	
	5.5. Biological characteristics (*e.g.* benthic community or biotope type: epibenthic, suspension feeding; infaunal, deposit feeding)	
6. Hydrodynamic Environment Summary	6.1. *e.g.* Description of high or low energy nature	

Table 3. Features and uses/users of the disposal site

Usage	Presence/Absence, Comments
1. Amenity/aesthetic grounds	
2. Recreation (actual/potential)	
3. Area (statutory designation, e.g. SPA, SSSI)	
4. Nature conservation importance	
5. Public interest	
6. Fishing activity	
7. Fishery resources	
8. Mariculture	
9. Land-based Discharges (Outfalls)	
10. Industrial Intakes	
11. Other vessel-based disposal (present)	
12. Other vessel-based disposal (historical)	
13. Gas/oil pipeline & activities	
14. Navigation	
15. Economic uses of adjoining areas including any port-related activities	
16. Marine archaeology	
17. Aggregate extraction	
18. Any other	

Table 4. Features and Uses/Users of the Far-field Area

Usage	**Presence/Absence, Location, Comments**
1. Amenity/aesthetic grounds	
2. Recreation (actual/potential)	
3. Area (statutory designation, e.g. SPA, SSSI)	
4. Nature conservation importance	
5. Public interest	
6. Fishing activity	
7. Fishery resources	
8. Mariculture	
9. Land-based Discharges (Outfalls)	
10. Industrial Intakes	
11. Other vessel-based disposal (present)	
12. Other vessel-based disposal (historical)	
13. Gas/oil pipeline & activities	
14. Navigation	
15. Economic uses of adjoining areas including any port-related activities	
16. Marine archaeology	
17. Aggregate extraction	
18. Any other	

Table 5. Evaluation of similarity of deposit and site material characteristics

Area Features/Component	Potential for Concern		
	Low	**Medium**	**High**
Seabed Dissimilarity to Disposed Material			

Table 6. Potential for impact at site (near-field)

Component		Not Applicable	Low	Medium	High
1. In Water Column	1.1. Biology				
	1.2. Physical Aspects				
	1.3. Chemistry				
	1.4. Aesthetic				
2. On Seabed	2.1. Biology				
	2.2. Physical Aspects				
	2.3. Chemistry				
	2.4. Aesthetic				

Table 7. Evaluation of the likelihood of impact on the uses and users of the near-field site

	Water Column: impact on uses and users																**Seabed: impact on uses and users**													
	Biology				**Physical Aspects**				**Chemistry**				**Aesthetics**				**Biology**				**Physical Aspects**				**Chemistry**				**Aesthetics**	
1. Result from Table (circle)	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L
Complete for those uses identified in Table 3:																														
Effect	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L
3. Aesthetic features																														
4. Recreation (actual/potential)																														
5. Area (statutory designation, *e.g.* SPA, SSSI)																														
6. Nature conservation importance																														
7. Public interest																														
8. Fishing activity																														
9. Fishery resources																														
10. Mariculture																														
11. Land-based Discharges (Outfalls)																														
12. Industrial Intakes																														
13. Other vessel-based disposal (present)																														
14. Other vessel-based disposal (historical)																														
15. Gas/oil pipeline & activities																														
16. Navigation																														
17. Economic uses of adjoining areas (including port-related activities)																														
18. Marine archaeology																														
19. Aggregate extraction																														
20. Any other																														
21. Comments																														

Table 8. Characteristics of far-field area (potentially impacted)

Area Features/Component		**Description and Quantitative Information** (if not known, use nk)
1. Area	1.1. Location (attach copy of chart); indicate known sensitivities	
	1.2. Shape of area (attach copy of chart, cross-refer to Table 3, Table 4)	
	1.3. Distance and direction from land (km, from MHWS)	
	1.4. Water Body Type (*e.g.* estuary, coast, open sea)	
2. Area History	2.1. *e.g.* previous disposal operation and any indication of degradation	
3. Water quality	3.1. Turbidity (*e.g.* NTU, mg l^{-1}, Secchi disk depth)	
	3.2. Chemical characteristics (*e.g.* salinity, DO)	
	3.3. Chemical characteristics (contaminants)	
	3.4. Biological characteristics	
4. Seabed characteristics	4.1. Type (*e.g.* rock, gravel)	
	4.2. Homogeneity	
	4.3. Bedform Activity (sediment transport)	
	4.4. Chemical quality (contamination, organic enrichment, Redox activity)	
	4.5. Biological characteristics (*e.g.* benthic community or biotope type: epibenthic, suspension feeding; infaunal, deposit feeding)	
5. Hydrodynamic Environment Summary	5.1. *e.g.* description of high or low energy	

Table 9. Evaluation of similarity of deposit to far-field site characteristics

Area Features/Component		Potential for Concern			
		Not Applicable	Low	Medium	High
Seabed Dissimilarity to Disposed Material	Far-field Area #1				
	Far-field Area #2				
	Far-field Area #3				
	Far-field Area #4				

Table 10. Potential for impact at far-field area(s)

Component		Not Applicable	Low	Medium	High
1. In Water Column	1.1. Biology				
	1.2. Physical Aspects				
	1.3. Chemistry				
	1.4. Aesthetic				
2. On Seabed	2.1. Biology				
	2.2. Physical Aspects				
	2.3. Chemistry				
	2.4. Aesthetic				

Table 11. Evaluation of the likelihood of impact on the uses and users of the far-field area

	Water Column: impact on uses and users																**Seabed: impact on uses and users**													
	Biology				**Physical Aspects**				**Chemistry**				**Aesthetics**				**Biology**				**Physical Aspects**				**Chemistry**				**Aesthetics**	
1. Result from Table 7 - (circle)	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L
2. Complete for those uses identified in Table 4:																														
Effect	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L	M	H	n/a	L
3. Aesthetic features																														
4. Recreation (actual/potential)																														
5. Area (statutory designation, *e.g.* SPA, SSSI)																														
6. Nature conservation importance																														
7. Public interest																														
8. Fishing activity																														
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12. Industrial Intakes																														
13. Other vessel-based disposal (present)																														
14. Other vessel-based disposal (historical)																														
15. Gas/oil pipeline & activities																														
16. Navigation																														
17. Economic uses of adjoining areas (including port-based activities)																														
18. Marine archaeology																														
19. Aggregate extraction																														
20. Any other																														
21. Comments																														

Table 12. Perceived interest in the disposal operation and the potential requirement for monitoring

1. Legislative and administrative requirement:
    1.1. compliance with licences, not just those concerned with solids disposal (including planning permission, etc.),
    1.2. compliance as required under local, national and international guidelines, conventions, protocols and pressures.

2. Scientific and environmental health reasons - increasing background information (for future use and licensing), feedback monitoring; potential for actual environmental problems (physical, chemical, biological, aesthetic).

3. Not all Statutory Bodies have a statutory remit with regard to the licensing, but may be statutory consultees as a result of legislation likely to be impacted and hence require reassurance and information. Stakeholders include Non-government Organisations (NGO's) and members of the public.

4. Socio-economic effects and sustainability of an area:
    4.1. management of the disposal operation (amount acceptable for management of the site and disposal operation).
    4.2 impact on other uses and users (*e.g.* fishing).

Reason	**Yes**		**No**		**Comment**
1.1. Statutory (legislative) compliance					
1.2. Compliance with guidelines					
Reason	**Not Applicable**	**Low Interest**	**Moderate Interest**	**High Interest**	**Further Comment**
2.1. Background information					
2.2. Feedback monitoring					
3.1. Reassurance to Statutory Bodies					
3.2. Reassurance to other stakeholders					
4.1. Disposal management needs					
4.2. Other users' concerns (see Table 3 and Table 4)					

4. MONITORING METHODOLOGY

It is beyond the scope of this DMDMTT report to recommend a single method or series of methodologies that could be utilised for the monitoring of environmental impact resulting from the sea disposal of dredged materials. Each disposal site is unique as is the nature and quantity of material to be disposed. Consequently, monitoring requirements will range from the minimalist approach of no monitoring required, right through to the large scale surveys costing £100,000+.

The methodology and rationale set out in the previous sections should identify the extent of relevant data available and, just as importantly, gaps in the information. The evaluation process then determines the specific areas of concern, the overall level of those concerns and at what locations. This then levels onto the formulation of monitoring hypotheses. These will define the type and extent of monitoring required, targeted to the specific concerns. The following gives reference to guidance and consideration of quality assurance, the formulation of sampling strategies and what monitoring techniques are suitable for gathering different data types.

Data acquisition is expensive and therefore should be of the highest quality. The DMDMTT strongly advocate participation in National Analytical Quality Control Schemes by all individuals involved in both sampling and analysis but realise that this may not always be practical, particularly with respect to sample collection. Data produced by non-accredited (or participant) organisations should be flagged and treated cautiously by the licensing authorities if the data appears to be inconsistent.

Guidelines for the design of sampling programmes, and for sampling methods should largely be met by those devised for sewage-sludge disposal sites as indicated by the Benthos Task Team (Rees *et al*., 1990). The Benthos Task Team drew special attention to the need for physico-chemical assessment of sediments in the receiving environment and of transport pathways, for the design of effective biological sampling programmes.

Monitoring is often dictated by historical practice, local preference and the availability of sampling equipment and expertise. DMDMTT advocates the principals of BATNEC (Best Available Technology Not Entailing Excessive Costs) and as such does not necessarily recommend the immediate purchase of the latest Hi-tech sampling equipment but rather the effective use of the appropriate equipment. The following section lists methods and techniques which are in usage currently but this list is by no means exhaustive. Table 4.1 gives outline examples of the methods which can be used to monitor the main environmental component characteristics necessary for evaluation of the effects of dredging and disposal operations. The list is, again, not exhaustive and methods will be site and case-specific. An overview of estuarine hydrography and sedimentation techniques can be found in Dyer (1979) and a similar overview of benthic methods is given in Holme & McIntyre (1984) and Baker & Wolff (1988). The National Marine Monitoring Programme (NMMP) 'Green Book' (MPMMG, 2000) details current acceptable methodologies for the derivation of physico-chemical and biological determinands. It is a live working document and available on the Aberdeen Marine Laboratory website (http://marlab.ac.uk). The JNCC Marine Monitoring Handbook (Davies *et al*., 2002) gives very detailed procedural guidelines on the majority of methodologies routinely used in marine habitat assessment. These include acoustic mapping techniques, video and photographic survey (both aerial and underwater), bathymetric studies, water and sediment chemical analyses, biotope mapping, sediment sampling (both remote grabbing/coring and diver operated methodologies), fish sampling and algal/vegetation surveys. The Marine Monitoring Handbook is very much a developing set of guidelines in that as new techniques are developed and tested they can be rapidly incorporated into the live version of the handbook which resides on the JNCC website (http://www.jncc.go.uk). The procedural guidelines detail background to the technique, methodology, equipment, costs and time, advantages/disadvantages, health and safety, logistics and QA/QC of produced data. The Handbook also has a detailed chapter offering advice on selecting appropriate monitoring techniques. While it may be argued that this publication is targeted at conservation agencies involved in monitoring Natura 2000 sites under the Habitats Directive, the methodologies are generic and applicable to all marine monitoring. Both the Marine Monitoring Hand Book and the MPMMG Green book offer full bibliographies and reference lists to all the appropriate methodologies in common usage within UK waters.

(It is of note that the inclusion of proprietary methods here does not imply an endorsement of the methods by DMDMTT.)

Table 4.1. Examples of techniques that can be used to monitor the main environmental components relevant to dredging and disposal operations

Component	Feature	Techniques
1.1. Water Column	1.1.1. Surface features (slick, foaming)	Aerial photography.
	1.1.2. Light penetration	Secchi disk (m) depth giving water transparency.
	1.1.3. Turbidity/ suspended solids	(i) use of water displacement samplers (Collins) at several depths, to give depth profile, then filtering water through GFC filters to give weight suspended solids (seston); (ii) use of turbidity meter (e.g. PARTECH) calibrated against natural sediment (NTU, mg l^{-1}).
	1.1.4. Water borne contaminants	Filter water samples to give suspended load and dissolved phase; for trace metals, petroleum hydrocarbons, halogenated hydrocarbons; employ AQC/QA techniques .
	1.1.5. Particulate organic carbon	Filter water samples and use either percentage Loss-on-Ignition, CHN analyser (e.g. Carlo-Erba, Perkin-Elmer) or use wet oxidation technique followed by spectrophotometry .
1.2. Hydrography	1.2.1. Tidal excursion	Subsurface drogues, followed by boat with radar and DGPS position fixing; monitored per tide with spring and neap coverage; allow for freshwater input in estuaries.
	1.2.2. Wind-driven circulation	Surface drogues followed by boat with DGPS under several wind conditions, OSCR and Acoustic-Doppler Profile Imaging.
	1.2.3. Bed currents	Seabed drifters - deployment of plastic drifters, each tagged and with reward for recovery.
	1.2.4. Short-term circulation	Direct-reading current meter (DRCM), deployed as depth-profiles, over tidal cycles and under differing spring-neap conditions; deploy in conjunction with other water parameter (depth, temperature, salinity/conductivity, oxygen, turbidity) to define water masses (use meter, e.g. Horiba); Acoustic Doppler Current Profilers (ADCP).
	1.2.5. Long-term circulation	Recording current meter (RCM) deployed over a lunar cycle.
	1.2.6. Sediment movement	Bottom landers deploying a range of optical sensors and water sampling equipment. A variety of tracers are in use e.g. fluorescent markers, most successfully used for non-cohesive sediments.
2. Seabed (Physical and Chemical Features)	2.1. Depth	Sonar - transducer mounted on boats, corrected for tidal depth, if possible use of nearest tidal gauge, echosounder or swathe techniques.
	2.2. Bathymetry	Accurate recording of bed profile; use of sonar.
	2.3. Bed forms	Photography to give presence of different ripple types, rock surfaces, crevices, sediment pockets in hard substratum.
		Side-scan sonar for sweep of area, 2-dimensional interpretation.
		Bed-profiling, e.g. RoxAnn, as modified sonar giving bed features (substratum types, bed forms, major changes of bed.
	2.4. Soft-sediment type	Subjective assessment following grab or core sampling, skilled visual assessment into mud, muddy-sand, mud, etc.
		Detailed particle size analysis of sample taken by grab (e.g. Shipek) or core; granulometric analysis using sieving for the coarse fraction and laser granulometry (e.g. Malvern, Frisch), Coulter Counter, or pipette analysis for the finer fraction if <5% by weight. (Similar techniques to assess particle size of material in hopper); employ AQC/QA techniques.

Table 4.1. Examples of techniques that can be used to monitor the main environmental components relevant to dredging and disposal operations (continued)

Component	Feature	Techniques
	2.5. Sediment chemistry - contaminants	Sampling by grab or core (non-contaminating material) then analysis by digestion and Atomic Absorption or Plasma-emission spectroscopy for metals, GCMS or HPLC for organic contaminants; petroleum hydrocarbons by extraction and gravimetry or GCMS; employ AQC/QA techniques.
	2.6. Sediment organic content	Sampling by core or grab to give undisturbed surface sediment then assess Loss-on-ignition (using muffle-furnace) or direct measurement of carbon and nitrogen by CHN analyser or wet oxidation technique for carbon followed by micro-Kjeldahl for nitrogen (problems with coal contamination).
	2.7. Sediment redox balance	Platinum electrode measurements at depth in sediment on a core sample to give Eh profile and depth of redox profile discontinuity level.
3.1. Seabed (Biology)	3.1.1. Biotope	Still and video photography using epibenthic sledge towed behind vessel; calibrate area observed; record megabenthic organisms and any surface features (pockmarks, burrow entrances).
		Use of remote operated vehicle (ROV) from vessel to obtain precise nature of biological features; if necessary ground-truth using core and grab sampling .
		Biotope mapping, e.g. RoxAnn or QTS with ground truthing by core and grab analysis.
	3.1.2. Epibenthos	Still and video photography (as in 3.1.1.).
		Use of remote operated vehicle (ROV) (as in 3.1.1.).
		Tow epibenthic sledge, naturalists dredge or scallop dredge from vessel, subjective onboard analysis.
		Seabed towed gear, e.g. Agassiz or beam trawl with onboard analysis of large and common forms but laboratory analysis for more precise identification.
	3.1.3. Infauna	Sediment profile imaging (e.g. Remots) to give photographs, and possible image analysis) of sediment type in relation to presence of organisms.
		Use of grab (Day, Van Veen) or core (Craib, Rhinek Box, Haps) samplers to provide fully quantitative samples; sieving on board and laboratory sorting and identification to give abundance, biomass and species richness per sample; employ AQC/QA techniques.
3.2. Top predators	3.2.1. Fish	Pelagic trawling of water column at risk; otter, beam or Agassiz trawling for demersal and benthic fishes; on-board analysis to give species, abundances, biomass and sizes of dominant species.
	3.2.2. Seabirds	Aerial and shore photography, visual recording.
	3.2.3. Sea Mammals	Photography, visual recording.

5. CASE STUDIES AND EXAMPLES

A number of recent case studies of monitoring dredged material disposal programmes conducted in the UK are presented below. Additionally, some example scenarios are presented to encompass a cross-section of situations that might require consideration for a monitoring programme.

Case study 1: Disposal of a large capital arising to a dredged material location off the Thames Estuary, United Kingdom

Background

The disposal of dredged material arising from port expansion to accommodate larger vessel sizes or increased trade can pose significant environmental challenges, because of the large amounts of material that may be generated over a relatively short space of time. The conventional management option has been that of sea disposal, for which licences are issued by the UK Department for Environment, Food and Rural Affairs (DEFRA) under the Food and Environment Protection (FEPA) Act, 1985, following a satisfactory outcome to a risk assessment of the environmental consequences.

The location

The 'Roughs Tower' disposal site is located in shallow water of 10 – 20 m off the Thames estuary, UK (see Figure 5.1), and is characterised by relatively strong tidal currents (>1 ms^{-1} on spring tides) and periodic exposure to the influence of wave action at the seabed.

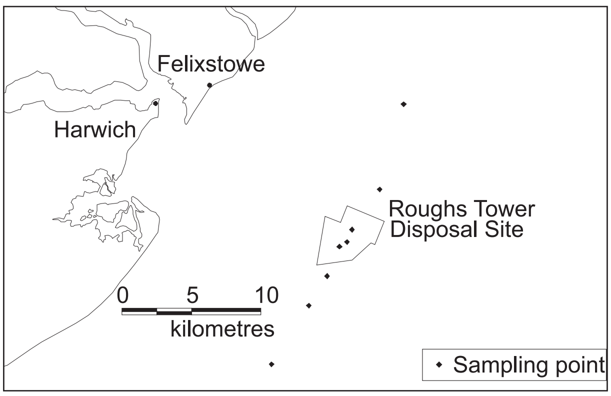


Figure 5.1. Location of the Roughs Tower disposal site (outer Thames estuary). Grab sampling stations along a transect through the disposal site are also shown

History of use

The site has been in use for many years as a recipient for maintenance dredgings and (until 1996) sewage sludge, as well as periodically for large capital arisings from earlier port developments at Harwich and Felixstowe (see Figure 5.2). In 1999, major port expansion at Harwich resulted in the need to dispose of up to 30 million tonnes of dredged material.

In the build-up to the capital works, significant effort was devoted to identifying possible alternative uses of the dredged material, in particular to counter the effects of net erosional regimes in the adjacent Stour and Orwell estuaries, and to replace intertidal habitat as a result of port development. A number of schemes were subsequently implemented, and are the subject of ongoing evaluation, both by the industry and regulatory interests. However, sea disposal was the only realistic option for the majority of the dredged material (some 27 million t wet wt) and this was eventually licensed for sea disposal at the Roughs Tower site.

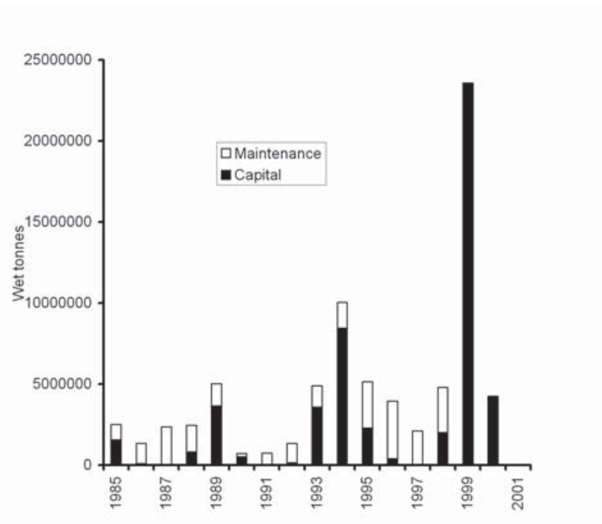


Figure 5.2. Disposal of dredged material to the Roughs Tower site

The problem

Concerns over the dispersive capacity of the local environment in the vicinity of the disposal site had increased in recent years, especially in relation to the development of a nearby crustacean fishery. The problem had been accentuated by periodic use of the site for the disposal of large amounts of material over a relatively short space of time (see Figure 5.3). The proposed 1999/2000 deposit therefore carried a risk of exceeding the dispersive capacity of the site, if the disposal operation were to be licensed to proceed in the conventional way.

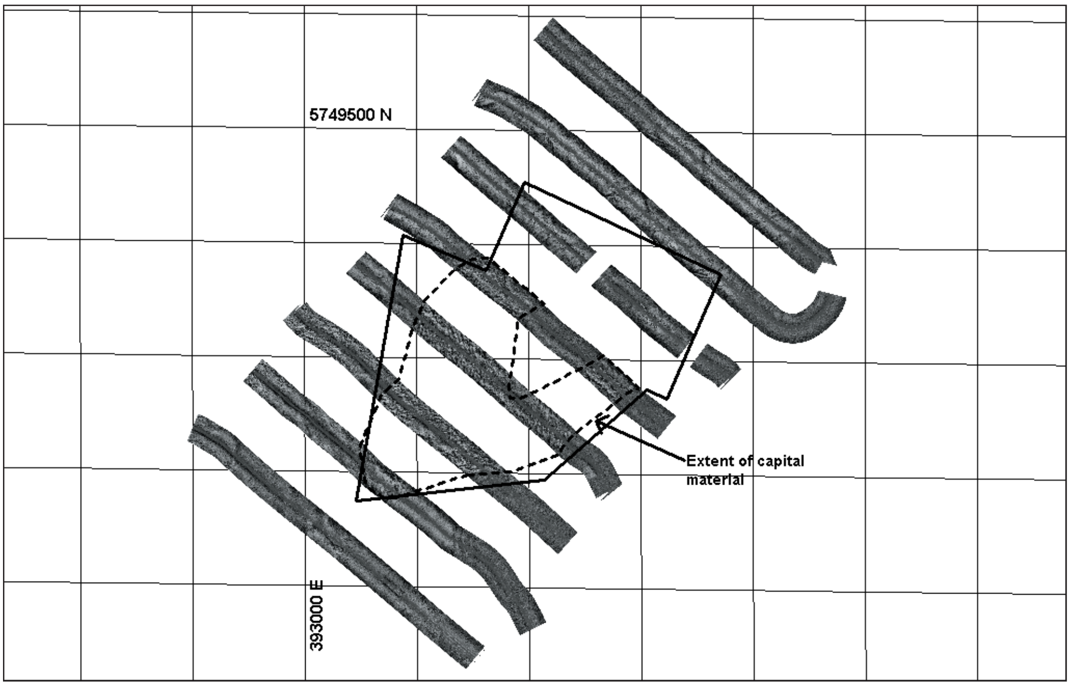


Figure 5.3. Outcome of sidescan survey, June 2001

The solution

As a result of the above concerns, approval of the application for sea disposal was subject to the condition that it would be accompanied by effective closure of the site. Additionally, the disposal operation was to be conducted in such a way as to promote containment of the material within the licensed boundary, and a final sprinkling of gravel was intended to create a habitat suitable for commercial shellfish.

Impact hypotheses

1. Containment of the majority of the deposited material within the site would result in a measurable but acceptable decrease in water depths, which would pose no hazard to shipping.

2. The benthic fauna at the disposal site would be adversely affected, but would recolonise relatively rapidly (i.e., within months) and would be structurally comparable to adjacent assemblages within 3 years.

3. Physical and biological changes to sediments arising from the 1999/2000 deposit would be limited to the immediate vicinity of disposal.

4. Disposal would not give rise to significantly enhanced contaminant concentrations in sediments in the vicinity of the site.

5. Following stabilisation, the deposited material would have a neutral or even positive impact on commercial shellfish resources.

In order to test these hypotheses, a multi-disciplinary *monitoring programme* was initiated by the regulatory authority and by the industry.

Outcome of monitoring/testing of hypotheses

1. *Containment of the majority of the deposited material within the site would result in a measurable but acceptable decrease in water depths, which would pose no hazard to shipping.*

Containment of the majority of the dredged material was facilitated by the initial construction of a bund, involving the placement of consolidated clay and rock along the western perimeter of the deposit area. Following sequential infilling with dredged material, the area was then closed off by the deposition of more consolidated material along the eastern perimeter.

Monthly bathymetric surveys by the licensee (Harwich Haven Authority) during disposal, and less frequent surveys thereafter, served a dual purpose of providing an indication of the build-up of material at the sea bed, and its relative stability in response to tidal currents and wave action. Following the cessation of disposal, the sea bed presented a relatively even profile at water depths which posed no hazard to shipping. A side-scan sonar survey conducted by CEFAS in 2001 provided independent confirmation of the integrity of the bunded area some two years after initiation of disposal, indicating that the bulk of the deposited material was still retained within the licensed site (Figure 5.3).

2. *Physical and biological changes to sediments arising from the 1998/2000 deposit would be limited to the immediate vicinity of disposal.*

Sediments in this part of the outer Thames estuary are naturally heterogeneous in nature, and particle size characteristics can differ markedly on small spatial scales. This accounts for the significant within-station variability in mean grain size along a transect of stations through the disposal site (Figure 5.4). Overall, there has been a net coarsening of sediments at the disposal site both as a result of recent and historical disposal activity.

During recent disposal, and in its immediate aftermath, the benthic fauna inhabiting these sediments was reduced, but not absent, at stations within and immediately adjacent to the site (Figure 5.5(a),(b)). The outcome of a survey conducted in June 2001 showed a marginal (but not significant) increase in numbers of taxa at the disposal site, and a significant increase at two stations to the SW (Figure 5.5(a)). There was also a significant increase in densities at the disposal site, and at two stations to the SW, in June 2001, which was largely accounted for by a recent settlement of the sand-mason worm *Lanice conchilega* (Figure 5.5(b)).

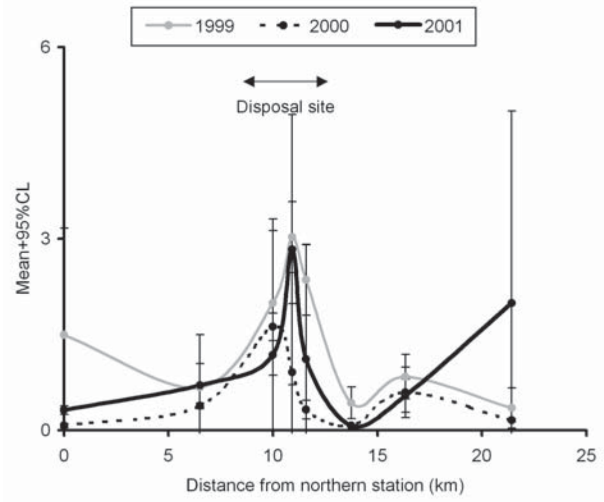
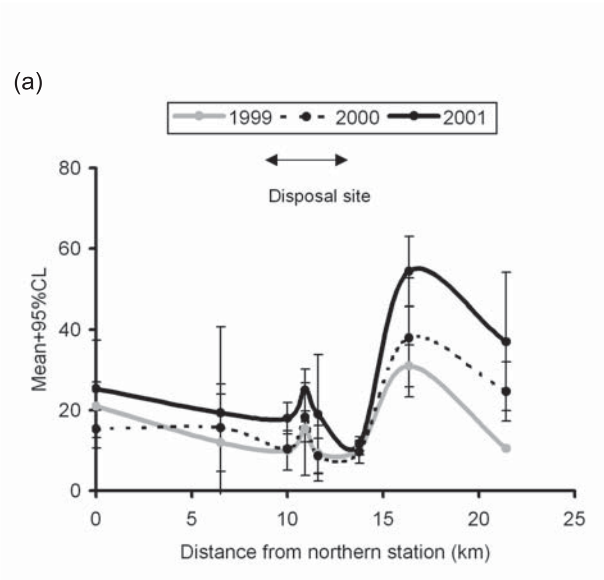


Figure 5.4. Trends in mean grain size (mm) along a transect of stations through the Roughs Tower disposal site. Three samples were collected at each station using a 0.1 m^2 Hamon grab

The post-cessation increases in numbers of taxa and densities to the SW of the disposal site suggest that, historically, the fauna here may have been adversely affected by dispersing fine particulates, especially those arising from the disposal of maintenance dredgings. These increases also indicate that, to date, ongoing processes of erosion and then transport of the finer component of the recently-deposited capital material are insufficient in scale and magnitude to sustain the apparent inhibitory effect of earlier disposal activity.



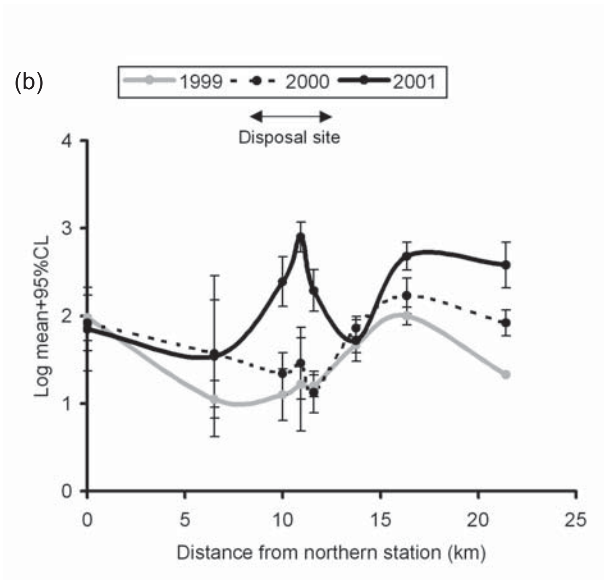


Figure 5.5. Roughs Tower disposal site: (a) numbers of taxa and (b) densities

3. *The benthic fauna at the disposal site would be adversely affected, but would recolonise relatively rapidly (i.e., within months) and would be structurally comparable to adjacent assemblages within 3 years.*

Although, some 14 months after cessation of disposal, there is evidence of recolonisation of sediments within the disposal site, the diversity is still reduced compared with similar sediments nearby. Therefore, the fauna could not yet be considered to be structurally comparable to adjacent assemblages, and annual monitoring is continuing until there is evidence that a new equilibrium state has been reached.

4. *Disposal would not give rise to significantly enhanced contaminant concentrations in sediments in the vicinity of the site.*

The presence of relatively low levels of trace metal contaminants was established through analyses of samples of the material prior to disposal, as part of the licensing procedure. The outcome of field sampling confirmed that, as expected, contaminant concentrations in the vicinity of the disposal site were not significantly enhanced following disposal. As an example, the mean concentrations of 5 trace metals in the vicinity of the disposal site during and after cessation, compared with an offshore reference site sampled in 1998. (The data were normalised against Aluminium concentrations in sediments to account for natural geological variability). It can be seen that levels were generally at or below those encountered at the reference site.

5. *Following stabilisation, the deposited material would have a neutral or even positive impact on commercial shellfish resources.*

Seven groups of five prawn pots (small fine-meshed, small entrance pots for the common prawn Palaemon serratus) have been hauled weekly since July 2000 and the contents recorded. The groups are located at six sites within the boundary of the Roughs Tower disposal site and the seventh is on nearby lobster ground to the east. The catch of lobsters (accumulated over a one-year period from July 2000 to July 2001) ranged between 6 and 34% of the catch of lobsters at the nearby control site. Similarly, the catch of edible crabs ranged between 31 and 64% of the catch at the control site. It should be noted that the gear only catches small animals due to the limiting size of the entrance.

The information to date provides encouraging evidence of the suitability of the benthic habitat within the disposal site for these commercial shellfish species. Additional catch data are required to establish whether population sizes of juveniles have stabilised at the disposal ground relative to the nearby control site and, over a longer time period, to determine the extent to which these findings are translated into enhanced catches within the commercial fishery.

Conclusions

The results to date appear to confirm earlier predictions concerning containment of the recently deposited material, and the localisation of physical and biological impacts arising from this recent activity to the immediate vicinity of disposal. Furthermore, there is evidence of amelioration of these impacts over time, as evidenced by the recolonisation of surface sediments by the benthic fauna, and the presence of appreciable densities of juvenile crabs and lobsters at the disposal site. This suggests that the approach adopted to the environmental management of this large capital disposal operation has been effective. Monitoring of the sediments and the benthic fauna at the Roughs Tower disposal site will continue, in order to establish the time-scale for attainment of a new and acceptable equilibrium state.

(An extended account of this case study can be found in *Proceedings of the 28th International Conference on Coastal Engineering*, Cardiff, 7-8 July 2002, in press).

Case Study 2: Port Edgar Marina in the Forth Estuary - maintenance dredging

Reason for dredging

Port Edgar Marina experienced siltation problems over a number of years as a result of river borne materials being deposited at the entrance and in the berths. The areas have been dredged infrequently removing approximately 50,000 m^3 *in situ* silty clay. Maintenance dredging of ports involving the use of techniques such as grabs, backhoes and trailer suction dredgers is often a prohibitively costly procedure. In recognition of this fact more cost-effective solutions were investigated and as result of enquiries a water injection dredger (WID) was selected to undertake work at Port Edgar.

Dredging process

The water injection process creates a dense layer of material ranging in thickness from 1 m to 3 m, which can then move under natural processes. The dense layer of agitated sediment is mobile and can flow down a seabed gradient or is driven by tidal flows. In Port Edgar the gradient of the channel is steep, ranging from 2.6 m at the marina entrance to more than 20 m over a distance of 150 m. The strong tidal stream effectively provides an excellent current for advection of either surface or bottom waters and particularly for density currents with steep gradient to assist initial transportation.

Dredging area

Port Edgar Marina lies on the southern shore of the Forth Estuary, Scotland (Figure 5.6) in close proximity to the Forth Road Bridge and the town

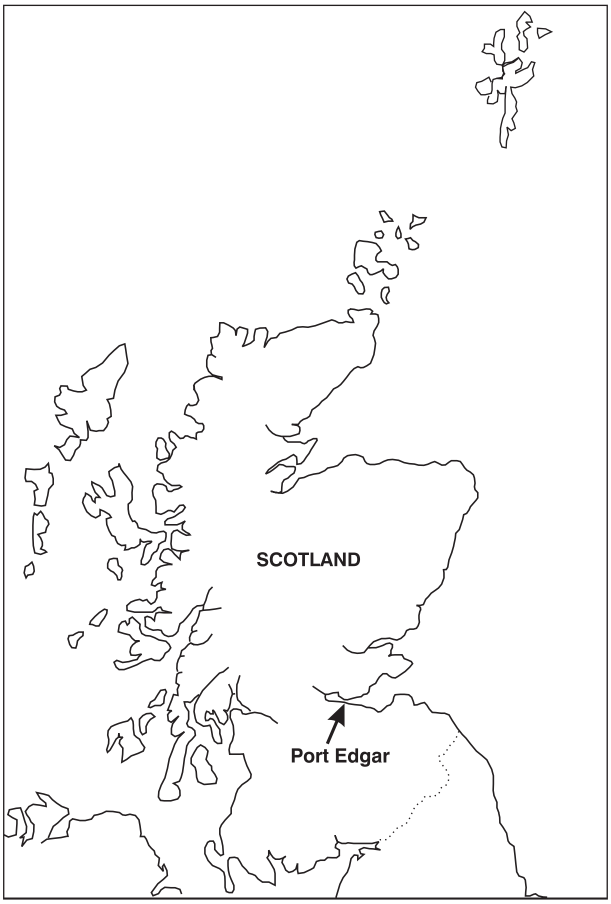


Figure 5.6. Location of Port Edgar in the Forth Estuary'

of South Queensferry. The marina site covers 40 hectares, of which 23 hectares are covered by water at high tide. The opening to the approach channel is approximately 220 m wide and protected by two rock mound breakwaters on either side which jut out into an estuary forming an obstacle to the natural tidal flow. The entrance channel is shallow 1-3 m (low water) with the marina berths ranging from 0.0 m to 1.0m and obviously some areas dry out low water.

The approach channel is approximately 400 m long running from the estuary between two rock breakwaters and an inner-floating breakwater. The tidal currents in the estuary are very much greater than those in the marina where they range from 0.05 to 0.3 m/s. On the flood tide a circulation of water within the entrance to the marina flows in an anti-clockwise direction (depth – averaged). This forms a convergent flow at the sediment bed level and divergent flow at the surface. The convergence will enhance sedimentation at the centre of the gyre since the flow of water will draw in material to the centre region of the gyre from outer areas. The sediment bed of the marina is organic silty-clay of marine origin.

Scope of study

The study had to be designed to fulfil the following objectives:

- To monitor the movement of dredged material during the water injection dredging operation and estimate the efficiency of the dredger in removing material;
- To monitor the transport of fluorescent tracer particles injected into the sediment dredging area by collecting seawater and bed sediment samples from within and out with the marina in the estuary and Firth of Forth;
- To assess the transportation rate of dredged material out of Port Edgar Marina and whether increased sedimentation is likely at the sample locations;
- To determine the siltation rates and confirm the areas of high sedimentation within the marina;
- To estimate the amount of dredged material that is returning to the marina and over what timescales.

Potential environmental risks and problems

The following were identified during discussions with interested parties:

- Impacts on navigation due to mobilised sediment accumulating at sensitive positions in the estuary;
- Mobilised sediment not leaving the marina area and accumulating in the entrance or returning prematurely to the marina berths;
- Impacts on water quality.

Impact hypothesis

Due to careful selection of dredging conditions to maximise dilution and dispersion characteristics, impacts were expected to be localised and transient. The water injection method is sufficiently effective to remove the majority of the mobilised sediment from the marina. Minimal localised smothering of the seabed is unlikely to cause severe impacts as it is postulated that native flora and fauna have adapted to exist in a dynamic environment. For example, the erosion and deposition cycles existing naturally within estuaries have a major effect on sediment dynamics. Similarly, the potential impact on navigation and adjacent beaches and mudflats is probably not measurable above the naturally variable background suspended solid loading. The release of the sediment load at or near the seabed is likely to have no measurable impact on water quality.

Monitoring undertaken to confirm hypothesis

In order to establish the pathways of the sediment layer movement and any areas of increased sedimentation, the monitoring has been separated into investigating sediment movements inside the marina and the transport of material outside the marina in the estuary.

The sediment pathways both within and outside the marina were determined by labelling a volume of the dense sediment layer with a fluorescent tracer. The tracer should have similar physical characteristics to the dredged material. The fluorescent tracer is injected into the dredging mechanism at the start of the ebb tide. Bed sediment sampling and water samples from within the marina and outside in the estuary were collected during the following week. Similarly samples were collected at the entrance to the marina to determine whether dredged sediment re-entered the marina from the estuary.

It was considered essential to undertake post-operation monitoring after a period of weeks following cessation of the dredging operation.

Outcome of monitoring

- The dredging technique provided an efficient maintenance-dredging programme with an estimated maximum of 64% of the dredged material leaving the marina and entering the Forth Estuary. The sediment layer moved out of the dredged access channel and was detected (by tracer) at 25-31 m water depth in less than 1 hour after dredging.
- The fluorescent tracer particles injected into the sediment layer by the dredger were transported by gravity flow out into the Estuary and Firth of Forth.
- Approximately 4% of the tracer remained in the marina indicating that deposition of dredged sediment would also occur.
- Water samples collected from the adjacent waters of the Estuary and Firth of Forth indicated no vertical mixing of tracer and sediment.
- Tracer particles were detected in the majority of the samples collected from inside Port Edgar Marina and in two thirds of the samples collected from the Estuary and Firth of Forth.
- There was no evidence to suggest that increased sedimentation occurred at any of the sampling locations since the tracer/sediment layer is thought to have remained mobile. Due to the degree of mixing, the dilution of tracer and sediment, and the minimum excursion distances of 3.5 km to the east and 1.5 km to the north west, increased sedimentation is unlikely and was not detected at the sampling sites, despite the detection of tracer at all sampling sites throughout the study period.
- The tracer study indicated that during a period when the dredger ceased to operate after 40 hours of steady state tidal conditions nearly twice the amount of tracer had settled out on the bed within the marina.
- The tracer study indicated that up to 4 weeks after the tracer injection no tracer appeared to have returned into the main flood tide circulation gyre at the marina entrance. After 15 weeks tracer was detected at low levels in the marina entrance.

Conclusions

The tracer study suggested that dredged material began to return to Port Edgar after 5 weeks. After 6 weeks it is thought that the dispersed dredged material comprised a negligible percentage of the total suspended sediment in the adjacent Estuary and Firth of Forth. The tracer study also indicated that once dredged, sediment does leave the marina and it does not return immediately afterwards, but actually becomes incorporated in the natural sediment and is transported by natural processes.

Example I:
Yacht marina requiring maintenance dredging

1. Dredging reason, methods and material

The scenario is a yacht marina basin initially carved into the banks of a rather turbid water macro-tidal estuary. This basin is filling quite rapidly, mainly with mud. A maintenance dredging campaign is needed to remove a deposit of about 80,000 tonnes and thereafter about 30,000 tonnes per year. Dredging is by a hydraulic excavator mounted on barge and the material is somewhat organic, anoxic and partially cohesive black mud with a high BOD, but without significant industrial contamination.

2. Disposal operation constraints

Due to constricted space in the marina only a small hopper barge with 80 tonne capacity can be used. Sea-keeping qualities of the hopper and navigational limitations in the estuary severely limit the choice of disposal locations. Added constraints due to locally important shellfish beds which might be liable to damage by the grounding of a larger barge or excessive turbidity if on site jet dispersal of deposits were widely used. The hopper will most often load during low water and go out and back the disposal ground on the same high water.

3. *Disposal site characteristics*

Inshore, depth 10 metres, well sorted rippled sand with tidal stream 1.8 knots at springs. Sheltered from prevailing SW wind but 60 mile fetch exposure to N. Amenity sand beaches within 4 miles.

4. *Predictions*

On discharge from the hopper the cohesive mass of mud will mainly sink to the bed but will give off a black turbid plume which will be most concentrated close to the seabed. During neap tides turbulent mixing will not be sufficient to prevent ephemeral deposition into the lows of the rippled sand over each slack water. On spring tides quite rapid dispersion of the mud will take place, most especially during winter storms. Near-bed residuals will mainly carry the dispersing material towards the adjacent estuaries and the shores with localised accumulation in nearby depositional pockets. Owing to the high BOD of the mud, some reduction in oxygen at the seabed around the disposal site can be expected in the summer, which will exacerbate intermittent de-oxygenation events following the collapse of phytoplankton blooms.

5. *Potential environmental risks and problems*

1. Damage to commercial shellfisheries either by physical damage from hoppers in transit or loss of condition of shellfish through water quality effects from wash-over dispersion from the hoppers.

2. Degradation of the seabed environment beyond the immediate boundaries of the licensed disposal ground due to the high BOD of mud.

3. Far field deposition of mud films on amenity beaches.

6. Impact Hypotheses

   - There will be transient damage to commercial shell-fisheries from physical impact, but no longer term loss of condition of shellfish.
   - That the small size of dredging operation limits seabed degradation to transient local effects.
   - That there will be no detectable deposition of mud film on amenity beaches.

7. Additional Work and Monitoring to be Considered:

A Confirmation and Refinement of Predictions:

A1 Dispersion rates and residual advection. Near-bed water sampling and turbidity measurements on spring and neap tides, including oxygen measurements at the critical season. Measurements of tidal variations in resuspension.

A2 Grab sampling, looking particularly for atypical black turbidity in water overlying the samples and for the presence of mud clasts in otherwise sandy sediment.

A3 Side-scan survey of the disposal site to confirm the dispersion of the hopper load mounds. Survey before disposal begins, soon after the major campaign and after 6–9 months, or after winter period.

B Post-operational Monitoring:

B1 Condition monitoring of shellfish samples at monthly intervals.

B2 Air photographs of intertidal shellfish beds before dredging campaigns start to aid the interpretation of any claims arising from accidental grounding of hoppers on beds.

B3 Periodic surveillance on foot of amenity beaches to check for ephemeral mud films.

B4 Small-mesh beam trawl sampling around the disposal site to detect whether sensitive benthic infaunal species such as *Corystes cassivelaunus* and *Echinocardium cordatum* have been caused to emerge from the sediment.

C Ecological Quality Standards Compliance:

Not likely to be needed for this type of dredging operation unless far-field areas with relevant Conservation Designations are deemed to be at risk.

Example 2: Estuary crossing project requiring capital dredging

1. *Dredging reason, methods and material*

Construction of structures requires capital dredging deep into glacial till and outwash clay deposits lying under the seabed near the mouth of an estuary. About 1.8 million tonnes of boulder clay to be removed in a 3 month dredging campaign using a variety of plant, followed by some suction dredging of sand for 9 months to keep works open. Materials without significant industrial contamination.

2. *Disposal operation constraints*

Tidal navigation constraints mean that self-propelled hopper barges will reach the disposal site to discharge near low water and will return on the flood. Initial dispersion will be in the flood direction.

3. *Disposal site characteristics*

Offshore, depth 30 metres, mixed lag gravel veneer with sand ribbons, currents 2.2 knots at springs. Not fully exposed to ocean swell but with 100 mile fetch exposure to some storms. Rocky reefs of conservation and sports diving interest 8 miles away in direction of dominant tidal axis.

4. Predictions

On discharge from the hopper the boulder clay will mainly sink to the bed as a coherent mass but will give off a substantial turbid plume which will mix throughout the water column on spring tides. Subsequently erosion of the barge load mounds will take several months. Much of the material will disperse into the water, but clay 'boulders' and 'pebbles', partially armoured by gravel adhering to their surfaces, will spread from the disposal site by rolling on the seabed. Water clarity may be slightly reduced over a wide area for about a year and there will be additional ephemeral deposits of fines at far-field locations before the extra fine material is incorporated again into semi-permanent deposits.

5. Potential environmental risks and problems

1. Interference to fishing gear by lumps of dredged material rolled away from the disposal site.
2. Decreases in water clarity influencing the amenity enjoyed by sports divers.
3. Erratic far field deposition of mud films inshore on the fronds of sublittoral macro-algae and other sensitive sublittoral rocky substratum forms such as sponges, in quantities sufficient to cause ecological damage but which are too small and localised for dispersion models to predict.

6. Impact hypothesis

Intermittent interference to fishing gear adjacent to the disposal site from lumps of dredged material rolled away from the disposal site. Water clarity will be reduced, at times of discharge close to the dumping vessel and to a lesser extent as fine material mixes through the water column. Occasional short-term interference with sports diver activities from intermittent occurrence of reduced water clarity at the reef. No measurable disposition on seaweed fronds, or changes to epifaunal communities in far-field rocky areas.

7. Additional work and monitoring to be considered

A Confirmation and Refinement of Predictions:

A1 Refinement of dispersion rates and residual advection as modelled. Near-bed water sampling and turbidity measurements on spring and neap tides. Measurements of variations in resuspension, perhaps using recording instruments logging *in situ* during storms.

A2 Side-scan survey of the disposal site to confirm the dispersion of the hopper load mounds. Survey before disposal begins, soon after the major campaign and after 6–9 months, or after a winter period.

A3 Video or photo-sledge observations around the disposal site.

B Post-operation Monitoring:

Bl Liaison with fishermen's representatives to assess the scale of any gear fouling problem.

B2 Regular measurement of water clarity by simple means such as Secchi disk or nepholometer at all popular local dive locations.

B3 Surveillance within kelp beds in the far-field zone for atypical depositions of fines on seaweed fronds.

B4 If there are hard substratum dive locations within the far-field zone where there is previous data on the biological variability of the communities, try to get these sites worked again.

C Ecological Quality Standards Compliance:

Cl Using photo-monitoring methods, devised for monitoring hard substratum fixed quadrats, gather detailed data on the changes to epifaunal communities in the far-field rocky reef area within the area statutorily designated as of conservation importance.

Example 3: Industrial estuary maintenance dredging

A) Dredging

1. Dredging reason, methods and material

Major port approach channel previously capital dredged into various glacial materials to provide deepwater approach channel for large vessels. Maintenance dredging is required to ensure safe navigational depths with low tolerance. This dredging involves removal on a continuous basis of some 0.5 M cubic metres of fine sand and silt each year by trailer suction hopper dredger.

2. Dredging operation constraints

Dredger(s) require to operate in exposed deepwater approach channel; spring tide range 6 m, wave height 3 m.

3. Dredging site characteristics

Approach channel extends about 3 km into open sea subject to severe wave action and cross currents. Channel bed consists of fine sand with seasonal deposits of silt, all overlying glacial till.

4. Predictions

During the dredging, turbidity will be created by the draghead moving over the bottom and by overflow from the hopper. The material disturbed by the draghead will remain close to the bottom and settle quickly following the operation. The overflow from the hopper will migrate in the direction of the predominant current and will settle through the water column at slack water.

5. Potential environmental risks and problems close to dredging site

1. Damage to adjacent fish spawning grounds, mudflats and salt marshes due to smothering by overflow material.
2. Disturbance of seasonal salmon run.

6. Impact Hypothesis

Restriction of dredging to outside salmon migration season will avoid impact with salmon run. Resuspension of fine material will be ephemeral, hence no observed impact on adjacent sensitive sites.

7. Monitoring to be considered

A Confirmation and Refinement of Predictions:

- AI Dispersion rates and residual advection as modelled. Near-bed water sampling and turbidity measurements during the dredging operation on spring and neap tides. Current and salinity measurements through the water column.
- A2 Bathymetric survey of adjacent navigable channel area to ensure maintenance of depths.

B Post-operational Monitoring:

- BI Aerial photography of intertidal mud flats and salt marsh.
- B2 Periodic walk survey of mudflats and sampling regime to establish baseline and changes to invertebrates.
- B3 Bed sampling.

C Ecological Quality Standards Compliance:

- CI Discussions with Environment Agency and DEFRA regarding acceptable levels during operations

B) Disposal of dredged material

1. Dredging reason, methods and material

Major port approach channel previously capital dredged into various glacial materials to provide deepwater approach channel for large vessels. Maintenance dredging is required to ensure safe navigational depths with low tolerance. This dredging involves removal on a continuous basis of some 0.5 M cubic metres of fine sand and silt each year by trailer suction hopper dredger.

2. Disposal operation constraints

There are no tidal constraints on use of existing disposal area, but in severe weather operations may be restricted.

3. Disposal site characteristics

Existing site 5 km from coast in 30 m water depth which has been used for about 100 years. Dispersive site, tidal stream of about 2 knots. Site located within approach to port anchorage area. Amenity beaches extend along coast. Littoral drift north to south.

4. Predictions

On discharge from hopper the majority of the coarse grained material will sink to the bottom in the usual discharge plume. Finer material will migrate through the water column. The majority of the material will remain within the disposal site until severe storms cause dispersion of the finer sands and silt.

5. Potential environmental risks and problems close to disposal site

1. Damage to adjacent spawning grounds within the area due to degradation of the seabed environment beyond the immediate boundaries of the disposal site.
2. Far field deposition of mud on amenity beaches.
3. Reduction in navigable depth in port approaches.

6. Impact hypothesis

Placement of dredged material in disposal site will be managed to ensure navigable depths are maintained. No measurable far-field depositing of mud on amenity beaches. No measurable damage to spawning grounds.

Additional Work and Monitoring to be Considered:

A Confirmation and Refinement of Predictions:

- A1 Dispersion rates and residual advection. Near-bed water sampling and turbidity measurements on spring and neap tides. Current measurements to establish tidal atlas of area.

B Precautionary Surveillance:

- B1 Bathymetric survey of disposal site to confirm material dispersal and maintenance of depths.
- B2 Grab sampling, looking in particular for atypical black turbidity in water overlying samples.
- B3 Periodic walk survey of amenity beaches to check for ephemeral mud films.
- B4 Small mesh beam trawl around limits of disposal site to check sensitive infaunal species.

C Ecological Quality Standards Compliance:

C1 Discussions with Environment Agency and DEFRA regarding acceptable water quality during operations.

Example 4: Small fishing harbour maintenance dredging

A) Dredging

1. Dredging reason, methods and material

Small fishing harbour experiences siltation during storms as a result of sand being moved into approach channel. Maintenance dredging is required to ensure safe navigational depths for fishing vessels. The dredging involves removal on a periodic basis (varying between twice a year and once every two to three years) of between 5,000 and 10,000 in-situ cubic metres of clean sand. Dredging normally undertaken by small self-propelled grab hopper dredger.

2. Dredging operation constraints

Approach channel is shallow (about 3 m) at low water and subject to wave action. Dredging activity constrained by tides and weather.

3. Dredging site characteristics

Short approach channel (500 m) running from very exposed open sea into channel between breakwaters. Tidal currents not significant. Channel bed consists of compacted sand with occasional gravel and seaweed deposits, all overlying stiff clay.

4. Predictions

During the dredging some turbidity will be created by the grab and by overflow from the hopper. The material will settle quickly close to the dredging area.

5. Potential environmental risks and problems

None.

6. Impact hypothesis

No adverse impacts.

7. Additional work and monitoring to be considered

A Confirmation and Refinement of Predictions:

None.

B Post-operational Monitoring:

None.

C Ecological Quality Standards Compliance:

None.

B) Disposal of dredged material

1. Dredging reason, methods and material

Small fishing harbour experiences siltation during storms as a result of sand being moved into approach channel. Maintenance dredging is required to ensure safe navigational depths for fishing vessels. The dredging involves removal on a periodic basis (varying between twice a year and once every two to three years) of between 5,000 and 10,000 in-situ cubic metres of clean sand. Dredging normally undertaken by small self-propelled grab hopper dredger .

2. Disposal operation constraints

Disposal site is located about 2 km offshore in water depth of about 12 m at low tide. Site is very exposed and subject to severe storms and heavy swell. Operation of small dredgers is frequently restricted.

3. Disposal site characteristics

Site is licensed site and has been in use for over 50 years. The seabed consists of sand very similar to the dredged material. The site is highly dispersive during storm conditions. The site is clear of navigation routes, clearly marked on charts and not a known fishing area. Some seabed crustaceans exist, but are used to the very dynamic environment. Amenity beaches exist close by and there is some coastal erosion.

4. Predictions

During the disposal all the material will reach the seabed very quickly after dumping. The material will remain within the site until dispersed by wave action.

5. Perceived environmental risk and problems

Some localised smothering of seabed creatures but these are adapted to dynamic environment and are commonplace in the surrounding area. No impact on beaches, navigation and erosion so long as material is retained within coastal sediment cell.

6. Impact hypothesis

Material will remain within disposal site, no impact outside disposal site.

7. Additional work and monitoring to be considered

A Confirmation and Refinement of Predictions

None.

B Post-operational Monitoring

Periodic (about every 10 years) bathymetric survey of disposal area.

C Ecological Quality Standards Compliance

None.

6. SUMMARY AND RECOMMENDATIONS

The DMDMTT has developed a protocol for defining the monitoring of marine dredging and disposal. This has included the development of a transparent mechanism to determine in a logical and reasoned way whether there is a requirement for monitoring, the components to be monitored, and additionally provides information on the choice of suitable monitoring methods. The protocol provides guidance to licensors and licensees, and other stakeholders on monitoring programmes appropriate to the individual activity. It requires that the programme should be scientifically, technically and legislatively defensible, cost effective, and should provide sufficient information to evaluate the impact of the activity.

A key recommendation is the sharing of good practice between legislators and practitioners, and that data should be of an acceptable quality for both the evaluation of the activity and the sharing of information nationally and internationally.

Recommendations for monitoring.
Monitoring must be:
- Proportional to the problem and linked to an assessment of the effects;
- Case and site specific;
- Based on the DMDMTT framework.

Recommendations to Statutory and Competent Authorities.
Authorities should:
- Encourage use of the DMDMTT framework for setting monitoring requirements;
- Ensure reporting of monitoring data for feedback into the assessment processes.

Recommendations for MPMMG (UK Authorities) to consider for further action:
- Continued development of EcoQO for dredging and disposal areas and development of Performance Indicators for dredging and disposal activity;
- Review and develop standard protocols to ensure the provision of data of an appropriate scientific quality and comparability to national and international standards;
- Ensure quality assurance of methods used by monitoring practitioners through membership of schemes such as The National Marine Biological Analytical Quality Control Scheme (NMBAQC), Quality Assurance Laboratory Performance Studies for Environmental Measurements in Marine Samples QUASIMEME and Biological Effects Quality Assurance in Monitoring Programmes (BEQUALM);
- Share good practice through proactive supply of monitoring information into the marine environment community.

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ANNEX I. TERMS OF REFERENCE OF DREDGING AND DREDGED MATERIAL DISPOSAL MONITORING TASK TEAM

1. Review the potential impacts of dredged material disposal against the objectives set by GCSDM for the quality of areas used for dredged material disposal.

2. Propose guidelines for the methods to be used for monitoring such areas.

3. Propose standards by which the meeting of objectives can be assessed taking due account of the nature of the receiving area and the different types of dredged material likely to be involved.

4. Advise on situations where monitoring may or may not be required and as appropriate suggest minimum frequencies of monitoring for the assessment of compliance with the defined objectives and standards.

5. Time meetings in advance of meetings of GCSDM and report to GCSDM on progress with these tasks.

A subsequent addition to the Terms of Reference was the consideration of monitoring at the dredging site.

ANNEX II. MEMBERSHIP

Mr J Breen	Industrial Research & Technology Unit
Mr M Dearnley	H R Wallingford Ltd
Dr M Elliott	The University of Hull
Dr L Murray	The Centre for Environment, Fisheries & Aquaculture Science
Mr M Pearson	Tees & Hartlepool Port Authority Ltd
Mr I Rees	University of Bangor
Dr J Riddell	University of Strathclyde
Mr P Whitehead	Marine Environmental Research Ltd
Mr P Elliott	NI Environment and Heritage Service
Mr J Mckie	Fisheries Research Services, Marine Laboratory