ME1104 Research and Support for Developing a UK Strategy for Managing Contaminated Sediments: An Analysis of Project Findings

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Report for
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RESEARCH AND SUPPORT FOR DEVELOPING A UK STRATEGY FOR MANAGING CONTAMINATED SEDIMENTS: AN ANALYSIS OF PROJECT FINDINGS

EXECUTIVE SUMMARY

Study Background

Effective, long-term management of contaminated marine sediments (dredge material) is fundamental to ensuring UK ports continue to operate and that their activities are sustainable and not detrimental to the environment. In 2006, Defra completed an internal review of the current situation regarding contaminated marine sediments. It identified that there is a lack of information on the extent of contaminated marine sediments in UK waters, and that clarity was required on the current options for the dredging and disposal of contaminated marine sediment, as well as on related liability and legislation issues. At that time there was no comprehensive guidance in place to help government (and industry) address the issue nor was there clarity on various legal, regulatory, technical and socio-economic aspects related to management of contaminated marine sediments. The present study (ME1104: Research and Support for Developing a UK Strategy for Managing Contaminated Sediments) was conducted to address these issues in order to support development of a strategy for managing contaminated dredge material.

The research was delivered through a series of six commissioned work packages, or Tasks, each of which is available as a separate report. The Tasks were:

- Task 1 Characterising the Issue and Delivering a National Database of Contaminated Marine Sediments in UK Waters.
- Task 2 Exploring Liability and the Polluter Pays Principle.
- Task 3 Identifying Existing Relevant Legislative and Regulatory Barriers, and Guidelines and Protocols with respect to contaminated dredge material.
- Task 4 Establishing Best Practice for the Prevention of Pollution arising from contaminated dredge material.
- Task 5 Establishing Best Practice for Current Disposal and Treatment Options for contaminated dredge material.
- Task 6 Identify relevant marine sediment research and development relevant to the management of contaminated dredge material.

This report comprises a summary of the principal findings from ME1104.
Key Findings

Section 4 of the report presents the data collated within a national database of contaminated marine sediments (metals, TBT) in UK waters developed in Task 1 using a variety of data sources. An overview of the extent of contamination (in relation to contaminated dredge material management) in seabed sediments for the major industrialised England-Wales ports/estuaries is presented (the Humber, Severn, Thames, Mersey, Tyne, Tees, and Fal). A set of examples and a Case Study from the Fal estuary are given to illustrate the range of GIS tools which allow for data to be visualised temporally and spatially, and for generation of statistics, for coastal and estuarine regions.

Some issues of database maintenance and end user access are still to be determined. It was recognised by the project that data including CDM volume (and clean DM volume) and licence application reference were not available, and future integration of these will substantially increase the generic utility of the database. A proposal is made to derive a process, or protocol, to capture/summarise regional information within the database to aid management of future (individual) licence applications.

The major findings are as follows. Contamination due to (multiple) metals is prevalent to a greater or lesser extent in all the major industrialised estuaries in the UK. For many estuaries (with possibly the exception of the Thames estuary) concentrations for many metal species lie between the two CEFAS Action Levels. The chief contaminants driving concentrations in this category include Cr (Forth), Cr and Ni (Humber), Cu, Zn and Pb (outer Clyde/Gare Loch, Tyne, Tees, Humber), Cd and Hg (Tyne, Tees) and Cr/As (Tees, Humber). For these estuaries, further evaluation may be required by the FEPA regulator in order to judge suitable disposal options for many licence applications. Broad-scale spatial trends in the level of contamination are found in some estuaries e.g. in the Mersey the north shore is measurably more contaminated than the south shore. High concentrations of metals (and TBT) i.e. at levels thought sufficient to potentially cause environmental impacts if disposed of at sea are found predominantly at inshore berth and dock areas. Different contaminant species are found in different estuaries (e.g. numerous Zn hotspots are found in the Tyne; Ni/Pb/Zn are found at Goole [Humber estuary]; As in the Fal; Hg in the Forth)). For these areas the FEPA regulator will likely not licence disposal to sea, which may impose additional complexity and potentially additional cost to dredging projects.

TBT is a contaminant species that is found nationally around the England-Wales coast. 85% of samples contain low concentrations of TBT (<0.1 mg kg\(^{-1}\)) which are of no environmental concern. The data indicate that, all other things being equal, sea disposal of TBT contaminated sediments may be an option for the majority of future dredge applications for many but not all estuaries. 3-13% of samples exhibit concentrations where sea disposal may not be permitted without further evaluation. Localised (hotspot) areas occur in the Severn ports (especially Swansea), and the Tyne, Tees and Fal estuaries. In all estuaries, the TBT occurs in hotspots (e.g. close to industrialised dock areas, berths etc.). The widespread occurrence of metal/TBT contamination in estuarine sediments around the UK indicates that there may be scope for sharing a management solution between various port authorities, notwithstanding constraints imposed by different sediment characteristics.

Section 5 of the report summarises the legislative background to CDM management in the UK and describes the differing processes currently in operation for the management of contaminated dredge material (CDM) at sea and on land. An evaluation of these leads towards an overall (joint) framework that seeks to bring together the sea and land frameworks together. Consideration of the processes within the joint framework have highlighted a number of uncertainties associated with both the land and sea...
regimes and their interaction, but that relatively few specific legal barriers have been identified. The main issues identified relate to:

- Uncertainties relating to the interpretation of EC Directives in relation to the evaluation framework for sea disposal;
- Uncertainties relating to the criteria and policies to be applied for re-use, recycling and recovery of CDM on land;
- Clarification of whether controlled waste under the waste management regime on land can be disposed of at sea and how the chain of custody might be completed;
- Interpretation of the provisions of the OSPAR and London Conventions on the classification of marine sediments that have been treated to reduce contaminant concentrations.

The study recommends that interpretations and clarifications of the provisions under OSPAR, the London Conventions and the revised Waste Framework Directive are sought in relation to each of these issues, and that the foundation for these uncertainties i.e. whether they are grounded within perception, (inconsistent) interpretation nationally and internationally, or policy or regulatory areas, is identified. For many this will require activity at a higher (political) level.

Section 6 of the report examines the chief issues associated with historic and contemporary sources of contamination to estuarine areas as well as contamination arising from the management and handling of CDM. It also examines the costs of managing, moving and disposing of CDM and liability/polluter pays principle issues that arise during these processes.

Source Issues:- The sustainable maintenance of ports and waterways must consider the assessment and control of historical and ongoing sources of contaminants to marine sediments and this is a fundamental tenet of the London/OSPAR Conventions.

In order to determine best practices that will lead to source control with respect to sediments becoming contaminated there is a need to identify the sources and pathways within estuarine systems, which have the potential to lead to contaminated marine sediment. ‘Pathways’ of contaminants from their source to a target or location under consideration can be described as ‘upstream’ and ‘downstream’. An upstream pathway is one by which contaminants can move from any identified source, through the marine system to the location where sediment needs to be dredged. Although the study finds that the UK already has sufficient legislation in place to control the input of many contaminants into a water body and to control their potential to cause pollution through various assessments, licences and consents, the manifold pathways for sediment-associated contaminants means that at times it is difficult to predict or to trace contamination movement. Task 4 provided a conceptual approach to upstream pathway identification for contaminated sediment, in conjunction with a review of various practical preventive measures, which may be useful to Defra and its associates on both a generic and a practical level.

A downstream pathway is one in which CMS disturbed results in the further transport or release of contaminants. Downstream pathways introduced by operational management have the potential to introduce new risks, control and/or monitoring obligations and contingent liabilities (see below). Task 4 also provided a conceptual framework for the assessment and control of downstream sources generated by CDM management and considered in depth the management practices that might be imposed to
ensure that dredge disturbance and relocation activities do not cause pollution to the water body in question.

Cost and Liability Issues:— As operational management costs for managing CDM have increased and are likely to go on increasing significantly in the future, more focus has fallen upon the question of who should be responsible for paying for these costs as well as who should bear the risks associated with the management of CDM. The increased operational management costs for managing DM affected by historic pollution has led to the question of how the Polluter Pays Principle (PPP) should be applied and whether transferring those costs and any associated liabilities to those ‘responsible’ for causing the presence of contaminants within CMS in the first place can be justified. The study finds:

- There are no general answers to questions relating to the recovery and transfer of costs (and liabilities) incurred as a result of operational dredging activities to those who were responsible for historic contamination;

- Individual cases will present specific legal and practical challenges to establishing such liability;

- The prospective nature of the Environmental Liability Directive (2004/35/EC) and implementation regulations mean that it cannot be retrospectively applied to historic contamination sources, and the nature of the liability under the Directive/Regulations is such that it would not normally cover the general operational management costs;

- The PPP cannot impose liability in the absence of specific legal liability regimes to implement it;

- Whilst the PPP could be applied to persons who create environmental risks (‘contingent liabilities’) during operational management activities in port etc. regions, there may be significant legal and practical obstacles to actually securing compensation even where requirements for establishing liability under a specific legal liability regime can be met;

- A range of structures and techniques are available for the management of contingent liabilities in order to allocate and address legal risks, and

- Ownership of CMS sites, and disposal sites, can form the basis for some types of legal liability, but will but will not usually be the case when dredging is for capital or maintenance (rather than remedial) purposes.

Section 7 of the report presents an outline of the various treatment and disposal options accessible currently within the UK, together with a discussion on the selection of management options.

A technical review of known treatment options indicates that the major techniques are found in the UK on a commercial basis, and the capability exists to process the chief contaminants of concern (TBT, metals, organics). However, there remains uncertainty about the precise level of experience in relation specifically to CDM, and this points to a need for a critical review of the experience and commercial availability of CDM processing technologies in the UK. The choice of treatment of CDM depends upon the class of contaminant, the degree of contamination, the desired end use for clean sediment and the availability of space and infrastructure as well as economic factors. It is often the case that CDMS will contain more than one class of contaminant and its treatment can involve one or more of the technologies. However, some of the treatments described are only viable for one contaminant class and
certain technologies are only applicable to sediments with certain grain size and water content. It was found that treatment costs can be very case-specific, and that economies of scale were important. In the management process every effort is made to reduce the CDM volume, and yet the commercial sector operates (in the main) most effectively on larger volumes; the prospect therefore exists that in trying to reduce the CDM volume certain treatment options may become uneconomic. An holistic approach is necessary to evaluate the range of treatment options. The study finds routes for the (beneficial) re-use and recycling of DM on land, but clarification is sought in this area on the point at which CDM is recovered from the waste stream, the definition of ‘non-hazardous’ for CDM in relation to various treatment approaches (including potential uses of cleaned’ DM), and on the potential for the use of treated CDM in the sea.

Categories of dredge material disposal include unconfined ocean disposal, relocation or beneficial re-use (if not CDM), (pre-) treatment/processing (followed by re-use, recycling or disposal) and a range of controlled disposal options (often following pre-treatment or treatment). Some disposal options (e.g. CAD cells, geotextile bags) have to date not yet used within the UK but these have been included in the review as they are deemed promising (and legal) approaches. Selection of a specific disposal option is a complex function of project-specific and regulatory criteria, and will continue to be considered on a case-by-case basis.

One of the chief issues associated with disposal of lightly to moderately contaminated DM in the sea are the uncertainties concerning the long-term efficacy of these approaches and the need for an evaluation of potential contingent liabilities. Future exploitation of as yet untried disposal options (e.g. CAD cells, geotextile bags) must necessarily proceed in tandem an evaluation of all risk pathways (through time) and development of appropriate monitoring frameworks.

This study considered the selection of appropriate management strategies for CDM, and has identified and characterised a number of potential decision parameters that can be used in CDM management option selection (including technical issues, upstream source, project volume and frequency, technology cost, maturity and availability, downstream exposure pathways and contingent liabilities, the Waste Hierarchy, other social and sustainability factors). Transparent decision frameworks should be designed to allow for the consistent evaluation of these factors, but project-specific evaluation of decision criteria are required to inform management strategy selection. Clear ranking factors can help identify trade-offs that can be weighted and communicated. Ultimately, such approaches can at least identify a short list of options that can be taken further before selection.

Section 8 of the report presents an assessment of potential research activities that would support development of a strategy to manage CDM in the UK. Three themes emerged during this course of this assessment:

- Multidisciplinary research to understand links between sediment contamination and its actual risk;
- A need to address new contaminants and constantly review target compounds; and
- Evaluation of treatment, land-based and at sea disposal methods (both mature and innovative) through pilot and field studies.

These recommendations can also be supplemented by the following, based upon a review of other task outputs:
• There is the need for monitoring frameworks for various containment strategies, possibly based upon those developed for UK marine disposal sites.

• There is the need for a comprehensive review of UK CDM remediation capability, technically and commercially.

• Further development of the project GIS database to include CDM volume (and clean DM volume) for projects, licence application reference and grain size data.
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The authors of this report gratefully acknowledge the assistance of Judy McKay and Juliet Breuer in preparation of this report. We also thank the contribution of various UK remediation contractors who provided information in relation to the current national CDM remediation capability, and comments from the Executive Steering Committee and Steering group membership.
1. INTRODUCTION

1.1 General Context

It is UK Government policy to promote the use of the sea for the transport of goods around the UK and also to encourage a modal shift from road to water. There is an increasing demand for port capacity and the UK’s success in the global market place depends, in part, upon the ability of ports to adapt and operate efficiently as gateways to international trade (DfT, 2007). There is, therefore, a fundamental need to ensure ports continue to operate and that their activities are sustainable and not detrimental to the environment. Because ports tend to be in coastal areas and estuaries that can be depositional sedimentary environments, and because safe navigation requires the maintenance and/or deepening of navigational areas, sustainable port activities require that both maintenance and capital dredging are carried out.

Maintenance dredging is the ongoing or periodic removal of sediment that has accumulated in navigation channels or berth boxes over a period of time and is undertaken to maintain previously achieved navigation depths. As maintenance dredging is the removal of recently accumulated material it consists mostly of silt, which may at times be contaminated, if there are ongoing sources of contaminants to the area. Capital dredging refers to projects for which berth pockets or channels need to be deepened or where new port developments require dredging. Therefore, capital dredging has the potential to encounter sediments which may have been impacted by historical contamination.

Because many bays, harbours and coastal areas are located near industrial and urban areas, sediments often contain chemical substances from these sources. Whilst sediments can sequester contaminants, limiting their (bio)availability, changes in physical, biological and geochemical conditions during sediment removal, transport and re-use can result in contaminant releases and changes in chemical availability. These changes can result in potential risks from natural and anthropogenic components such as metals, organics and nutrients; unless properly managed, these may adversely affect water quality and aquatic or terrestrial organisms (and potentially humans). A significant amount of work has previously been undertaken, in the UK and elsewhere, on the risks of in-water and upland disposal of dredged materials under various conditions. However, uncertainties regarding policies such as the designation of these materials as wastes, regardless of risk, can limit the sustainable use of materials. There is thus a need to develop a consistent, transparent and effective management approach to dredging and disposal of contaminated seabed sediments in port regions in which a balance can be found between sustainable economic development and environmental protection.

Dredged material is usually either disposed of at sea (in open marine disposal sites subject to chemical and biological screening criteria) or, when contaminant levels are too high, transported and disposed of in landfills. To date, there has been limited investigation into the treatment, disposal or beneficial use of contaminated dredged sediment in the UK, and other than the Oslo Paris Convention (OSPAR) and London Protocol Guidelines there is no formal sediment management framework that details the procedures for the beneficial use, treatment, or disposal of contaminated marine sediment.
2. PROJECT BACKGROUND

In 2006, Defra completed an internal review of the current situation regarding contaminated marine sediments. It identified that there is a lack of information on the extent of contaminated marine sediments in UK waters, and that clarity was required on the current options for the dredging and disposal of CDM, as well as on related liability and legislation issues. There is currently no comprehensive guidance in place to help government and industry address the CDM issue nor is the legal, regulatory, technical and socio-economic information on this topic available through a common portal.

In May 2006, as part of a Defra initiative, a Contaminated Marine Sediment Steering Group, comprising representatives from CEFAS, Natural England, the Welsh Assembly, the Scottish Executive, The Crown Estate, representatives from industry including port authorities (ABP, BPA, PLA), conservation agencies and green NGOs (e.g. CCW, JNCC, MCS) was set up. The aim of this group was to discuss and formulate a programme of research work to underpin a comprehensive guidance document (‘strategy’) for managing contaminated dredged marine sediments in the UK. The specific Terms of Reference for this group was;

‘to assist and facilitate the development of the UK strategy for handling and managing contaminated material to be dredged from UK marine waters, and to support and advise on the practical implementation of the strategy’.

Extensive consideration of the principal issues gave rise to a research framework comprising 6 work packages (Tasks) that commenced on 1st April, 2007.

2.1 Project Scope

This project was conceived within several highly specific terms-of-reference. These are that:

- the sediment is contaminated (although the severity of contamination is not known); and
- a decision to dredge has already been made;
- minor revisions to existing legislative statutes can be entertained;
- all UK waters and thus potentially out to 200 nautical miles (and inland as far as tidal limits) are considered.

These terms indicate that the research is directed specifically to the issues associated with the management and handling of contaminated sediments after a decision to dredge has been made, but its findings are relevant to project preparation (by the developer) and to the evaluating and permitting stages by the regulator.
2.2 Overarching Project Objectives

Specific project objectives in relation to each of the individual project tasks were not formulated by the designers of the project. Rather, a set of overarching policy-led objectives were developed which relate to the development and implementation of a strategy for managing contaminated dredge material. These are:

1. Aid in the transparent and objective assessment of all dredged material disposal options through the Best Practicable Environmental Option (BPEO) assessment process, taking into consideration the principles of sustainable development (including the polluter pays principle and the precautionary principle) on a case by case basis.

2. Take into account the scale, extent, implications and impacts of dredged CMS on the marine environment.

3. Act as a focus for existing work, draw together best practice and ensure work is not duplicated elsewhere e.g. The London and Oslo Paris (OSPAR) Conventions, World Association of Waterborne Transport and Infrastructure (PIANC), Central Dredging Association (CEDA) etc.

4. Produce a simultaneous and inclusive consultation process to replace the current methodology of approaching one regulator at a time in order to make disposal solution decisions.

5. Identify where regulations are preventing the BPEO from being used and reflect the associated risks to the marine environment these represent. Examples where flexibility in regulations allows the common sense approach to prevail will be highlighted.

6. Define the nationwide scale of the problem and disposal solutions at sea as well as beneficial use, identify current sea disposal sites receiving contaminated, but acceptable, material and suggest guidance for their use, identify remedial measures for material deemed acceptable for sea disposal and establish guidelines for preventing further contamination.

The project contributes towards objectives 1, 2, 5, and 6 but not to objectives 3 and 4.
2.3 Project Tasks

The research was delivered through a series of six commissioned work packages, or Tasks. These were let through a competitive tendering process. The project co-ordination was also let via the same process and was awarded to Partrac Ltd (Glasgow). Table 1 summarises the six tasks.

Table 1 Summary of the six commissioned work packages within the project.

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Final reports (and additional project outputs) for each of these Tasks are available separately to this report. Final reports (and additional project outputs) for each of these Tasks are available separately to this report².


3. REPORT SCOPE

The vast majority of DM disposal applications in the UK are approved for unconfined marine disposal. However, if sediments are deemed to pose a risk if disposed of at sea, the situation is much more complex. Due to the potential risks posed by the removal, transport, management and disposal of contaminated dredged material (CDM), these operations are much more tightly controlled and regulated. In such cases, as a result of increased regulation and other requirements, there are increased operational costs of managing, moving and disposing of CDM, regardless of who was originally responsible for the contamination that is in the CDM. However, the management of contaminated dredged material is further complicated by the fact that the process of removing, transporting, treating and disposing of CDM has the potential to introduce new pathways of contaminant release, transport and exposure, all of which must be managed and can themselves result in new costs, risks and potential, ‘contingent’ liabilities. Thus, the small fraction of DM disposal applications that involve CDM have the potential of being much more costly, uncertain and complex, and as yet there is no consistent management framework within England (and the wider UK) for assessing and managing CDM.

This document summarises a number of the principal regulatory, legal, technical and scientific issues investigated by the individual project Tasks (Table 1) that must be combined in order to address this situation. It should be noted that this report is being written at a time of legislative and organisational change within government (i.e. the new Marine and Coastal Access Act (2009) and secondary legislation will bring in a new consolidated licensing regime with a target date of early 2011 which will replace FEPA and a new Marine Management Organisation (MMO) will replace the Marine Fisheries Agency from April, 2010). Every effort has been taken to reflect the general implications of future changes. The decision framework Defra is currently formulating for the management of CDM will be adopted in England by the Marine Management Organisation and by the Welsh Assembly government. The devolved administrations in Scotland and Northern Ireland may choose to adopt the framework.

3.1 Definition of ‘Contaminated Marine Sediment’ and ‘Contaminated Dredged Material’

Clear definitions of terms such as ‘contaminant’, ‘pollution’, ‘contaminated marine sediment’ and ‘contaminated dredged material’ are fundamental to the development of a framework strategy to determine best practice in the management of contaminated sediments and dredged material.

Marine sediment (MS) can be defined as soils, sand, organic matter or minerals present on the bottom of the sea (or an estuary). Dredged marine sediment (DMS) or dredged material (DM), on the other hand are defined, for the purposes of this report, as marine sediment that is being considered for dredging, or has been dredged, for navigation or construction (but not for remedial) purposes. Whilst DM is sediment, not all sediment is DM.

Contamination (in sediments) is defined as the presence of a substance where it should not be or at concentrations above background, whilst pollution is contamination that results in or can result in adverse biological effects to resident communities (Chapman, 2007). The 1996 Protocol to the London Convention, Article 1, paragraph 10 states that pollution:

"...means the introduction, directly or indirectly, by human activity, of wastes or other matter into the sea which results or is likely to result in such deleterious effects as harm to living resources and marine ecosystems.

3 Note that dredge material can include rock, often dredged by cutter suction or bucket ladder dredgers, but that this is rarely contaminated.
hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of seawater and reduction of amenities’.

Thus, whilst all pollutants are contaminants, not all contaminants are pollutants. Sediments may contain various levels of a number of contaminants, but differentiating pollution from contamination cannot be done solely on the basis of chemical analyses because such analyses provide no information on bioavailability or on toxicity (Chapman, op cit.). Definitive determination of whether contaminants at given levels in a specific sediment pose risks to ecological and/or human health requires a weight of evidence assessment using various lines of evidence addressing links between a sediment and receptors of concern within the context of a regulatory, policy or management framework. A determination of risk is dependent upon the identification of endpoints of concern, exposure scenarios envisioned, desired level of protection and uncertainty tolerance. Thus, although informed by science, risk assessment is also inextricably tied to management or policy decisions.

Whilst there are millions of chemicals that can potentially be found in the environment, not all can be analysed for. Thus, various regulatory programmes lay out lists of substances that should be analysed for. Potentially contaminating substances in the marine environment that are currently examined are listed in:

- OSPAR Convention Guidelines For The Management of Dredged Material (2004), where substances are divided into:
  - Primary Contaminant List; and
  - Secondary Contaminant List


There can be no absolute definition of contaminated marine sediment (CMS) (USEPA, 1998; Simpson et al., 2005); the definition differs as a function of context. However, the above discussion makes clear that sediment can contain a range of contaminants without raising regulatory concern. In general, sediment is deemed to be of concern if contaminant levels are causing pollution (potential impact). Whilst there is ongoing work within the context of the Water Framework Directive to assess the chemical status of waters, and in some cases, sediments and associated biota, these designations are outside the context of this project, which focuses on the management of dredged marine sediment. In spite of the above discussion, the term contaminated sediment, rather than polluted sediment is used to imply not just the presence of contaminants, but also their potential risk, and thus contaminated marine sediment (CMS) can be defined, for the purposes of this report as:

‘sediment (soils, sand, organic matter or minerals) present on the bottom of the sea (or estuary) that contains one or more chemicals at concentrations that are above background, exceed an environmental quality standard or guideline and may pose an adverse threat to the environment or to human health.’

Within the context of this project, the objective is to develop frameworks for the management of contaminated dredged marine sediment. Thus, the designation of ‘contaminated’ must be within the context of dredged material (DM) assessment and management. Within the context of the indicative decision-making framework, based upon the OSPAR/London Convention, proposed DM is characterised and evaluated in terms of the question ‘Is the material likely to be acceptable for sea disposal?’ The basis and context of this analysis is described in greater detail in Section 4, but contaminated dredged material (CDM) can be defined, in the context of this project, as:
"a sediment being evaluated for a DM disposal permit, for which initial evaluation indicates that sea disposal is unlikely to be acceptable unless some modification to the disposal method/location and/or contaminant concentrations/loadings is made."

Whilst a more detailed evaluation of a given sediment can remove the CDM designation from a sediment, it can also confirm it. Then, within the framework of the OSPAR/London Convention (see Fig. 6; left panel), if the answer to the question ‘can the material made suitable for sea disposal’ (Box 4) is ‘no’, the proposed DM is designated CDM, the marine sediment is considered contaminated marine sediment (CMS), and the dredging, transport and disposal of the DM may require special technical, legal and regulatory evaluation and/or measures which are the subject of this report.
3.2 Definition of CDM in a UK context: The UK Licensing Pathway

The OSPAR Convention has developed 'Guidelines for the Management of Dredge Material', that have been revised periodically to provide the context within which the evaluation of the suitability of dredged material for disposal at sea is carried out within the UK. This procedure is implemented via the UK Licensing Pathway (Figure 1). More details of the licensing pathway may be found in Defra (2006).
Figure 1: The UK licensing pathway. Note the DfT and MoD are not consultees on every licence application. Source: ABPmer (2009b) (Task 3).
3.2.1 Cefas Approach for Sediment Assessment

In the UK, construction activities affecting the seabed or deposits of dredged material are regulated by the Part II of the Food and Environment Protection Act (1985) as amended (FEPA). The assessment process required for FEPA contains an Environmental Impact Assessment (EIA) screening and scoping procedure as well as an assessment of the contaminant status of the material to be disturbed or deposited. This process uses the OSPAR Guidelines as a base. As part of this licensing assessment to determine the suitability of the material to be deposited in the particular water body there is a requirement to assess contaminant levels in sediment.

The purpose of this assessment is to prevent marine pollution and to ensure that disposal of DM at sea does not adversely affect the surrounding environment or interfere with other legitimate uses of the sea. In terms of the OSPAR and London Conventions, there are a number of terms of relevance to the assessment of DM for marine disposal:

- A characteristic is an attribute of the dredged material (e.g., copper, mercury, silt, petroleum compounds, pathogens) or a biological response to the dredged material (e.g., mortality, growth, bioaccumulation).
- A metric is a measurement that can be made on the characteristic (e.g., concentration, percent survival).
- A benchmark is a point on the range of the metric (e.g., 4 mg kg\(^{-1}\) copper, 20% amphipod mortality) that is used to identify where environmental concern may be low or high for that characteristic. These can be referred to as the lower benchmark and upper benchmark.
- An Action List comprises a number of characteristics to be considered for measurement in the dredged material.
- An Action Level is a decision guideline based on the findings of one or more characteristics in comparison to the respective benchmarks.

If a decision guideline is based solely on chemical levels, benchmarks can form the basis of Action Levels. In other cases, rules may be based on chemical benchmarks and other lines of evidence, either in a clearly prescribed manner or on a case-by-case basis.

The licensing assessment method used by Cefas, as the Regulatory advisor to the Marine and Fisheries Agency (MFA), uses a risk-based weight of evidence approach based on a number of lines of evidence to assess the suitability of DM for disposal at sea. The results of contaminant analysis are used in conjunction with other assessment methods (for example bioassays) as well as historical data and expert knowledge regarding the site, to make a decision regarding the fate of the dredged material following disposal or disturbance. This integrated approach balances multiple lines of evidence concerning ecological assessment as an aid to decision making (OSPAR, 2004b).

In England and Wales, Cefas uses a procedure based on two geochemical benchmarks (which are called Action Levels in the UK) for (at a minimum) the contaminants listed in the OSPAR Guidelines to assess dredged material and its suitability for disposal at sea. The UK Cefas benchmarks, or ALs, summarised in Table 2, have been set, based on monitoring and evaluation of environmental effects at historical disposal sites, as well as on bioassay tests, along with comparisons of equivalent systems and levels used in other countries. In addition, CEFAS (2005) provides a framework for taking into account regional levels of naturally high metal concentrations when comparing DM to Action Levels. Within Scotland and Northern Ireland, Marine Scotland and the Northern Ireland Environment Agency both test for the same suite of contaminants and use the same actions levels described for England and Wales.
Table 2 Action Levels used by Cefas in the evaluation of proposed DM (mg kg⁻¹ dry weight). Source Cefas (2003).

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Action Level 1</th>
<th>Action Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>Chromium</td>
<td>40</td>
<td>400</td>
</tr>
<tr>
<td>Copper</td>
<td>40</td>
<td>400</td>
</tr>
<tr>
<td>Lead</td>
<td>50</td>
<td>500</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>Nickel</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>Zinc</td>
<td>130</td>
<td>800</td>
</tr>
<tr>
<td>Di-Butyl-Tin</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Tri-Butyl-Tin</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>PCBs, sum of ICES 7</td>
<td>0.01</td>
<td>-</td>
</tr>
<tr>
<td>PCBs, sum of 25 congeners</td>
<td>0.02</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Cefas do not routinely test for the whole suite of contaminants. The set of contaminants to be examined is determined on a case by case basis, consistent with the OSPAR Guidelines, depending on a number of factors which can include:

- type of material (in terms of composition and disturbance history);
- historical knowledge of the usage of the area;
- background contamination levels; and
- previous analytical results and potential sources of current contamination.

In England and Wales (and within the UK as a whole) these ALs are not designated as standards in the legislation, therefore they do not constitute ‘pass/fail’ thresholds but are used as one line of evidence in a weight of evidence approach. In general, however, contaminant concentrations in dredged material below AL1 are considered to be of no ecological concern and thus sediments below these levels are not considered to be CMS. Sediments to be disposed of or disturbed that have contaminant concentrations above AL2 are (generally) considered ‘contaminated’ and to be unsuitable for unconfined sea disposal. They will most likely require treatment and/or containment at some stage. Material with contaminant concentrations between AL1 and AL2, which may qualitatively be referred to as lightly-moderately CMS, are likely to be subjected to analysis considering further lines of evidence to reduce uncertainty about whether contaminant levels are posing risk. A weight of evidence assessment may determine that the contaminants do not pose a risk, and then sediments may be deemed to be suitable for marine disposal, or they may be determined to be CDM, and thus unsuitable for marine disposal without some management or treatment.
4. THE EXTENT OF CONTAMINATION IN THE UK: POTENTIAL IMPLICATIONS FOR DM MANAGEMENT

4.1 Introduction

Chemicals within estuarine waters arise from a variety of sources. The main types are a) naturally occurring constituents (e.g. minerals including metals which occur through natural geological sources), b) anthropogenic point source emissions and discharges originating from factories, workshops, large industrial installations, transportation spills, abandoned mines and their spoil tips and sewage treatment works, and c) anthropogenic diffuse sources, which originate from agriculture, households, amenity use, transport, run-off from roads, and the use of products containing the chemicals (e.g. copper and lead piping, galvanised products, fuel combustion). Diffuse and point sources can also come from reservoirs of contaminants that have built up over the years in water bodies (surface and groundwater), sediments and soil as a result of historic contamination.

Whilst the remit of this study was to encompass all UK waters to 200 nmi, the management consequences of contamination are most important in estuarine, coastal and port environments. Therefore, the focus of this review is on the industrialised estuaries of England, Scotland and Wales, namely: the estuaries of the Humber, Severn, Thames, Mersey, Tyne, Tees, Fal, Forth and Clyde. The review aims to summarise the distribution of contamination in these estuaries, with an emphasis on data and knowledge gaps that may be relevant to the future management of CDM in these locations. The aim is also to demonstrate how the GIS, and associated query tools developed within Task 1 (ABPmer, 2009a), can be used to visualise data and generate statistics. A Case Study using the Fal estuary is presented to illustrate these.

4.2 The Broad Picture

This project has collated and organised data from a variety of sources (all UK-wide FEPA-licensing related data plus data from MEDIN, ABPmer projects, ICES, and NSB) from 1995 to 2007 within a GIS (ABPmer, 2009a; Task 1). Whilst the GIS database contains a large quantity of data on contamination in seabed sediments, these data in isolation do not provide information on the more general distribution of contamination in estuarine sediments. This is because many of the samples are from localised, mostly inshore areas (i.e. areas where dredging may be required) rather than in the wider estuary. The database, for example, does not show the high concentrations (>100 mg kg\(^{-1}\)) of zinc and copper in bottom sediments at the mouth of the Tyne estuary and extending southwards in a plume along the coast to the Tees estuary (Stevenson et al., 1995). The GIS database, therefore, cannot and should not be used to draw together a detailed overview of the nature and extent of contamination on an estuary-wide, national basis. This would involve integration of many datasets from differing sources, including data sets held by BGS, Cefas, POL and Defra.

This study has identified several datasets which would be useful in drawing together a national picture. These include:

- Stevenson et al. (1995)— an atlas of the most current spatial inventory (30,000 samples) of the concentration of a range of chemical species in UK seabed sediments (North Sea and Scotland only).

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4 The major estuary in Northern Ireland is the Lagan, which flows through Dublin. However, there are no samples from this estuary in the database and therefore it is not included in this synthesis.

• Defra Charting Progress 1 (Chapter 3 Hazardous Substances):— this is a national integrated assessment of the state of UK seas undertaken by Defra/WAG/SE called the UK Clean Seas Environmental Monitoring Programme (CSEMP). The programme fulfils the UK’s commitment to European directives including its mandatory monitoring requirements under the Oslo and Paris Convention (OSPAR) Joint Assessment Monitoring Programme (JAMP).

Figure 2 is presented to illustrate the difference that an analysis based solely upon the Task 1 GIS database archive and one that included these additional datasets (in this example the CSEMP data) can make. These datasets have been created for different purposes, and there are there are specific technical issues that need to be considered in combining datasets (including the analytical methodology used and the grain size fraction tested). Nonetheless, because a synthesis of this nature would integrate data from many more sampling locations in estuaries, a more coherent picture of the distribution of contamination would result and government would be in a stronger position to evaluate licensing dredging of new seabed areas.

Formerly the National Marine Monitoring Programme (NMMP).
Figure 2 Sample locations from the Severn estuary from the CSEMP (top panel, purple dots) and Task 1 GIS (bottom panel, black dots) illustrating, respectively, more general and highly localised sampling.
4.3 Contamination in Estuaries

4.3.1 Introduction

The objective of this section is to present a summary overview of the contamination levels in estuaries of the Humber, Severn, Thames, Mersey, Tyne, Tees, Fal, Forth and Clyde using the data within the project GIS, and to highlight the principal DM management consequences. The database does not contain data on PCBs and PAHs and therefore discussion is limited to metals and TBT/DBT only.

Table 3 summarises the numbers of sediment samples for each river/estuary over the period 1999-2008 for which the overview of contamination levels are based. For some estuaries e.g. the Severn and Tyne the data density is high, whereas for others e.g. the Thames, the data density is low. Appendix 1 shows maps of sampled locations within these estuaries, and these show differences in data density clearly; in addition, it is immediately obvious (as mentioned previously) that the majority of samples are from areas close to the shore (e.g. Fig. 2 lower panel), and these correspond to maintained areas, in-dock approach channels, areas of sediment accretion etc., which are sampled for capital dredge projects. With the exception of the Medway Channel in the Thames (which reflects sampling for maintenance dredging purposes), estuary-wide data are very sparse. A description of available data therefore necessarily focuses on the inshore areas only.

Table 3 Summary of project GIS database contaminant data statistics from the major industrialised estuaries in England, Scotland and Wales. The Lagan estuary in Northern Ireland has been omitted due to a paucity of data. Data from 1995 have been omitted because of very few samples.

<table>
<thead>
<tr>
<th>Estuary</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humber</td>
<td>3</td>
<td>14</td>
<td>21</td>
<td>20</td>
<td>0</td>
<td>12</td>
<td>33</td>
<td>30</td>
<td>19</td>
<td>0</td>
<td>152</td>
</tr>
<tr>
<td>Severn</td>
<td>3</td>
<td>56</td>
<td>23</td>
<td>0</td>
<td>69</td>
<td>64</td>
<td>5</td>
<td>22</td>
<td>46</td>
<td>0</td>
<td>288</td>
</tr>
<tr>
<td>Thames</td>
<td>0</td>
<td>35</td>
<td>1</td>
<td>8</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>13</td>
<td>0</td>
<td>68</td>
</tr>
<tr>
<td>Mersey</td>
<td>0</td>
<td>21</td>
<td>23</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>37</td>
<td>47</td>
<td>0</td>
<td>0</td>
<td>145</td>
</tr>
<tr>
<td>Tyne</td>
<td>0</td>
<td>10</td>
<td>31</td>
<td>23</td>
<td>52</td>
<td>34</td>
<td>10</td>
<td>6</td>
<td>34</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Tees</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>67</td>
<td>38</td>
<td>32</td>
<td>19</td>
<td>24</td>
<td>0</td>
<td>183</td>
</tr>
<tr>
<td>Fal</td>
<td>0</td>
<td>0</td>
<td>16</td>
<td>17</td>
<td>0</td>
<td>38</td>
<td>5</td>
<td>19</td>
<td>0</td>
<td>0</td>
<td>95</td>
</tr>
<tr>
<td>Forth</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Clyde</td>
<td>6</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17</td>
</tr>
</tbody>
</table>

4.3.2 Description of Available Data (National Perspective)

The GIS is a powerful data manipulation tool with a wide range of data presentation methods. A broadscale (national) view of the level of contamination can be generated for each contaminant. As an example, Figure 3 shows all data for Pb plotted in relation to the Action Level 1 and 2 benchmarks. An important issue in representing data at this scale is that of resolution; the detail within estuaries and other coastal areas is not available, although a ‘zoom’ function in the database can zone in on specific areas. In addition, not all data points can be shown at this scale and there may be data values which are on top of each other, or within closely spaced sampling clusters which cannot be represented. However,

6 For brevity chemical symbols are used to represent contaminant species in the report as follows: Arsenic As, Cadmium Cd, Chromium Cr, Copper Cu, Mercury Hg, Nickel Ni, Lead Pb, Zinc Zn, TBT, DTB.
in terms of assessing the first order, nationwide distribution of a specific contaminant, and evaluating the relative proportion of samples that fall within the CEFAS Action Level categories, the GIS is a valuable tool.

The GIS can also be used to generate statistics. In this example for lead (Pb):

- 78.3% of the dredged material samples have contained <50 mg kg\(^{-1}\) Pb (the AL1 value; see Table 2);
- 20.1% of the dredged material samples have contained between 50 and 500 mg kg\(^{-1}\) Pb; and
- 0.6% of the dredged material samples have contained >500 mg kg\(^{-1}\) Pb.

These data can be used to judge the relative proportions of DM nationally which may be classified as generally acceptable for sea disposal, for which more detailed consideration is necessary, and the proportion which is contaminated and may therefore require specialised treatment/disposal options. The inference from both the graphic and statistical analysis is that whilst Pb contamination is widespread geographically around the UK coastline (not unexpected on account of the presence historically in petrol and other products), there is concern over the environmental impacts for only a very small number of samples/cases. This type of analysis can be repeated for the range of contaminants held within the database.
Figure 3 National (UK) map generated using the GIS showing the distribution of sediment lead concentration around the coast in relation to the CEFAS Action Level classification.
4.3.3 Description of Available Data (Individual Estuaries)

An inspection of the entire contaminant dataset for all years for each of the estuaries of interest provides a general survey of the distribution of contamination for the major industrialised estuaries within within the UK. Table 4 summarises all the data in terms of the proportion (%) of samples by estuary and by contaminant falling into various classes when compared to CEFAS Action Levels. This provides a relative, general basis that can be used to delineate the chief contaminants of concern in the different the Action Level categories for each estuary and to discern which estuaries/ports are more contaminated. The locations of the sampling points is given in Appendix I. The following section summarises the nature and extent of contamination for each of the estuaries.

Contamination due to metals is prevalent to a greater or lesser extent in all the major industrialised estuaries in the UK. In the Thames estuary most samples exhibit metal concentrations < Action Level 1 (including for TBT), except in the Rochester/Chatham tributary for Hg, Cr and Ni. The majority of samples arise from the area known as the Medway Channel (most probably sampled for maintenance dredging purposes), and thus the major area of the estuary is almost entirely unsampled. The low number of samples limits the inferences that can be made from the database, however the outer Thames, southern shore region of the estuary may, in general terms, be considered a dominantly uncontaminated sedimentary environment. However, the enclosed, marsh/estuary area inshore of Sheerness is contaminated.

In the Severn estuary the port areas of Newport, Cardiff, Port Talbot, Swansea and Avonmouth/Bristol which have been sampled. For some contaminants such as arsenic and copper concentrations, samples are similar to expected background levels in many areas (e.g. 80% of Cu analyses are < AL1 values; Table 4), however for many contaminant species including Ni, Cr, and Zn, pockets which might be regarded as ‘clean’ co-exist and are co-located with pockets of contamination (concentrations values between the two Action Levels). The data highlight localised patchiness in contamination (on a scale of 10s to 100s of metres) and this is found in all estuaries. The database GIS tools can be used to explore the spatial distribution for specific metals at these length scales. In an analysis of this sort it should be remembered that each sample derives from a sediment grab which is at most 0.25 m$^2$ in area, from which the level of contamination in a much wider sediment volume/area is derived.

Contaminant hotspots, where concentrations exceed Action Level 2, are found for Pb and Zn in Port Talbot, and for Cd and TBT in Swansea in particular (TBT is also found at Cardiff and Newport).

The Humber estuary has been sampled predominantly at Hull, Grimsby and Goole, although there are data from ~6 samples from the main estuary body and offshore of the estuary mouth. Generally, concentrations for most metals lie between the two CEFAS Action Levels, although values for Hg and Cd are mostly <AL1. The exception to this generalisation is found at Goole. The interior dock area at Goole has been sampled and high (>AL2) concentrations are found for Zn, Pb and Cu; Cr is also high than elsewhere in the estuary. The only other locations where such high concentrations are found is for Hg at two locations, one in the central main estuary and one on the Skeffling mudflats on the northern estuary shore. TBT is found in the estuary at Hull and Goole where concentrations fall between the two AL values.

Samples have been collected in the Mersey estuary along the southern (Wirral) and northern (Liverpool) shores. The trend for most contaminant species reflects a greater level of contamination along the northern shoreline; whereas concentrations for all contaminant species are <AL1 values along the southern shoreline, corresponding north shore values are generally between AL1 and AL 2. High concentration hotspots are found only along the north shore, at Bootle docks for Zn. Hg (plus TBT) is also found at high concentrations at Bootle, and Hg also at Garston on the inner estuary north shore.
Offshore from the mouth of the estuary concentrations values for all contaminants are within expected, regionally adjusted background levels.
Table 4 The proportion (%) of samples by estuary and by contaminant falling into various classes when compared to CEFAS Action Levels. There are no data for PCB7 or PCB25. Example: in the Tyne Estuary concentrations for copper in excess of the AL2 benchmark were found in 4% of all samples collected over the monitoring period (1995 to 2007) (n=200, so in 8 samples).

<table>
<thead>
<tr>
<th></th>
<th>Humber</th>
<th>Severn</th>
<th>Mersey</th>
<th>Thames</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;AL1</td>
<td>AL1&lt;&gt;AL2</td>
<td>&gt;AL2</td>
<td>&lt;AL1</td>
</tr>
<tr>
<td>Arsenic</td>
<td>49</td>
<td>51</td>
<td>0</td>
<td>85</td>
</tr>
<tr>
<td>Cadmium</td>
<td>69</td>
<td>31</td>
<td>0</td>
<td>73</td>
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<td>Chromium</td>
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<td>Copper</td>
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<td>80</td>
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<td>1</td>
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</tr>
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<td>72</td>
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<td>57</td>
</tr>
<tr>
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<td>34</td>
<td>64</td>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td>Zinc</td>
<td>38</td>
<td>59</td>
<td>3</td>
<td>53</td>
</tr>
<tr>
<td>TBT</td>
<td>70</td>
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<td>77</td>
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<tr>
<td>DBT</td>
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<table>
<thead>
<tr>
<th></th>
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<th>Forth</th>
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<tr>
<td></td>
<td>&lt;AL1</td>
<td>AL1&lt;&gt;AL2</td>
<td>&gt;AL2</td>
<td>&lt;AL1</td>
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<td>69</td>
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<td>36</td>
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<tr>
<td>Chromium</td>
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<td>Copper</td>
<td>51</td>
<td>46</td>
<td>4</td>
<td>37</td>
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<tr>
<td>Mercury</td>
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<td>1</td>
<td>19</td>
</tr>
<tr>
<td>Nickel</td>
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<td>30</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>Lead</td>
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<td>2</td>
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The Tyne estuary has been heavily sampled along its length both within creeks/tributaries, alongside wharfs and in the main channels. The overall picture is of a greater degree of contamination in the inner and mid-sections of the estuary and a comparatively cleaner region towards the estuary mouth. The chief contaminants are Pb, Zn, Cu, Cd and TBT, although for most contaminants tested values fall between the two AL values. As, Ni, Pb and Cr appear to be less of a concern generally, although it is entirely dependent on where the samples are taken. Numerous high concentration hotspots are found for Zn, Pb, Cu, and TBT, in particular at the point where the river channel beds to the south near Wallsend; additional hotspots for As, TBT, Zn and Pb are found in the river section through Newcastle, and for TBT at the mouth on the southern riverbank near South Shields. TBT, in particular, is replete throughout the estuary, with >80% of all samples possessing concentrations >AL1. The hotspot areas are mostly at shoreline berths etc., but high values are also found mid-channel.

The Tees estuary is an industrialised estuary, which is now dammed at the upstream cross-section. It has been sampled extensively along its length at both inshore berth/infrastructure locations, in the main channel at the intertidal Seal Sands area in the lower estuary. As in the Tyne estuary, there is a noticeable trend of generally decreasing concentrations in a downstream direction, but this is apparent only for some metals (Cd, Cr, Zn, Cu, Hg, and Pb). For other metals, including Ni, As and also TBT, samples which may be considered not contaminated (i.e. <AL1) are found together with samples which are moderately contaminated (between AL1 and 2). Again, the data are highly location specific. The straight river section up to Middlesbrough would appear, generally, to be the most contaminated, and samples indicative of hotspots are found for TBT, Cu, Hg, As, Zn, Cd, Cr and Pb. In addition, there is a notable area of high concentration of Pb in sediments upstream towards Billingham.

The Forth and Clyde estuaries have generally far fewer samples than most of the English estuaries (Table 3), and there would appear to be no TBT data for these estuaries. The Clyde has been sampled in the inner estuary and in the Gare Loch; generally the pattern is for relatively clean sediments in the inner estuary (Ni, Pb, Zn, Cu concentration < AL1), with concentrations higher (between AL 1 and 2 for all metals) in the loch. Contaminated sediments with concentrations above AL2 are not reported from any sample location.

The Forth estuary/Firth, with the exception of two Hg hotspots (west of Charleston on the inner estuary, south of Leven in the outer estuary) may be regarded as lightly-moderately contaminated. Concentrations of Cu, Pb, Ni and Zn are generally < AL1 although sediment contaminated Pb is found near GrangemOUTH, and with Zn and Cu upstream around Stirling/Alloa; Ni values between the two
Action Levels are found in the channel areas. Values for Cr are between the two AL values throughout the estuary.

4.3.4 Implications for DM Management

The foregoing analysis indicates that contamination due to metals and TBT is prevalent to a greater or lesser extent in all the major industrialised estuaries in the UK. With the exception possibly of the Thames, concentrations for many contaminants of concern are between the Action Level 1 and Action Level 2 benchmarks, which indicates that simple disposal to sea is not immediately permitted; further evaluation will be required by the FEPA regulator in order to judge suitable disposal options for many license applications.

The chief issue associated with ‘further evaluation’ is cost; re-instituting sampling, conducting further (chemical) analysis or using bioassays to establish more effectively the risks to the environment inevitably cost additional money, and therefore the burden on the licence applicant (for whom there are no cost transfer/recovery mechanisms). On occasions where additional sampling is required to delineate more precisely contamination hotspots, although the survey work costs additional money, cost savings can arise later where investigations result in a smaller volume of CDM required to be dredged. Savings are then made in relation to subsequent treatment/disposal costs for the CDM/hotspot.

Time may also be an important consideration; recommendations to undertake further evaluation may delay projects, which may have socio-economic consequences. There are a number of ways to reduce project delays, and these are most effective when introduced as part of early planning. Clydeport, for example, address this issue by conducting their own sampling and chemical analysis (to CEFAS standards and protocols) prior to formal submission of the FEPA licence.

Although high contamination, hotspot areas represent only a small volume of DM that is dredged (and therefore relatively few cases might be expected each year), the disposal of DM containing one or more contaminants at concentrations above AL2 is more complex since their presence makes these likely to be deemed unacceptable for sea disposal. The range of technical remediation options discussed in detail in Task 5, and summarised in Section 7, together with the considerations discussed in Sections 7.4 and 7.5, are relevant to the management of these contaminated sediments. What is clear, however, is that the prevalence of the same contaminants within many England-Wales estuaries presents the same management issues. In terms of remediation approaches, there may be scope for sharing a management solution between various port authorities, taking into account differences in sediment characteristics (which can define, to an extent, the remediation approach; see Section 7). If this may be a reality, then there could be potential for cost sharing amongst various authorities. For example, the commercial sector will respond only where there is an economic level of business; where several ports have a similar TBT contamination issue, a mobile plant for remediation of TBT-contaminated sediments could be commissioned to operate at each location with the costs shared amongst the port authorities. In order for such a proposal to come to fruition a significant public-private/inter-agency/stakeholder engagement will be necessary.

4.3.5 Improvements to the GIS Database

The database is a powerful tool which can be used by the regulator to underpin CDM management. In the present format there are no data on organics (PCBs, PAHs), dredge volume data (for both clean and contaminated fractions) is not incorporated and licence application codes are not included at the point of data assimilation. In order for the database to be used more effectively on a practical level and in a more strategic manner, these issues need to be addressed, perhaps at a policy level. Moreover, the combination or integration with other data sources alluded to previously, so that at least extant data sources can be included into the GIS query tools, would considerably enhance the utility of the database in summarizing the extent and magnitude of contamination for the UK. The latter point
would contribute significantly to increasing the data coverage for many estuarine areas, which in turn may aid the assessment of future license applications.

4.4 The Fal Estuary: A Case Study

The Fal estuary has been selected as a Case Study. The Fal estuary is a commercially active port area in which the management of contaminated dredge material has impacted, and continues to impact, operational activities in the port (Royal Haskoning, 2008). Several developers (the Harbour Commissioners and the marina operators) face significant challenges in terms of finding adequate solutions to the disposal of CDM.

The Case Study is also a useful means of demonstrating how the data within the Task 1 GIS database, and the interactive software tools developed within the database, may be used by CEFAS/MFA to manage CDM issues in estuary regions. In particular, the GIS is used here retrospectively to investigate the broad management/policy implications of (future) changes to CEFAS Action Levels.

4.4.1 Distribution of Contamination

The Fal estuary is contaminated by numerous contaminant species including TBT, As, Cu, Hg, and Zn. Although it has a minor contemporary sediment input, historically it has received waste from mines. The estuary sediments have been sampled in two major areas (i) to the northern (inner tributary) area and (ii) at an area around the western estuary mouth/outside Falmouth Dock.

The GIS can be used to create spatial plots for a particular contaminant for every year on a map of the estuary, from which it is possible to judge the following:

- areas with sparse or no coverage;
- sample locations from different years;
- the spatial distribution and magnitude of contamination in relation to the CEFAS Action Level classification; and
- any spatial trends within and between contaminants.

Figure 4 shows maps for the following contaminants: zinc, TBT, copper, arsenic. A zoom tool enables the user to expand on an area of interest and clicking on a point provides the numeric concentration value.

Zinc is found in concentrations throughout the estuary above the Action Level 2 value (800 mg kg\(^{-1}\)) except for at two clusters in the offshore area at the mouth and inshore (2002). Zinc contamination is due mostly to historic mining activities and the principal river (the Carnon via Restronguet Creek which enters into the northern sampled area) is known to have very high concentrations in both the water and sediment (e.g. Bryan and Gibbs, 1983; Burt et al., 1992). Drainage of old mine adits and erosion of old spoil heaps by water have also contributed to high arsenic and high copper values. For both these species concentration values are largely between the two Action Level benchmarks or above the Action Level 2 value in both the northern and southern sampled regions. For these areas, a classification by CEFAS would describe these areas in general terms as either ‘moderately contaminated’ or ‘contaminated’. Although CEFAS apply a weight of evidence approach to sediment assessment which introduces additional information, such co-located high values indicate that any DM from these areas would be unlikely to be suitable for sea disposal simply on the basis of the concentrations of these metals alone (CEFAS, 2005). The area east of Falmouth Dock (towards the open estuary mouth), and the area immediately to the west (Pendennis) appear generally less contaminated by these three metals, with concentration values commonly <Action Level 1 (i.e. equivalent to background values adjusted for expected natural metal concentrations; CEFAS, 2005).
Although TBT has been a problematic issue historically (e.g. the Falmouth Cruise terminal project; Royal Haskoning, 2008; Mylor Harbour; Envirotreat, 2008) the data indicate that it is at concentrations believed to cause environmental harm in only a few locations. In the northern sampling region concentration values are largely < Action Level 1 values. In the southern region, concentrations at similar low values are found in the inner creek area; intermediate (i.e. with concentrations between Actions Levels 1 and 2) and high concentrations were reported for 2004 in the lower estuary (outside Falmouth Harbour). The high concentration (‘hotspot’) region creates distinct management problems, some of which have been explored within license historic applications, and for which consideration of many issues discussed in this report will be necessary. The inshore (2002) samples (from Pendennis) will under the present CEFAS system require further evaluation (e.g. additional sampling, bioassays); the area of higher concentration, which is also contaminated with metals, presents additional complexities not only in relation to disposal options; the mere act of dredging (creation/deepening of approach channel) of such highly contaminated sediments may via resuspension create new downstream contamination pathways and increased risks to both the licence applicant (financial, legal) and to the wider environment. These issues are discussed in Sections 6.
Figure 4 Spatial maps generated from the Task 1 database for copper, zinc, arsenic and TBT in the Fal estuary, SW England. The red and blue boxes indicate the only regions of the estuary which have been sampled and the colour of the symbols shows data values in relation to the CEFAS Action level classification.
4.4.2 Time-Series Analysis using the GIS

The GIS enables plots of contaminant concentration through time to be produced. The time-history of concentration is a useful means of exploring whether contaminant sources to an estuary are decreasing, stable or increasing. This was the central theme of Task 3 (ABPmer, 2009c), and evaluation of sources and their status with regard to estuaries is a key component of DM management/best practice.

Preferably, time-series should be derived from multiple sampling at single point locations. Currently, however, very few locations in the database have been sampled recurrently. It is therefore only possible to consider a region within an estuary as a sampling unit, and to explore trends in concentration within this region through time with the GIS tools. Figure 5 shows the data for zinc for the northern part of the Fal estuary. The plot indicates an increase in zinc in sediments from 2002 to 2006, and a similar trend (not shown) is apparent for both copper and arsenic (TBT appears stable). An initial and generalised conclusion might be that fluvial inputs to the Fal estuary continue to flush metals into the estuary from source areas (mine adits, spoil heaps etc.), and at an increasing rate, and this may indeed be the case. However, an appropriate way in which to treat the data contained in the GIS is to compare it with other data to see whether any trends are consistent. Thus, for example, in the Fal the Environment Agency (1997 and 2005/06) conducts routine monitoring for common contaminants including metals in both the water and bottom sediments, and various conservation agencies (EN and JNCC) may also have historical data for sediments. The CSEMP Benthic and Sediment Contaminants Programme also contains relevant, regional data for sediments which includes the Fal. These data should be used where possible in any assessment. The project GIS database is therefore useful as it provides some indication to historical variation in contamination in sediments, but a more definitive view of any trends will be forthcoming via an integration of different datasets.

Figure 5 Time-series plot of zinc concentration in the northern Fal estuary. The symbols indicate the range of concentration values available for specific dates and the orange and red lines indicate CEFAS Action Level 1 and 2, respectively.
4.4.3 Future Use of the GIS Database Data

Now that the data have been organised within a single location, and specific tools have been developed to query and visualise the data, it may be of benefit to develop a protocol or process that could be applied in relation to future dredge licence applications. This would be directed towards a systematic evaluation and summarisation of all relevant data from within the GIS for a specific location (e.g. a region within an estuary). Such an approach is found for maintenance dredge applications in relation to marine conservation assessments (Maintenance Dredging Protocol, Defra, 2007), for which a ‘Baseline Document’ is produced which summarises all relevant existing information. The intention is for all estuaries to have a Baseline Document to assist with Maintenance Dredge licence renewal applications. Defra might wish to make the GIS Data or application available to authorities leading Baseline reviews. Summary reports could be generated to a standard format, and added to the range of other information/evidence (e.g. regional background data, other data e.g. EA monitoring etc.). Development of such a process would significantly aid processing of licence applications. Standard information could include:

- spatial maps for all contaminants by year;
- time-series plots to examine historic/ongoing trends (i.e. to establish any contaminant inputs cf. Task 3);
- tables of Action Levels;
- proposed sampling areas;
- distances of historic sampling locations from above/buffer zone analysis.

Some issues of database maintenance are still to be determined. It was recognised by the project that historic data did not include CDM wet/dry tonne volumes (and clean DM volume where it arose) or specific data on final DM disposal/treatment fate. If these metrics can be included within the GIS in future, then these too should be published as standard information as they are useful for any assessment process.
5. OVERVIEW OF LEGISLATION RELEVANT TO CDM MANAGEMENT IN THE UK

A wide range of legislation is relevant to the management of marine dredge material at international, European, and national (devolved administration) level. Furthermore, the legislative frameworks for the management of material at sea and on land are distinctly different. Table 8 summarises the main relevant provisions that apply at sea and on land in the UK. The principal statutes are presented here; for a more detailed discussion refer to Appendix 1 of ABPmer (2009b) (Final Report for Task 3)\(^8\).


5.1 Policy Affecting CDM Management at Sea and on Land

5.1.1 Policy Affecting CDM Management at Sea

At an international level, the London Convention and Protocol and the OSPAR Convention are particularly important in setting requirements for the management of dredged material disposal at sea. In contrast, waste management on land is primarily defined by EC Directives, in particular the Waste Framework Directive and revised Waste Framework Directive. The regulatory requirements that apply to the management of (C)DM at the national level thus depend on whether the material is to be disposed of at sea or taken to land for treatment, recovery or disposal.

The OSPAR guidelines for the management of dredged material and the dredged material guidelines of the London Convention both require an evaluation of disposal options to be made before making a decision on whether the dredged material will be allowed to be disposed of in the sea. These guidelines are invoked in British Law by Section 8 (2) of the Food and Environment Protection Act 1985. The technical assessment of the suitability of dredged material for disposal is undertaken by Cefas using a weight of evidence approach, as described in Section 3.2.1. The assessment takes account of information on the physical and chemical properties of the disposal material and the characteristics of the proposed disposal site.

The UK Marine and Coastal Access Act (2009) provides a framework for a new marine licensing regime due to come into force in early 2011. The overall objective of this regime is to regulate sustainable development in the marine environment in a way that minimises adverse impacts to the environment, human health and legitimate uses of the sea. The Marine and Coastal Access Act effectively integrates a number of existing UK and EU legislation and Directives including EU Marine Strategy Framework Directive. In the UK, the Marine and Coastal Access Act include new powers, including the creation of the Marine Management Organisation (MMO), which will play a significant role in marine planning and licensing activities\(^9\). The licensing regime under the Act will apply to activities undertaken in...
terrestrial waters around England, Wales and Northern Ireland and for all UK waters beyond 12 nautical miles as measured from the baseline of the territorial sea. In the Devolved Administrations, there are variations in relation to specific areas (these are beyond the scope of this report).

Table 5 Summary of main legislative provisions relevant to the management of CDM at sea or on land. Some provisions e.g. the Bathing Water Directive, have only a minor relation to CDM management. Source ABPmer (2009b).

<table>
<thead>
<tr>
<th>Sea</th>
<th>Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>International</td>
<td></td>
</tr>
<tr>
<td>• London Convention and 1996 Protocol (including the Dredged Material Guidelines)</td>
<td></td>
</tr>
<tr>
<td>• The Convention for the Protection of the Marine Environment of the Northeast Atlantic (OSPAR Convention).</td>
<td></td>
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<tr>
<td>• International Convention for the Prevention of Pollution From Ships 1973 as modified by the Protocol of 1978 (MARPOL 73/78)</td>
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<tr>
<td></td>
<td>European</td>
</tr>
<tr>
<td>• Birds Directive (79/429/EEC)</td>
<td></td>
</tr>
<tr>
<td>• Bathing Water Directive (76/160/EEC) and Revised Bathing Water Directive (2006/7/EC)</td>
<td></td>
</tr>
<tr>
<td>• Shellfish Waters Directive (2006/113/EC)</td>
<td></td>
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<tr>
<td>• Dangerous Substances Directive (76/464/EEC)</td>
<td></td>
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<tr>
<td>• Environmental Impact Assessment Directive (97/11/EEC)</td>
<td></td>
</tr>
<tr>
<td>• Strategic Environmental Assessment (SEA) Directive (2001/42/EC)</td>
<td></td>
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<tr>
<td>• Environmental Liability Directive (2004/35/EC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>National</td>
</tr>
<tr>
<td>• Food &amp; Environment Protection Act 1985 and Coast Protection Act 1949 (shortly to be replaced by new marine licensing arrangements under the Marine &amp; Coastal Access Act (and equivalent devolved administration provisions).</td>
<td>• Environmental Protection Act 1990 (England, Scotland, Wales)</td>
</tr>
<tr>
<td>• Marine Works (EIA) Regs 2007</td>
<td>• Waste &amp; Contaminated Land (Northern Ireland) Order 1997 and Pollution Control and Local Government (Northern Ireland) Order 1978</td>
</tr>
<tr>
<td>• Local powers under Harbour Empowerment Orders (many and varied rights and duties; normally applied for through Harbour Works licenses.</td>
<td>• Environmental Permitting (England &amp; Wales) Regulations 2007</td>
</tr>
<tr>
<td></td>
<td>• Waste Management Licensing Regulations 1994 and Pollution Prevention and Control (Scotland) Regulations 2000 (Scotland)</td>
</tr>
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<td></td>
<td>• Waste Management Licensing Regulations (NI) 2003, Environment (Northern Ireland) Order 2002, Pollution Prevention &amp; Control Regulations (NI) 2003</td>
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</table>
5.1.2 Policy Affecting CDM Management on Land

Where CDM is brought to land it will be classified as waste, although whether it is classified as ‘hazardous waste’ requires further consideration. Certain rules and regulations apply to the classification of waste. The European Waste Catalogue (EWC) categorises different types of waste into basic categories (‘inert’, ‘non-hazardous’, ‘hazardous’). The properties of hazardous waste are laid down in Annex III to the Waste Framework Directive and have been slightly modified in Annex III of the revised Waste Framework Directive. There is also additional guidance on national criteria for classifying waste (e.g. Environment Agency, 2008).

Because the composition of many waste streams is variable, the Catalogue often includes two separate entries for the same waste (known as ‘mirror entries’). This provides for such waste to be classified as ‘hazardous’ or ‘non-hazardous’ depending on the specific properties of that particular batch of waste. DM containing dangerous substances is identified as a ‘mirror entry’ waste in the catalogue (M17 05 05). The guidance indicates that DM potentially includes such a broad range of potentially hazardous constituents that it should be considered under all the hazards H1 to H14. If the chemical constituents of the waste are unknown, it should be treated as hazardous unless tested.

Alongside the robust regulatory framework for managing risks to human health and the environment, waste policy is strongly governed by the waste hierarchy. In accordance with the revised Waste Framework Directive this comprises:

- Prevention;
- Preparing for re-use;
- Recycling;
- Other recovery (including energy recovery); and
- Disposal.

The hierarchy places a strong emphasis on preventing waste. Where waste cannot be avoided, the hierarchy seeks to re-use, recycle or recover waste, with disposal to landfill sites as the last resort. National waste strategies seek to identify and deliver key actions to deliver overall objectives and targets for waste management and, in particular, the principles of the waste hierarchy. The waste hierarchy is central to the handling of CDM from the point of dredging to the point of final disposal.

The revised Waste Framework Directive (not yet transposed into UK law) amends the definition of waste and hazardous waste and establishes specific criteria relating to recycling and recovery of waste to determine the point at which waste can be considered to have been fully recovered from the waste stream:

- The substance or object is commonly used for specific purposes.
- A market or demand exists for such a substance or object.
- The substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products.
- The use of the substance or object will not lead to overall adverse environmental or human health impacts.

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10 Annex III of the Hazardous Waste Directive contains a list of generic waste types (e.g. ‘flammable’, carcinogenic’, ‘infectious’ etc.). The list H1 to H14 provides the common technical basis for the definition of Hazardous Waste in the United Kingdom (Environment Agency, 2008).
5.2 Bringing Sea and Land Processes Together

Two frameworks influence the management on CDM in the UK:

1. The ‘Specific Guidelines for the Assessment of Dredged Material’ developed by the London Convention 1972 parties, is contained within the guidance document ‘Specific Guidelines for the Assessment of Dredged Material’. This framework has become a widely accepted framework for assessing dredged material. In addition, the latest version of the OSPAR Guidelines for the Management of Dredged Material 2009 adopted at the 2009 meeting of the OSPAR Biodiversity and Ecosystems Committee provides a scientific and technical framework in the form of guidelines primarily for assessing dredged material proposed for disposal at sea.

2. A land decision-making framework based upon the European waste strategy.

The sea and land frameworks interact at two key points. Where dredged material is considered unsuitable for sea disposal because of contamination issues and is brought to land, it becomes subject to the waste management system. Such material may remain on land, in which case it remains subject to waste management controls unless it is recovered from the waste stream for re-use or recycling. Alternatively, following treatment, the material may be suitable for sea disposal and/or beneficial use at sea, in which case it would be subject to controls under FEPA/the new marine licence, although discussions with Cefas and their international OSPAR partners suggests that there is significant resistance to even beneficial use of treated DM. An overall framework that seeks to bring together the sea and land frameworks for the management of CDM disposal is presented in Figure 6.

It is clear from Boxes 2 and 3 of Figure 6, one of the first steps in the DM decision-making process is the evaluation of potential beneficial uses of DM. Thus, the waste hierarchy has relevance; it is reflected in the OSPAR guidelines in the requirement to pursue source reduction and to prioritise beneficial use. MFA has endeavoured to minimise the disposal of clean dredged materials - especially sands and gravels - in favour of identifying beneficial uses such as beach nourishment, the reclamation of salt marshes or mud flat enhancement. This also serves to reduce the loss of material from coastal sediment cells. The Marine Environment Team of the MFA of Defra will endeavour, wherever possible, to work with licence applicants, nature conservation bodies, coast protection authorities, the EA and others, to identify potential schemes to utilise dredged material in a practical and appropriate manner (Defra, 2006). In support of this objective, they have generated a procedure for the identification of alternative uses for DM which depends upon sediment contaminant levels and grain size distribution (Figure 7). This procedure addresses both the beneficial use of clean DM and, potentially, the beneficial re-use of ‘cleaned up’ fractions of DM. However, the perception among some that even clean DM is a waste has, in spite of this policy, resulted in dredging applicants at times having difficulty gaining permission to beneficially re-use DM even on land (e.g. Clay et al., 2008), and there may be perception, policy and/or regulatory barriers for the marine disposal or re-use of DM once it has been treated on land. These are summarised in Section 5.3.

If a site is to be dredged, there are a range of DM management options; the selection of the ‘best’ option depends upon a number of legal, regulatory, technical, socio-economic and environmental issues. These options can be evaluated in terms of both the land-sea decision-making framework and the alternative uses procedure as addressed in Figures 6 and 7, but a complete assessment of alternatives will need to consider a range of project-specific issues, some of which are addressed in Sections 7.4 and 7.5.
Figure 6 Co-alignment of land and sea decision-making frameworks. Source: ABPmer (2009b) (Task 3).
Figure 7 Technical procedure for identifying alternative uses for dredge material. It should be noted that this figure does not address the socio-economic issues that must also be considered in option selection, as will be required in the new Marine Licensing regime under the Marine and Coastal Access Act. Source (2006).
5.2.1 Managing CDM on the Land and Sea within the Waste Hierarchy

Whether the ultimate fate of the sediments is on land or at sea, the range of DM management options can be classified in terms of the waste hierarchy and the European waste strategy. A recent evaluation of the volumes of DM in Europe that fell into each category of the waste hierarchy identified sediment that was being processed for beneficial re-use as recycling (Mink et al., 2006). However, the definition of re-use is the use of a material in the same form (albeit sometimes cleaned or separated). By definition, a material is not a waste if it is to be re-used, although processing for re-use may require an end-of-waste designation. On the other hand, recycling is defined as the use of materials in another form (Pongrácz, et al., 2004). In terms of regulatory complexity and end-of-waste requirements it is important to distinguish between the re-use and recycling of sediments. Given this distinction, the processing of sediments can lead to beneficial re-use, either at land or at sea (if permitted), recycling, or disposal. Sediment treatment technologies, as described in Section 7.1, may prepare DM for various levels of the waste hierarchy. The different pathways of DM management, and how they fit into the waste hierarchy, are described below. Figure 8 illustrates one approach to how some of the approaches fit within this interpretation of the waste hierarchy, but it is important to remember that this will only be one factor in a DM management decision, and that this application of this approach is subject to a number of regulatory uncertainties and barriers that are addressed in Section 5.3.
Figure 8 Potential classification of DM management options using the waste hierarchy. From Apitz, S.E., (submitted).
Pollution Prevention – DM management can be classified as pollution prevention under a few circumstances, including the withdrawal, refusal, or minimisation of a dredging application or via the reduction of sediment and contaminant sources. Pollution prevention can result from a consideration of the London Convention question: ‘Is dredging necessary?’ It may also result from a reduction of the dredging footprint to reduce waste, or from a permit refusal or withdrawal if no acceptable DM disposal options are found. Over time, pollution prevention results from the application of source control (both sediment and pollutant) to reduce the amount of dredging that is required and the volume of DM that cannot be beneficially re-used.

Re-use – Technically, DM can be beneficially re-used (as in Figure 7) with or without treatment; on land or sea, though the range of options may be limited by DM contaminant status and various regulatory issues, as addressed in Section 5.3. Sediments that are processed for re-use can be cleaned or sorted, but, for their use to be considered re-use, they must be in the same form as the original material. Thus, cleaned sand is re-used, but if it is made into another product it is recycled. Relocation of DM at selected locations, defined as placing dredged material at specific locations in the environmental so that it fulfils its role in the sediment balance, is considered re-use by some parties, though the regulatory status of any CDM placement at sea is complex (see Section 5.3.3.1). Placement of DM in environmental compliance (the disposal of dredged material at suitable disposal locations, in such a manner that it helps maintain sediment balance without posing risks to human health or the environment) can also be considered a re-use of DM. However, the question of whether CDM that is re-used in various ways is waste or not is still open to debate.

Processing/Preparation for re-use - Treatment or management of DM for either re-use (see above), recycling or disposal (see below) is a process that can lead to different levels of the waste hierarchy. ‘Preparing for re-use’ is a new waste management term included in the revised Waste Framework Directive and is defined as the ‘checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing’. Fundamental to the ‘preparing for re-use’ category is the requirement that the waste product is returned to the form for which it was originally intended, though such re-use will require an end of waste designation (Lee and Nash, 2009). When sediment is being processed, it is the ultimate destination of the processed DM (re-use, recycling, disposal) that defines the waste hierarchy status of the DM. At times, different fractions of DM have different destinations – clean sand may be beneficially used, whilst a more contaminated fraction may still be disposed of. However, any re-use, on land or at sea, must be consistent with regulatory regimes and treaties. Some barriers to such an approach are discussed in Section 5.3.

Recycling - By most definitions, if a material is to be recycled, it is a waste and most likely must be subjected to ‘end of waste’ procedures (JRC and IPTS, 2008). DM is recycled, rather than re-used, if it is in form other than its original form, so bricks, aggregates, and other materials made from processed DM are recycled materials. Most uses of materials made from recycled CDM will be on land; beneficial use of such material at sea even for such applications as reef building have met with considerable resistance (Vivian, pers. comm.), although the foundation for such concerns (perception, policy, regulatory) is unclear.

Recovery - If biomass or energy are recovered from the DM management process, this classified as recovery in the waste hierarchy. This should not be confused with the use of the term ‘recovery’ in which a material that has been classified as a waste is given an end-of-waste designation so that material can be re-used or recycled. There are currently very few examples of recovery during CDM management, however.
Disposal – the range of disposal options are presented in Section 7.3 and Figure 11; disposal can be on land or at sea. In terms of the Waste Hierarchy, disposal should be an option of last resort. Disposal, both at land and at sea, are subject to extensive regulatory control as described in Section 5.3.

To support recovery of waste from the waste stream, the Environment Agency has been taking forward the development of a number of ‘waste protocol’ projects\(^{11}\) to seek to develop guidance on when waste might be considered to have been fully recovered from the waste stream. As part of this programme, a study has been undertaken in relation to dredged material of marine origin. While the study has recognised that there is potential for such material to be re-used, the project identified a number of issues that make it difficult to develop generic guidance at this stage. Most dredged material does not meet standard engineering criteria for fill material (one of the most common expected beneficial uses for DM) and therefore may not meet the end of waste criteria for this product. Furthermore for waste to be considered to have been fully recovered, it must not lead to overall adverse environmental or human health impacts. The variable composition of both natural constituents and contaminants in dredged material makes it difficult to provide a sufficiently protective generic risk assessment for the beneficial use of DM, and thus it remains likely that the beneficial re-use of CDM will need to be evaluated on a case-by-case basis.

The use of the above definitions is not unambiguous, in terms of their use in the literature or even in their interpretation in a legal sense. In one UK case study (where uncontaminated DM was under discussion), based on a strict reading of the waste definition (‘…any substance or object which the producer or the person in possession of it discards or intends to discard’) it was concluded that once dredged material is targeted for re-use, recycling or even for recovery, it is no longer waste, or it has never been waste in the first place. This hinges on the meaning attributed to ‘discard’, and Lord Kingsland, in a legal opinion about the beneficial use of clean sand for construction material concluded that, as long as the holder of the material intends to re-use or recycle, it never becomes waste on the way; if the material is intended to be recovered there is some leeway for interpretation. However, he suggested that even in this case it does not become waste. However, if it is considered a waste under an interpretation of the waste Framework Directive, the part that is recovered turns into a ‘product’ or a ‘by-product’ and thus is no longer waste. Only material that the holder explicitly intends to discard, or is forced to discard, is thus ‘waste’ under the definition (Mink et al., 2006). This discussion makes clear that there are difficulties even when seeking to beneficially use uncontaminated DM, but also suggests that CDM that can be prepared for re-use or recycling may not be a waste, if there is never an intent to dispose of it (if consistent with regulatory frameworks and treaties). This makes very clear the regulatory gaps identified in this project; there is a need for clarity on waste classification and where it happens in both the decision and the DM management process (see Fig. 6 for a potential approach), as discussed in Section 5.3 below. The range of options available to licence applicants may be significantly limited by how these issues are interpreted.

5.3 Possible Barriers Relating to the Management of CDM within a Land-Sea Combined Framework

The framework in Figure 6 permits an evaluation of the CDM management process within a wider context, and serves as a basis to examine regulatory barriers to effective management of CDM in the UK. Regulatory barriers and issues associated with the management of contaminated marine dredge material have been identified (by Task 3; ABPmer, 2009b) based on the project team’s experience, discussions with regulators and their advisors and with port and harbour authorities. While the considerations relating to the management of CDM at sea and on land are complex, and the discussions

above have highlighted a number of uncertainties associated with both the sea and land regimes and their interactions, relatively few significant legislative barriers have been identified. The main issues identified relate to uncertainties regarding the interpretation of EC Directives in terms of the evaluation framework for sea disposal, and uncertainties relating to the criteria and policies to be applied for re-use, recycling and recovery of CMS material on land. Whilst these barriers have been invoked in the discussion above, the four main issues identified, and suggestions for addressing them, are separately discussed in the sections below.

5.3.1 Uncertainties in the interpretation of EC Directives in relation to the evaluation framework for sea disposal.

Article 2(3) of the revised Waste Framework Directive indicates that where dredged material is 'proven' to be non-hazardous (in accordance with the criteria in Annex III of the Directive) and is relocated within surface waters, it is exempt from the requirements of the Directive. There is currently no guidance on how regulators and advisors might apply this provision and so determine whether the material is - or is not - subject to the requirements of the Directive. This is particularly important because determination of a non-hazardous material would mean that DM could, arguably, be 'relocated inside surface waters' (EC Waste Directive [2008/98/EC], Section 3 with effect from 12 December 2010).

While it may be possible to require prior evaluation of dredged material against the Annex III criteria, such assessments may be expensive and, in terms of some of the criteria, may not be relevant to the consideration of environmental risks specifically associated with sea disposal. In particular the requirement of Annex III to consider the ecotoxicity of leaching is not a meaningful criterion to apply in the marine environment, as the process of leaching, after deposition, is primarily a terrestrial phenomenon (although assessment for the potential of contaminants to leach (desorb) from sediments in suspension during the dredging and disposal process is standard in some international protocols). Policy guidance could clarify how the requirements of Article 2(3) might be discharged. The application of the Annex III test also raises further questions about the compatibility between the existing assessment procedures applied within the sea disposal evaluation process, the requirements of Annex III and potentially differing interpretations between agencies (e.g. MFA and EA). There is a concern that a strict application of the Annex III criteria could result in significant quantities of dredged material being categorised as hazardous in the context of the revised Waste Framework Directive criteria, with possible requirements for material to be brought to land for treatment, recovery or disposal, whether this is technically necessary or not.

5.3.1.1 Potential Solutions: Interpretation of EC Directives

Interpretation of EC Directives is ultimately a matter for the European Courts. Nevertheless, the UK develops and implements policies to apply the requirements of EC Directives based on its current understanding of those requirements. Further policy developments or interpretations are likely to be of value in the following areas:

- Interpretation and application of the Priority Substances Directive (EQS) in terms of the implications of dredging and disposal activities to the achievement of Good Chemical Status; some further clarification may arise from the current work to develop a framework for navigation dredging, although further Defra policy guidance may be needed.

- Development of an approach for 'proving' that dredged sediments are non-hazardous in terms of Annex III criteria in the revised Waste Framework Directive, within the context of routine DM assessment frameworks.
• Alignment of the DM chemical testing and assessment procedures for sea disposal and for the purposes of Annex III of the revised Waste Framework Directive.

• Modification of the current DM assessment process for sea disposal to apply requirements of the revised Waste Framework Directive in circumstances where the material is classified as hazardous.

5.3.2 Uncertainties in the criteria and policies to be applied for re-use, recycling and recovery of CDM on land.

Where contaminated dredged material is brought to land it will be classified as waste. Waste policy is strongly governed by the waste hierarchy, as described in Section 5.1.2, which promotes waste prevention, else re-use/recycle with disposal regarded as a last resort.

In spite of publications from the revised Waste Framework Directive and other, recent work (e.g. the EA ‘waste protocol’ project for DM; JRC and IPTS, 2008) one of the main uncertainties concerning CDM under the waste management regime on land in the UK relates to criteria for determining at what point such material might be classed in the categories considered prepared for re-use, recycling or recovery (see Section 5.1.2). In terms of recovery, these issues are primarily a function of the nature of marine dredged material rather than the provisions of the regulatory regime. Although there are unique difficulties associated with preparing CDM for re-use/recycling which preclude development of generic guidance (variable level of contamination, differing sediment types, non-compliant geotechnical characteristics, limited re-use options, immature market-place for products), for re-use and recycling there are currently no clear policies in place at UK or devolved administration level. Guidance or policy development from Defra in relation to the preparation of CDM for re-use/recycling would therefore be useful.

5.3.2.1 Possible Solutions: Interpretation of End of Waste Criteria

Waste policy needs to be developed to consider whether it is possible (and if so at what point and under what circumstances) to prepare marine dredge-material for re-use or to recycle such material. If it is possible, guidance could usefully be prepared on those specific requirements and circumstances to assist project promoters, commercial CMS treatment companies and regulators. Sections 7.4/7.5 describes a classification of various CDM management strategies in terms of the waste hierarchy in support of management options selection, but such an approach is still subject to regulatory review and clarification.

5.3.3 Uncertainty on whether controlled waste under the waste management regime on land can be disposed of at sea.

If CDM is brought to land it will be classified as waste. In cases where CDM that is brought to land might subsequently be taken back to sea, a number of possible regulatory barriers have been identified. If CDM is brought to land for treatment to address contaminant issues with a possible view to subsequently disposing of such material at sea (assuming it meets the relevant criteria) clarification is required on whether such material might be said to have been prepared for re-use or recycled. For a
variety of wastes generated on land, this is subject to clear guidance and there is a well-defined use for the material that has been prepared or recycled. However, in the context of CDM, the meaning (and regulatory status) of such terms are less clear.

In cases where CDM is proposed for beneficial use in the sea following treatment on land (see Figure 8), it might be argued that the treatment process had prepared the material for re-use or recycling, providing that there was sufficient assurance that the material would then be used for the stated purpose. In such cases, regulatory clarification is required on the classification of treated material and on whether such treated material can be returned to the sea in any case. Any clarifications must necessarily consider the range of treatment options, from relatively simple treatments such as physical separation, which (arguably) may not significantly change sediment characteristics to more aggressive ones, which may solidify or stabilise sediments (see section 7.1).

A further possible potential barrier is that the material that is not deemed to have been recovered from the waste stream remains classified as ‘controlled waste’. It is likely that such a designation would preclude sea disposal. Where such a conclusion limits sustainable management options, this issue should be addressed.

5.3.3.1 Possible Solution: Clarification of requirements for the disposal of Controlled Waste at Sea

If contaminated marine dredge material which has been treated on land with a view to its subsequent disposal at sea is considered not to have been recovered from the waste stream and remains classified as controlled waste, further consideration needs to be given to the legal mechanisms, processes and procedures by which such material might subsequently be disposed of at sea.

If it is not possible to declassify the material as controlled waste under the current regulatory regime (because it doesn’t meet the criteria for re-use, recycling or recovery), it may be possible to deal with the matter administratively by ensuring that the relevant consignment note identifies that the material has been taken for sea disposal (with suitable safeguards to ensure that the stated disposal takes place). A further possibility may be to create a special category of recovery for such material (i.e. recovery for sea disposal), although this might require clearance at European level. A close continued working relationship with the Environment Agency ‘waste protocol’ project for DM is critical to delivery of a successful policy in this area.

5.3.4 Uncertainty on OSPAR and London Convention provisions for the classification of marine sediments that have been treated to reduce contaminant concentrations.

This project has concluded that there is a perception that once CDM has been treated on land, it may no longer be sufficiently of marine origin under the London and OSPAR Conventions to be acceptable for sea disposal (Vivian, per comm.). There are a number of reasons why treated dredged material might be considered unacceptable for sea disposal (C Vivian, pers. comm.):

- Treated material may be regarded as industrial waste that is banned from sea disposal rather than dredged material;
- Treatment may change the characteristics of CDM such that it may no longer be considered dredged material irrespective of its contaminant and sediment properties;
• Treated material may be regarded as land-based waste and might thus preclude the disposal at sea of such material; and/or

• Any chemical or stabilisation treatments could leave at least traces of the chemicals involved and might render the material unacceptable for sea disposal.

While it must be recognised that the process of transferring marine dredged material to land, storing it and treating it may affect not just contaminant properties but also its general sediment properties, if these factors are taken into account in evaluating the environmental risks, there is not necessarily a technical or scientific reason precluding subsequent sea disposal. Indeed, it might be seen as perverse that sediment that had been refused a licence for sea disposal solely on the grounds of a concentration of a particular contaminant, should still be refused a licence once that contaminant had been removed. However a number of contracting parties to OSPAR have outstanding concerns that these activities are not consistent with the Conventions (Vivian, pers. comm.), and thus, if treated CDM is to be re-used, recycled or disposed of at sea, the UK will need to directly address these concerns in policy and in discussions with their international partners.

5.3.4.1 Possible Solution: Re-visiting Interpretation of London and OSPAR Conventions

If the UK wishes to advocate the disposal of treated CDM at sea, it will need to address the concerns of its OSPAR and London Convention partners, and to address, in technical and policy terms, the issues laid out above. Whether the bases for the objections to the marine disposal or re-use of land-treated CDM are grounded in realistic technical concerns, perception, differing interpretation of policy or specific regulatory issues (or a combination of these) should be determined. Scientific and legal discussions should be held with partners at relevant meetings of parties to the Convention, with a view to establishing procedures and processes that might be followed (if possible) to permit the at-sea disposal, re-use or recycling of land-treated CDM. Appropriately addressing the concerns listed above requires a combined consideration of policy implications and objectives, assessment strategies and monitoring requirements.
6. MANAGING LIABILITIES, SOURCES AND COSTS

6.1 Introduction

The classification of DM as ‘contaminated’ is a complex regulatory decision; this is discussed in Section 3.2.1. However, if sediments are deemed to pose a potential risk if disposed of at sea, the DM permit process is much more complex than if it is deemed uncontaminated. Due to the potential risks posed by the removal, transport, management and disposal of CDM, these operations are much more tightly controlled and regulated. In such cases, as a result of increased regulation and other prohibitions, there are increased costs of managing, moving and disposing of CDM, regardless of who was originally responsible for the contamination. Such costs can be termed ‘operational management’ costs. However, the management of CDM is further complicated by the fact that the process of removing, transporting, treating and disposing of CDM has the potential to introduce new pathways of contaminant release, transport and exposure, all of which must be managed and can themselves result in new costs, risks and potential ‘contingent’ liabilities. The selection of a CDM management strategy must consider all these issues, within international, national, regional and site-specific legal, regulatory, technical and socio-economic constraints. YLS (2009 (Task 2) reviewed the issues surrounding liabilities and costs, and ABPmer (2009c) (Task 4) summarised the issues surrounding source control.

We have been dredging, and thus managing, sediments for centuries. Dredging technology is arguably one of the triumphs of human ingenuity in the battle to control nature. Notwithstanding some of its current press, it has given us our greatest cities, fuelled trade empires and continues to keep nations from disappearing beneath the sea. However, over time, this process grew more complex. The waste products of our other technological triumphs bound with the sediments that were to be dredged. Thus, dredged material (DM) slowly evolved from a precious resource to a waste material, and environmental assessment and control became a “burden” that was added onto long-established processes. Over time, dredgers developed containment, treatment and disposal technologies to handle these wastes, and thus clever engineering solutions have been developed and applied. However, costs became higher and options were restricted (Apitz et al., 2006).

The management of contaminated marine sediments is a complex issue in its own right; the question of when to intervene to contain or clean up (remediate) contaminated sediments in place depends upon a broad range of ecological, regulatory, scientific, political, technological and socio-economic issues, but it is outside the scope of this report. The focus of the strategy being developed by Defra is on the management of marine sediments to be dredged for maintenance or capital purposes, which are contaminated at levels that affect disposal options. However, although a national strategy for the management of contaminated marine sediments is outside the scope of this discussion, the sustainable maintenance of ports and waterways must consider the assessment and control of historical and ongoing sources of contaminants to marine sediments.

Source control is a fundamental tenet of the London Convention and the subsequent London Protocol. The guidelines developed under the Protocol for the assessment of wastes or other matter that may be considered for dumping state:

‘For dredged material and sewage sludge, the goal of waste management should be to identify and control the sources of contamination. This should be achieved through implementation of waste prevention strategies and requires collaboration between the local and national agencies involved with the control of point and non-point sources of pollution’.
When considering sources of contaminants in marine dredged material, it is useful to think in terms of ‘pathways’ of contaminants from their source to a target or location under consideration. In terms of CDM, contaminant pathways can be described as ‘upstream’ and ‘downstream’:

- An upstream pathway is one by which contaminants can move from any identified (or unidentified) source, through the marine system to the location where the sediment needs to be dredged, or is to be disturbed by infrastructure development.
  - If the accumulated contaminant concentration levels are high enough at the site that the sediments, if dredged, will be considered CDM, then these pathways can result in increased operational management costs;

- A downstream pathway is one in which CMS disturbed during infrastructure development or dredging, transport and disposal of CDM results in the further transport or release of CMS and/or associated contaminants and other constituents into the marine, terrestrial or atmospheric environment.
  - Whilst it is possible to reduce, minimise or eliminate some of these pathways, potential pathways introduced by CMS and/or CDM management have the potential to introduce new risks, control and/or monitoring obligations and contingent liabilities.

Table 3 in ABPmer (2009c) (Task 4) (not presented here) summarised the main types of control mechanisms – physical, management, legislative – that are available to control pollution upstream and downstream pathways.

6.2 Upstream Pathways and Operational Management Impacts

OSPAR guidance suggests that high priority should be given to the identification of sources, reduction and prevention of further contamination of sediments and should address both point and diffuse sources and concludes that implementation of prevention strategies will require collaboration among national agencies with responsibility for the control of point and diffuse sources of contamination. The important role of source control within these frameworks is illustrated by its inclusion at the earliest levels in the London Convention/OSPAR indicative decision making framework and the co-aligned land-sea decision-making framework (Figure 6).

Upstream pathways for sediments and any associated contaminants to the marine environment are driven by the interactions between local-scale and catchment-scale landscape, land use and hydrodynamic processes driving inputs into and transport through river basins, and ultimately to estuaries and coastal regions. Sediment (and contaminant) transport conditions are affected by a number of physical, geochemical and biological processes that are variable and interacting along many space and time scales. Figure 9 provides a conceptual approach to addressing the question of pathway identification for CMS, as well as some strategies for managing sources and pathways. However, this is a complex problem. The pathways of movement of sediment containing contaminants from any given source to a location where it may deposit in the marine environment, are driven by a complex web of forcing processes, including: land characteristics and management practices, runoff delivering sediments from sources to the river basins, tidal processes, waves, wind, sediment/water/contaminant geochemical interactions, flocculation, settling, erosion and biological influences. Thus, although study finds that the UK already has sufficient legislation in place to control the input of many contaminants (major
point sources) into a water body and to control their potential to cause pollution through various assessments, licences and consents, the myriad source inputs makes the clear identification of specific direct pathways between source and sediment in many cases be extremely difficult.

When these complex processes result in CMS deposition in docks, riverside berths and navigation channels, a proposed maintenance dredging site may have a CDM problem. The discussion of the extent of contamination (Section 4) indicates that contaminants frequently concentrate in contaminant hotspots such as docks, riverside berths etc. (Fig. 4). In these situations it can be argued that the ports and harbours have ‘inherited’ the CMS and the operational management costs of managing it, rather than being the cause of the contamination. Whilst not responsible for the cause of contamination, they may, however, be responsible for dealing with the consequences of its presence. Also, because areas requiring maintenance dredging are often natural depositional areas, without upstream source control, CDM problems may continue in the future, potentially causing long-term operational management costs though their cause will often be outside the control of the port developers.

An integrated approach requiring upstream and sometimes catchment-scale management of sediment and contaminant inputs and involving multiple stakeholders is a realistic means of dealing with source control effectively in most industrialised estuaries. In particular, the combination of funding from various sources via multiple stakeholder involvement for a project, such as instituted recently in the Tyne estuary (the Tyne Sediment Study), can provide substantial benefits. Within this framework port developers can co-operate with private and/or governmental organisations that may be able to control, to some extent, future source inputs. A wide range of physical (e.g. filters, interceptor basins) and management controls (e.g. non-statutory guidance from government; best practice guidance from industry bodies; implementation of Environmental Management audits etc.) and are possible. Port developers and operators may, however, act singularly to consider investing in CDM treatment or containment infrastructure that will help in the long-term, cost-effective management of CDM. In some cases, a focused effort to control one or a few sources may significantly reduce the CDM problem in the near future, and an upstream source control effort will be justified. If CMS in a port is the result of a one-off or rare point source event, or if dredging is expected to be very infrequent, then CDM management strategies chosen may be quite different from those for which large volumes or frequent dredging provide an economy of scale for infrastructure investment. In some cases of historical contamination, contaminated sediment sources may be so widespread upstream of a port that CMS inputs can be expected to be a problem for some time (e.g. as in the Tyne river-estuary), even if all current inputs are controlled. The long-term (18 months) field monitoring programme developed for the Tyne is a means of understanding the inputs of CMS over longer time frames, and such data will be useful in developing a CDM strategy for the port. Which efforts and approaches are cost-effective for port developers depends upon the anticipated frequency of dredging, and the traceability, nature, extent and timescale of inputs.
Figure 9 Simplified flow diagram illustrating source – pathway control. Source: ABPmer (2009c).
6.3 Operation and Management (OM) Costs, Liability and the Polluter Pays Principle (PPP)

As operational management costs for managing CDM have increased and are likely to go on increasing significantly in the future, more focus has fallen upon the question of who should be responsible for paying for these costs as well as who should bear the risks consequent to, and associated with, the management of CDM. The increased operational management costs for managing DM affected by historic pollution has led to the question of whether the polluter pays principle (PPP) is a justification for transferring those costs and any associated liabilities to those ‘responsible’ for causing CMS in the first place. One underlying assumption is that the principle has an accepted meaning. In the context of historic contamination the PPP would suggest a simplistic link between those who have ‘caused’ the contamination in the first place and the costs of having to ‘clean up’ the contamination. Unfortunately this interpretation is not as clear as it might first seem and there is little consensus as to what the PPP means in a practical context.

The concept of the ‘Polluter Pays Principle’ is used by different people in different ways in different contexts. The origins of the principle can be traced back to the OECD in the early 1970s. In its earliest form, the principle was used as shorthand for approaches which made the producer of goods or other items responsible for the costs of preventing or dealing with any pollution caused by the production process. More recently the principle has been defined in broader terms to encompass a general economic approach to allocating the so-called externalities of pollution to those who cause the pollution. In this sense, the internalisation of the costs of pollution occurs when the polluter pays for all costs associated with the pollution. In the absence of such an allocation, costs are shifted to others including the community and those who suffer the consequences of dealing with the effects of the pollution. More specifically, in the context of the management, movement and disposal of CDM, the increased costs and liabilities associated with operational activities are externalised to those responsible for those activities in the absence of other internalising recovery or transfer mechanisms. Although expressed as a single principle, it does not have any single coherent application although it is often used as a justification for imposing new environmental liability schemes (including restorative, redistributive, preventative and punitive approaches), taxation or regulation.

Liabilities relating to historically contaminated marine sediments can be grouped within two categories:

- ‘Operational Management’ liability (reflecting the increased costs of managing, moving and disposing of CDM); and
- ‘Contingent Liabilities’ (arising from such operational management).

Liability concepts, when applied to a number of CDM Case Studies (refer to Task 2 Final Report for details of these Case Studies), suggest that there are no general answers to questions relating to the recovery and transfer of costs and liabilities incurred as a result of operational dredging activities to those who were responsible for historic contamination. Each set of facts will give rise to different considerations. It was possible, however, to identify some general points raised by the application of the polluter pays principle (‘PPP’) in the context of liability for the management, movement and disposal of historic CMS.

Costs and liabilities cannot, however, be transferred or recovered unless there is some specific legal mechanism which allows them to be transferred or recovered. The limitations of private law liability regimes include difficulties in establishing that ‘duties of care’ existed at particular times (required to establish liability in negligence), and that damage was ‘foreseeable’ at the time when contaminating activities were undertaken (required to establish liability in nuisance).
With regard to statutory/regulatory liability regimes, one of the distinguishing features of contamination that occurred in the past - sometimes, many years distant - as compared to current contamination, is the likely regulatory lawfulness (compliance) of the actions that caused the presence of the contaminative substances. Thus, the application of liability regimes and principles to CDM Case Studies suggested that liability on the part of ‘historic polluters’ will not be imposed in most cases of ‘Operational Management’ liabilities. On the other hand, it may be argued that ‘downstream pathways’ of sediments and their associated contaminants during CDM management may raise new contingent liabilities that will be addressed in the next section.

6.3.1 CDM Management and Downstream Pathways

A downstream pathway is one in which CMS disturbed during infrastructure development or dredging, transport and disposal of CDM results in the further transport or release of CMS and/or associated contaminants and other constituents into the marine, terrestrial or atmospheric environment. Whilst it is possible to reduce, minimise or eliminate some of these pathways (and guidance is available to reduce contamination release at the point of dredging; Bray et al., 2007), potential pathways introduced by CMS and/or CDM management have the potential to introduce new risks, control and/or monitoring obligations and contingent liabilities. Figure 10, from ABPmer (2009c) (Task 4), provides a conceptual framework for the assessment and control of downstream sources generated by CDM management. ABPmer (2009c) also considered in depth the management practices that might be imposed to ensure that dredge disturbance and relocation activities do not cause pollution to the water body in question.

Figure 10 indicates that sources from all steps of the management process must be considered. A range of physical, management and legislative controls exist that can be applied to reduce downstream pathways generated from CDM management. Both the conceptual framework and table of management should be useful to Defra and their technical advisors in formulation of a management framework for CDM. Indeed, these outputs (perhaps with revision) would also aid port authorities etc. and other end users in understanding source management within their jurisdictions.

The selection of a CDM management strategy must consider potential downstream pathways resulting from all phases of CDM management. Whilst some downstream pathways, such as the resuspension of CDM during dredging, are relatively short-term, some pathways, such as the potential loss of CDM from a disposal site, may persist for long periods of time. If a management strategy being considered does not completely remove or immobilise contaminants, it is possible that potential pathways of contaminant release will require long-term monitoring, management and possible legal or contractual approaches to manage contingent liability. The costs of such approaches may need to be balanced against the costs of management approaches which may be initially be higher but have lower long-term costs.
Figure 10 Conceptual framework for the assessment and control of downstream sources generated by CDM management (source: ABPmer, 2009c).
6.3.2 CDM Management and Environmental Monitoring\(^\text{12}\)

A number of dynamic pathways may contribute to contaminant transport and exposure at CMS and CDM disposal sites. These include the effects of bed transport, bioturbation, diffusion and advection, resuspension and deposition, and transformation and degradation. The relative rates of these processes help define the potential risk of contaminant loss, pathways of exposure that must be controlled and, potentially, mechanisms of natural recovery of the sediment. An understanding of the relative importance of these processes will help in strategy selection, contingent liability evaluation and monitoring design. Such an evaluation should provide sufficient information to support decisions about which sediments can responsibly be contained, how aggressively they should be monitored or controlled, or whether they should be treated. The significance of natural processes is influenced heavily by site-specific characteristics. These characteristics must be assessed prior to the selection, design, and optimization of any sediment management options, or may be monitored after management actions have been carried out.

As described above, the pathways of exposure and risk of concern are highly dependent both on the site of concern, or in terms of post-management monitoring, the type of treatment or disposal selected (e.g., upland, shoreline, confined aquatic, unconfined open water) and on the specific design choices of a given disposal option. Furthermore, the type of monitoring necessary to assess contaminant fate in place or to validate efficacy of a controlled disposal option depends upon these factors. For example, monitoring for a disposal option designed to reduce the risk of bio-magnification will be different from that for other classes of contaminant, and monitoring for the efficacy of a simple cap will be different from that for a confined disposal facility or a constructed wetland. Once potential pathways of exposure and risk, and ways of assessing them, have been identified, potential monitoring tools can be identified.

Selection, design and optimisation of remedial and containment technologies for CDM require an understanding of many factors, including: a) ultimate effectiveness of the technology with CDM; b) potential risks associated with application of the technology or resulting from the residual contamination left by the technology; c) methods for measuring and evaluating the performance of the technology when applied to CDM; d) economics of the technology when applied to CDM, including the effects of scale and the balance between capital and operating costs; and e) uncertainties in application of the technology or in evaluating its potential risks and benefits.

The primary goal of the application of CDM treatment and disposal approaches is the control of human health and ecological risks incurred during CDM operational management. The ultimate goal of any disposal monitoring program is to ensure the continuing control of CDM pathways of exposure, and to ensure the success of the remedy at protecting human and ecological receptors. In addition, monitoring programs should include efforts to evaluate the effectiveness of the remedy implementation.

It is often difficult to monitor the resource at risk, and to measure changes in human or ecological health resulting from CDM management actions. There may be sources of exposure other than the CDM being managed. The water body containing the CMS is likely receiving inputs from non-point runoff, sediments in other portions of the surface waters, and the atmosphere. In addition, it is even more difficult to measure the success of the chosen management options relative to other options that might have been chosen.

\(^{12}\) From Apitz (2010).
Monitoring programs can be roughly categorized into three types:

- **Surveillance monitoring** is designed to assess spatial and temporal changes to selected parameters. The purpose is the verification of the hypotheses made during the project preparation;

- **Feedback monitoring** or adaptive monitoring is a special type of surveillance monitoring in which a few fast reacting and (possibly) predictable variables are forecast by modelling and then monitored during dredging and disposal operations. The purpose is to ensure that exceedance of environmental criteria can be forecast, and adaptive management can be implemented; and

- **Compliance monitoring** ensures compliance with contractual restrictions such as dredging depth, location or transport mode, turbidity, sedimentation rate at a vulnerable site, attention to environmental windows or quality-related issues.

Commonly used measures include evaluation of contaminant levels in sediment, bathymetry, visual inspection of cores/grabs, mass of contaminant removed, volume of sediment removed, confirmation of cap placement, contaminant concentration in fish/shellfish, and ecological community surveys/toxicity testing. Clearly, the criteria that are relevant depend upon the objectives of the project, as described above.

In the UK, it is noted that monitoring may have serious resource implications and thus, before embarking on a monitoring program there must be a clear understanding of both its objectives and potential benefits. It is assumed that not every dredging and disposal activity will have a significant near- or far-field impact, so monitoring programs should be designed to be proportional to the problem and linked to an assessment of the effects (MEMG, 2003).

PIANC describes the design of monitoring programs for controlled marine disposal of DM. Most monitoring described in this document focuses on physical stability and the assessment of chemical pathways, with little or not consideration of biological measures. As with other guides, monitoring programs focus on site- and project-specific issues and on assessing the success of containment of specific contaminant loss pathways (PIANC, 2002).

### 6.3.2.1 Contingent Liability

As with the application of the PPP, the relevance of the Environmental Liability Directive (transposed into national legislation in 2009) to CDM management is most likely limited to the potential Contingent Liabilities that might arise when undertaking operational management activities. These might include damage caused to protected habitats, or deterioration of water quality, for example. However, the nature of Contingent Liabilities that might arise can be complex. The potential liabilities that might arise are in fact dependent upon, and may involve a number of parties. It is not possible to say exactly which parties will be liable, to what extent, should contaminants escape from operational management activities, as this will be determined by the precise circumstances of each case, but important factors will include the nature of the resulting damage, the performance standards of each of the parties (e.g. the design, implementation, subsequent monitoring, etc), and other circumstances which might have contributed to the contaminant escape or damage. Precisely where liability ultimately falls may also be influenced be the legal agreements in place between the parties (such as the warranties and indemnities in place), as well as regulatory controls. Where operational activities create extra costs and/or liabilities, it should not be assumed that the original source of the historic contamination is seen to be a part of the chain of causation within which such costs can be apportioned.
A range of structures and techniques for the management of Contingent Liabilities can be employed in order to allocate and address legal risks; these include insurance, indemnities and Special Purpose Vehicles. Without these, the uncertainties of such liabilities might inhibit operational management of CDM, and the use of novel techniques in particular. There are strengths and weaknesses for each of these and the appropriate ‘blend’ will need to be identified on a case-by-case basis. For novel operational management methods in particular, an important consideration may be the regulatory acceptance of some techniques. Thus, these factors must be considered when a CDM management strategy is being selected.
7. CDM MANAGEMENT TECHNOLOGIES AND APPROACHES

Section 5.1.2 classifies the range of CDM management strategies in terms of the waste hierarchy but it is important to remember that the classifications are quite broad; there are a number of specific pre-treatment, treatment and disposal technologies and approaches that can be applied to carry out the strategies described above. ENTEC (2009) (Task 5) provides a comprehensive review of the technologies available for the treatment and disposal (including beneficial re-use) of CDM. The report assesses in detail treatment and disposal options and provides national and international case studies for the application of each. Categories of DM management include unconfined marine disposal, relocation or beneficial re-use (if not CDM), (pre-) treatment/processing (followed by re-use, recycling or disposal) and a range of controlled disposal options (often following pre-treatment or treatment). This work has focused on treatment and disposal options which are presently available in the UK on a commercial basis, however some options (e.g. CAD cells, geotextile bags) not yet used within the UK but deemed promising have been included. Because the focus of this project is on the management of contaminated dredged material, not the remediation of in place sediments, only ex situ sediment management strategies are considered. A brief description of the range of treatment and disposal options will be followed by an analysis of these CDM management options in terms of a number of selection criteria that are relevant to the CDM management process.

7.1 Treatment/Processing Options Overview

Treatment processes are designed to either render contaminants in CDM less bioavailable or toxic or to prepare CDM for further treatment, use and/or disposal using physical (including thermal), chemical and/or biological mechanisms that can concentrate, isolate, destroy, degrade or transform either CDM or its associated contaminants (Table 6). For a detailed review of treatment options the reader is referred to ENTEC (2009) (Task 5).

Dewatering of CDM is a precursor to most treatment and disposal options as it reduces dredge slurry volumes, and thus, if required, the costs and handling steps required for this pre-treatment must be included when other options are being considered. Treatments to destroy contaminants are designed to change contaminant chemistry or state, which can involve high-energy consumption. Immobilisation approaches reduce the bioavailability of contaminants by encapsulating or binding them. Extraction of contaminants can result in waste streams that may require further treatment, disposal or, in some cases, may provide a beneficial product. Each method has advantages and disadvantages and the choice of treatment option(s) requires project-specific evaluation. Because CDM is rarely contaminated by a single class of contaminants and CDM even from a single dredging project may have a range of sediment characteristics, effective management may require a “treatment train” which applies a series of technologies. Each treatment or handling step increases costs, treatment time, and potential pathways of exposure, and thus the selection of a CDM management strategy must consider a broad range of site- and project-specific issues.

7.1.1 National Capability

Whilst a number of parameters must be considered in CDM management strategy selection, important parameters in the evaluation of treatment technologies are the technologies’ ability to treat the sediment type (grain size, organic content, mineralogy) and class(es) of contaminant(s) of concern and the commercial availability of the technology(ies). Although ENTEC (2009) presented a thorough review of treatment and disposal techniques, it was beyond the task scope to summarise remediation capability within the UK specifically in relation to CDM. This knowledge gap has been addressed in recommendations for future studies/R&D (Sections 8 and 9). However, for the purposes of this summary report a telephone consultation was conducted with all major remediation companies to establish, in general terms, the UK capability. Table 6 includes the data from this consultation. The
commercial capacity for many remedial technologies exists within UK in the context of soils community to address all types of contaminants (metals, organics, TBT); these are operated on a commercial scale by a number of companies. There is practical experience, especially within Dutch-operated companies, with respect to the remediation of CDM (i.e. marine sediments) specifically. For example, DEME-Augean operate an advanced treatment plant (including physico-chemical treatment and bioremediation) at Port Clarence (Middlesborough, UK\textsuperscript{13}) which is capable of dealing with most organic contaminants such as TPH, PAHs and PCBs and inorganic contaminants such as heavy metals and cyanides. The plant also incorporates water treatment technologies. The riverside location of this plant, in particular, makes it amenable to inputs of CDM from ships.

The chief barriers surrounding the remediation sector and its application within a CDM context are a poor knowledge base regarding the cost-effectiveness of various options in relation to DM volume (especially for smaller companies), the lack of awareness by the remediation sector of the CDM market and market opportunities (e.g. many companies do not know the annual volumes of CDM on even a general basis), and uncertainty regarding the number and range of recycling/re-use options following treatment which can be targeted in the UK.

Gathering of more detailed knowledge concerning the sector capability is a research recommendation arising from this project (see Section 9).

\textsuperscript{13} This specific company is aiming to open a plant on the UK west coast to provide the nation with remediation solutions on the east and west coasts.
Table 6 Summary of ex situ treatment options presently available in the UK at commercial scale. Mechanical dewatering is nearly always a necessary prerequisite to most other treatment processes. $ indicates partial applicability. Source: ENTEC (2009) with input from K Black.

<table>
<thead>
<tr>
<th>Category</th>
<th>Technique</th>
<th>Detail/Experience</th>
<th>Technology Availability in UK</th>
<th>No. of companies with CDM Experience</th>
<th>Metals</th>
<th>PAH</th>
<th>PCB</th>
<th>TBT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dewatering</td>
<td>Natural Dewatering</td>
<td>Removal of CDM water through evaporation, mechanical compaction of CDMs; waste water needs treating</td>
<td>Technology Available</td>
<td>6</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Mechanical Dewatering</td>
<td>Artificial compaction of sediments; use of geobags</td>
<td>Technology Available</td>
<td>6</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Contaminant Separation</td>
<td>Classification</td>
<td>Mechanical separation e.g. hydro-cyclones</td>
<td>Technology Available</td>
<td>6</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Sorting</td>
<td>Via differential sedimentation</td>
<td>Technology Available</td>
<td>6</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Soil Washing</td>
<td>Simple, or with added chemicals</td>
<td>Technology Available</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Contaminant Destruction</td>
<td>Thermal Desorption</td>
<td>Heating &gt;650°C</td>
<td>Technology Available</td>
<td>7</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Biological reduction/ chemical &amp; thermal oxidation</td>
<td>Destruction through oxidation/incineration or combination into inert form</td>
<td>Technology Available</td>
<td>✓$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Landfarming/ Phytoremediation</td>
<td>Destruction via biological degradation</td>
<td>Technology Available</td>
<td>8</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Technique</td>
<td>Detail/Experience</td>
<td>Technology Availability in UK</td>
<td>No. of companies with CDM Experience</td>
<td>Metals</td>
<td>PAH</td>
<td>PCB</td>
<td>TBT</td>
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</tr>
<tr>
<td>Contam' immob'n</td>
<td>Chemical Oxidation / Stabilisation</td>
<td>Immob. through addition of chemicals</td>
<td>Technology Available</td>
<td>8</td>
<td>✔</td>
<td>X</td>
<td>X</td>
<td>✔ 5</td>
</tr>
<tr>
<td></td>
<td>Thermal Immobilisation</td>
<td>Incineration followed by fixation of contamination in solid form</td>
<td>Technology Available</td>
<td>8</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

Contam' immob'n: Contamination immobilisation.
7.1.2 Dewatering

The separation of solids from water is the simplest treatment process. Natural dewatering, by evaporation requires substantial space and time, which may be at a premium close to the dredge location, whilst mechanical dewatering processes have smaller footprints and higher throughput, but at higher financial and energy cost. If dewatering sites (or for that matter, any type of treatment or disposal sites) are not available nearby, then transport to a suitable site, at additional cost, may be necessary. Dewatering is generally effective and economical, but natural dewatering can be slow, and the water generated, which may contain contaminants, may also require collection and disposal or treatment (a process which also requires a licence). Mechanical methods to dewater CDM currently in the UK include centrifugation, filter pressing and gravity thickening. Many treatment and disposal options cannot be performed on water-rich slurries, and thus dewatering is often only the first step in a treatment or disposal scheme.

7.1.3 Separation Technologies

Particle Separation: Both organic and inorganic anthropogenic contaminants, when introduced to sediments as a result of sorption or exchange from the aqueous phase, have a tendency to associate with the finer-grained sediment fractions (with a higher specific surface area and higher organic content), whilst anthropogenic inputs to sediments directly from the particulate phase do not necessarily favour the fine-grained fraction. Fine-grained sediment fractions are also, however, the result of age, weathering and breakdown of minerals during and after their transport from the catchment basin to sedimentary deposits. These fine-grained particles also contain higher natural concentrations of trace metals than their less weathered, often coarser-grained (>63 µm), parent mineral matrix. These coarser-grained fractions that survived transport are made up of more resistant minerals (e.g., quartz grains) that generally contain smaller amounts of metals within their structure and have lower specific surface areas. Thus, these two main fractions are mixed and deposited in variable proportions as a function of the hydrodynamics of the system throughout a sedimentary basin, and a general regional tendency is to have a “mixing curve” of contaminated fines, and relatively uncontaminated coarse-grained sediments (Apitz and Degetto, 2009), which can be separated by mechanical means as described below. As noted above, however, there are exceptions in which contaminants are introduced into sediments in the particulate form. Because this is often the case in ports and harbours, where a substantial portion of contaminant input can be from antifouling paint chips, drains and spills from loading, it is important to understand the contaminant/grain size distribution at a site of concern, before selecting particle separation as a treatment option (Apitz et al., 2004).

If it is determined that, for a given CDM, the finer, higher organic content particles have higher contaminant levels, and if this more contaminated fraction does not comprise the bulk of the sediment volume, separation technologies may be cost-effective. The different sizes and densities of different sediment fractions, and thus their differential behaviour in fluids, form the basis of particle separation technologies, largely adapted from mineral processing technologies used by the mining industry. Separation is not an effective treatment for all sediments and does not destroy contaminants but can concentrate them into a smaller volume, leaving a larger volume of only slightly contaminated, or uncontaminated sediment. As with dewatering (which is used generally in combination with separation), the reduction of the CDM volume by separation can reduce volumes of material to be disposed of, preserving limited CDF and landfill storage space. Given the generally high costs of more aggressive treatment technologies, reduction of volumes to be treated can be cost-effective. However, as each treatment step can add handling and transport costs and downstream exposure pathways, all costs and risks must be considered when selecting a complete CDM management strategy.
Two main methods are widely used for particle separation; mechanical and longitudinal classification. Longitudinal classification (sorting) is carried out using sloped flushing fields (or sedimentation basins) which are elongated basins with a gently sloping base through which sediment slurry transits slowly from one end to the other. As the sediment moves across the slope it settles out of the water. Longitudinal separation relies upon the differential settling behaviour of fine and coarse particles which enables the separation of slightly contaminated from highly contaminated sediments. Mechanical classification, also often known as soil washing, can be achieved using sieves and/or hydro-cyclones or separation of fine from coarse particles using sediment basins or a variety of apparatus such as upstream-current-classifiers, spirals, jigs, flotation-cells (Vanthuyne et al., 2003) (which are mechanical devices for separating sediments by size).

Physical/chemical separation: A more complex form of sediment/soil washing utilises a combination of mechanical actions, water and chemical additives to remove contaminants from CDM. This approach extracts contaminants from CDM fractions using washing solutions (which are then a waste stream requiring further treatment and/or disposal). This approach has been applied to CDM containing a broad range of inorganic and organic contaminants, in both fine and coarse grained sediments, although higher contaminant removal efficiencies have been reported with coarse-grained fractions. Washing is reported to be most suitable for more weakly bound metals in the form of hydroxides, oxides and carbonates, but the addition of biodegradable biosurfactants has been demonstrated to remove low exchangeable fraction metals from soils with high efficiencies (up to 100% zinc and 70% copper in some cases). General removal efficiencies of 60-80% have been reported for a range of contaminants in fine-grained sediments. Higher efficiencies are possible with coarse-grained material, but the likely efficacy of this approach must be evaluated on a project-specific basis. Factors affecting potential removal efficiencies include initial contaminant concentration and type(s) and sediment characteristics including grain size, mineralogy and total organic carbon content. As some vendors provide project-specific and sometimes proprietary washing solutions, specifics of treatment approach, including cost, extent of treatment, efficacy and type and volume of waste streams must be evaluated on a case-by-case basis.

Thermal Desorption: For CDM that contains contaminants that can be volatilised at temperatures <650˚C, thermal desorption can be used. Typical contaminants for which such an approach may be applicable include PAHs, PCBs, mineral oil, aromatics, cyanides, chlorinated solvents and TBT. Thermal desorption technologies can involves several steps. It may be necessary to desalinate CDM by washing with fresh water, and dewatering may be needed to reduce the moisture to <30%. After pre-treatment CDM is heated in a rotary kiln where contaminants are volatilised, the gases are then removed and treated. Multi-stage gas treatment systems have been developed which can remove particles, destroy the contaminants (up to 99.99% efficiencies have been reported; NRC, 1997). Thermal desorption has been reported to be capable of removing organic contaminants with concentrations up to many thousands of mg kg\(^{-1}\). With the exception of volatile metals such as Hg, inorganic compounds cannot be removed using this technique. In some cases, treated CDM can be clean enough to be considered suitable for re-use, if regulatory frameworks permit it.

### 7.1.4 Contaminant Destruction Technologies

In these approaches, contaminants are destroyed using biological degradation, chemical oxidation or thermal oxidation (incineration).

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14 A hydrocyclone is a mechanical device in which sediments are rotated or 'spun' which allows differential settling of the various grain sizes which enables them to be separated.
Biological destruction involves the degradation of organic contaminants into degradation products through the action of micro-organisms such as bacteria or fungi. Complete mineralisation results in the destruction of compounds to CO2, water and some residual elements, but partial biodegradation can result in breakdown products which are, ideally, less toxic and/or bioavailable than the original contaminants of concern. Such techniques are generally not suitable for recalcitrant contaminants such as metals (except some organometallic compounds including TBT), many complex or purely man-made compounds, low-level, tightly bound or highly toxic contaminants. Bioremediation also tend to be slower than some other treatment technologies. Engineered tanks (bioreactors) equipped with mixing devices, or spreading the CDM over a wide area (land farming), are used to enhance conditions for the desired biodegradation processes, usually to optimise redox conditions for the desired processes, either aerobic biodegradation or anaerobic digestion. The technique is most suitable for contaminants that degrade relatively rapidly such as low ring PAHs and mineral oils, Cleanup efficiencies from 10 – 90% (Seidel et al., 1998) have been reported, but efficacies are highly project-specific. Costs, space required, treatment times and efficiency of treatment are all highly project dependent and can range from low to prohibitive depending upon project specifics.

Chemical oxidation involves the addition of a chemical reactant to chemically break down contaminants. Mainly organic contaminants are transformed, ideally into non-toxic compounds, by chemical oxidation. These chemical processes are more rapid than their biological counterparts, but, as with biological processes, efficacy is highly project-specific and depends upon the mix and form of contaminants in CDM. Depending upon the chemicals used, different effluent and waste stream control processes must be considered.

Thermal oxidation can be used to remove, breakdown and/or immobilise many contaminants. Incineration is a thermal treatment process that has been reported to destroy up to 99.9% of PAHs, PCBs and dioxins but does not destroy metals. There is considerable commercial experience in destroying hazardous waste by incineration. Although incineration has the highest reported effectiveness of any remediation technology it has high running costs, due to energy costs and emission controls.

7.1.5 Contaminant Immobilisation Technologies

These are designed to reduce the bio-availability of contaminants in CDM using chemical or thermal mechanisms. Following dewatering, CDM is treated at high temperatures or with a range of chemical additives designed to stabilise contaminants and render the CDM suitable for disposal, recycling or beneficial re-use.

The addition of a chemical immobilising agent reduces the mobility and/or bio-availability of contaminants but does not remove them from the sediment. Chemical immobilisation can be used on CDM contaminated with a range of inorganic and organic contaminants including TBT. Some stabilisation additives are proprietary however a range of additives are known; these include cement, calcium aluminates, fly-ash, bentonite, various clays, phosphates, lime, oil residue, silicate fume and activated carbon. This approach has several benefits including simplicity, a history (in the USA and elsewhere) of use with sludge, and the capability of improving the handling of sediments.

Bricks, artificial basalt and light-weight aggregates are three examples of products that can be made using CDM that has had contaminants immobilised through immobilisation. Products have also been used for fill in port infrastructure (e.g. at Mylor Harbour, Cornwall [TBT contamination]). Thermal immobilisation directly destroys organic pollutants and fixes contaminants such as heavy metals in the mineral phase at high temperatures. CDM of appropriate grain size can be utilised after pre-treatment as a substitute raw material (e.g. fine grain-sized material is a substitute for clay in brick production).
Although this technique is not widely used in the UK, various final products have undergone rigorous testing in Europe where they have been found to satisfy environmental standards for contaminant leaching. The presence of a market for the various end-products is a key factor affecting commercial viability of this approach. Like other thermal techniques, thermal immobilisation can be an expensive technique due to the high temperatures used, and it is infrequently applied.

CDM that has been subjected to immobilisation technologies must still be disposed of or re-used; the selection of these options will depend upon the characteristics of the treated material and the regulatory framework. In terms of the waste hierarchy, most uses of CDM subjected to chemical immobilisation will be considered recycling rather than re-use as these treatments change the form of the material. With the exception of disposal to landfill, all other recycling products are subject to fulfilment of leachability criteria (a programme run by the EA) to ensure the contaminants are effectively contained.

7.2 Beneficial Use Overview

It is possible to put CDM to beneficial use both without and following treatment. Such use reduces the quantity of material for disposal and hence reduces pressures on valuable disposal space. A risk-based approach is required when using CDM for beneficial uses and risks need to be considered on a case by case basis.

Under the present FEPA licensing, the applicant must consider alternative means of disposal of marine dredged material that may include the beneficial use of CDM following treatment (MCEU 2006). However, it appears that few ports and harbour authorities actually consider sediment re-use due to legislative barriers, lack of disposal space, excessive costs and environmental concerns. Most dredged material in the UK is also composed of mud, which because of its geotechnical properties is generally unsuitable for use in land reclamation and only really suitable for projects such as wetland and mudflat restoration.

Where the characteristics of the dredged material are such that contaminant levels exceed criteria for disposal at sea (e.g. the material fails to meet OSPAR Convention requirements or exceeds Cefas Action Levels) treatment options may be considered. Such options can be used to reduce or control impacts and can use several treatment techniques (see Section 7.1) such as separating contaminated fractions that make the material suitable for beneficial use and can be considered as alternatives to disposal sea.

There are few options for the beneficial use of highly contaminated CDM and re-use is generally restricted to material that has been treated (such as thermal treatment to volatise contaminants) followed by using the sediment in the manufacture of construction material such as bricks. There is, however, a level of consumer resistance to products such as bricks made from CDM even where contaminants have been removed or immobilised or reduced to safe levels and do not pose a risk. It is, however, possible to use a risk-based approach to the use of CDM that has received no treatment before disposal, if this is consistent with regulatory regimes. CDM that is not too contaminated is also used in The Netherlands and Belgium for various purposes including road embankments and raising the level of the land.

The beneficial re-use of CDM is challenging because of the physical and chemical nature of such sediments and the requirement that contaminated material is separated from the non-toxic sediment fraction so that on re-use the risk to the environment and /or human health is minimal. Owing to increasing concerns over the placement of CDM and lack of disposal space, and increased scope for separation and stabilisation treatment to reduce the contamination risk, there has been growing interest in the beneficial use of dredged material and increasingly such material is considered far from a waste but an important environmental and economic resource (PIANC 2009). Aside from sediment that is contaminated with radioactive substances, many contaminants in CDM can, following suitable
treatment, be used as a resource and put to beneficial use, although the additional step in the treatment chain does result in higher costs for the handling of contaminated dredged material, and regulatory issues must be considered.

Treatment of CDM may be undertaken to reduce and/or remove contaminants from CDMS so that the resultant material is suitable for beneficial use. There are numerous potential uses of treated CDM (including CDM that has been mixed with cement to immobilise contaminants) for both engineering and environmental purposes. There is, however, a need to balance the benefits of reuse of treated CDM with the risks in gaining consent in the UK for such operations (e.g. there have been instances when dockyards could not use cement treated CDM for landscaping) although there are examples of using treated CDM to create high value intertidal habitat and use in flood defences elsewhere in the world. Additionally, treatment of highly contaminated CDM may be necessary to render the material suitable for disposal (e.g. after treatment, contaminant concentrations may be reduced to acceptable levels for disposal of the material). Examples of re-use include Newlyn, where CDM mixed with cement and an additive was used it to raise land levels in an area for future development (DPC, 2006).

The beneficial use of treated CDM in the UK is largely driven by the need to do something with the dredged sediment rather than due to a demand for the material. It has been estimated that about 60-70% of dredging costs are attributable to disposal and there is considerable scope for diverting finances associated with obtaining licences, monitoring and cost of disposal into the beneficial use of such dredged material. Reviews of the beneficial use of CDMS are provided by The Department for Transport (1996), USACE15, Brandon and Price (2007), Murray (2008) and PIANC (1992) and are only summarised below. There are numerous potential beneficial uses of treated CDMS and the USACE website also provides guidance on the material type that can be used in each project and also lists case studies. These may include the following subject to treatment where appropriate to remove or reduce contaminant levels and subject to compliance with the appropriate marine or land-based regulatory regime:

- **Engineering**
  - beach nourishment;
  - shoreline protection, coastal defence structures;
  - reclamation and land formation (mud is unsuitable for later construction of buildings but the reclaimed land may be suitable for other purposes such as landscaping, recreation and car parks);
  - capping of CDMS placed in open sea sites or in confined aquatic disposal (CAD) facilities;
  - construction materials including bricks;

- **Environmental Enhancement**
  - wildlife habitat creation such as islands for birds, mudflat and saltmarsh creation;
  - fishery habitats (e.g. provision of refuge habitats for fish);
  - wetland restoration;
  - maintaining sediment supply to estuarine systems through transport in the water column or direct recharge of the foreshore;

- **Agricultural Use**
  - agriculture (e.g. for non-food crops), forestry, horticulture.

There are numerous criteria that must be evaluated when considering the potential beneficial use options for treated CDM, as detailed by the US ACE, including the contaminated status of the material, site selection, technical feasibility, environmental acceptability, cost/benefit analysis and legal considerations.

In the UK, to date there has been little incentive for the beneficial use of dredged material despite the need to consider such alternatives as part of the FEPA licensing regime. However, with regard to uncontaminated dredged material, progress has been made, albeit slowly, and over the past 10-15 years quite large volumes of dredged material considered not to pose a risk to the environment have been used for various coastal engineering schemes, such as flood defence, raising land levels (Clay et al., 2008) and wetland creation (e.g. Wallasea Island in the Crouch Estuary). There has been a recent example of using CDM beneficially in the UK at the Port of Falmouth\textsuperscript{16} but the port operator encountered numerous environmental and legislative constraints that resulted in only a small proportion of the dredged material being put to a useful purpose; the majority was disposed of in landfill.

The EU Waste Framework Directive regards dredged material as waste. However, the recently agreed exception in Article 2(3) exempts the relocation of sediments for specified purposes from the provisions of the Directive, although it is still waste:

'Without prejudice to obligations under other relevant Community legislation, sediments relocated inside surface waters for the purpose of managing waters and waterways or of preventing floods or mitigating the effects of floods and droughts or land reclamation shall be excluded from the scope of this Directive if it is proved that the sediments are non-hazardous.'

'Proving' a non-hazardous status for CDM is discussed in more detail in Section 5.3.1, and there are significant challenges here. However, a project-specific, risk-based approach to the beneficial use of treated and untreated (where not highly contaminated) CDM would go a long way in reducing the costs often encountered for disposal, reduce pressure at disposal sites and help stimulate options for the beneficial use of material that can be a valuable resource. With advances in equipment, treatment and handling technologies the options for beneficial use are increasing (ENTEC, 2009). If such techniques could be accepted by the public and regulators, then there could be the potential to improve sediment management in the UK through a wider acceptance of beneficial use.

### 7.3 Disposal Options Overview

The objective of CDM disposal options is to contain contaminated dredge sediments that do not comply with standards for relocation or beneficial use in a manner that controls pathways of contaminant release or exposure to the environment. Depending upon the disposal option selected, CDM may have been subject to one or more treatment processes as described above. Treated CDM may, at the time of disposal, still pose ecological risks which must be controlled, or contaminants may be completely removed and/or immobilised. Whilst the aquatic or on land disposal of CDM may a useful technique there are those who feel that such options are not environmentally acceptable. The

\textsuperscript{16} Such use reduces the quantity of material for disposal and hence reduces pressures on valuable disposal space.
containment of CDM at sea is often perceived as ‘harder to sell’ as the remedy of choice for regulators and the general public as contaminants are left in place (or simply relocated within the sea) (Forstner and Apitz, 2007). Unlike treatment technologies that may completely destroy, remove or immobilise contaminants, disposal approaches do not remove or destroy contaminants, and thus potential pathways for contaminant loss or exposure remain. Although most disposal approaches are designed to control these pathways, there are uncertainties concerning the long-term efficacy of these approaches that may require long-term monitoring, management, and which pose potential contingent liabilities. On the other hand, many treatment technologies introduce a range of short- to long-term downstream contaminant loss or exposure pathways, waste streams, transport requirements and energy costs. The long-term pathways and costs of disposal approaches may need to be balanced against the pathways and costs of treatment-based approaches which may be initially be higher but may be lower in the long-term.

The range of disposal options that are available for a given CDM are a complex function of project-specific and regulatory criteria, and must be considered on a case-by-case basis, but the general categories, described below and depicted schematically in Figure 11, include:

- Unconfined marine disposal (not an option for most CDM);
- confined disposal facilities (CDF);
- contained aquatic disposal (CAD);
- level bottom disposal at sea with capping (placement of CDM directly on the seabed followed by capping with clean sediment);
- disposal in geotextile bags; and
- landfill/upland disposal (engineered impermeable basins above the groundwater).

Within the UK, the most common CDM disposal practices are in CDFs, landfills and using level bottom disposal at sea with capping.
Confined Disposal Facilities: CDFs are (purpose-built) engineered structures for the containment (isolation) of contaminated dredge sediments with the purpose of controlling potential releases to the environment (PIANC, 2002). CDFs are suitable for CDM containing most contaminant types without the need for treatment. The use of CDFs is well established and tested at many locations including The Netherlands, Norway. CDFs are one of the most widely used CDM disposal options in the USA. In the UK, one of the most common forms of CDF is the use of disused docks in port areas (although CDFs are not common in absolute terms in the UK), whereas elsewhere 'island' or 'open water' CDFs are widely used.

CDFs are designed to be impermeable to control pathways of contaminant loss and/or exposure. In Europe various methods, including the use of stiff clays and geo-membranes, are used to ensure an impermeable container although this impacts on the costs of disposal. Previously constructed structures, such as disused docks, if they are available locally, can reduce transport distances, and thus costs, but they may require engineering to ensure contaminant pathway containment. Once such a facility is full, capping of contained CDM with a layer of clean material can allow beneficial use of the dock surface. Although use of old facilities obviates the need to specifically construct a CDF (and thus reduces costs), such an approach is limited by their limited availability and capacity within UK ports. In addition, it should be noted that infilling a dock to above the MHWS tide datum will invoke environmental permitting regulations which may significantly complicate matters and create further costs.
Confined Aquatic Disposal/In Situ Capping: CAD/ISC facilities allow for the open water disposal of CDM followed by covering (capping) with clean natural or engineered material. CADs are generally in pits deliberately excavated into the seabed for that purpose (Fig. 8) that receive CDM, although some CADs are developed in pits excavated for other purposes, in natural depressions or natural deep water basins. In situ capping is the placement of CDM either onto the level seabed, else in a natural depression, followed by capping with clean material. CADs have not been used in the UK (although the option was posited in Falmouth) but have widely used in other countries including in Hong Kong (Whiteside et al., 1996), Belgium, The Netherlands (Hakstege, P. and Heineke, D. 2008), Norway, and USA. The efficacy of CADs depends upon site geology; for example in Boston (USA) the underlying geology is composed of stiff glacial clays (similar to that beneath the Thames estuary), which provide excellent low-permeability containment for CDM. If a CAD/ISC site is near the dredge site, transport costs can be quite low (USACE, 1987).

Once capped, CAD cells can control or slow downstream pathways of contaminant loss and exposure (Fredette, 2006). However, CADs are ‘open facilities’ during backfilling operations and until they are capped, CDM is not fully isolated from the receiving environment. In addition, unless piping or pumping into the cell is used, there are concerns about dispersal of contaminated material into the ecosystem during the process of placement, creating short-term contaminant loss and exposure pathways. Since CAD facilities are engineered structures, there are costs associated with dredging/creation of these. Some of these costs may be offset as it may be possible to obviate a dewatering process for lightly contaminated sediments.

ISC can be a cost effective disposal option for CDM disposal in which placement of the dredged material occurs directly on the seabed rather than in an excavated pit (Figure 11). There are, however, a number of downstream contaminant loss and exposure pathways introduced during the placement of CDM onto the seafloor before, during and after capping that must all be evaluated, controlled and monitored. This approach has been extensively used, particularly in the USA, but in the UK there has been single application in the form of a trial involving predominantly TBT-contaminated CDM at the Port of Tyne (refer to ENTEC (2009) (Task 5) for further detail).

The design of both CAD and ISC approaches must consider potential impacts of seabed use such as fishing, dredging, offshore port anchorages etc., as well as natural events such as storms, biological activities, tidal events, ice and other processes which may compromise the integrity of caps and must be engineered against. Although Marine Spatial Planning will be directed towards examination of potential use conflicts, it is currently difficult to exclude other users of the sea from legitimate activities and rarely are exclusion zones implemented at offshore CDM disposal sites. Thus, these risks pose potential for contingent liability and the potential for long-term monitoring and management. Whilst currently there are no monitoring guidelines within the UK for CAD/ISC disposal sites, PIANC guidance (e.g. PIANC, 2002) and monitoring guidance for marine disposal sites could be modified for this purpose. However, the monitoring programme developed for the Tyne capping trial can be used as an example, and that was based on the USACE Capping Manual monitoring guidance (USACE, 1987).

Disposal in Geotextile Bags: A special sub-class of sub-aqueous containment, at least for small volumes of material, is the containment of CDM in woven or non-woven permeable synthetic fabric bags. Such containment may reduce contaminant loss pathways during placement and help to contain CDM on the seafloor. The use of this approach may be appropriate where upland disposal sites are at a premium, or far from the CDM dredging site. Geotextile bags can – in principle - be used alone, capped using clean material on a level seabed or placed within a pit (natural/excavated) and capped, and thus can be seen as design feature of other disposal classes.
Geotextile bags have yet to be used for CDM disposal within the UK, but there are nine UK companies offering this technology. Fabric has been used for decades to make various types of receptacles for clean material; sandbags, geotextile tubing and geotextile containers been used for scour protection, artificial surfing reef construction (including Bournemouth, UK), shoreline stabilisation and riverbank engineering. Successful field trials of this approach for CDM disposal have been undertaken in Hong Kong and California, USA. Concerns about bag integrity are similar to those for other capping and containment approaches; a broad range of natural and/or anthropogenic activities must be controlled or monitored to ensure integrity. As with other disposal methods, potential pathways of contaminant loss and exposure must be considered and possibly monitored and/or managed.

Upland/landfill Disposal: Upland disposal (disposal to landfill) is the only disposal technique suitable for highly CDM that cannot be disposed of at sea, although there are restrictions in this area with respect to the type of waste individual landfill sites can accept. Landfill sites are licenced in the UK by the EA. Although CDM sent to landfill is currently exempt from landfill tax, one of the chief issues associated with the use of landfills for CDM is distance and the costs associated with the transport to landfill, which must be added to dewatering and treatment costs, which can make landfill disposal costs significantly higher than those for sea disposal. The generally small number of landfills permitted to accept hazardous wastes is a practical limitation to their use for CDM disposal, and restrictions on the classes of waste going to landfill means that this may no longer a viable option for some types of CMS.
7.4 Assessment for the Selection of Management Options

The selection of CDM management options can be a highly politicised and potentially newsworthy process. There is an increasing use of comparative assessments or similar tools that consider all risks (and, potentially, benefits) of a treatment or disposal option, including those of removal, residuals (any remaining contamination), treatment, transport disposal and/or re-use. Ideally, all appropriate and available CDM management strategies should be evaluated prior to selection; careful planning may be necessary to ensure that sampling and analysis plans are designed to address these disparate needs in a meaningful and comparable way. While it is important to develop decision frameworks that consider factors other than risk management (the control of upstream and downstream pathways, in the context of this report), within an environmental context, risk-based decision-making is widely considered a critical foundation for managing CDM.

A quantitative risk of remedy analysis compares different sediment treatment/disposal options. Implementation risks to workers and the local community associated with transportation, construction, and operation of the strategy can be considered, as can pathways of short-term ecological risk during construction and operation such as habitat or land use loss, water quality impact, recreational activities, and impacts on aquatic life. Sediments that are removed and then treated or contained pose exposure pathways during removal, transport, treatment and during and after disposal. Whilst dredging may remove contaminants from the aquatic system (although there are a number of concerns about residual risks/pathways), simply moving risks to other regions may be inconsistent with the basin-scale and regional-scale objectives. Thus, decisions that only address a single, sectoral regulatory driver (such as a desire to remove contaminants from a water body or enable the use of berth by shipping) may result in a net detriment to the environment, and the consequences of such choices require a policy-based evaluation.

Section 6.3 summarises approaches to the assessment and control of risk pathways generated during the dredging and disposal of CDM. Capital or navigation dredging of CDM is preceded and followed by a number of processes ultimately leading to sediment disposal or reuse, and the potential risks of all these steps must be considered in an overall comparative risk assessment, as well as in the design of monitoring strategies. It is also important to remember that any sediment treatment technologies may have several pre-treatment, treatment, and disposal and/or reuse steps, which may introduce various pathways of exposure to humans and the environment. Such potential exposures differ in many details as a function of the technology selected, and thus are outside the scope of this report, although it is important to remember that many treatment technologies are selected because, although they may create a number of relatively short-term exposure pathways, they are generally expected to significantly reduce long-term exposure risks when compared to containment approaches.

A well-designed decision approach identifies the trade-offs among risks, costs, and benefits that must be made in choosing the best course of action among multiple management alternatives. Available tools that can be used in making these trade-offs include risk analysis, cost-benefit analysis, and decision analysis (NRC, 1997). A number of PIANC and other documents (PIANC, 2002; 2006; 2009a,b; USACOE, 1987, 2003; USEPA/USACOE, 2004) provide specific guidance on the assessment of the risks of various aspects of the CDM management process, and suggest that these aspects must be taken into account in the selection, design and monitoring of strategies. They note that Comparative Risk Assessment (CRA), however conducted, is an inherently subjective, value-laden process. Although this raises objections by some, due to its perceived ‘lack of scientific objectivity’, it is important to remember that CDM management frameworks are not purely scientific tools, but rather, when properly

17 From Apitz (2010).
designed, are tools for using science to inform decisions within a policy-based structure. These principles have been applied to the evaluation of CDM disposal options (including aquatic containment facilities, upland containment, and treatment with beneficial re-use) (Kane Driscoll et al., 2002).

Risks to human health and the environment were modelled and compared based upon the complete management processes being envisioned, as well as other technical and socio-economic parameters. Whilst this and related frameworks were designed for their project-specific regulatory and socio-economic context, it is important to critically assess the selection and development of criteria, to ensure that they are appropriate to the scientific and policy objectives of a given country and project. This report has examined a number of UK- and European-specific decision drivers for CDM management that may be relevant to UK CDM decision frameworks.

7.5 The Selection of CDM Management Options with the UK: Balancing Disparate Decision Drivers

As described above, the selection of an appropriate management strategy for CDM generated from a specific navigation or capital dredging project is driven by a number of complex, and potentially competing factors. Specific CDM options, such as the marine disposal of CDM after land-based treatment, may be prohibited based upon specific regulatory or policy barriers. However, even when only options which are feasible within a regulatory structure are considered, there is often no obvious single choice. Some treatment strategies may be relatively high cost, but, once complete, may pose little long-term risk of exposure or liability, whilst seemingly lower cost disposal options may cost more over time due to monitoring and liability management requirements. A comparative assessment of management options seeks to put these disparate parameters into terms that can be evaluated across approaches, but the final weighting or prioritisation of various parameters is a value judgement that must be made by decision-makers, not their technical advisors (Apitz 2010).

This report addresses a broad range of issues that may affect project-specific strategy selection, including legal, regulatory, scientific, technical and socio-economic factors, all of which must be taken into account in a comparative assessment. Whilst, at this point, no comparative assessment framework is presented, the following sections evaluate various CDM management approaches in terms of a series of potential decision criteria.

7.5.1 Technology Cost, Maturity, and Availability

Critical factors in CDM management selection are the costs, availability and maturity of all technological steps in a process being considered. Costs must consider all steps, from site preparation and dredging to transport, pre-treatment, and re-use or disposal (and monitoring). Maturity of technologies is critical – an approach only tested at the bench scale is unlikely to be approved for full-scale implementation. Furthermore, technology availability is critical. Not only must the key technologies being considered be available, but also any supporting technologies must also be available, including dredging technologies supportive of the management strategy and containment and transportation infrastructure to link the steps. Tables 8 and 9 address these issues only broadly for the CDM management approaches discussed, but specific ranking factors for specific projects will require project-specific information.

7.5.2 Downstream Exposure Pathways and Contingent Liabilities

The management of CDM is complicated by the fact that the processes of removing, transporting, treating and disposing of CDM have the potential to introduce new pathways of contaminant release,
transport and exposure, all of which must be managed and can themselves result in new costs, risks and potential ‘contingent’ liabilities. The selection of a CDM management strategy must consider all these issues, within international, national, regional and site-specific legal, regulatory, technical and socio-economic constraints. As discussed in Section 7.4, different CDM management strategies create different short-term and long-term exposure pathways. Whilst these exposures cannot always be quantified, they can be put in relative terms. A number of the comparative and decision approaches are based upon the number of complete exposure pathways (ecological and human) or the degree of exposure, which will both be specific to all aspects of the CDM management strategies being considered, from site preparation to long-term containment. Whilst these pathways will be highly process- and project-specific, Table 7 provides a relative ranking for the magnitude of short- and long-term exposure pathways that may increase risk, as well as potential monitoring, and risk and liability management costs. A pathway-based ranking factor will consider these issues for each complete CDM management strategy being compared.

### 7.5.3 The European Waste Hierarchy

Whether the ultimate fate of the sediments is on land or at sea, the range of DM management options can be classified in terms of the waste hierarchy and the European waste strategy. Section 5.1.2 introduced the relationship between various CDM management options and the levels within the waste hierarchy. Table 10 categorises various treatment and disposal technologies in terms of the same hierarchy – various approaches class sediments in these terms in the context of their ultimate fate. However, it is important to note that CDM from a given project may ultimately meet a range of fates – for example, a given percentage of the CDM may be re-used after treatment, whilst a fraction may still be disposed of. Thus, a waste hierarchy-based ranking factor to be used for various CDM management strategies could be based upon a weighted score for a process – weighted hierarchy “scores” for a given option could be based upon the percent of a given CDM volume that results in pollution prevention, re-use, recycling, and/or disposal, with each potential outcome having a given score, and a volume-weighted average score being generated for comparison.

The Waste Framework Directive states:

> When applying the waste hierarchy...Member States shall take measures to encourage the options that deliver the best overall environmental outcome. This may require specific waste streams departing from the hierarchy where this is justified by life-cycle thinking on the overall impacts of the generation and management of such waste. Member States shall ensure that the development of waste legislation and policy is a fully transparent process, observing existing national rules about the consultation and involvement of citizens and stakeholders. Member States shall take into account the general environmental protection principles of precaution and sustainability, technical feasibility and economic viability, protection of resources as well as the overall environmental, human health, economic and social impacts...

Thus, there may be times when the best DM management options, in terms of the waste hierarchy, are not the best option in terms of other parameters. Given the distinct nature of the land and sea regimes for the management of CDM (Figure 7) there is a risk that specific requirements of one regime may unnecessarily distort the decision-making process and simply transfer a CDM problem from one environmental compartment (the sea) to others (the land and air). Indeed, given the physical characteristics of marine sediments and the volumes that are often involved, taking CDM to land can at times potentially create greater environmental problems that it solves. While the environmental risks of taking material to land can, to a certain extent, be managed, this may entail the creation of some potential pathways of contaminant release, higher costs, increases in the use of energy and thus...
emissions of pollutants and CO2 to air. Ultimately, the selection of CDM options are highly site-specific, and require a balance of a range of parameters, only one of which is the waste hierarchy.
## Table 7 Risks and benefits of various CDM management options.

<table>
<thead>
<tr>
<th>Option</th>
<th>Sustainability Benefits¹</th>
<th>Risk / Liability / Monitoring Issues</th>
<th>CO₂ ‡</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Short-term Exposure²</td>
<td>Long-term Exposure³</td>
</tr>
<tr>
<td>&quot;Contaminated&quot; Sediment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dewatering</td>
<td>Reduced volumes</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Particle separation</td>
<td>Clean fractions</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Thermal desorption</td>
<td>Clean product</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Bioreactor</td>
<td>Clean product</td>
<td>*</td>
<td>* to **</td>
</tr>
<tr>
<td>Landfarming</td>
<td>Clean product, biomass</td>
<td>*</td>
<td>* to **</td>
</tr>
<tr>
<td>Phytoremediation / Phyto-extraction</td>
<td>Clean product, biomass, metals</td>
<td>*</td>
<td>* to **</td>
</tr>
<tr>
<td>Thermal immobilization</td>
<td>Clean product</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Stabilisation / chemical immobilization</td>
<td>Contaminants immobilised - “clean” product</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>In-situ treatment/containment (not for DM)</td>
<td>Site recovery</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Open sea with capping</td>
<td></td>
<td>*</td>
<td>* to ***</td>
</tr>
<tr>
<td>CAD/open sea disposal with capping</td>
<td></td>
<td>*</td>
<td>* to ***</td>
</tr>
<tr>
<td>Geotextile bags for disposal</td>
<td>Structures, fill, groynes</td>
<td>*</td>
<td>* to ***</td>
</tr>
<tr>
<td>CDFs</td>
<td>Recreational space</td>
<td>*</td>
<td>* to **</td>
</tr>
<tr>
<td>Landfill disposal</td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>&quot;Clean&quot; or Cleaned sediment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relocation</td>
<td>Sediment balance; habitat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement</td>
<td>Sediment balance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beneficial re-use</td>
<td>Reduction in extraction; product; habitat creation; C emission savings</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

1. * Potential  
2. ** Based upon potential pathways of exposure during processing. Many require control or monitoring. Number of * represents relative extent of exposure pathways during and shortly after process.  
3. *** Based upon potential long-term risk after process. Although these can be controlled, they represent risk pathways, potential issues for liability and potential monitoring costs. Number of * represents relative potential number of extent pathways after process.  
4. ‡ Based on process energy needs and potential transport; rough estimate; number of ‗s indicates relative carbon emissions from low to high.
7.5.4 Other ‘sustainability’ factors

As well as waste prevention, there may be requirements to consider other risks (such as loss of land use, CO2 emission, aesthetics, public opposition) or benefits (such as beneficial use, habitat replacement, energy recovery, useable products) to sustainability. Whilst these may not be a major decision driver, they can be an important factor in gaining public acceptance to a project, and their importance in decision frameworks may increase in the near future. Various aspects are summarised in Table 10.

7.5.5 Combining decision criteria for option selection

A comparative assessment will consider the various factors described above, for the specific management strategy (from site preparation to re-use or disposal) in a transparent manner. Once critical decision criteria are selected, each option under consideration can receive a ‘score’ for that parameter based upon a clear set of criteria. Clearly, the resulting ranking table for various options only generates a table of ‘apples and oranges’ – consistent ranking factors for disparate decision criteria of differing importance. It is up to decision makers, taking into account inputs from various stakeholders, to decide how important each ranking factor is, to weight them, and then to prioritise the various options being considered. Whilst, given uncertainty and disparate priorities, this may not always designate a clear ‘winner’, this approach often removes a number of options from consideration, as various rankings may result in the top two or three options. Resources can then be focused on selecting the most reasonable option by reducing uncertainty in what are decided to be critical factors.
Table 8: Mapping of various CDM treatment and disposal options in terms of the European Waste Hierarchy. Note that not all options will be permissible for a given CDM; actual selection requires a project-specific evaluation that must consider technical, socio-economic and policy issues.

<table>
<thead>
<tr>
<th>Option</th>
<th>Processing</th>
<th>Disposal</th>
<th>Re-use (placement without processing)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For re-use</td>
<td>For recycling</td>
<td>For recovery</td>
</tr>
<tr>
<td>Dewatering</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Particle separation</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Thermal desorption</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioreactor</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landfarming</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Phytoremediation / Phyto-extraction</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Thermal immobilization</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stabilisation / chemical immobilization</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-situ treatment/containment (not for DM)</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>For re-use</td>
<td>For recycling</td>
<td>For recovery</td>
</tr>
<tr>
<td>Open sea with capping</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>CAD/open sea disposal with capping</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geotextile bags for disposal</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>CDFs</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landfill disposal</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Re-location5</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement6</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beneficial re-use1</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Re-use is the use of the material in the same form (through cleaning or separation is acceptable). Beneficial use.
2. Recycling is the use of material in a different form after processing. Can be beneficial use, but material is changed (bricks, aggregate etc)
3. Recovery of energy, biomass or other materials (metals?)
4. Aquatic or upland
5. Placing dredged material at specific locations so that it fulfils its role in the sediment balance (Mink et al, 2006); without treatment

The disposal of unprocessed dredged material at disposal locations. Mink et al (2006) argue that this can be classed as re-use as it supports sediment balance.

<table>
<thead>
<tr>
<th>Option</th>
<th>Costs</th>
<th>Benefits</th>
<th>Uncertainties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Economic</td>
<td>Environmental</td>
<td>Social</td>
</tr>
<tr>
<td>Natural dewatering</td>
<td>£7-18/m3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mechanical dewatering</td>
<td>Fixed - £7-22/m3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Particle separation</td>
<td>£2.8/m3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Thermal desorption</td>
<td>£37.52/ton</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bioreactor</td>
<td>&gt; £74/m3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Landfarming</td>
<td>£8.2/m3 * dewatering</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phytoremediation / Phyto-extraction</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td>Thermal immobilization</td>
<td>Brick £11-22/m3 LWA £11-26/m3 Artificial basalt - £52/m3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Stabilisation / chemical immobilization</td>
<td>Covering Land £7-11/m3 Construction £17-30/m3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Option</td>
<td>Costs</td>
<td>Benefits</td>
<td>Uncertainties</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-------------------------------</td>
<td>----------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td></td>
<td>Economic</td>
<td>Environmental</td>
<td>Social</td>
</tr>
<tr>
<td>In-situ chemical</td>
<td>£44-74/m³</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-situ biological</td>
<td>£11-22/m³</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CDFs</td>
<td>£8-59/m³ +dewatering + monitoring costs</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>Landfill disposal</td>
<td>£1-205/t</td>
<td>-</td>
<td>- -</td>
</tr>
<tr>
<td>CADs</td>
<td>£4-26/m³ + monitoring costs</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>Open sea with capping</td>
<td>£33/m³ + monitoring costs</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>Geotextile bags for disposal at sea</td>
<td>£80/m³</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Subjective scale:
Economic (impacts in addition to those monetised): + (-) small; ++ (- -) medium; +++ (- - -) high
Environmental: + (-) no further deterioration/improvement; ++ (- -) small change; +++ (- - -) major change.
Social: + (-) small; ++ (- -) medium; +++ (- - -) high
8. RESEARCH NEEDS

The sustainable management of CDM within the UK must consider and integrate a range of social, economic, legal, environmental, and technology-related criteria. The development and improvement of CDM management nationally requires a strategic approach directed towards specific issues, especially in the current economic climate, in which funding will undoubtedly be limited.

NOC (2009) (Task 6) carried out literature searches on CMS research to assess the range of research in the field, using a range of on-line resources. The focus was on recent papers, and resources found (2013 references) were placed in an EndNote10 searchable bibliographic database delivered with the project. A review of literature focused upon reports from previous workshops and projects and suggested key research and development (R&D) priorities summarised below:

- Multidisciplinary research to understand links between sediment contamination and its actual risk is required:
  - Understanding bioavailability for a range of contaminants will improve predictability and modeling of risk and effects;
  - This will lead to more realistic Action Levels, therefore better risk and cost-benefit analysis in relation to CDM management.

- There will always be a need to address new contaminants and constantly review target compounds using:
  - New, improved bioassays, including small-scale multi-species tests, microbial tests and artificial receptors;
  - All these have strengths and weaknesses that must be understood.

- The efficacy of treatment, land-based and at sea disposal methods (both mature and innovative) should be investigated:
  - Pilot and field studies are needed.
  - Contaminant release pathways for various strategies should be studied.
  - In situ monitoring techniques should be developed.

These recommendations can also be supplemented by the following, based upon a review of other task outputs:

- There is the need for specific monitoring frameworks for various containment strategies, possibly based upon those developed for UK marine disposal sites, and inclusive (potentially) of legal but as yet untested (within the UK) approaches e.g. submerged geotextile bags.

- There is the need for a comprehensive review of the UK CDM management capability (inclusive of the terrestrial soil remediation sector), technically and commercially.

- There is the need for the development of CDM management decision frameworks.
9. **SUMMARY AND WAY FORWARD**

Managing CDM is a complex and politically charged issue. It is set within an evolving regulatory and socio-economic context, and requires an integrated strategy for affordable, sustainable long-term maintenance of ports and waterways. This project was carried out in support of strategy development.

Historically, sediment has been considered a valuable resource, and as much as possible has been used beneficially. If not usable, the goal is to cost-effectively and safely dispose at sea. But, contaminants in sediments mean that not all sediments can be used or disposed of at sea. In the short term, this means that there is a need to select and obtain permits for alternative management approaches. In the longer term, contaminant sources should be controlled so that sediments can be re-used or disposed of without controls. This project supports a strategy for these objectives.

Key project components include:

- CMS problem definition on national scale – database development
- Review of legal context and Polluter Pays Principle (PPP)
- Review of regulatory context
- Examination of source identification and control approaches
- Review of sediment treatment and disposal options and technologies
- Review of scientific literature and research needs
  - Within a sustainable development framework
  - All considering BPEO
  - With wide consultation

9.1 **Characterising the extent of the CDM issue in the UK**

To characterise the CDM issue, a national database of contaminated marine sediments (metals, TBT) in UK waters was developed in Task 1 (ABPmer, 2009a), using a variety of data sources. The database is designed to be used to establish the contaminants driving the classification of sediments as ‘clean/lightly contaminated’, ‘moderately contaminated’, and ‘contaminated’ for which management approaches are, or may potentially be, different. GIS tools, using ESRI’s ArcGIS software provided a user-friendly and intuitive data display interface. The final storage location for the database is yet to be confirmed by Defra. Section 4 of this report highlights, through example, the range of GIS tools which allow for data to be visualised temporally and spatially, and for generation of statistics, for coastal and estuarine regions. Specific queries provide question-focused and exportable maps, charts and outputs, either nationally or regionally. A User Manual provided by the project describes these in more detail.

Some issues of database maintenance and end user access are still to be determined. It was recognised by the project that data including CDM volume (and clean DM volume) and licence application reference were not available, and future integration of these will substantially increase the generic utility of the database. A proposal is made to derive a process, or protocol, to capture/summarise regional information within the database to aid management of future (individual) licence applications.

The data can be put in the context of Action Level thresholds, which can be the UK values, or can be customised for regional or site-specific concerns. These action levels put contaminant levels into an ecological and regulatory context and can be used to highlight sites/regions that may be classified as CMS/CDM or may require further study. Within this framework, the data were used to summarise the extent of contamination for the following estuaries: the Humber, Severn, Thames, Mersey, Tyne, Tees, and Fal. This review indicated that all industrialised estuaries are, to a greater or lesser extent,
contaminated by (multiple) metals. For many estuaries (with possibly the exception of the Thames estuary) concentrations for many metal species lie between the two CEFAS Action Levels. The chief contaminants driving concentrations in this category include Cr (Forth), Cr and Ni (Humber), Cu, Zn and Pb (outer Clyde/Gare Loch, Tyne, Tees, Humber), Cd and Hg (Tyne, Tees) and Cr/As (Tees, Humber). For these estuaries, further evaluation will be required by the FEPA regulator in order to judge suitable disposal options for many licence applications. Broad-scale spatial trends in the level of contamination are found in some estuaries e.g. in the Mersey the north shore is measurably more contaminated than the south shore. In both the Tyne and Tees estuaries, the estuary mouth region appears less contaminated than more upstream regions. High concentrations of metals (and TBT) i.e. at levels thought sufficient to potentially cause environmental impacts if disposed of at sea are found predominantly at inshore berth and dock areas. Different contaminant species are found in different estuaries (e.g. numerous Zn hotspots are found in the Tyne; Ni/Pb/Zn are found at Goole [Humber estuary]; As in the Fal). For these areas the FEPA regulator will likely not licence disposal to sea, which may impose additional complexity and potentially additional cost to dredging projects.

TBT is a contaminant species that is found nationally around the coast. 85% of samples contain low concentrations of TBT (<0.1 mg kg\(^{-1}\)) which are of no environmental concern. The data indicate that, all other things being equal, sea disposal of TBT contaminated sediments may be an option for the majority of future dredge applications for many but not all estuaries. 3-13% of samples exhibit concentrations where sea disposal may not be permitted without further evaluation. Localised (hotspot) areas occur in the Severn ports (especially Swansea), and the Tyne, Tees and Fal estuaries. In all estuaries, the TBT occurs in hotspots (e.g. close to industrialised dock areas, berths etc.).

The widespread occurrence of metal/TBT contamination in estuarine sediments around the UK indicates that there may be scope for sharing a management solution between various port authorities, notwithstanding constraints imposed by different sediment characteristics. Given the nature of the commercial sector to respond only where there is an economic level of business, this would require a significant public-private/inter-agency/stakeholder co-ordination in order to be realised on a practical level.

9.2 Exploring liability and the Polluter Pays principle

As operational management costs for managing CDM have increased and are likely to go on increasing significantly in the future, more focus has fallen upon the question of who should be responsible for these costs as well as who should bear the risks consequent to, and associated with, the management of CDM.

To explore the compatibility of historical legacy issues with the ‘polluter pays principle’, YLS (2009) (Task 2) focused on some specific issues. Using appropriate case studies to identify generic issues, they explored potential legal liability regimes and set out principles for resolving liability/indemnity issues, with specific assessment of the implications of the Environmental Liability Directive (ELD).

They found that liabilities relating to historically contaminated marine sediments can be grouped within two categories:

- "Operational Management" liability (reflecting the increased costs of managing, moving and disposing of CDM); and
- "Contingent Liabilities" (arising from such operational management).

The study finds that there are no general answers to questions relating to the recovery and transfer of costs and liabilities incurred as a result of operational dredging activities to those who were responsible
for historic contamination. The regulations implementing the Environmental Liability Directive (2004/35/EC) do not apply before March, 2009. As these are directed at ‘environmental damage’, nor will they usually provide for compensation between parties in relation to normal operational management.

The principal relevance is to the potential for Contingent Liabilities which might arise when undertaking operational management activities in which a new pathway is created through which contaminant risk to the environment is increased e.g. at the point of dredging, or at the point of or subsequent to marine disposal ('downstream pathways'). In these situations, the Environmental Liability Directive/Regulations may be applicable, and so provide a means of applying the PPP to those who created these pathways.

The selection of a CDM management strategy must consider potential downstream pathways resulting from all phases of CDM management. Whilst some downstream pathways, such as the resuspension of CDM during dredging, are relatively short-term, some pathways, such as the potential loss of CDM from a disposal site, may persist for long periods of time. If a management strategy being considered does not completely remove or immobilise contaminants, it is possible that potential pathways of contaminant release will require long-term monitoring, management and possible legal or contractual approaches to manage contingent liability. The costs of such approaches, particularly for any novel disposal techniques, may need to be balanced against the costs of management approaches which may be initially be higher but have lower long-term costs.

Should contaminants escape, the potential liabilities amongst parties are case-dependent, and may be influenced by legal agreements between parties, as well as regulatory controls. A range of structures and techniques for the management of Contingent Liabilities can be employed in order to allocate and address legal risks; these include insurance, indemnities and Special Purpose Vehicles, which can be utilised. Without these, the uncertainties of such liabilities might inhibit operational management of CDM, and the use of novel techniques in particular.

**9.3 Identifying existing relevant legislative and regulatory barriers, guidelines and protocols, with respect to CDM**

Specific objectives for Task 3 (ABPmer, 2009b) were to:

- Outline and interpret relevant directives and legislation and identify overlaps and cross-linkages;
- Ascertain the implications of current and potential future legislation on the strategy and consider possible future options for moving forward;
- Clarify the legal issues surrounding the classification/ categorisation of DM as waste or reclamation material and hence the broad options available for disposal/re-use; and
- Work with industry to identify examples of barriers to the common sense approach and the implementation of the spirit of legislation.

International, European, and national legislation are relevant to DM management. London Convention and Protocol and the OSPAR Convention are particularly important for DM disposal at sea. These require an evaluation of disposal options to be made before making a decision on whether DM can be disposed of at sea. In the UK, FEPA licence application requires a review of the alternatives, including a cost assessment. The technical assessment of the suitability of DM for disposal is undertaken by Cefas using a weight of evidence approach.
On land, requirements that apply to CDM depend on whether it is to be disposed of at sea or taken to land for treatment, recovery or disposal. Waste management on land is primarily defined by EC Directives, in particular the Waste Framework Directive(s). Where CDM is brought to land it will be classified as waste, although whether it is classified as "hazardous waste" requires further consideration.

While the management of CDM at sea and on land are complex, relatively few significant legislative barriers have been identified. The main issues identified relate to:

- Uncertainties relating to the interpretation of EC Directives in relation to the evaluation framework for sea disposal.
- Uncertainties relating to the criteria and policies to be applied for re-use, recycling and recovery of contaminated marine dredge material on land.
- Clarification of whether controlled waste under the waste management regime on land can be disposed of at sea and how the chain of custody might be completed.
- Interpretation of the provisions of the OSPAR and London Conventions on the classification of marine sediments that have been treated to reduce contaminant concentrations.

The study recommends that interpretations and clarifications of the provisions under OSPAR, the London Conventions and the revised Waste Framework Directive are sought in relation to each of these issues. It is critical that the foundation for these uncertainties i.e. whether they are grounded in perception, interpretation nationally and internationally, policy or regulatory areas, is identified.

9.4 Establishing best practice for the prevention of pollution arising from CDM

Source control is fundamental to OSPAR and the London Convention:

"For dredged material and sewage sludge, the goal of waste management should be to identify and control the sources of contamination. This should be achieved through implementation of waste prevention strategies and requires collaboration between the local and national agencies involved with the control of point and non-point sources of pollution."

In terms of CDM, "pathways" of contaminants from their source to a target or location under consideration can be described as 'upstream' and 'downstream'. An upstream pathway is one by which contaminants can move from any identified source, through the marine system to the location where sediment needs to be dredged. If the accumulated contaminant concentration levels are high enough at the site that the sediments, if dredged, will be considered CDM, then these pathways can result in increased operational management costs.

Task 4 (ABPmer, 2009c) provided a conceptual approach to pathway identification for CMS, as well as some strategies for managing sources and pathways. However, this is a complex problem. This study finds that the UK already has sufficient legislation in place to control the input of many contaminants into a water body and to control their potential to cause pollution. However, the manifold pathways for the introduction of contaminants into the marine environment have the potential to integrate inputs from so many diverse contaminant sources that at times it is difficult to predict or to trace contamination movement. The clear identification of specific direct pathways between source and sediment will in many cases be extremely difficult.

A downstream pathway is one by which CMS disturbed during operational management results in the further transport or release of contaminants. Whilst it is possible to reduce, minimise or eliminate some of these pathways, pathways introduced by operational management have the potential to introduce new risks, control and/or monitoring obligations and contingent liabilities. Task 4 provided a conceptual
framework for the assessment and control of downstream sources generated by CDM management and considered in depth the management practices that might be imposed to ensure that dredge disturbance and relocation activities do not cause pollution to the water body in question. Sources from all steps of the management process must be considered. A range of physical, management and legislative controls exist that can be applied to reduce downstream pathways generated from CDM management. The conceptual framework should be useful to Defra and their technical advisors in formulation of a management framework/strategy for CDM. In addition, delivery of the frameworks in present or modified versions to those with CDM problems may also be of benefit to aid their local management of CDM.

9.5 Establishing best practice for current disposal and treatment options for CDM

Task 5 (ENTEC, 2009) sought to identify best practice, within the UK nationally and internationally, for the disposal and/or treatment of CDM in close liaison with industry and contractors. Their review considered environmental, economic, social and legislative aspects, strategic and public acceptability aspects. To achieve this, they provided case studies of good and bad management in order to capture and understand the reasons behind successes and failures, and they assessed currently available techniques including newly emerging technologies and existing novel ideas currently employed in other applications. A range of CDM treatment and disposal options were critically assessed in terms of economic, environmental and societal costs and benefits, uncertainties, degree of maturity and technical strengths and weaknesses. The Task 5 report forms Best Practice Guidelines for the treatment and disposal of CDM incorporating current disposal protocols, although it does not capture the present UK CDM remediation capability in any depth.

Task 3 and this synthesis together set the range of disposal and treatment technologies and practices, in terms of their technical, environmental, economic and market characteristics as well as within the context of the Waste Hierarchy.

9.6 The selection of CDM management options with the UK: balancing disparate decision drivers

The selection of an appropriate management strategy for CDM generated from a specific navigation or capital dredging project is driven by a number of complex, and potentially competing factors. Specific CDM options, such as the marine disposal of CDM after land-based treatment, may be prohibited based upon specific regulatory or policy barriers. However, even when only options which are feasible within a regulatory structure are considered, there is often no obvious single choice. Such decisions can be aided by evaluating various management options in terms of a range of decision criteria. These include: technical issues reviewed in Task 5, issues of upstream source, project volume and frequency, technology cost, maturity and availability, downstream exposure pathways and contingent liabilities, the Waste Hierarchy, other social and sustainability factors, and a consideration of regulatory and perceptual barriers. The consideration of all these factors is critical to formulation of both a strategy and decision-making framework for CDM. This project finds that appropriate comparative assessment of management options seeks to put these disparate parameters into terms that can be evaluated across approaches, but the final weighting or prioritisation of various parameters is a value judgement that must be made by decision-makers, not their technical advisors. These observations may aid government to separate responsibility for framework and strategy development.

9.6.1 Technology cost, maturity and availability

It was found that costs can be very case-specific, and that economies of scale were important. In the management process every effort is made to reduce the CDM volume, and yet the commercial sector operates (in the main) most effectively on larger volumes. Thus, at single sites, certain treatment
options may not achieve economies of scale that could be achieved for repeated or regional management approaches. Task 5 concluded that there was 'a lack of proven treatment technologies for CDM, most such techniques having only been tested at the pilot scale.' However, a parallel review by Kevin Black (project co-ordinator) investigating the range of UK remediation companies concluded that 'there are many; 29 companies in coastal areas, which means shipping/handling costs could be minimised'. It is possible that the differing conclusions are based upon the difference between those companies having treated CDM and those who have treated soil and state they can treat CDM. Past experience suggests such expertise is not always directly transferable, so the reason for these different conclusions must be critically assessed. This points to a clear need for a critical review of the experience and commercial availability of novel and mature CDM management technologies in the UK.

9.6.2 Upstream source, project volume and frequency

Contamination can result from many types of sources, active and historic. Unless major sources are managed, CDM problems can return, continue and/or spread. The types of upstream sources, their controllability (Task 4), and the projected need for dredging must all be considered when CDM management strategies are developed. Public-private initiatives including stakeholders (such as the recent Tyne Sediment Study) are a valuable approach to characterising contaminant inputs to estuaries and developing holistic sediment management plans where ongoing source inputs are acute and not easily controlled. If upstream pathways can be controlled, however, it may be worth upstream investment to offset management costs. On the other hand, if long-term inputs and the need for dredging are anticipated, then investment in treatment or disposal infrastructure may be justified. In such cases, regional investment or shared resources may help spread the cost of the capital investment for management technologies, and the licensing and development of regional disposal facilities may be considered. If either contamination or the need to dredge is, on the other hand, expected to be a one-off, other options may be best, as the economies of scale for long-term management may not be met.

9.6.3 Downstream exposure pathways and Contingent Liabilities

The management of CDM can introduce downstream pathways, which must be managed and can themselves result in new costs, risks and potential 'contingent' liabilities. The selection of a CDM management strategy must consider these issues:

- Technical aspects of this are addressed in Tasks 4 and 5;
- Legal aspects are addressed in Task 2;
- Research gaps are identified in Task 6; and
- Monitoring issues are addressed in Section 6.3.2.

Different CDM management strategies create different short-term and long-term exposure pathways. Whilst these exposures cannot always be quantified, they can be put in relative terms. Approaches can be compared based upon the number of complete exposure pathways (ecological and human) or the degree of exposure, which will both be specific to all aspects of the CDM management strategies being considered, from site preparation to long-term containment. These pathways will be highly process- and project-specific, but short- and long-term exposure pathways may increase risk, as well as potential monitoring, and risk and liability management costs. The long-term costs of managing pathways may, at times, offset the cost savings for disposal vs treatment. How such issues are to be compared, evaluated, controlled, regulated and monitored are critical gaps that must be addressed in a successful strategy.
9.6.4 The European Waste Hierarchy

Whether the ultimate fate of the sediments is on land or at sea, the range of DM management options can be classified in terms of the waste hierarchy and the European waste strategy. Various treatment and disposal technologies can be classified in terms of the same hierarchy. However, CDM from a given project may ultimately meet a range of fates. A given percentage of the CDM may be re-used after treatment, whilst a fraction may still be disposed of, and any management framework for CDM must possess the flexibility to optimise this partitioning of sediments during assessment and handling.

9.6.5 Other social and ‘sustainability’ factors

It may be useful to consider other risks (such as loss of land use, CO2 emission, aesthetics, public opposition) or benefits (such as beneficial use, habitat replacement, energy recovery, useable products) to sustainability. Whilst these may not be major decision drivers, they can be important factors in gaining public acceptance for a project. Their importance in decision frameworks may increase in the near future. Many of these aspects were reviewed in Task 5. Selected parameters, tailored to process and project-specific issues, can be used in a comparative assessment of CDM management strategies.

9.6.6 CDM Management Strategy Decisions

This project has identified a number of potential barriers to effective CDM management (summarised in Section 9.3). These barriers must be addressed, and for many this will require activity at a higher (political) level. This project has also identified and characterised a number of potential decision parameters that can be used in CDM management option selection. At times, these decision parameters, when considered alone, suggest different optimal choices. Transparent decision frameworks should be designed to allow for the consistent, but project-specific evaluation of decision criteria are required to inform management strategy selection. Clear ranking factors can help identify trade-offs that can be weighted and communicated. Ultimately, such approaches can at least identify a shortlist of options that can be taken further before selection - at best they can guide final selection.

9.7 Literature review, research gaps and priorities

Task 6 (NOC 2009) carried out literature searches on CMS research to assess the range of research in the field, using a range of on-line resources. The focus was on recent scientific and technical papers, and resources found (2013 references) were places in an EndNote10 searchable bibliographic database delivered with the project. A review of literature focused upon reports from previous workshops and projects and suggested key research and development (R&D) priorities summarised below:

- Multidisciplinary research to understand links between sediment contamination and its actual risk is required:
  - understanding contaminant[s] bioavailability will improve predictability and modeling of effects;
  - This will lead to more realistic Action Levels, better risk and cost-benefit analyses; and
  - A potential reduction in CDM.

- There will always be a need to address new contaminants and constantly review target compounds using:
  - New, improved bioassays, including small-scale multi-species tests, microbial tests and artificial receptors.
All these have strengths and weaknesses that must be understood.

- The efficacy of treatment, land-based and at sea disposal methods (both mature and innovative) should be investigated:
  - Pilot and field studies are needed.
  - Contaminant release pathways for various strategies should be studied.
  - In situ monitoring techniques should be developed, in particular for legal, novel (but as yet untried in the UK) disposal options (e.g. geotextile bags).

These recommendations can also be supplemented by the following, based upon a review of other task outputs:

- There is the need for monitoring frameworks for various containment strategies, possibly based upon those developed for UK marine disposal sites;
- There is the need for a comprehensive review of UK CDM remediation capability, technically and commercially; and
- There is the need for the development of CDM management decision frameworks.
10. REFERENCES


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Defra 2006 The control of marine works dredging /disposal at sea and approval of oil dispersants. 38pp.


Envirotreat 2001 Case Study: Ex-situ Immobilisation. Mylor Harbour, Cornwall. 2pp


PIANC(2002) ‘Environmental guidelines for aquatic, nearshore and upland confined disposal facilities for contaminated dredged material’


11. **APPENDIX I SUMMARY MAPS OF DATA DENSITIES FOR SELECT UK ESTUARIES.**

The black dots indicate data from the project GIS (Task 1); the purple dots indicate data from the database.

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**Tyne**

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**Fai**