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Guidance on the Beneficial Use of Dredge Material in Ireland

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Executive Summary

Dredging is essential to maintaining navigable access to Ireland's main ports and harbours. Sustainable management of both the coarse and fine grained fraction of the generated dredge material is required. Disposal at sea has been, to date, the most common dredge material management approach practiced in Ireland, although a range of different beneficial uses have been implemented, particularly for coarse grained dredge material.

This report provides guidance on the beneficial use of dredge material in Ireland. It provides information on dredge material characterisation, best international practice in dredge material management, a summary of current practice in Ireland and guidance on the relevant governing legislation.

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Abbreviations

AL	Action Levels
BS	British Standard
BES	Bentonite Enriched Soil
C&D	Construction and Demolition
CCL	Compacted Clay Liner
CDMS	Contaminated Dredge Material Sediment
CEFAS	Centre for Environment, Fisheries & Aquaculture Science (UK)
DBT	Di-Butyl Tin
DAFM	Department of Agriculture, Food and the Marine
DAHG	Department of Arts, Heritage and the Gaeltacht
DECLG	Department of Environment, Community & Local Government
DEFRA	Department of Environment, Food and Rural Affairs (UK)
DM	Dredge Material
DOER	Dredging Operations and Environmental Research Programme (USA)
DOP	Damen Onderwater Pomp
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
GIS	Geographic Information System
HELCOM	Helsinki Commission
IMO	International Maritime Organisation
JAMP	OSPAR Guidelines for Monitoring Contaminants in Sediments
MALSF	Marine Aggregate Levy Sustainability Fund
MMO	Marine Management Organisation
MS	Manufactured Topsoil
MSW	Municipal Solid Waste
NCDENR	North Carolina Department of Environment and Natural Resources
NRA	National Roads Authority
OMC	Optimum Moisture Content
OPC	Ordinary Portland Cement
OSPAR	Oslo and Paris Convention
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PIANC	Permanent International Association of Navigation Congresses
PREMIAM	Pollution Response in Emergencies: Marine Impact Assessment and Monitoring
SAC	Special Area of Conservation
SedNet	European Sediment Network
SPA	Special Protection Area
SPI	Sediment Profile Imagery
SQGs	Sediment Quality Guidelines
TBT	Tributyl tin
TIE	Toxicity Identification Evaluation
USACE	U.S. Army Corps of Engineers
WMA	Waste Management Act

1. INTRODUCTION

1.1 Introduction

This report has been prepared by Cork Institute of Technology under the Environmental Protection Agency STRIVE Small Scale Study Programme.

This report provides guidance on the beneficial use of dredge material (DM) in Ireland. It provides information on DM characterisation (including contaminated material) in the context of DM management in Chapter 2. Chapter 3 presents a review of best international practice (and current practice in Ireland) and the different options available for beneficial use of DM. Guidance on the relevant governing legislation for dredging and DM management is presented in Chapter 4 and Chapter 5 presents an illustrative case study.

DM can be considered to be a valuable resource of sediment material if properly applied in a beneficial manner. Such beneficial use of DM allows different and innovative DM management practices to be implemented, may significantly reduce the environmental impacts associated with the disposal of the DM and may reduce project costs with the potential added benefit of re-using a material which has traditionally in many cases been considered to be a waste material.

In recent decades a significant volume of research work has been conducted on potential beneficial uses of DM and the trend in DM management practice internationally has been towards greater application of beneficial use of DM and also implementation of a wider range of beneficial uses. The positive outcomes may include reduction in disposal volumes of DM, reduction in negative environmental impacts, project cost savings and in some cases creation of a useful product from the DM.

This international trend towards the more sustainable use of DM, which has been driven by economic and environmental considerations and encouraged and facilitated by legislation, is also evident in Ireland.

This report provides information on a range of potential beneficial uses of DM in an Irish context. It is intended to support and enhance the decision-making process for DM management and in turn contribute to the increased beneficial use of DM in Ireland.

1.2 Dredging and DM Management Practice in Ireland

Dredging is essential to maintaining navigable access to Ireland's main ports and harbours which account for 99% of Ireland's imports and exports by volume and 95% by value (Shields et al., 2005).

DM volumes generated in Ireland are relatively small by international standards with an annual maintenance dredging requirement of approximately 0.64 million dry tonnes. The capital dredging requirement varies significantly and has been primarily generated by port expansion and/or modernisation works, and tunnel and pipeline construction. To date only a relatively small number of dredging projects in Ireland have encountered contaminated DM.

Disposal at sea has been the most common DM management practice in Ireland; practically all maintenance DM, which is fine grained in nature, is disposed to licensed offshore disposal sites. In contrast approximately 40% of capital DM in recent years has been reused beneficially, primarily the coarse grained sediment fraction. Recent work by Sheehan et al. (2009) indicates that, overall, approximately 20% of DM generated in Ireland over the previous decade was beneficially used.

Disposal of DM at sea in Ireland is regulated by the Environmental Protection Agency (EPA) under the Dumping at Sea Acts 1996 to 2010. These Acts recognise the potential beneficial uses of DM and permission to dump at sea is granted only if the EPA and the OSPAR requirements for re-use of materials are satisfied that there is no suitable alternative means of land-based disposal, treatment or reuse of the material.

It may be concluded that while a range of beneficial uses of DM has been implemented in Ireland, there is significant potential to increase both the level of application of beneficial use of DM and also the range of beneficial uses implemented.

2. DM CHARACTERISATION

2.1 Overview

Accurate assessment and characterisation of dredged sediments is essential to ultimately achieving the sustainable management of DM. Reliable and standardised evaluation techniques are required to define the sediments' physical, chemical and biological properties. Information on these properties is essential to the selection of an appropriate DM management option for a specific site.

Sampling, testing and analysis to characterise DM is required at the planning stage of a dredging project. Section 2.2 presents recommended methods for sampling, testing and analysis to characterise DM. There are, however, currently no formal standards for assessing dredged sediment in Ireland in the context of beneficial use. However, a range of international guidelines are used including the OSPAR (2009) guidelines for DM management and characterisation and CEFAS (2002) which presents recommended standards for DM sampling and assessment. Other guidelines commonly used include PREMIAM (2011), IMO (2005), MALSF (2011) and the Marine Institute (2006). A brief summary of these is presented in Table A1 in Appendix A.

The Irish Marine Institute (2006) has published guidelines on the assessment of DM for disposal at sea in Irish waters where National Sediment Quality Guidelines (SQGs) are presented. The purpose of these guidelines is to establish a comprehensive national framework for assessing the quality of dredged material and its potential contaminants.

Dredge material contamination and the management of this contaminated material is an important topic. Guidance is presented in DEFRA (2010) but to date no such guidance has been published in Ireland. The treatment of contaminated DM is presented in Section 2.4.

2.2 Dredge Sediment Surveying, Testing and Sampling

The first step in characterising DM is to gather in-situ sediment samples at the potential dredging site sufficient for subsequent testing and analysis. It is important that an adequate survey plan be prepared in conjunction with implementation of best sampling practice to ensure sufficient quality control.

DM properties are site specific hence the importance of developing independent surveying and sampling plans for a specific dredging project. These may vary according to the nature and perceived sensitivity of the environment, the volume and area to be dredged, and the need to address other activities nearby (CEFAS, 2002). A number of guidelines provide recommendations on surveying and sediment sampling including PREMIAM (2011), the OSPAR Commission (2009) and the Marine Institute (2006). Pre-application consultation initially with the EPA and then with the relevant public authorities (e.g. the Marine Institute, relevant government departments) is strongly advisable at an early stage in the development of a surveying and sampling plan.

Figure 2.1 presents a recommended sequence for developing a pre-dredge survey.

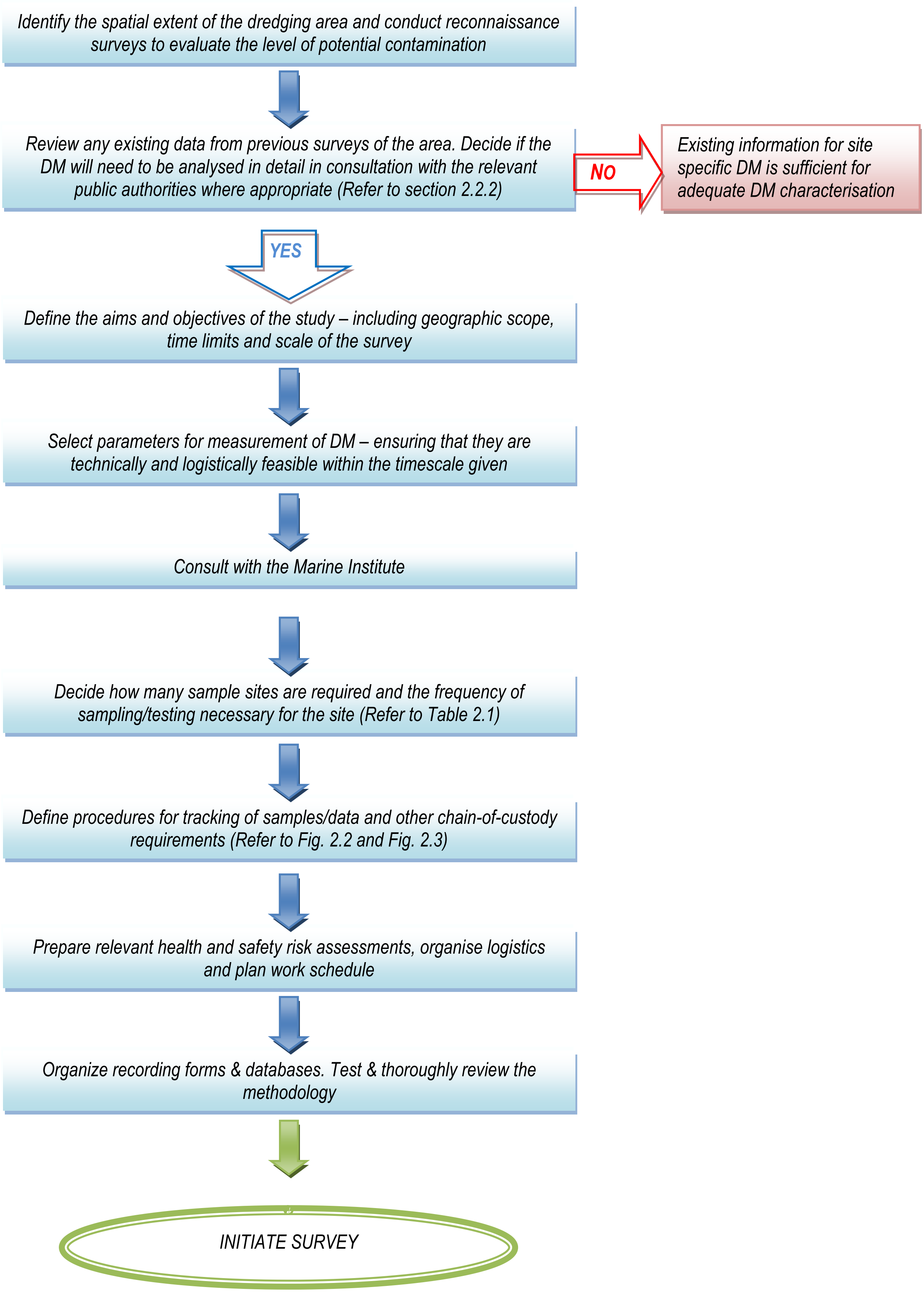


Figure 2.1 Steps for developing a pre-dredge survey (adapted from PREMIAM, 2011)

Once the survey plan has been finalised the distribution and depth of the sampling required to be undertaken can be determined. The sampling programme should reflect the size and depth of the area to be dredged, the volume to be dredged and the expected variability in the horizontal and vertical distribution of any contaminants present (OSPAR, 2009). The number of sampling stations chosen will depend on the project constraints and the level of statistical rigour required for the sample data. Recommendations for the number of individual direct sampling stations relative to the volumes of DM are presented in Table 2.1. Detailed guidance on the spatial extent and design layout for sampling may be found in IMO (2005).

Table 2.1 Recommended Number of Sampling Stations for Direct Sampling Techniques (OSPAR, 2009)

Volume Dredged (m^3)	**Number of Stations**
Up to 25,000	3
25,000 – 100,000	4 - 6
100,000 – 500,000	7 - 15
500,000 – 2,000,000	16 - 30
> 2,000,000	extra 10 per million m^3

2.2.1 Guidance on DM Sampling Methods

The range of sampling equipment required and the associated size and capability of the survey vessel needed for the sampling will depend on the spatial extent of the sampling, the number of samples required, and the existing available data (CEFAS, 2002).

Sampling methods can be categorised as:

- *Direct sampling* includes various types of mechanical grabs and corers customised for different sediment types and used to obtain physical sediment samples.
- *Indirect sampling* describes the use of GIS mapping, acoustic sampling and Sediment Profile Imagery (SPI) to obtain in-situ sediment data whilst minimising disturbance to the local environment.

Greater detail is provided in Bray et al. (1997) and MALSF (2011).

Table 2.2 provides a summary of some common indirect sediment sampling techniques used.

Table 2.2 Selection of indirect sediment sampling methods (Freitas, 2005; Coggan and Birchenough, 2007; USGS, 2012)

INDIRECT SAMPLING METHOD	**DESCRIPTION**	**COMMENTS**
Geographic Information System (GIS) Mapping	IT system capable of capturing, storing, analysing, and displaying geographically referenced information acquired using various surveying techniques.	Collates data from sources such as underwater photographs, sonar etc. or a combination of different data sets combined to produce a mapping of the area of sea-bed, indicating variations in sediment properties.
Acoustic Sampling	Uses high-resolution acoustics to profile the sea bed based on the Doppler effect.	Well established, popular method of non-intrusive sea-bed profiling. Ability to cover large areas with almost continuous data collection. Requires extensive calibration prior to use.
Sediment Profile Imagery (SPI)	Involves penetrating the sediment in-situ with a prism-type 'camera' that takes numerous photographs of the cross-sectional area of sediment.	Provides a more detailed and accessible image of the sediment but to maximum depth range of 20cm below the seabed. Not as wide ranging as acoustic sampling.

2.2.2 Frequency of Sampling and Testing

Some relevant recommendations on the frequency of sampling and testing for maintenance dredging projects are provided in OSPAR (2009) and HELCOM (2007):

- *"If the results of the analyses indicate that contamination of the material is below the upper action level (paragraph 5.14), sampling in the same area need not be repeated more frequently than once every 3 years, provided that there is no indication that the quality of the material has deteriorated."*
  (Ref.: HELCOM, Section 7.5, p. 7)

- *"It may be possible, following assessment of the results of an initial survey, to reduce either the number of sampling stations or the number of determinants and still provide sufficient information for permitting (or licensing) purposes. If a reduced sampling programme does not confirm the earlier analyses, the*

full survey should be repeated. If the list of determinants is reduced, further analysis of the complete list of determinants is advisable every 5 years.”
(Ref.: OSPAR, Section 7.6, p. 7)

- *“In areas where there is a tendency for sediments to exhibit high levels of contamination, analysis of all the relevant determinants should be frequent and linked to the permit (or licence) renewal procedure.”*
  (Ref.: OSPAR, Section 7.7, p. 7)

IMO (2005) have stated that the frequency of measurement “generally will depend on the quantity of material involved, sensitivity of the receiving environment, known inputs of contaminants and any problems revealed by previous investigations”. They also state that “where previous investigations have shown the sediment quality to be relatively consistent over time and there are no new pollution sources, it may be necessary to <u>*sample only every 3-5 years*</u>…….”

2.2.3 Exemptions from Testing

In some circumstances detailed testing and analysis of sediments may not be required where the sediments are unlikely to be contaminated. DM <u>**may**</u> be exempted from testing if any of the criteria below are met, adapted from OSPAR (2009) and IMO (2005):

a) it is composed of previously undisturbed geological material; or
b) the volume to be dredged is estimated at <10,000 tonnes; or
c) it is composed almost exclusively of sand, gravel or rock with a low fine material content and/or the content of total organic carbon is low; or
d) sufficient information from previous investigations indicating the absence of contamination is available; and
e) there are no known significant sources (point or diffuse) of contamination or historic inputs

2.3 DM Characterisation Techniques

Accurate physical, chemical and, if necessary, biological characterisation of dredge sediments is essential to the decision making process.

It is recommended that normalisation of the analytical results is undertaken to improve the accuracy of the data. Normalisation is the procedure for correcting contamination levels to account for natural differences in sediment composition. It is commonly used to correct site data for sediment grain size, organic matter and mineralogy. Guidance on employing normalisation techniques can be found from the Marine Institute (2006) and OSPAR, 2009 (Technical Annex 2).

2.3.1 Physical Characterisation

Introduction

The physical properties of DM are an important consideration in the overall decision making process. Physical testing of the sediments should be initially undertaken as the results may establish the need for further chemical or biological analysis.

Reasons for testing

The physical characteristics of DM are important indicators of its engineering properties and any potential environmental impacts. These engineering properties also can be used to determine DM suitability for specific beneficial uses. Typical engineering properties which may influence potential beneficial use of the DM include particle size distribution, permeability, sediment settling characteristics, plasticity and mineralogy. It should be noted that some of these physical properties may actually be altered by the dredging process.

What type of testing should be undertaken?

The primary physical characteristics to be assessed and the associated laboratory test(s) are presented in Table 2.3.

Table 2.3 Primary physical characteristics of DM and associated tests (Sheehan, 2012)

PHYSICAL CHARACTERISTIC	**ASSOCIATED TEST (as per BS 1377, 1990)**
1. Particle size distribution	Standard sieve and hydrometer tests
2. Water content	Moisture content test
3. Engineering properties	Compaction test
4. Permeability characteristics	Permeability tests
5. Atterberg Limits	Plasticity and liquidity tests
6. Organic content	Ignition test

Greater detail on testing procedures for physical characterisation of DM is presented in IMO (2005) and MALSF (2011).

2.3.2 Chemical Characterisation

Introduction

Chemical analysis of DM indicates the presence of chemicals within the sediment which may have potentially negative environmental impacts. Sediment chemical characteristics are influenced both by natural geological variation and by anthropogenic sources of contamination. These chemical characteristics are generally classified as follows (PIANC, 1992):

1. Nutrients
2. Metals
3. Organics
4. Radioactive substances

Reasons for testing

The chemical characteristics of the sediment may significantly influence the potential DM management technique that can be applied, both in terms of potential environmental impacts and the influence that certain chemical characteristics may have on the suitability of the DM for a specific beneficial use.

The chemicals that are considered to be the most detrimental to the aquatic environment are those that are persistent, toxic and bio-accumulate in the food chain and include:

- Heavy metals (e.g. mercury, lead, arsenic, zinc, cadmium)
- Organotin compounds (e.g. Tri-Butyl Tin *[TBT]*, Di-Butyl Tin *[DBT]*)
- Polychlorinated Biphenyls – PCB's (e.g. paints, plastics, adhesives)
- Polycyclic Aromatic Hydrocarbons – PAH's (e.g. Oils, diesel, hydraulic fluid)

It is common international best practice for individual countries to develop 'Action Lists' of potential contaminants together with 'Action Levels' which set lower (AL1) and upper (AL2) limits on acceptable levels of contaminant concentration. Ireland is contracted to the OSPAR Commission which requires each member to produce its own Action List and Action Levels. Ireland's Action List with lower and upper limits for assessing the suitability of DM for disposal at sea is presented in Table 2.4.

If concentrations of any of the contaminants included in the Action List presented in Table 2.6 exceed the upper limit levels, then the DM is likely to require some degree of treatment before it may be beneficially used. The treatment options available in Ireland are presented in detail in Section 2.5.

- DM which contains contaminants below the upper limit but above the lower limit will need further consideration to determine its suitability for beneficial use.
- DM which contains contaminants with concentrations below the lower limits can be considered acceptable for beneficial use.

OSPAR (2009) recommends that chemical characterisation of dredge sediments may not be necessary if sufficient, reliable information on the specific area being analysed is available from existing sources and that this testing has occurred within the last five years. Recommendations on the frequency of sampling are presented above in Section 2.2.2.

Table 2.4 Ireland's Action List; with associated limits (OSPAR, 2008a)

CHEMICAL COMPOUND	UNITS (dry weight)	LOWER LEVEL – AL1	UPPER LEVEL – AL2
Heavy Metals			
Arsenic (As)	mg/kg	9	70
Cadmium (Cd)	mg/kg	0.7	4.2
Chromium (Cr)	mg/kg	120	370
Copper (Cu)	mg/kg	40	110
Lead (Pb)	mg/kg	60	218
Mercury (Hg)	mg/kg	0.2	0.7
Nickel (Ni)	mg/kg	21	60
Zinc (Zn)	mg/kg	160	410
Organic Contaminants			
PCB 28	µg/kg	1	180
PCB 52	µg/kg	1	180
PCB 101	µg/kg	1	180
PCB 118	µg/kg	1	180
PCB 138	µg/kg	1	180
PCB 153	µg/kg	1	180
PCB 180	µg/kg	1	180
Sum PCB_7	µg/kg	7	1260
γ - Hexachlorcyclohexane	µg/kg	0.3	1
Hexachlorbenzene	µg/kg	0.3	1
TBT + DBT	mg/kg	0.1	0.5
Total Extractable Hydrocarbon	mg/kg	1000	-
PAH_{16}	µg/kg	4000	-

What type of testing should be undertaken?

The three general options for chemical testing with implications in terms of complexity and cost (IMO, 2005) are as follows:

1. Preliminary assessment e.g. smell, colour, visual inspection, contaminant history of sites, possible local contaminant sources
2. Laboratory testing by a qualified/certified analytical laboratory
3. Send the samples abroad for analyses by a qualified/certified analytical laboratory where there is no or limited access to such appropriate laboratory facilities in Ireland

The chemical compounds presented in Table 2.4 are classified as contaminant compounds which have an associated 'action level' to determine their potential impact on the environment. However, these contaminant compounds are not the only chemical properties which may need to be determined for a full DM chemical characterisation; the other relevant chemical compounds which may be required to be analysed are presented in Table 2.5.

Table 2.5 Primary chemical properties of DM and associated tests (adapted from DOER, 1999)

CHEMICAL PROPERTY	ASSOCIATED TEST
1. Organic Content (e.g. plant, animal, and microbial residues)	Total Organic Carbon (elemental [CHN] analyser), C:N Ratio
2. Ionized hydrogen (H+)	pH testing
3. Salinity and soluble salts	Electro-conductivity, Sodium Absorption Ratio (SAR)
4. Nutrient content (Nitrogen and Phosphorus)	Percentage N; Extractable P; Total Phosphorus/Orthophosphorus
5. Potassium, magnesium and Sulphur	Extractable potassium, magnesium and sulphur tests
6. Contaminants (e.g. TBT, PAH's, heavy metals)	Refer to Table A.2 in Appendix A

A substantial list of appropriate characterisation tests for chemical properties of DM to determine suitability for beneficial uses can be found in Table A.2 of Appendix A, with greater detail provided in the JAMP guidelines (JAMP, 2007).

2.3.3 Biological Characterisation

Introduction

Biological characterisation is generally only undertaken when the results from the physical and chemical characterisation process are insufficient to fully assess the DM. Careful consideration must be given to the type of biological testing required as many techniques are costly with potential implications for project expenditure.

Reasons for testing

Biological testing determines the toxicity and bio-accumulative properties of the dredged sediment and provides insight into potential environmental impacts that may not have been established by the physical and chemical analyses. Assessing the levels of toxins in the sediment and the likely effects of bioaccumulation on the local ecosystem is important for the potential beneficial use planned, for example in the case of environmental enhancement such as wetland creation/restoration where there may be a potential impact on the local species.

What type of testing should be undertaken?

Some common biological tests include:

- Toxicity bioassays
- Toxicity Identification Evaluation (TIE)
- Biomarkers
- Microcosm experiments
- Mesocosm experiments
- Field observation of benthic communities

These tests integrate existing sediment conditions and evaluate the bioavailability of contaminants in the sediment. The chemical species (form) of contaminants determine their bioavailability and potential for uptake, bioaccumulation, and toxicity once they reach their site of action in living organisms, not simply their presence in DM. Toxicity Identification Evaluation (TIE) procedures can represent a useful approach for identifying acutely toxic compounds in sediments (DOER,1999). Greater detail on biological testing techniques is provided in JAMP (2007) and the Marine Institute (2006).

2.4 Treatment of Contaminated DM

To date only a relatively small number of dredging projects in Ireland have encountered contaminated dredge material. The DM contamination encountered has been associated with current and historical industrial activities, mining activities and wastewater inputs (Clenaghan et al., 2005). The primary contaminants found in DM in Ireland include heavy metals (e.g. mercury), organo-metal complexes (e.g. tributyl tin – TBT) and various organic congeners (e.g. Polychlorinated Biphenyls – PCBs and Polycyclic Aromatic Hydrocarbons – PAH's). TBT contamination from marine paints has been encountered at Castletownbere Harbour and Killybegs Harbour, lead and PAHs have been encountered at Dublin Port while a range of heavy metals have been found in dredge sediments in Arklow Harbour. The DM management approach implemented in these scenarios has varied, from isolation to stabilisation and export for treatment to confinement of the contaminated material.

Contaminated DM has not been treated in Ireland to date excluding basic stockpiling and de-watering. It may be noted that Ireland's capacity to treat contaminated material in order to render it less hazardous is currently very limited and investment in the commercial treatment of contaminated soil in Ireland remains unattractive due to the variable quantities of contaminated soil and sediment produced and the relatively low gate fees of hazardous waste facilities in other EU countries. However a range of economically viable treatment options are now available increasing the potential for beneficial use of treated DM.

If the levels of contaminants exceed specific parameters as set out in the relevant Sediment Quality Guidelines (SQG), then appropriate action must be taken. Recommended SQGs for Ireland are presented in Table 2.6 from the Marine Institute (2006).

Legislation for Contaminated Dredged Marine Sediment (CDMS) and its potential classification as hazardous waste may lead to difficulties in achieving an efficient and economic solution for re-use or disposal. Contaminated DM is categorised as a hazardous waste material under the EU Waste Framework Directive (and under the European Waste Characterisation Code and the Hazardous Waste List) inhibiting its potential beneficial use and resulting in the only feasible option being treatment (as presented in Table 2.6) and disposal of the DM. There is potential for the beneficial reuse of contaminated material after treatment as outlined in Chapter 3.

As presented in Section 2.2 above, it is essential to provide accurate analysis of the DM characteristics and identification of potential contaminants at the preliminary stage of any dredging project to optimise the decision making process for the beneficial use of DM.

2.4.1 Treatment Options Available for Ireland

The objective of any treatment phase is to reduce, remove or immobilise the contaminants and in doing so to render the DM less hazardous to the marine environment and human health. In general these treatment processes account for most of the cost of a remedial dredging project. The typical removal rates for contaminants vary considerably depending on the type and the level of contamination present, the particle size distribution of the sediment to be treated as well as the number of treatment cycles to be applied. For example the achievable removal rates from one treatment cycle of Soil Washing include 80-90% for PAHs, 65-75% for heavy metals and >90% for mineral oils.

One of the potential problems with any treatment process is that any specific method may be only designed to eliminate or reduce a particular type of contaminant. Therefore if the sediment contains more than one contaminant the costs incurred can be considerable and sometimes even make the proposed project uneconomic. The by-products of treatment including gas and water also need to be considered.

Table 2.6 outlines some of the different treatment options currently available for Ireland (generally ranked in order of the most common applications internationally) and the types of contaminant that each treatment can remove and the category of sediment (DM) that it is best suited to. Some approaches that are only at a research/test phase are also included, detailed investigation is required prior to implementation of any specific treatment option.

In a national context it has been suggested that Ireland could become self-sufficient in treating its own contaminated waste through the use of cement kilns, hazardous waste landfill and incineration (Sheehan and Harrington, 2012a). The existing cement kiln network, for example, could be used for destroying contaminants and immobilising heavy metal contaminants to produce a cement product. Mobile soil treatment plants, for example, thermal desorption and soil washing, are all available in Ireland and may be a viable alternative to reducing the quantity of contaminated DM treated or exported.

Table 2.6 Treatment options for Ireland (Hakstege, 2007; SedNet 2007; Reddy, 2005; Aquacritox, 2010)

Treatment Options for Contaminated Dredged Material		**Applicability for Common Contaminants**				**Sediment (DM) Type**					
TITLE	**COMMENTS**	Heavy Metals	PAH	TBT	PCB	Saltwater	Soft Clay	Silt –Soft Clay	Sand – Silt	Consolidated Clay	Gravel-Sand Mix
1. Soil Washing	Contaminated sediment is separated from the reusable DM. The left-over CDMS is stabilised as a filter-cake ready for further treatment/disposal.	✓	✓	✓	✓	✓	✗	✓	✓	✗	✓
2. Mechanical Dewatering	Filter presses are used to reduce the water content of DM by up to 80%, removing suspended/soluble contaminants. Filter-cake is produced. Commonly used as a pre-treatment for other treatment methods.	✓	✓	✓	✓	✓	✓	✗	✓	✓	✗
3. Geotextile Tube Dewatering	Tubes are fabricated from synthetic geotextile that 'sieves' the DM, reducing contaminant concentrations and allowing the treated water to filter out, whilst retaining and consolidating the solid matter of the DM.	✓	✗	✓	✗	✓	✓	✓	✓	✗	✗
4. Thermal Desorption	Hazardous organic compounds, and some volatile metals, are heated and converted into gases/liquids which are collected for safe disposal.	♦	✓	♦	✓	✗	✓	✓	✓	✗	✓
5. Landfarming or Ripening	DM is spread over land and undergoes natural aerobic degradation removing organic contaminants. Heavy metals may also be removed using additional treatments (see 11 & 12).	✗	✓	✗	✓	✓	✓	✓	✓	✗	✗
6. Bio-reactors	Varying sizes of vessels are used to contain the DM whilst it undergoes various microbiological processes to degrade organic contaminants. % degraded depends on the length of treatment time.	✗	✓	♦	✓	✓	✓	✓	✓	✓	✓

7. Stabilisation	Chemical compounds (e.g. cement) are added to the CDMS; stabilizing &/or immobilising the material for use in construction or to reduce leachability and bio-availability on disposal. May require pre-treatment dewatering.	✓	♦	✓	♦	✓	✓	✓	✓	✓	✗
8. Thermal Immobilisation	Dewatered DM is melted and crystallised. Organic contaminants are destroyed in the process whilst inorganics are accumulated for safe disposal or treatment.	✓	✓	✓	✓	✓	✓	✗	✓	✓	✗
9. Thermal-chemical Immobilisation using cement kiln	DM is mixed with fuel, air, and modifiers in a cement kiln. Organic contaminants are destroyed and heavy metals are immobilized in the cement matrix. A clinker-material is produced which can form cement.	♦	✓	✓	✓	✓	✗	✓	✓	✗	✓
10. Pyrolysis	Organic contaminants are destroyed in anaerobic conditions. Organic and inorganic compounds are separated in the process. Requires extensive pre-treatment dewatering.	✗	✓	♦	✓	✓	✓	✗	✓	✓	✗
11. Super-Critical water oxidation*	New technique currently being researched in Ireland. DM is heated under high pressure causing the water content to enter 'super-critical' stage which destroys all organic contaminants. Inorganics are mineralised into sterile compounds which may have beneficial uses.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
12. Dewatering using Wetland Plants*	Studies have concluded that certain species of wetland plants are adept at dewatering and subsequently removing contaminants from DM.	✗	✓	✗	✓	✓	✓	✓	✓	✗	✓
13. Electro-osmotic Dewatering*	A small electric potential is applied across the DM inducing rapid flow of water as a result of physio-chemical and electro-chemical processes. Hydraulic conductivity and shear strength of consolidated DM are also increased.	✓	✓	✓	♦	✓	✓	✓	✓	✓	✓
14. Electro-kinetic Extraction*	Electro-kinetic technology is a technique that employs a low direct current to facilitate the ionic metal transport through porous media (DM).	✓	♦	✓	♦	✗	✓	✓	✓	✗	✓

Key: ✓ *Suitable* ♦ *Partially suitable* ✗ *Unsuitable*

** Treatment method still undergoing research as to its applicability in practical DM treatment on an industrial scale*

3. BENEFICIAL USES OF DM

3.1 International Best Practice

A wide range of beneficial uses of DM have been practiced; these may generally be categorised as:

1. *Engineering uses*: Involves beneficially using DM typically as an alternative to land based resources (for example quarry aggregate) and is common in many engineering projects, e.g. land reclamation, beach nourishment and coastal protection works.
2. *Environmental Enhancement*: Involves using DM as a resource with the potential for environmental enhancement when managed in a sustainable manner, e.g. habitat creation or sediment cell maintenance.
3. *Agricultural and Product uses*: Suitable DM may be used to form useful products or in the agricultural sector once the appropriate physical, chemical and biological properties comply with the appropriate industry standards, e.g. manufactured topsoil, landfill cover or production of ceramics/bricks/concrete.

The rate of beneficial use of DM in Ireland has been estimated at approximately 20% with a very limited reuse of the fine grained fraction (Sheehan et al., 2009). Higher levels of beneficial use (and also a wider range of types of beneficial use) are practiced in other developed countries with some examples presented in Table 3.1.

Table 3.1 Summary of a Selection of International DM Re-Use (Sheehan et al., 2009)

Country	**Percentage of Total DM Re-used (%)**	**Comments**
Ireland	20	Insignificant use of maintenance DM; 44% of capital DM reused (Sheehan et al., 2009)
United States	20 – 30	Uses include: habitat development; development of parks and recreational facilities; agricultural, forestry, and horticultural uses; strip-mine reclamation/solid waste management; shoreline construction; construction/industrial; and beach nourishment (USACE, 2007)
Netherlands	23	4% of this material is treated before reuse, 4% has a direct reuse and 15% is spread on land (Palumbo, 2007)
Spain	76	Used primarily for land reclamation and beach nourishment projects (Vidal, 2006)
Japan	90	Engineering uses (e.g. Construction of airport with DM stabilized with cement) and environmental enhancement e.g. Tidal Mudflats (DPC, 2009)

In a European context, countries with a significant tradition of dredging and DM management include the Netherlands, Germany, Norway, Belgium, France and Italy where developing and implementing efficient and sustainable DM management practices have priority. A summary of these countries' national strategies and practice for DM management is presented in Table A.3 in Appendix A; some information on DM management practice in the USA is also included.

The EU Waste Framework Directive (2008/98/EC) establishes a hierarchy for prioritising the management of waste streams. Figure 3.1 presents this hierarchy in a DM management context. The hierarchy ranges from the least favourable disposal option to the most favoured prevention option or in practice minimising the dredge volume generated.

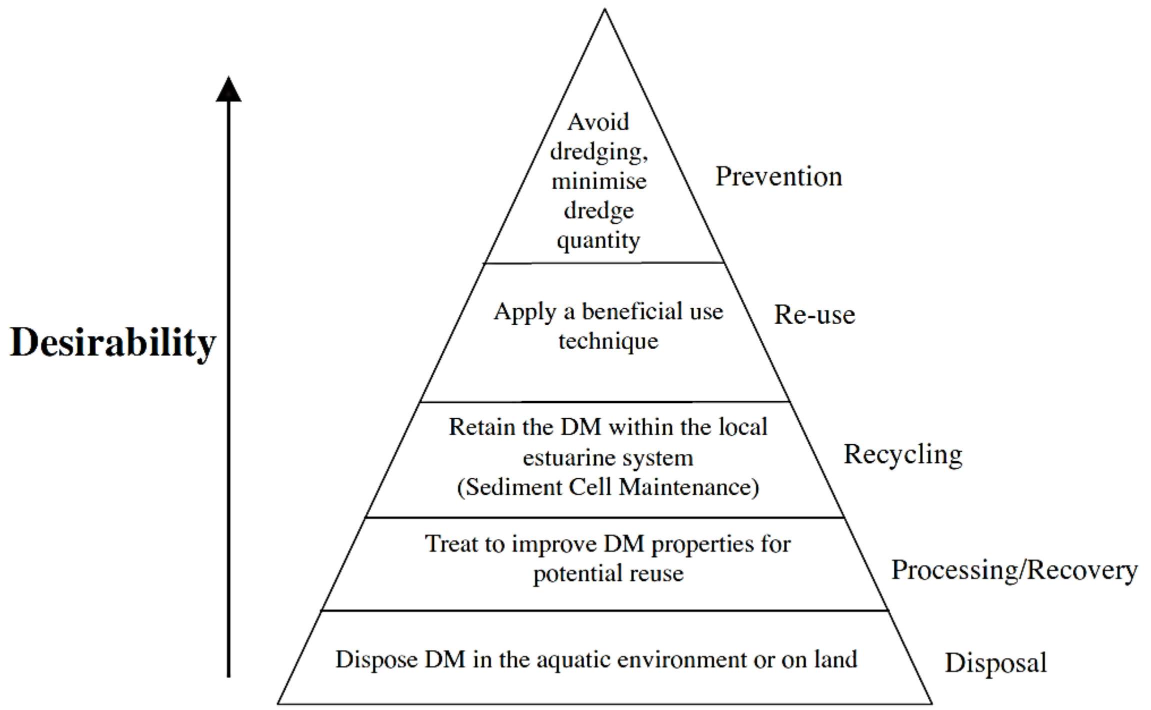


Figure 3.1 Hierarchy for Prioritising DM Management (adapted from Waste Framework Directive, 2008)

3.2 Options for Beneficial Use of DM

Sections 3.3, 3.4 and 3.5 presented below describe the most common beneficial use options available for different types of DM under the headings of Engineering Uses, Environmental Enhancement and Agricultural & Product Uses. These beneficial uses are briefly described and some of their most significant details highlighted. Implementation of any of these technical uses at a particular site will require significant additional study. In some cases specific beneficial uses presented on one category could as easily be presented under another category, e.g. beach nourishment is presented as an engineering use although it may also provide environmental enhancement in the coastal zone. In other cases a number of similar technical uses are described under a single heading for purposes of simplicity, e.g. land improvement is presented with land reclamation.

Table 3.2 presents the main types of beneficial use of DM currently practiced internationally, with comparison to Irish practice. Ireland's application of the engineering uses is considerable with a significant number of projects completed to date with different end uses. There is also potential for greater implementation of agriculture and product uses of DM which to date has been quite limited in Ireland.

Table 3.3 presents a summary of some recently completed dredging projects in Ireland that have featured different approaches to DM management including the innovative beneficial use of DM. Table 3.4 presents a similar summary for a range of international dredging projects. Table 3.5 presents some of the different beneficial use options available and suggests the type of DM that may be generally applicable for each use.

Table 3.2 Types of Beneficial Use Practiced Internationally with Comparison to Ireland (Sheehan, 2012; Van Der Wal, 2010; Hakstege, 2008; Pennsylvania DEP, 2001)

Type of Beneficial Use	**Practiced in Ireland (up to 2013)**	**Comments**	**No. of Projects in Ireland (up to 2013)**
		Engineering Uses	
Beach Nourishment	✓	Common practice internationally. Recently used in Rosslare Europort, Drogheda, Bray and Greystones, Co. Wicklow for amenity conservation and coastal protection	>4
Land Reclamation	✓	DM has been used at various sites throughout Ireland to reclaim areas of land and to raise the level of flood prone land, e.g. Killybegs (Co. Donegal).	>5
Landfill Cover	✓	Recently used in Dublin Royal Canal Dredging project after dewatering by geotubes	1
Coastal Protection	✓	DM has been used internationally for coastal protection works through geotubes or more commonly by the use of the rock or gravel, used in breakwater constructions in several locations in Ireland.	>4
Offshore Berm Creation	X	Artificial offshore berms of DM have been constructed in the US, South Africa, The Netherlands, and Australia	0
		Environmental Enhancement	
Wetland Habitat Creation / /Enhancement	✓	Numerous projects in the UK and elsewhere have been successfully completed. Most common beneficial use for fine grained DM. Recently used in Ireland (Shannon Wetland) for wetland creation as part of a tunnel construction project	1
Sediment Cell Maintenance	X	Used in the River Thames, London, for example, to prevent erosion and maintain sediment balance	0
Fill for Quarries / Mines	X	Fine grained DM used as inert fill material (combined with a cementitious compound) throughout the US, and the Netherlands, in abandoned mines, quarries and borrow pits.	0
Upland Habitat restoration / Creation	X	Numerous projects completed internationally	0
		Agricultural & Product Uses	
Concrete manufacture	✓	Used internationally as raw material for various products. Recently used at Caladh Mor Harbour as a raw material (aggregate) for the manufacture of precast and insitu concrete members.	2
Road sub-base construction	X	Used in France (Dunkirk Harbour) where fine grained DM was successfully used as a raw material in road sub-base construction.	0
Landfill Liner	X	Several research programmes have established the potential suitability of DM as an alternative landfill liner material; Riordan et al. (2008), Zhang and Wu (2005) and Kaewkaorop (2007)	0
Manufactured Topsoil	X	Evaluated for its feasibility and used in Scotland, the United States and France on individual projects. Comprehensive study (Sheehan et al., 2010) for fine-grained DM from Port of Waterford used to produce manufactured topsoil yielded positive results.	0
Production of Ceramics / Bricks	X	Various studies in Belgium, Germany and Spain have concluded that using suitable DM (and contaminated DM) as a raw material in brick manufacture is feasible	0

Table 3.3 Examples of recent dredging projects in Ireland involving beneficial use of DM (Sheehan & Harrington, 2012)

Project Type	Irish Site Details	Project details & management techniques used
Capital Dredging	Caladh Mor harbour, Aran Islands, Co. Galway. Completed in 2008.	Dredging of rock to form a harbour basin and associated navigation channel; and an offshore breakwater to protect the new harbour facility. Dredging of approx. 25,000 m^3 of pre-blasted rock and offshore dredging of approx. 4,000 m^3 of limestone rock All dredged rock brought ashore for use as infill material for the core of the breakwater and pier, and also crushed to manufacture precast and in-situ concrete for the works.
Capital Dredging	Limerick Tunnel construction, Co. Limerick. Completed in 2010.	Dredging consisted of a 400 m long, 16 m deep trench across the River Shannon, which produced 400,000 m^3 of DM DM pumped into sedimentation lagoons which ensured that the turbidity of the return water fell within strict environmental limits. The tunnel was backfilled and surrounded by 75,000 tonnes of rock and approximately 250,000 m^3 of the original DM. The constructed lagoons planned as a wetland area in a locally designated Special Area of Conservation (Shannon wetlands creation).
Capital Dredging	Royal Canal, Co. Dublin. Completed in 2010.	Dredging of approximately 15,000 m^3 of freshwater sediment. Particle size distribution was 70% clay, 20% silt, 10% sand and gravel with 50% organics. Geotubes used to dewater the DM prior to trucking away (dry) and to allow rapid return of the effluent to the canal system. Dried material trucked to landfill as permanent landfill cap.
Maintenance Dredging - irregular	Rosslare Europort, Co. Wexford. Completed in 2011	Dredging approximately 156,000 m^3 of sand. DM used as beach nourishment material at nearby Rosslare Strand.
Capital and Remedial Dredging	Castletownbere Harbour, Co. Cork. Completed in 2006.	Dredging of 100,000m^3 of material, approximately 35% of which was contaminated DM. Contaminated DM treated on site; sieved to separate coarse and fine particles, larger material re-cycled in road construction. Finer material placed in specialist hopper and mixed with cement to stabilise the material. It is then stored in a lagoon for dewatering and further stabilisation prior to being shipped abroad for treatment/disposal.
Capital and Remedial Dredging	Killybegs Harbour, Co. Donegal. Completed in 2004	Dredging of approx. 510,000 dry tonnes of sediment. Silt fraction of DM accounted for 10% of total and was disposed at sea. Remaining coarse fraction re-used to form a reclaimed pier area. TBT contamination present but avoided due to excessive cost of management/treatment.
Capital and Remedial Dredging	Dublin Port, Co. Dublin. Completed in 2005	225,000 dry tonnes of sediment excavated to accommodate large draft vessels. DM contaminated with Lead and PAH's which was removed with grab and stored on barge. Area was then excavated to a depth of 3m whereupon the CDMS was replaced and covered with 2m of clean material, remaining clean DM disposed at sea.

Table 3.4 Examples of International dredging projects involving beneficial use; (Kirby, 2012), (USACE, 2012); (Hakstege, 2008), (USACE & USEPA, 2007), (MERR, 2012)

Project Type	International Site Details	Project details & management techniques used
Maintenance Dredging	Port of Leer, Leda Estuary, Germany.	Sediment cell maintenance of the Port is achieved by sloping the floor of the dock so that settling sediment flows down the gradient into a collecting sump. An automatically operating dredge pump is sited in the base of a conical collector attached to a discharge pipeline back to the estuary. Operation of the device is controlled by a silt sensor. This system has now operated successfully for 8 years without any additional back-up; the payback time was 3.2 years *(Kirby, 2012)*
Maintenance Dredging	Ocean Beach, San Francisco, California, USA	One of numerous examples of offshore berm deployment along the US coast. Sediment dredged from the San Francisco navigation channel totalling approx. 900,000 cu yd, was placed offshore of a local erosional hot spot in the vicinity of Ocean Beach, California. Sediments were placed in the nearshore to mitigate erosion impacts along this beach through both wave attenuation and sediment supply. *(USACE, 2012)*
Maintenance Dredging	Kaliwaal, Druten Region, the Netherlands.	Former sandpits, adjacent to the river, were filled with suitable DM. After filling, the site will be transformed into a nature reserve area, a project supported by the World Wildlife Fund. *(Hakstege, 2008)*
Capital & Maintenance Dredging	Baptiste Collette Bayou, Plaquemines Parish, New Orleans, Louisiana, USA	DM used to create and restore wetland habitats between 1977-1995. Pumped DM via pipeline used to build six bird islands. 700,000 to 900,000 cubic yards annually from 1977 through 1994. Over 542 acres of habitat created. Created habitats include: marsh, shrub/scrub, bare land, and beach. The bird islands at Baptiste Collette have been nominated as a United States Important Bird Area. (*USACE & USEPA, 2006)*
Maintenance Dredging	Lymington Harbour, Lymington, Hampshire, England.	DM removed during maintenance dredging of the harbour area used to raise the level of an area of intertidal mud within the adjacent saltmarsh. The raised level of sediment will prevent further erosion from wave-attack and help replenish the protected habitat of the saltmarsh. *(MERR, 2012)*

Table 3.5 Beneficial Use options for DM (adapted from Sheehan, 2012)

		DM Suitability based on Characterisation									
Category of Beneficial Use	**Type of Beneficial Use**	Uncontaminated	Contaminated	Freshwater	Saltwater	Soft Clay	Silt –Soft Clay	Sand – Silt	Consolidated Clay	Gravel-Sand	Rock
Engineering Uses	Beach Nourishment	✓	X	✓	✓	X	X	X	X	✓	♦
	Land Reclamation	✓	♦	✓	✓	✓	♦	✓	✓	✓	✓
	Landfill Cover	✓	♦	✓	✓	✓	✓	✓	X	X	X
	Offshore Berm Creation	✓	X	✓	✓	✓	✓	✓	✓	✓	✓
	Coastal Protection Works	✓	✓	✓	✓	X	X	✓	✓	✓	✓
Environmental Enhancement	Wetland Habitat Creation/Enhancement	✓	X	✓	✓	♦	♦	✓	✓	✓	X
	Sediment Cell Maintenance	✓	X	✓	✓	✓	X	✓	✓	♦	X
	Fill for Abandoned Mines/Quarries	✓	✓	✓	✓	✓	♦	✓	X	X	X
	Upland Habitat Restoration/Creation	✓	X	✓	X	♦	✓	♦	✓	✓	✓
Agricultural / Product Uses	Concrete Manufacture	✓	♦	✓	♦	X	✓	✓	X	✓	X
	Road Sub-base Construction	✓	✓	✓	X	X	♦	✓	✓	✓	X
	Landfill Liner	✓	♦	✓	✓	X	♦	X	✓	X	X
	Manufactured Topsoil (MS)	✓	♦	X	✓	✓	✓	✓	X	X	X
	Production of Ceramics/Bricks	✓	✓	✓	✓	✓	X	✓	✓	X	X

Key: ✓ Suitable ♦ Partially Suitable X Unsuitable

3.3 Engineering Uses

3.3.1 Beach Nourishment

Description

DM may be beneficially used to protect a coastal area suffering erosion; supplementing lost beach material periodically to sustain the shoreline and mitigate the impacts of erosion. While beach nourishment is an option to help manage coastal erosion it can also prevent localised flooding, lessen the impact of storm damage by dissipating wave energy and maintain a recreational beach benefitting local tourism. This beneficial use of DM may be used in conjunction with near shore feeder berms which act as a natural source of nourishment material for the beach; berms constructed from DM are presented in Section 3.3.4 below. Hanson et al. (2002), for example, investigated international beach nourishment practice and concluded that beach nourishment is as an effective means of coastline preservation and that this soft engineering approach is likely to continue to gain in popularity in coastal engineering practice.

Advantages & Disadvantages

ADVANTAGES	DISADVANTAGES
Helps to prevent localised flooding and control coastal erosion	Detailed engineering analysis required to accurately assess the local wave climate and beach erosion rates.
Facilitates and supports local tourism by maintaining a wider beach area	If dissimilar material (texture, colour etc.) is used from the in-situ natural beach material then the aesthetics of the beach may be negatively impacted.
Provides a 'soft' engineering approach instead of or in conjunction with traditional 'hard' engineering solutions such as construction of sea walls and groynes.	

Where can it be applied?

Beach nourishment can be applied to a shoreline or beach where erosion is occurring. The design of a beach nourishment project may be complex due to the nature of the sediment transport and wave climate at the shoreline. The most important design parameters to consider include the length of shoreline of the nourishment area, the wave climate at the site, the background erosion rate and the characteristics of the sediment.

The length of shoreline or beach to be nourished is important as it impacts on the time required to complete the project, which is influenced by the rate of background erosion and nourishment losses.

Most suitable type(s) of DM

The material used for beach nourishment must have a suitable particle size distribution for the wave climate and beach slope at the nourishment location. In general, it is desirable that the nourishment material be slightly coarser than the existing beach sediment and should have a similar composition, colour and texture with comparable physical and chemical characteristics to the natural in-situ material. However this may, on occasion, be balanced by the need to reuse DM. It must be free of contaminants and must not cause environmental problems at the placement site. Generally overfilling is required as some of the fine sediment will be lost. The nourished beach will naturally be reshaped over time due to incident wave action. It is often common for ‘hard’ engineering structures (e.g. groynes, revetments or offshore breakwaters) to be installed to stabilise the beach in conjunction with a beach nourishment project.

Logistical requirements

There are a number of key aspects that must be established when assessing the suitability of DM for beach nourishment:

- Source of nourishment material;
- Dredger selection;
- Transport/placement method.

The proximity of the DM source is an important factor in a beach nourishment project, for example it has been estimated that approximately 95% of all material used for beach nourishment projects originates from inshore and offshore sources located within 20km of the nourishment site (Dean, 2002). *British Standard 6349, 2000* may be used to make a preliminary assessment for dredger selection. It provides useful preliminary guidance on beach nourishment and land reclamation using DM as presented in Table 3.6. The DM is transported , by split-hull hopper dredger, by hydraulic pipeline or by truck to the eroding beach (USACE, 1987).

Table 3.6 Guidance on the selection of dredge plant for beach nourishment (and land reclamation) (BS 6349, 2000)

Site Conditions	Standard Trailer	Light Trailer	Cutter Suction	Bucket Wheel	Grab Hopper	Grab Pontoon	Bucket	Backhoe
BED MATERIAL								
• Fine sand	1	1	1	1	X	2	2	2
• Medium sand	1	1	1	1	X	2	1	1
• Coarse sand	1	2	1	1	X	2	1	1
• Gravel	1	3	1	1	X	2	1	1
• Cobbles	2	X	2	2	X	2	2	1
• Very weak rock	3	X	1	2	X	3	2	1
• Weak rock	X	X	2	3	X	X	X	1
SEA CONDITIONS								
• Enclosed water	X	3	1	1	X	1	2	2
• Sheltered water	1	1	1	1	X	1	1	1
• Exposed water	1	3	3	3	X	X	3	3
PLACING BY:								
• Direct dumping	3	2	X	X	X	1	1	1
• Direct pumping	X	X	1	1	X	X	X	X
• Transport and pump	1	2	X	X	X	2	2	2
• Dump and pump	1	1	X	X	X	1	1	1
QUANTITIES								
• <100,000 m^3	2	1	1	1	X	1	2	1
• <250,000 m^3	1	2	1	1	X	2	1	1
• <500,000 m^3	1	2	1	1	X	2	1	1
• >500,000 m^3	1	3	1	1	X	3	2	2
HEAVY TRAFFIC	1	1	3	3	X	2	3	2
CONFINED WORKING	X	3	3	3	X	1	3	2

KEY:
1 = Suitable; 2 = Acceptable; 3 = Marginal; X = Not usually suitable
Note: other factors not referred to may influence the choice of dredger. The table provides only a preliminary engineering guide.

3.3.2 Land Creation/Reclamation or Land Improvement

Description

Land creation or reclamation using DM is one of the most common beneficial uses of DM and is achieved by filling, raising and if necessary protecting an area to create new land that might otherwise remain submerged. Material from capital dredging is often used. Land improvement involves placing DM in a partially or periodically submerged area which requires improvement. These beneficial uses are particularly attractive where the DM recovery site and the proposed reclamation/creation site are in close proximity.

Advantages & Disadvantages

ADVANTAGES	DISADVANTAGES
Reclaimed land can provide an economic incentive for dredging stakeholders where benefits to tourism, ports and industry may be realised.	Final land use of the reclaimed land may be restricted depending on the type of DM used.
Potential profits to be made from reclaimed/improved land may be substantial	Reclamation may not be possible where water depths are excessive.
It may be less expensive to place the DM in a reclamation area than transport to a disposal site	Consolidation and drainage is slow, and the final strength achieved may be low.
The creation of reclaimed land may be more environmentally acceptable than disposal at sea.	Potential land ownership issues must be resolved
	May require extensive environmental impact analysis

Ref.: USACE, 1987; Bray et al, 1997; PIANC, 1992 & 2009; Burt, 1996; Sheehan, 2012

Where can it be applied?

The viability of this beneficial use of DM is primarily dependent on the targeted end use of the reclaimed/created land (e.g. industrial, recreation etc.) and the physical characteristics of the DM itself. Common end uses include creation of new land areas for harbours and ports, development of major infrastructural projects such as Hong Kong International Airport, creation of 'new' coastlines and offshore islands, for example in Dubai, and raising land areas to protect against the potential impacts of flooding.

Most suitable type(s) of DM

Coarse DM is usually acceptable for all types of final land use due to its superior engineering properties. However, fine grained DM may also be considered and, in this case, a more detailed analysis of the DM characteristics and site investigation of foundation soils must be undertaken to assess its suitability. Finer material will also require a longer time to drain and consolidate; therefore the strength achieved may be low, limiting the land to recreational uses such as park or other land uses where the imposed loads are low. Table 3.7 presents some information related to the type of DM used and appropriate land use.

Table 3.7 Land creation options for various types of DM (Sheehan, 2012; Chen & Tan, 2002)

Type of DM	Comments on Recommended Land Reclamation Use
Coarse material (rocks/gravels)	Load bearing capacity allows supporting heavier loads. Minimal pre-treatment required before placement of DM. Used for industrial sites or to accommodate roads/railways.
Finer grained material (sands/gravels)	Requires longer time to drain and consolidate. Shear strength achieved may be low thus allowable imposed loads may be limited. Recreational uses only e.g. parks.
Soft silty/clayey material	Commonly found in maintenance DM from rivers/estuaries. Very low structural properties. Not generally recommended for land creation.

Some important properties of DM which must be considered when assessing its suitability for land reclamation/creation include organic matter content, variability of sediment texture, reduced permeability and pH level. Such properties of the DM should be analysed to determine the final structural and mechanical strength of the reclaimed (or improved) land.

Logistical requirements

Land reclamation using DM requires the sourcing, dredging, transport and placement of the material. The sourcing of appropriate material is crucial in achieving the desired subsoil conditions for the land's designed use.

The type of dredger used for the project will primarily depend on the quantity of material required and its location. Preliminary assessment for dredger selection is similar to that used in beach nourishment and the British Standard 6349 (2000) can be used to provide useful preliminary guidance on land reclamation and beach nourishment using DM (see Table 3.6 above).

Hydraulic dredgers are more efficient and are the most commonly used dredger in land reclamation projects (Sheehan, 2012). DM transport is undertaken by pipeline transport or hopper transport with rainbowing/bottom door discharge. The placement process is either within a bunded area (for pipeline transport) or in an open area (for hopper transport). There are also a number of associated activities required in such projects including compaction, surcharge, geotechnical instrumentation, vertical drains and environmental monitoring (Van Doome, 2004).

3.3.3 Landfill Cover

Description

Suitable DM can be used as an alternative barrier material to traditional natural clays which act as a capping layer for municipal waste landfills; it may be applied as a daily, intermediate or as a final permanent capping layer. The purpose of this semi-permeable layer is to control nuisances (e.g. flies, birds, rodents), minimise escape of odours and landfill gas, and reduce the infiltration of rainfall and/or lateral egress of leachate (Nolan, 2009).

Advantages & Disadvantages

ADVANTAGES	DISADVANTAGES
Potentially improves the aesthetics of the area upon completion of landfill cover	Contamination levels must be at a level suitable for the materials intended use.
Creation of potential amenity and/or recreation area for local community.	Dewatering is typically required, desalination of DM may be required to stimulate plant growth
Potential environmental benefits through the regeneration of plant life	
Potential increase in surrounding land values	

Ref.: USACE, 1987 & 2006; Bray et al, 1997; PIANC, 1992 & 2009; Burt, 1996

Where can it be applied?

Ireland remains dependent on landfill for residual waste disposal and of the 2.8 million tonnes of municipal waste generated in Ireland in 2010, some 1.5 million tonnes (53%) was disposed to landfill (EPA, 2012). The country's 32 operating landfills require a significant volume of suitable cover material. The specific parameters of the landfill cover depend upon the intended final end use of the land. The EPA (1999 and 2000) divided these final land use options into four categories as presented in Table 3.8 which included amenity restoration (e.g. sports and recreation, nature conservation) and hard end use (e.g. warehouses, factories, parks, car parks, roads and playgrounds); the parameters for the cover material in both the topsoil and the subsoil were also specified.

Table 3.8 Requirements for final landfill cover (EPA, 1999)

Parameter	Amenity Restoration	Woodland Restoration	Agricultural Restoration	Hard End Use
Requirements	Ideally, sandy loams and/or loamy sands should be used with a mix of 3 parts sand to 1 part topsoil being most suitable.	Soils should not be compacted and if possible should be *alleviated using subsoil ripping ?*. The depth of soil required will need to be increased where freely draining soils are used.	The use of soils with a high stone content is not recommended. Organic matter content should be at lease 1-2% by dry weight; pH level should be between 5 and 8. Avoidance of soils with high silt/clay content is recommended.	Non-soil material such as granular fill, glacial till, recovered aggregates etc.
Topsoil Depth	150mm	1000 to 1500mm	150 to 300mm	Not required
Subsoil Depth	1000mm	Combined depth of between 1000 to 1500mm	700 to 850mm minimum	Not required
Comments	These soils should be reasonably fertile to promote good grass growth and have suitably hard wearing surface capable of withstanding heavy use and wear in all weather.	Topsoil is not essential for amenity tree planting as a topsoil encourages vigorous grass and weed growth which competes for available nutrients, moisture and light.	Successful restoration for agricultural production depends upon a supply of good quality soils which when replaced provide fertile soils which are free draining and have a high available water capacity.	Geotechnical investigation of the site is required prior to the design of foundations or other structures.

Most suitable type(s) of DM

Both coarse and fine grained DM may be deemed suitable depending on the cover material required. A DM with a low moisture content would generally be most suitable as dewatering and desalination (if salt content is > 500mg) of the DM is recommended for the 'ideal' DM capping layer before use (Mohan et al., 1997). Ideally the DM should be free draining and, preferably, of low clay content with low permeability characteristics to provide the most efficient cover material. The following is recommended when assessing DM as viable landfill cover material:

- The recommended cap should consist of a 0.61m layer of fine clayey DM (low permeability layer) covered by a 0.31m layer of coarser DM (vegetative layer);
- The pH should be between 5.5 and 8;
- A minimum organic content of 1.5% by weight;
- A maximum soluble salt content of 500mg/l

(Mohan et al., 1997)

Other parameters relevant to the characterisation of the DM for application include organic matter content, nitrogen, phosphorous and any potentially toxic contaminants, e.g. PAHs and PCBs. It is recommended that stakeholders refer to the EU Landfill Leachate Criteria (2003/33/EC) for further guidance on the use of DM as cover in a landfill site.

Logistical requirements

When considering recovery methods, the DM's moisture content should be minimised to reduce the subsequent dewatering time. The use of a mechanical dredger (e.g. grab, backhoe) allows DM to be removed near its in-situ moisture content but would require barge transport to the shore to the dewatering site. Alternatively hydraulic dredging (e.g. trailer suction hopper dredger) in conjunction with pipeline transport would require dewatering either in a lagoon or using geotubes. Desalination of the DM would also be required. The DM would then be transported to the landfill site for placement (usually via truck).

3.3.4 Offshore Berm Creation

Description

Offshore coastal protection structures may be fully submerged, constructed using DM such as rock, sand, clay or any mixture of these and forming a prominent, submerged, man-made, positive-relief feature. There are generally two types of offshore berm with differing applications; a feeder (or active or dispersive) berm, in which sand is transported shoreward to the beach and a stable (or non-dispersive) berm where the material remains in the vicinity of the berm and causes damping of the waves and thus sheltering of the landward beach (Otay, 1994). Seasonal variations in sediment transport and wave climate may impact on the potential dispersion of the berm (Kraus, 1992).

Placing clean dredged material in shallow water in the form of shore-parallel subaqueous berms benefits the nearshore zone by providing material to the littoral system and reducing wave action landward of the berm (Pollock and Allison, 1993). It has been suggested that significant cost savings may be achieved if the DM can be placed offshore rather than on the beach in the expectation that natural processes will transport the material shoreward to the beach (Yang, 2010). Such offshore berms may also provide refuge and benefits for fish species.

Advantages & Disadvantages

ADVANTAGES	**DISADVANTAGES**
Established international technology (e.g. applied in Taiwan, USA, and Japan).	For berms designed to be stable they may yet be prone to erode with the erosion rate dependent on the local wave climate.
Recovery site and application may be close reducing DM transport costs.	May not be suitable for locations where conflict with fisheries, ports, outfalls etc. may arise.
Can provide an environmentally acceptable "soft-engineering" solution to coastal protection.	Optimum placement area must be located and be sufficiently shallow to mitigate wave effects.
May be created by simple discharge of DM from hoppers	

Ref.: USACE, 1987; Bray et al, 1997; PIANC, 1992 & 2009; Burt, 1996

Where can it be applied?

Offshore berms are typically aligned parallel to the shoreline with the optimum alignment at a specific site determined by the direction of the most intense wave action (PIANC, 1992). Although the main function of the berm is to absorb wave energy, it may also be designed to alter wave direction and modify the rate of local sediment transport.

Most suitable type(s) of DM

A wide range of locally sourced clean DM may be used with berm creation often undertaken in conjunction with beach nourishment as the two processes can mutually interact in a beneficial way (Johnson, 2005).

Fine to medium sand is often considered the most suitable type of DM for constructing feeder berms while coarser, more substantial DM such as rock and gravel are more appropriate for use in stable berms. Offshore berms constructed from fine muddy material have also been successfully used (Bray, 2008). If a berm is placed in the nearshore region (close to the shoreline), natural processes may sort the material in the berm, removing fines, with some of the beach grade DM, sand suitable for placement on the beach, then washed ashore, thus lessening the negative impacts of dredging and providing additional coastal protection (Hands, 1992).

Logistical requirements

The formation of berms can provide a particularly attractive use for a wide range of DM as it can be deposited in-situ directly from bottom-opening dredger hoppers. This may significantly reduce the cost and complexity of transporting the DM from the source to the beneficial use or disposal site.

It is important to maintain a continuous monitoring system for the in-situ berms to measure changes in elevation and volume through successive bathymetric surveys. Monitoring programmes may also include gathering sand samples along the berm and possibly on the beach to measure changes in grain size (USACE, 1987). Sediment transport patterns in berms may also be monitored and tracked using tracers such as synthetic fluorescent sand tracers.

3.3.5 Coastal Protection Works (including geotubes)

Description

DM has been applied in coastal protection works internationally in a variety of different ways and has often involved the direct use on-site of DM generated locally as a construction material. It has commonly been used in the core of rubble mound breakwaters (typically sand) or potentially on the outer layers of breakwaters where the appropriate rock grading is available. In such cases the DM produced (rock or otherwise) must meet the specific design requirements of the particular coastal structure.

An alternative (and innovative) approach to the direct use of DM in coastal structures is to fill geotextile retaining material, geotubes, with DM. Geotubes are high tensile strength woven polypropylene geotextiles designed to receive and retain pumped material, with the water content allowed to escape through fine pores until the required density of contained material is achieved. Geotubes may then be used to retain and dewater DM to form the core of different types of coastal structure. DM may be pumped or hydraulically placed into the geotubes either directly from a dredging vessel or from a barge/storage area.

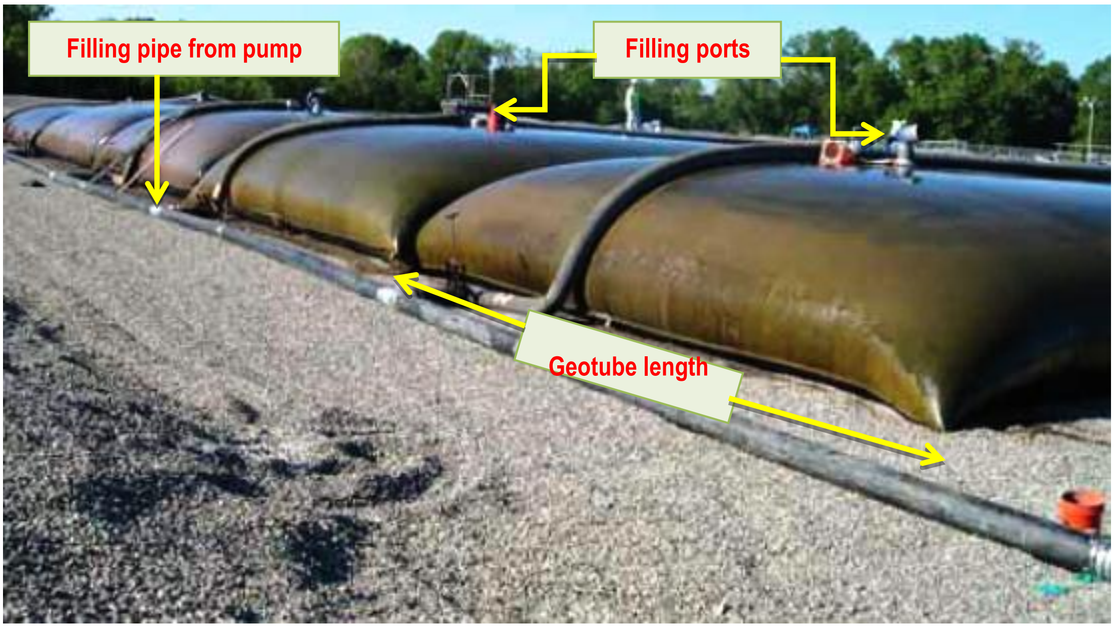


Figure 3.2 Typical geotube layout

Advantages & Disadvantages

ADVANTAGES	DISADVANTAGES
Versatile technology and relatively simple to implement	Risk of tearing / distortion of geotubes with potential to lead to instability and undermining of coastal structure
May provide an environmentally beneficial and economically viable alternative for elements of traditional rubble mound structures	Generally available in specific sizes which may not necessarily suit a particular application. Custom sizing may be expensive.
Use of geotubes can retain and isolate some forms of contaminants	Hydraulic equipment is required for geotubes

Ref.: USACE, 1987; Bray et al, 1997; PIANC, 1992 & 2009; Burt, 1996; Sheehan, 2012

Where can it be applied?

Geotubes have been widely used in coastal structures for flood and water control by raising dykes, but can also be used to control beach erosion, provide shore protection and act as river training structures. Typical dimensions for geotubes are 150m to 180m in length, 4m to 5m in width and 1.5m to 2m in height (Leshchinsky et al., 1996). It is recommended that the geotubes are buried when accessible to the public to avoid vandal/animal attacks which may impact on their effectiveness (Smith, 2009).

Most suitable type(s) of DM

Different types of DM may be dewatered using geotubes, although the fill material used is generally sand based where the DM should consist of a minimum of 40% solids (i.e. sand) when used for marine structures (Sheehan, 2012). The DM pumping pressure can exert significant stresses when the tubes are filled; this pressure governs the design criteria for defining the estimated force of the required geotubes, working under load conditions. Consultation with specialist geosynthetic contractors is necessary at the design stage to ensure that the appropriate design is achieved. For finer grained DM, adequate settlement and consolidation within the geotube must be ensured for structural use; however this is less of a concern for non-structural uses such as dykes and berms.

Logistical requirements

Recommended selection criteria for the use of geotubes in association with a dredging project include (USACE, 1998):

- Shallow water with low tidal range and low wave energy;
- The geotubes must be maintained and covered;
- There must be no threat to life or property if failure occurs;
- The project must have flexible height and alignment requirements;

Once the geotubes are placed in-situ and ready to be filled with DM, it is essential that they are filled continuously and as evenly as possible to the required design height to ensure that consolidation does not occur, deforming the shape of the geotube (Tencate, 2009). The type of dredger selected is restricted because of the need to pump a minimum of 40% solids, to fill the tubes. A small cutter suction dredger of type DOP (Damen Onderwater Pomp) with a 6 to 8 inch pipeline would be a typical plant of choice (Sheehan, 2012).

3.4 Environmental Enhancement

3.4.1 Wetland Habitat Creation/Enhancement

Description

A wetland is land that is covered intermittently, either seasonally or due to tidal or water table changes. Tidal variation, for example, causes the soil to reach saturation regularly, forming a combination of terrestrial and aquatic characteristics with unique aquatic organisms. DM has been widely used to establish new wetland areas, to nourish and enhance existing habitats or to provide stability to eroding wetlands.

Advantages & Disadvantages

ADVANTAGES	DISADVANTAGES
Environmental benefit with preservation of endangered ecosystems/habitats	Substantial physical, chemical and biological testing is required to determine feasibility
Restoration of wetland area can alleviate problems associated with flooding, erosion and reduced fish populations.	Assigning an economic value of beneficially using DM for wetland restoration is difficult and often subjective

Where can it be applied?

DM may be applied to different types of wetland and it may require development of an Environmental Impact Assessment (EIA) and/or appropriate assessment under the Birds and Natural Habitats Regulations 2011 before a scheme is deemed viable. The four main categories of wetland are:

1. *Estuarine wetlands:* generally found along the margins of estuaries.
2. *Riverine wetlands:* hydrology is heavily influenced by proximity to a stream or river, with overbank flow potentially important.
3. *Headwater wetlands*: exist in the uppermost reaches of perennial streams and are fed primarily by precipitation, overland runoff and groundwater discharge.
4. *Flat/depressional wetlands:* typically hydrologically disconnected from surface water and are fed by groundwater discharge, overland runoff, and precipitation.

(NCDENR, 2005).

Certain types of wetland enhancement projects will be more feasible than others. For example, DM can be used in thin layers to raise and restore degraded wetlands up to an intertidal elevation or dewatered DM may be used to provide wind and wave barriers to allow native vegetation to regrow and restore the viability of a wetland (PIANC, 1992).

The creation of new wetland areas involves considerable project investigation and planning and care must be taken to ensure protection to existing habitats, as appropriate. Extensive guidance on planning and implementation of wetland creation schemes using various types of DM can be found, for example, in Hayes et al. (2000).

Most suitable type(s) of DM

The types of DM used can vary widely. Wetlands can contain land areas with differing characteristics, with salt marshes and inter-tidal mudflats commonly occurring together. The constituent material in these wetlands varies from soft mud to sand, where a wide range of DM may be suitable for habitat restoration. For example, DEFRA in the UK has established that, in extreme cases, material as large as 10mm to 50mm diameter gravel can be used on soft but eroding muds to create stability and bird nesting sites (Dixon, 2009).

The chemical and physical characteristics of the DM are important when determining its suitability for a particular wetland site. Bolam and Whormersley (2003) found that the relatively rapid re-colonisation observed in constructed wetlands using DM can be attributed to the similarity of the dredged sediments to the in situ sediments in terms of organic carbon and silt/clay content. The organic content of the DM must be considered during the planning stages as elevated levels of organics can lead to longer re-colonisation times due to reduced redox potential and increased shear strength (Bolam et al., 2004). Similar studies have shown that matching the properties of the DM with that of the existing wetland increase the chances of successful restoration/creation of the wetland habitat.

Logistical requirements

The logistical requirements for wetland habitat creation/restoration are broadly generally similar to land reclamation (see Section 3.3.2 above), compaction of the DM is not required for wetland creation or enhancement. Dredging and transport requirements are also similar to land reclamation. Depending on the source of the sediment, the chemistry of DM can change significantly upon re-oxidation with thorough testing of the DM recommended prior to planning for use (Hayes et al., 2000).

The use of hydraulic transportation methods for relocating the DM should be prioritised if found to be viable due to the high efficiencies and low unit cost for large scale projects.

3.4.2 Sediment Cell Maintenance

Description

Sediment cell maintenance, also known as sustainable sediment relocation involves the placement of DM in tidal estuary systems potentially reducing the erosion of tidal mudflats, banks and saltmarshes and also potentially improving both shallow sub-tidal and intertidal habitats (Van der Wal et al., 2010). It typically applies to maintenance dredging projects where sediment contaminant levels are typically very low or entirely absent. This approach may be considered to combine traditional disposal with modern soft engineering practice to enhance the local ecosystem and reduce potential negative impacts from dredging activities.

Advantages & Disadvantages

ADVANTAGES	**DISADVANTAGES**
Contributes to maintaining the natural sediment regime of an estuarine system which may be affected by dredging activities.	Extensive DM characterisation and monitoring of the local ecosystem must be undertaken to ensure no negative impacts.
Relatively easy to implement with environmental benefits.	Likely to require advanced computer modelling and specialist involvement at the design stage.
Subtidal and intertidal habitats can be enhanced for benthic macro-fauna.	

Where can it be applied?

In many tidal estuaries, there is a net balance between the amount of material being deposited and eroded, with dredging potentially disturbing this delicate balance (Paipai, 2003). The relocated fine-grained DM contributes to maintaining sustainable levels of sediment in the local ecosystem by deposited in estuarine zones, sub-tidal and inter-tidal flats and any other system where the sediment regime is under threat.

Van der Wal et al. (2010), for example, have recommended placing the DM near eroding tidal flats, allowing the material to move slowly towards the flats with the new sediment regime. This creates a more effective 'ebb-flood' current distribution which sustains the multi-channel system and reduces dredging efforts in the long-term.

Most suitable type(s) of DM

The beneficial use of fine grained DM in sediment cell maintenance is suitable for maintenance dredging projects providing a continual and sustainable resource for the DM generated; the DM must be comparable in terms of physical, chemical and biological properties.

The types of sediment used may vary significantly in different zones of the system and hence, the use of a wide range of sediment may be required including sand, silt, mud and clay (Kirby, 2012). The type of dredged sediment which is appropriate depends on the site specific requirements.

Recent full scale research projects undertaken in Belgium and the Netherlands (Vos et al., 2009, Van der Wal et al., 2010) have studied the beneficial use of DM in sediment cell maintenance in large scale estuarine environments. Further more detailed information on this approach to sustainable sediment management can be found, for example, in SedNet (2009).

Logistical requirements

As the DM must be deposited in specific locations to ensure proper integration into the existing sediment system, the choice of dredger and method of transport is important. The sediment is commonly dredged using a hopper dredger and transported through a floating pipeline to a pontoon, from which it can be accurately deposited in the required area with a diffuser. When assessing a specific dredging site for the potential beneficial use of the DM in sediment cell management, it is important to include:

- Detailed field sampling and analysis of the existing sediment
- Multivariate studies of the micro-benthic and macro-benthic communities
- Computer modelling of the bed characteristics and sediment transport regime
- Post-disposal monitoring of the ecosystem to ensure no negative impacts.

3.4.3 Fill for abandoned mines/quarries

Description

Both uncontaminated and contaminated material containing metal and organic contaminants (within regulatory limits) can be stabilised using cementitious materials (e.g. alkaline activated coal ash) to form low permeability cementitious fill for abandoned mine and quarry reclamation, with potentially significant environmental benefits (Pennsylvania DEP, 2001). In certain cases a stabilising agent may not be required.

A similar approach using DM may possibly be taken for exhausted borrow pits, abandoned mines and quarries in Ireland. These sites often give rise to concerns related to environmental impacts on lands and watercourses from acid rock drainage and metal leaching; potential human and livestock exposure and ecotoxicity problems; dangers to public health and safety presented by openings, shafts, tunnels and underground workings that open to the surface and ground stability in general (EPA and DCENR, 2009).

More generally, DM may be used as a replacement fill for different cases including filling holes in the landscape, removal of soft soil layers with sandy DM and using clean DM to replace contaminated soil (PIANC, 1992).

Advantages & Disadvantages

ADVANTAGES	DISADVANTAGES
May be suitable for contaminated DM without a requirement for pre-treatment	Depending on the specific site; it may be seen as an alternate disposal route for DM as opposed to a beneficial use.
May contribute to providing a solution to minimising the potential environmental threat posed by abandoned mines/quarries.	
May be combined with other 'waste' products such as coal ash to provide a beneficial end use.	

Ref: Pennsylvania DEP, 2001; Hakstege, 2008

Where can it be applied?

DM can be used to restore exhausted mines/quarries/borrow pits by providing a suitable stable fill material, reducing the physical hazards at these sites and also reducing the risk to people and animals (Pennsylvania DEP, 2001).

Recent projects undertaken in the Netherlands have also shown that suitable DM can be used successfully to fill borrow pits without the need for a stabilising agent (Hakstege, 2008).

Most suitable type(s) of DM

This approach is suitable for a wide range of DM however priority should be given to the use of fine grained materials (either clean or contaminated) which may provide a suitable fill material when combined with a stabilising material.

Logistical requirements

The DM/cementitious composite material produced may be beneficially used to restore potentially dangerous/environmentally harmful mines and quarries. Site selection of suitable quarry/mining sites filled with this DM/cementitious material should be based on the following general parameters:

- Accessibility for transport vehicles (trucks, excavation equipment etc.)
- Surveys considering potential social and environmental impacts
- Field surveys to include geology, groundwater, effluent standards, ambient water quality, land costs, drainage, flora and fauna of surrounding lands.

DM transportation costs are a major consideration and thus quarries/mines would need to be located relatively close to DM source sites and/or suitable transportation systems to provide for beneficial use of DM as a feasible option (USACE, 1987).

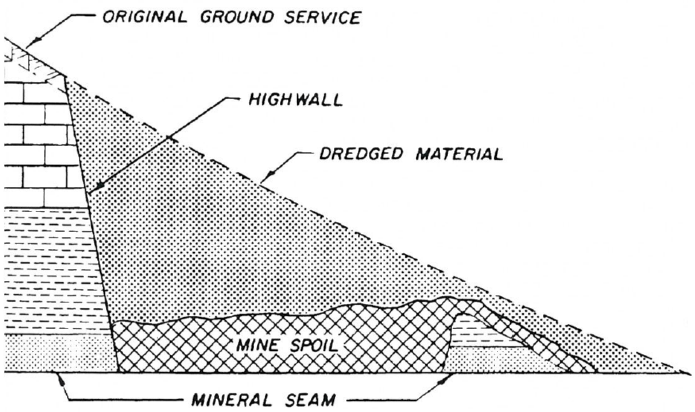


Figure 3.3 Typical cross-section of backfilled quarry using DM (USACE, 1987)

Figure 3.4 presents the major mining sites in Ireland and Figure 3.5 Ireland's main ports and harbours where DM is primarily generated. General locations where mine sites and sources of dredge material are in relatively close proximity are also identified.

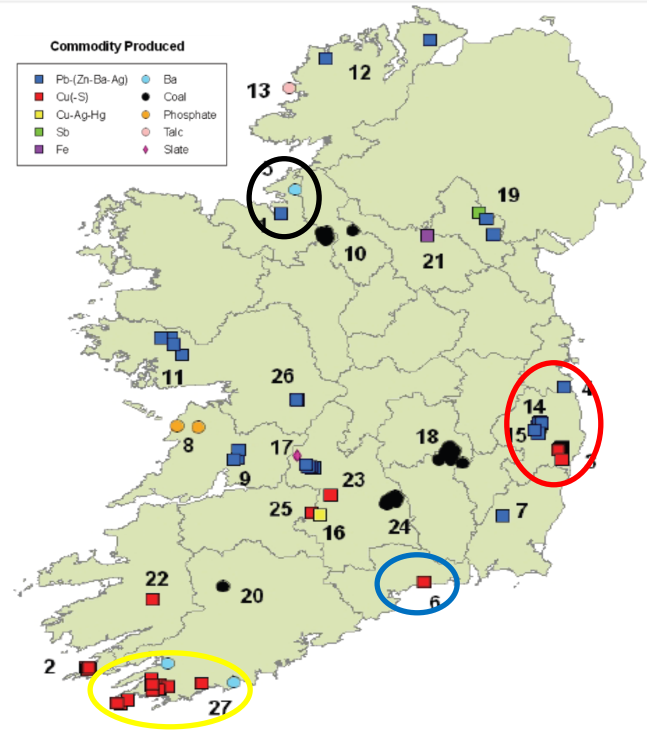


Fig. 3.4 Major Mining Sites of Ireland

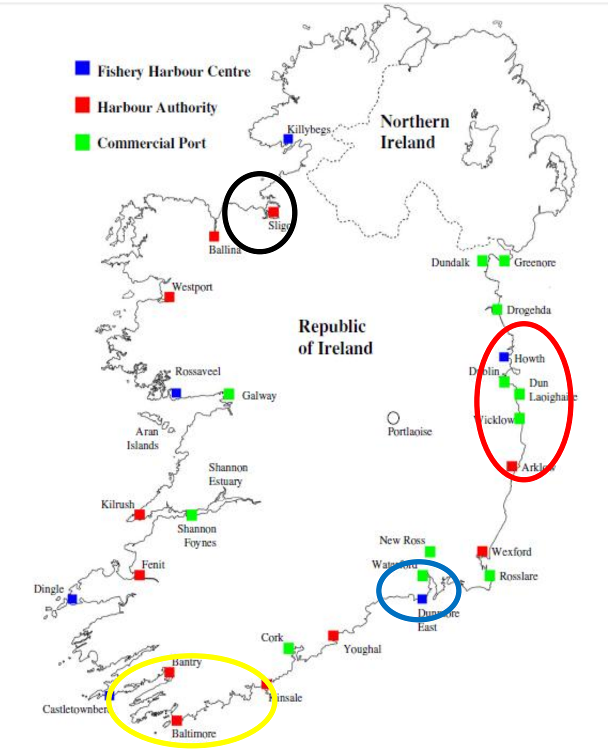


Fig. 3.5 Ireland's main ports and harbours.

Table 3.9 presents further detail on the primary mining sites identified.

Table 3.9 Primary Mining Sites in Ireland, (EPA and DCENR, 2009)

Mine name	Location	Commodities mined	PIN Index
Avoca*	Co. Wicklow	Cu, Au, Pb, Zn, Ag	1
Gortdrum	Co. Tipperary	Cu, Hg, Ag	1
Munster Coalfield	Cos. Cork and Limerick	Coal (anthracite)	1
Leinster Coalfield	Cos. Laois, Kilkenny and Carlow	Coal (anthracite)	1
Connacht Coalfield	Cos. Roscommon, Leitrim and Sligo	Coal (bituminous)	1
Slieve Ardagh Coalfield	Co. Tipperary	Coal (anthracite)	1
Silvermines*	Co. Tipperary	Pb, Zn, Ba, Cu, Ag	1
Tynagh*	Co. Galway	Pb,Zn,Cu,Ag,Ba	1
Allihies	Co. Cork	Cu (As, Mo, Pyrite)	2
Ballyshannon "2"	Co. Donegal	Pb (Zn, Ag)	2
Ballycorus	Co. Dublin	Pb, As	2
Castlecomer Brick	Co. Kilkenny	Fire-clay	2
Abbeytown	Co. Sligo	Pb, Zn	2
Glengowla	Co. Galway	Pb, Ag, Zn (Au, Cu, Ba, F)	3
Clements	Co. Galway	Pb, Ag (Fe, Zn, Cu)	3
Ternakill	Co. Galway	Ni, Fe, Cu, S, (Mo)	3
Keel	Co. Longford	Zn (Cd)	3
Kilnaleck	Co. Cavan	Silica sands	3
Victoria	Co. Tipperary	Slate	3
Glendalough	Co. Wicklow	Pb (Ag)	3

*In recent years some limited site characterisation work has been carried out by GSI, the EPA or by consultants on behalf of EMD at these sites.

3.5 Agricultural/Product Uses

3.5.1 Concrete Manufacture

Description

The basic raw materials for concrete production are cement, aggregate/sand and water. Coarse sandy DM has been used to supplement the aggregate component of concrete. Fine grained DM has recently been proposed as a fine granular corrector in partial substitution of raw sand (Limeira et al., 2011).

Advantages & Disadvantages

ADVANTAGES	DISADVANTAGES
May provide an alternative to quarry sourced aggregate in concrete manufacture, potentially reducing construction costs	The quantity of aggregate that can be replaced is dependent on the characteristics of the DM.
Dredged sediment is suitable for use in several types of concrete such as light weight and self-consolidating concrete.	Results for the fined grained component of DM only based to date on results of research work.
May potentially provide a beneficial use for contaminated DM without requiring expensive pre-treatment.	

Ref.: Limeira et al., 2011; Wang, 2008

Where can it be applied?

Capital dredging projects may be undertaken in conjunction with the construction of coastal structures, thereby providing a potential opportunity to use the DM beneficially and save on project costs, with a potential reduction in disposal at sea volumes. In the case of maintenance DM, there is potential for supply to concrete manufacturers as an alternate aggregate raw material. Pilot studies (Limeira et al., 2011 and Wang, 2008) have shown that fine grained DM has the potential to be used as a raw material in the manufacture of ordinary concrete, light weight concrete and self-consolidating concrete. Limeira et al. (2011), for example, compared a range of physical and mechanical properties of standard concrete and concrete with a 50% fine grained DM substitute for FA1 0/4mm aggregate with very positive results across a range of finished concrete properties (in some cases with performance exceeding that of standard concrete).

Most suitable type(s) of DM

Coarse grained DM is most suitable as a direct replacement for aggregate and should be clean, hard, durable and derived if possible from sources of proven quality and consistency For potential use of fined grained DM it is essential that the DM undergo extensive physical and chemical characterisation to ascertain the relevant DM properties, including water-soluble chlorides, sulphates, organic matter and heavy metals, particle size and density.

Guidance on the standards required of both coarse and fine grained aggregate for use in concrete production is presented in the European Standard EN 12620: 2002. The detail is provided in Irish Concrete's S.R. 16:2004, Annex C, Tables C.1 and D.1 for coarse and fine aggregates respectively, details regarding maximum chloride content levels are also provided.

Logistical requirements

On recovery, the DM is transported to land via open hulled vessel, barge or pipeline. Coarse grained material may be stockpiled on land, fine grained material will need to be dewatered prior to use. Once the suitability of the DM is confirmed, concrete material testing is required to assess its suitability to meet the design strengths required as outlined in *Part 1: Aggregates for concrete – Guidance on the use of BS EN 12620*. The range of properties to be tested for include slump, compressive strength, flexural tensile strength, impact resistance, abrasion, and porosity.

3.5.2 Road Sub-base Construction

Description

Coarse and fine DM can be used in different aspects of road construction, including both as a structural material and as a general fill for the construction of road embankments and roadworks.

Road construction involves the creation of an engineered structure consisting of several layers of material and is required to withstand prolonged use with minimum maintenance. The use of DM as a substitute, or partial-substitute, for road based construction material has been studied on a pilot-scale in both France (Dubois et al., 2009; Zentar, 2008) and the U.S. (Pinto et al., 2011). Dubois et al. (2009) concluded that the use of DM in road construction had potential. The focus of a pilot scheme undertaken in France was on the sub-base layer of a typical road where suitable DM was used as an alternative to sand and aggregate. The sub-base layer consisted of a stabilised, compacted layer supporting the upper road surface. A full scale road was constructed using fine-grained DM (stabilised with dredged sand in combination with cement and lime) and various mechanical tests were performed on the road (Zentar, 2008). In terms of engineering properties Zentar (2008) reported that the added components substantially improved the engineering characteristics of the DM. The potential use of dewatered sediment as a partial replacement for aggregate in the construction of pavement roads is reviewed by Pinto et al. (2011).

Advantages & Disadvantages

ADVANTAGES	**DISADVANTAGES**
Offers a range of potential uses in road construction	Fine grained DM requires the addition of a stabiliser, such as lime or cement, to obtain the required mechanical characteristics for the sub-base layer.
Contaminated DM may be used in the road sub-base construction.	Use of fine grained DM as a substitute still at experimental stage with pilot road construction in France an example of application
May contribute to providing a sustainable alternative to quarry sourced natural sand/aggregate.	

Where can it be applied?

Road and infrastructure projects in Ireland may potentially provide a destination for recycled DM; either coarse grained or potentially fine grained where the mechanical characteristics would need to adequately spread wheel loads (Siham et al., 2008).

Most suitable type(s) of DM

The material property standards used for road sub-base construction in Ireland are outlined by the National Road Authority (NRA, 2007) in the “Specification for Road Works” guidelines as a Series 800 (Road Pavements – Unbound Materials) material. Dewatered and cleaned DM appears suitable for use for two of the four types of Series 800 materials (type 803 and type 804). In general, coarse DM is more easily integrated into road construction than fine grained sediment.

For fine-grained DM, it is important to determine the saline and organic content of the DM asthese components impact on the viability of using DM in road construction due to their negative impact on mechanical strength when the DM is stabilised with cement (Kujala et al., 1996; Kaushik and Islam, 1995). These studies have shown that the high salinity of seawater has a negative effect on the development of mechanical strength, which may hinder its use in road construction.

Logistical requirements

The DM (coarse or fine-grained material) is recovered and transported to the shore-based site. Mechanical dredging is preferred in terms of minimising the moisture content of the DM. Fine-grained material will require dewatering and desalination as appropriate; the addition of cement and lime can be undertaken at the shore based site or at the road construction site as appropriate. Coarse-grained material may require crushing/grading as necessary.

3.5.3 Landfill Liner

Description

Landfill liners are designed and constructed to create a barrier between the landfill waste and the ambient natural environment and to redirect the leachate to a collection and treatment facility. Traditional landfill liner materials include compacted clays, bentonite enriched soils and flexible synthetic membranes. Several research studies have investigated the use of DM combined with a stabilising material as an alternative or supplementary material to these traditional systems (Riordan, 2008; Zhang and Wu, 2005; Giroud et al., 1997). These studies have generally concluded that DM may form a viable, inexpensive and efficient liner material.

Advantages & Disadvantages

ADVANTAGES	DISADVANTAGES
Can provide a less complex & less expensive alternative to bentonite-enriched soil (BES) or compacted clay liners (CCL).	Possible stabilisation and grading of DM may be required depending on physical characteristics.
Placing, testing and evaluating the DM will be similar to traditional liner materials, thus existing machinery and testing apparatus are appropriate for DM	Ideally only suitable for DM sourced from consolidated clay
	To date reliance on research pilot-type schemes

Ref.: EPA, 2000; Sheehan, 2012; Zhang, 2005

Where can it be applied?

Municipal Solid Waste (MSW) landfills require composite lining systems, generally consisting of a primary protection geomembrane and a secondary protection mineral liner with a hydraulic conductivity $k \leq 1 \times 10^{-9}$m/sec (EPA, 2000). This mineral layer may consist of DM in conjunction with another stabilising material (e.g. construction and demolition (C&D) waste, ordinary portland cement (OPC) or silica fume) to provide a suitable alternative to traditional mineral layer materials. A typical cross-section through a MSW landfill 'cell' is presented in Figure 3.6 where suitable DM would replace the layers of 'soil barrier' identified.

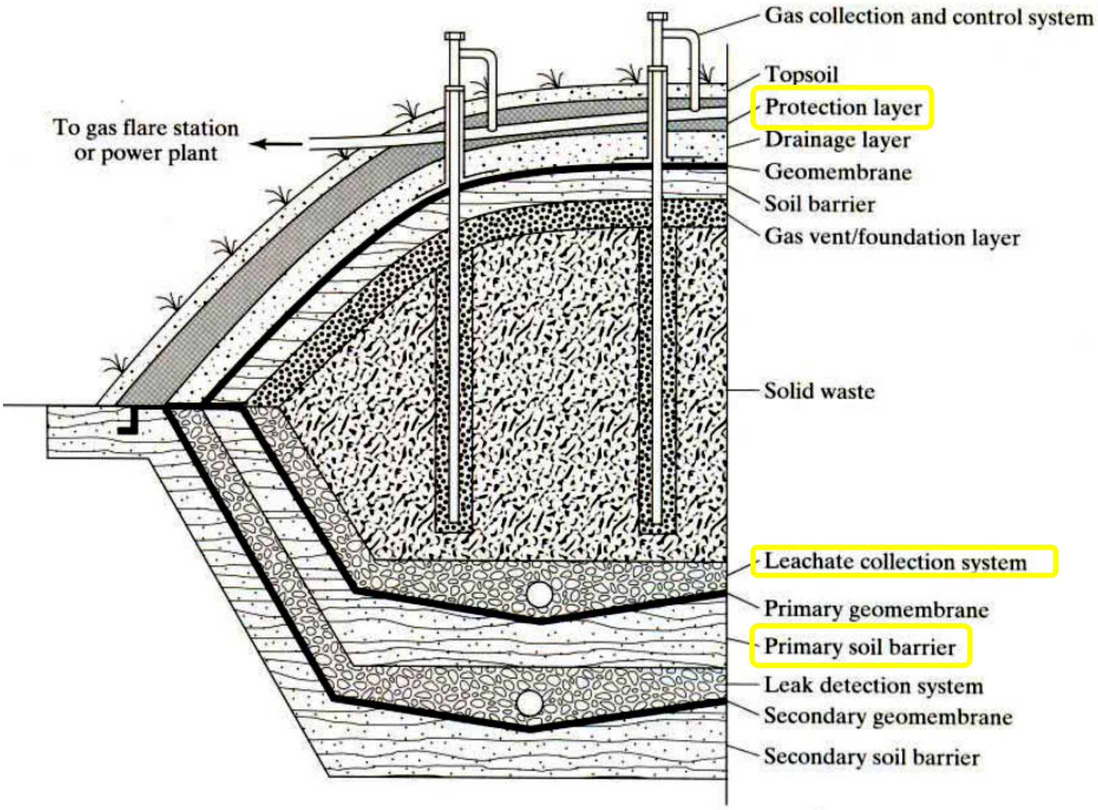


Figure 3.6 Schematic Diagram of a Municipal Solid Waste Landfill Containment System (Quian et al., 2002)

Most suitable type(s) of DM

Precise quality control of the DM and the stabilising material mix is essential as the strength, landfill stability, permeability and durability of the lining system are important factors in achieving a well-designed engineered landfill (Quian et al., 2002).

The EPA (2000) has developed requirements for the properties of compacted clay liner (CCL) which may be applicable when assessing the suitability of DM as a landfill liner; these are outlined in Table 3.10.

Table 3.10 Requirements for CCL (EPA, 2000)

Property	EPA Requirements (Range)	Recommended Test in accordance with BS 1377 (1990)
% fines (particles < 0.075mm)	≥ 20%	Particle Size Distribution (PSD)
% gravels (particles > 4.76mm)	≤ 30%	
Plasticity Index	10 – 30%	Liquid / Plastic limits (or Atterberg limits)
Maximum Particle Size	25 – 50mm	Compaction curves (dry density / optimum moisture content relationship)
Coefficient of Permeability (k)	$<1.0 \times 10^{-9}$ m/s	Permeability
Organic Content	0%	Natural moisture / organic content

Logistical requirements

When considering recovery methods the DM's moisture content should be minimised to reduce the subsequent dewatering time. The use of a mechanical dredger allows DM to be removed near its in-situ moisture content with barge transport to shore to the dewatering site. Alternatively, hydraulic dredging in conjunction with pipeline transport would require dewatering lagoons or geotubes for dewatering. Dewatering would then be followed by possible crushing/grading of the C&D waste with transport of DM and the stabilising material to the mixing/blending site followed by transport to the landfill site for placement.

The processing costs associated with the composite material are source dependent, but involve, at a minimum dewatering of the DM, and mixing or blending of the two source materials. The processed, or partially processed, source materials are then transported to the landfill site where further processing, for example mixing, may take place and the composite material is then placed as liner material (Riordan, 2008). The economic viability of this beneficial use is case dependent and will be significantly influenced by the location of the dredging site in relation to the dewatering, mixing and landfill sites.

3.5.4 Manufactured Topsoil

Description

DM may be directly used as topsoil material depending on its properties and the presence of organic material in the DM. However the use of engineered manufactured topsoil (MS) allows the use of DM combined with recycled organic waste material to produce a manufactured topsoil that can improve soil growth characteristics.

Advantages & Disadvantages

ADVANTAGES	DISADVANTAGES
May provide a potential income stream for ports/harbours that produce significant quantities of maintenance DM on a regular basis.	Relies on a market demand for the product near to the point of source
Significant research has been undertaken with several projects completed in the U.S. and the U.K.	Stringent requirements apply to the characteristics of the DM
May contribute to reduced organic municipal waste disposal costs as it is used with DM in the manufacture of topsoil	A reliable and consistent supply of suitable organic material is required
Both hydraulic and mechanical dredging can be used	

Where can it be applied?

It is suited to a location where a continuous supply of DM is available to supply an MS facility; an on-going and periodic maintenance dredging project is appropriate. In addition a source of organic material is required with a local demand in evidence for the topsoil produced. Sheehan et al. (2010) conducted a feasibility study and a technical assessment of topsoil production for DM sourced from maintenance dredging at the Port of Waterford. The DM was mixed with local organic household waste to produce MS. Testing of the MS produced from the study showed topsoil characteristics with good drainage, adequate nutrient and water retention capabilities and above average nutrient content and the study concluded that topsoil production from DM is technically viable and may compare favourably with topsoil market standards.

Most suitable type(s) of DM

Ideally a mix of coarse and fine grained DM should be used but the ratio of this mix, combined with a quantity of organic waste, needs to be determined on a site specific basis.

The optimum amount of organic material added must be quantified to produce a suitable topsoil material in the context of a scheme which is economically feasible.

Irish standards for MS are based on the British Standard 3882:2007 (BS: 3882, 2007) and must be met before the DM can be classified as a topsoil material (Table 3.11).

Table 3.11 Summary of British Standards for Topsoil

Parameter	**Multi-Purpose Topsoil**
Soil Texture % m/m • Clay content % • Silt content % • Sand content %	 5-35 % 0 – 65 % 30 – 85 %
Organic Matter % m/m • Clay 5 – 20 % • Clay 20 – 35 %	 3 – 20 % 5 – 20 %
Maximum Course Content % m/m • > 2mm • > 20mm • > 50mm	 0 – 30 % 0 – 10 % 0 %
pH	5.5 – 8.5
Plant Nutrient Content • Nitrogen % m/m • Extractable Phosphorus mg/l • Extractable Potassium mg/l • Extractable Magnesium mg/l	 >0.15% 16 – 100 121 – 900 51 – 600
*Exchangeable Sodium * %*	< 15
Visible Contaminants % m/m • 2mm …of which are plastics	 <0.5 <0.25

Note: *Need not measure if soil electro-conductivity <2800µS/cm

Logistical requirements

The transport logistics for producing an MS are complex, but are crucial to the subsequent treatment processes and economic feasibility. The DM is removed by hydraulic or mechanical dredger, then transported to shore via hopper, barge or pipeline and then transported to the production site where dewatering of the DM is required and desalination may also be required, depending on whether the DM is from a freshwater or a saline source. Organic material will also need to be sourced, transported and mixed with the DM to achieve the desired organic content.

3.5.5 Production of Bricks/Ceramics

Description

Dredge sediment has been used as a raw material for brick production (Hamer & Karius, 2002). Suitable fine-grained DM can be used as a substitute for sand and/or natural clay (depending on the specific DM characteristics) to produce bricks and ceramics without the need for any alteration in the standard manufacturing process (Romero, 2007). Contaminated DM may also be used, as the process of manufacturing bricks involves the thermal immobilization of contaminants in the stabilised finished product.

Advantages & Disadvantages

ADVANTAGES	DISADVANTAGES
Contaminated DM may be used with contaminants becoming neutralised in the manufacturing process.	Consistency of the DM characteristics required for successful brick manufacture.
Selling the DM as a raw material for the brick/ceramic manufacturing industry may provide an income stream.	To date only small to medium scale pilot schemes have been undertaken in France and Germany.

Where can it be applied?

Most studies to date have focused on the use of contaminated DM in brick production as an alternative to treatment and disposal of the contaminated material. However, uncontaminated dredged sand with finer sediment can also offer a viable alternative to traditional raw materials (Samara, 2008).

Hamer & Karius (2002) reviewed studies of the production of bricks and concluded that bricks manufactured with DM out-performed traditional bricks in all major parameters; with the added advantage that contaminant concentrations (heavy metals and organics) present in the DM raw material were immobilised in a way that the bricks were not hazardous to soil or groundwater.

Most suitable type(s) of DM

DM is considered a suitable raw material for brick manufacture if the sand content does not exceed 30%. The typical mineralogical properties of standard sand and clay used in brick manufacture are presented by Samara (2008).

Appropriate physical and chemical analysis of the DM is necessary to assess the suitability of brick/ceramic manufacture. Further guidance on brick specifications can be found in British Standard BS EN 771-1: 2011.

Logistical requirements

A major factor in the logistical requirements of this beneficial use is the proximity of the brick/ceramic manufacturing facility to the DM recovery area as the cost of DM transport may be significant and uneconomic for larger transport distances. Quality testing of the finished brick products is required.

3.6 Other Options for DM Beneficial Use

There are several other potential approaches to the beneficial use of DM. Table 3.12 presents a brief summary of some of these options.

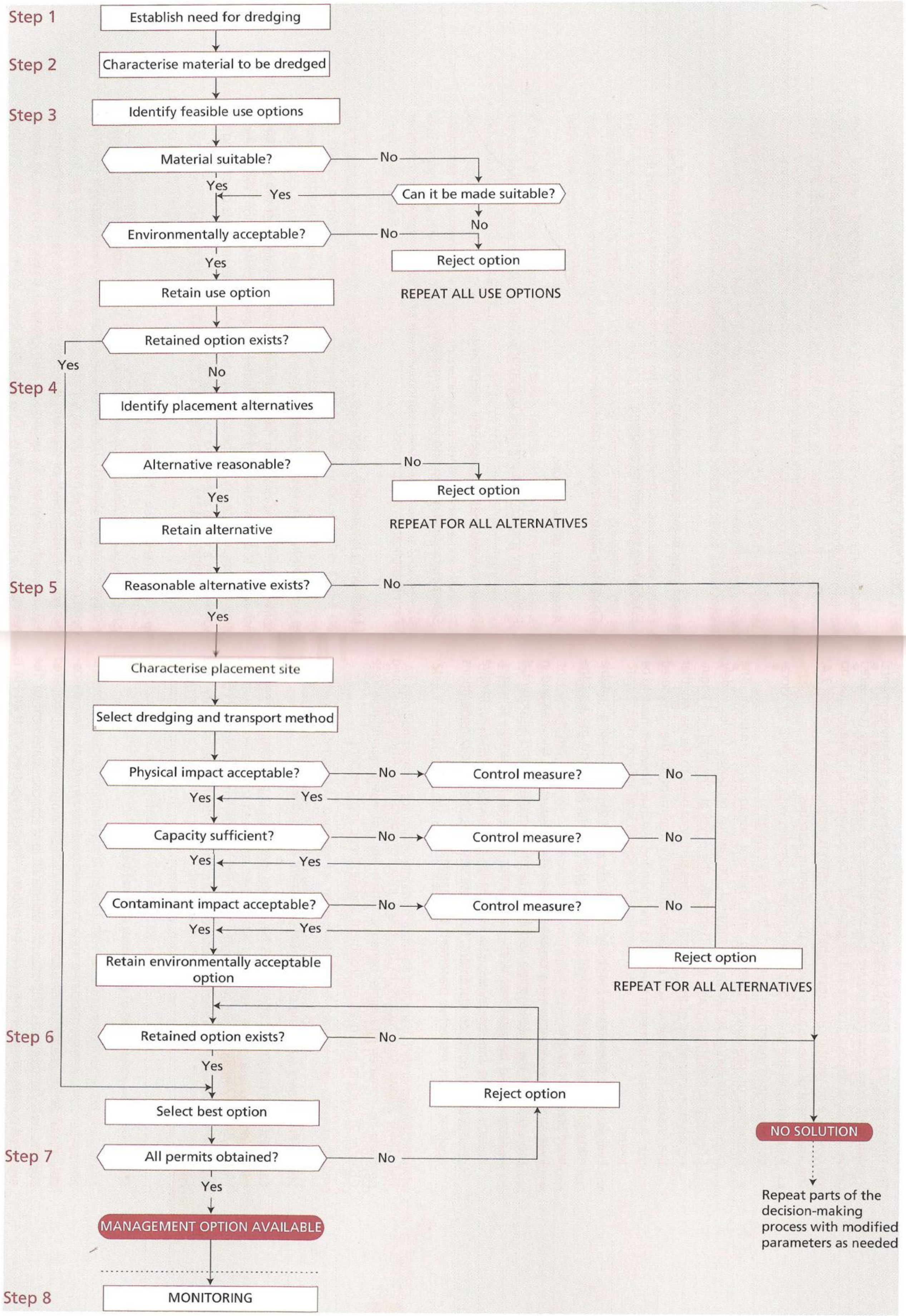
Table 3.12 Alternative options for the beneficial use of DM (USACE, 1987; USACE, 2006; Nakamura, 2005; USACE 2004; Vandecasteele et al., 2005; USACE, 2010; Millrath et al., 2002)

Type of Beneficial Use	Comments	Application
1. Earthen Dams	Dewatered DM may be used for construction of either earthen or earth-filled dams.	United States, The Netherlands
2. Fertiliser	Suitable DM with appropriate quantities of nutrients may be used as a land based fertiliser; either on its own or combined with a traditional fertiliser.	United States
3. Forestry	Several studies have concluded that DM can be spread on afforested land to aid in the growth of certain species of trees (poplar, spruce and willow). Afforestation of polluted DM landfills may also provide environmental benefits such as soil stabilisation and visual buffering combined with possible treatment of contaminants destroyed through the growth process of the trees/plants.	United States, Belgium
4. Aquaculture	Projects in the US have shown that marine disposal sites for DM can be structured to suit certain fish habitats providing new locations for aquaculture.	United States, U.K.
5. Construction of Tidal Flats/Shallows	Construction of tidal flats/shallows combined with 'sand capping' for environmental restoration using DM with potential benefits to the local benthic ecosystem.	United States, Japan
6. Offshore Mounds	Construction of offshore mounds formed from DM may provide refuge for different fish species.	United States
7. Decorative Landscaping Products	DM can be blended with recycled residual materials such as glass, gypsum, plastic bottles etc. to manufacture decorative garden ornaments including statues, water fountains and artificial rocks.	United States
8. Capping	This involves the placement of clean DM in open water over deposited contaminated material to form a wave and current resistant layer of material. This may allow the formation of suitable aquatic habitats. Capping may also be used in upland locations to isolate contaminated material.	Belgium, Germany, United States
9. Filler for Polymer Composites	Polymers, tyres, plaster and mortar may benefit from the addition of clay/sand filler from DM. Traditional inorganic fillers modify properties such as permeability, corrosion and durability; DM may potentially provide an alternative, organic filler additive.	United States

3.6.1 Decision Tree for DM Management

For information purposes an overall framework or decision tree to select the most appropriate DM management alternative in the context of environmental acceptability and human health is presented overleaf, based on Bray (2008).
It presents the main steps in the decision making process as:

1. Establishing the need for dredging
2. DM characterisation
3. Assessment of beneficial use options
4. Screening of placement (confined/unconfined) alternatives
5. Assessment of placement (confined/unconfined) alternatives
6. Selection for final design and implementation
7. Permit application and processing
8. Monitoring programme design


Step 1
Establish need for dredging
Step 2
Characterise material to be dredged
Step 3
Identify feasible use options
Material suitable?
No
Can it be made suitable?
Yes
Yes
No
Environmentally acceptable?
No
Reject option
Yes
Retain use option
REPEAT ALL USE OPTIONS
Retained option exists?
Yes
No
Step 4
Identify placement alternatives
Alternative reasonable?
No
Reject option
Yes
Retain alternative
REPEAT FOR ALL ALTERNATIVES
Step 5
Reasonable alternative exists?
No
Yes
Characterise placement site
Select dredging and transport method
Physical impact acceptable?
No
Control measure?
No
Yes
Yes
Capacity sufficient?
No
Control measure?
No
Yes
Yes
Contaminant impact acceptable?
No
Control measure?
No
Yes
Yes
Retain environmentally acceptable option
Reject option
REPEAT FOR ALL ALTERNATIVES
Step 6
Retained option exists?
No
Yes
Select best option
Reject option
NO SOLUTION
Step 7
All permits obtained?
No
Yes
MANAGEMENT OPTION AVAILABLE
Repeat parts of the decision-making process with modified parameters as needed
Step 8
MONITORING

4. LEGISLATION

This section presents relevant Irish and EU Legislation and Directives applicable to the management of DM; the legislative processes for different approaches to the management of DM are outlined.

4.1 General Legislative Framework

Table 4.1 presents a summary of current primary Irish Legislative Acts and EU Directives related to DM recovery and management including dredging, transport, disposal, waste authorisation, and environmental impact and conservation. The different local and national regulatory agencies responsible are presented together with some relevant commentary. The legislation related to the application of beneficial uses of DM is presented in greater detail in the following sections. This legislative framework is complex; consultation with the relevant responsible agencies is essential in the planning stage of a dredging project.

Table 4.1 Legislative Framework for Dredging, Dumping at Sea and Beneficial Use Projects in Ireland

LEGISLATION	RESPONSIBLE AGENCY	COMMENTS
Dredging/Dumping at Sea Legislation		
Foreshore Act (1933–2005) – Foreshore Lease or Licence	Department of Environment, Community and Local Government (DECLG) and the Department of Agriculture, Food and the Marine (DAFM)	Regulates removal of material from state owned foreshore, mineral extraction and placement of material on the foreshore. Application assessed by the Marine Licence Vetting Committee (MLVC) and may involve consultation with local authorities and Inland Fisheries Ireland and other relevant public authorities.
Planning and Development Act, 2000 as amended – Planning Permission	Local Authority, an Bord Pleanála	Planning Permission is generally required for all developments and may be required for large scale capital dredging works. Public consultation process required. .
Dumping at Sea Act (1996 to 2010) – Dumping at Sea Permit	Environmental Protection Agency (EPA)	Application assessed by the EPA and involves consultation with relevant public authorities. Recognises the potential beneficial use of DM with the requirement that alternatives to dumping at sea be assessed.
EIA Directive (85/337/EEC with subsequent amendments)	DECLG, DAFM, Local Authority, An Bord Pleanála	An Environmental Impact Assessment may be required for large scale capital dredging projects.
Birds and Natural Habitats Regulations 2011 (S.I. No. 477 of 2011)	National Parks and Wildlife Service (DECLG), other prescribed public authorities	Dredging and dumping at sea projects may impact on Special Protection Areas (SPA) or Special Areas of Conservation (SAC) under the Natura 2000 network. Appropriate assessment may be required to determine that the proposed plan will not have a significant impact on the qualifying interests of the Natura 2000 sites.

LEGISLATION	RESPONSIBLE AGENCY	COMMENTS
Beneficial Use/Treatment Legislation		
Waste Management Act (1996–2013) – Waste Licence (Waste Framework Directive 2008/98/EC)	EPA	Applies to all onshore disposal activities and to certain activities where waste material is segregated, stored or recovered onshore. Does not applies to any activity listed in Parts I or II of the 3rd Schedule of the Waste Management Facility Permit Regulations. A licence is required for the recovery of greater than 100,000 tonnes of waste material.
Waste Management Act (1996–2013) – Waste Permit (Waste Framework Directive 2008/98/EC)	Local Authority	Applies to activities listed in Part I of the 3rd Schedule of the Waste Management Facility Permit Regulations, 2007, S.I. No. 821 of 2007, amended by S.I. No. 86 of 2008. DM is specifically noted. Applies to recovery of quantities between 25,000 and 100,000 tonnes.
Waste Management Act (1996–2013) – CoR (Waste Framework Directive 2008/98/EC)	Local Authority / EPA	Least onerous form of waste authorisation. Certificate of Registration (CoR) may be granted by local authorities in respect of private sector facilities and by the EPA in respect of local authority activities. Relevant classes of activity are listed in Part II of the Third Schedule of the Waste Management (Facility Permit and Registration) Regulations, 2007, S.I. No. 821 of 2007, amended by S.I. No. 86 of 2008. DM is specifically noted. Applies to recovery of quantities between 25,000 and 100,000 tonnes.
Waste Management Regulations 2007 – Shipments of Waste (S.I. 419)	Local Authority – Dublin City Council	Applies to the Trans-Frontier Shipment of waste (i.e. the movement of waste outside the Republic of Ireland) for recovery or disposal.
Article 6 of the EU Framework Directive 2008/98/EC on Waste	EPA	Declassifies the sediment as a waste. The material is classified as a product to which waste legislation no longer applies.
Article 5 of the EU Framework Directive 2008/98/EC on Waste	EPA	Allows the DM to be considered as a by-product.
Waste Management Collection Permit Regulations 2008 (S.I. No. 87 of 2008)	EPA, Local Authority	Regulations apply where a haulier is transporting waste to and from a site, or transporting waste for disposal or recovery.

LEGISLATION	RESPONSIBLE AGENCY	COMMENTS
Directive on Environmental Quality Standards (Directive 2008/105/EC)	EPA	Required for placement of dredged material in near shore aquatic environments. Sets specific levels for certain metals, solvents, pesticides and other potential contaminants that may reduce the local water quality
Council Directive 1999/31/EC on the Landfill of Waste	EPA, Local Authority	Article 3, Part 2 defines activities which may be excluded including: The spreading of sludges on the soil resulting from dredging operations, for the purposes of fertilisation or improvement; The use of inert waste which is suitable in redevelopment/restoration and filling-in work, or for construction in purposes, in landfills; The deposit of non-hazardous dredging sludges alongside small waterways from where they have been dredged. The storage of waste prior to recovery for a period of three years or longer and the storage of waste prior to disposal for a period of one year or longer are subject to the Directive.
Foreshore Act (1933 to 2005)	DECLG, DAFM	Regulates placement of material on the state owned foreshore. Application assessed by the Marine Licence Vetting Committee (MLVC) and may involve consultation with local authorities and Inland Fisheries Ireland and other relevant public authorities.
Birds and Natural Habitats Regulations (2011) (S.I. No. 477 of 2011)	National Parks and Wildlife Service, (Dept. of Arts, Heritage and the Gaeltacht -DAHG)	Projects involving the management of DM may impact on Special Protection Areas (SPA) or Special Areas of Conservation (SAC) under the Natura 2000 network. Appropriate assessment may be required to determine that the proposed plan will not have a significant impact on the qualifying interests of the Natura 2000 sites.
EIA Directive	DECLG	An Environmental Impact Assessment may be required for certain projects.
EU Waste Acceptance Criteria for landfills 2003/33/EC (Acceptance of waste ; Article 16 of and Annex II to Directive 1999/31/EC)	EPA, Local Authority	Outlines the procedure to determine the acceptability of waste at landfills. Specifies leaching limit values and other limiting parameters for acceptable landfill materials.
LEGISLATION	**RESPONSIBLE AGENCY**	**COMMENTS**
General Relevant Environmental Legislation		
Fisheries Act 1959–2010	Inland Fisheries Ireland	Responsible for maintaining and improving environmental quality and the fishery resource.
Water Services Act 2007 (Water Framework Directive 2000/60/EC)	Local Authority (under the auspices of the DECLG)	Ensures water is maintained to a standard consistent with its various uses. This potentially can introduce additional controls on dredging and dredge disposal activities with potentially significant cost implications. The WFD aims to prevent further deterioration in existing waterways, maintaining high status of waters where it exists and achieving overall "good status" for all waters by 2015.
Marine Strategy Framework Directive (2008/56/EC)	DECLG	Main aims are to achieve good environmental status of the EU's marine waters by 2021 and to protect the resource base upon which marine-related economic and social activities depend. Similar implications to the Water Framework Directive for dredging activities.

LEGISLATION	RESPONSIBLE AGENCY	COMMENTS
Directive on Environmental Quality Standards (Directive 2008/105/EC)	EPA	The directive introduces environmental quality standards for priority substances and certain other pollutants. It also requires concentrations of priority substances in sediment and/or biota to be analysed and then minimised. Potential to oblige responsible clients to deal with local contamination.
EC Quality of Shellfish Waters Regulations 2006 (2006/113/EC)	DAFM and other prescribed public authorities	These prescribe shellfish water quality and designate the waters to which they apply. Designation of shellfish areas may impact on dredging and dumping at sea/beneficial use projects.
Birds and Natural Habitats Regulations 2011 (S.I.No. 477 of 2011)	National Parks and Wildlife Service, (Dept. of Arts, Heritage and the Gaeltacht - DAHG)	121 designated Special Protection Areas (SPA) under the Natura 2000 network in the Republic of Ireland for rare and vulnerable species with some potentially impacted by dredging and dumping at sea/beneficial use projects. An appropriate assessment may be required. Appropriate assessment may be required to determine that the proposed plan will not have a significant impact on the qualifying interests of the Natura 2000 sites. 413 designated Special Areas of Conservation (SAC) under the Natura 2000 network in the Republic of Ireland with some potentially impacting on dredging projects Over 1100 proposed National Heritage Areas (NHAs). Many overlap with SAC / SPA. Some may be impacted by dredging and dumping at sea/beneficial use projects.
Bathing Water Directive (2006/7/EC, S.I. No. 79/2008)	Local Authority	Dredging and dumping at sea/beneficial use projects may impact on designated bathing waters.
Quality of Salmonid Water Regulations 1988 (S.I. No. 293/1988)	Inland Fisheries Ireland	Dredging and dumping at sea/beneficial use projects may impact on migrating Salmonid populations.
EC Environmental Objectives (Surface Water) Regulations 2009 (S.I. No. 272 of 2009)	EPA, Local Authority	Applies to all surface water and aims to protect surface waters of good or high status and aims to restore surface water of lower status.

The following definitions are relevant to Table 4.1 in the context of the legislation identified (primarily from the Waste Directive Regulations (SI 126 of 2011):

Waste means any substance or object which the holder discards or intends or is required to discard. *Hazardous waste* means waste which displays one or more of the hazardous properties listed in the Second Schedule;

Recovery means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy

Recycling means any recovery operation by which waste materials are reprocessed into products, materials or substances, whether for the original or other purposes, including the reprocessing of organic material and does not include

(i) energy recovery, and

(ii) the reprocessing into materials that are to be used as fuels or for backfilling operations;

Treatment means recovery or disposal operations, including preparation prior to recovery or disposal;

Disposal means any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy,

Dumping is defined in the Dumping at Sea Act (1996-2010) as any deliberate disposal in the maritime area (including side-cast dredging, plough dredging, water injection dredging and other such dredging techniques) of a substance or material from or in conjunction with a vessel or aircraft or offshore installation.

Table A.4 in Appendix A presents a summary of some of the relevant legislation for the recovery and beneficial use of DM for a number of EU countries.

4.2 DM – Designation as a Resource

A key question for the management and potential beneficial use of DM is whether it can be designated as a resource, rather than as a waste. However in many cases it is common for some form of waste licensing/permitting requirement during the process of implementing a beneficial use of DM, pursuant to the designation of DM as a waste under the Waste Management Acts (WMA).

Dredge material is a waste where it falls within the definition of waste as set out in the European Communities (Waste Directive) Regulations 2011 (as outlined above). DM is listed in the European Waste Catalogue under section 17 05 05 where the DM is hazardous and under section 17 05 06 where the DM is non-hazardous.

Article 6 of the Waste Framework Directive (2008/98/EC) indicates when a waste ceases to be waste and the general criteria to be considered include that:

- the substance can be used for specific purposes;
- a market or demand exists for the substance;
- the substance fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and
- the use of the substance will not lead to overall adverse environmental or human health impacts.

Article 5 of the Waste Framework Directive (2000/98/EC) related to by-products is also relevant as an applicant may use this Article to show that the DM is a by-product. A material may be considered a by-product if it results from a production process the primary aim of which is not the production of that material and meets various criteria including:

- Further use is certain;
- The material can be used directly without any further processing other than normal industrial practice;
- Further use is lawful, i.e. the material fulfils all relevant product, environmental and health protection requirements for the specific use and;
- Will not lead to overall adverse environmental and human health impact.

In the case of the use of DM on land as a waste, the disposal or recovery activity generally requires waste authorisation and the type of authorisation required depends on the classes of waste activity as outlined in Table 4.1. The relevant disposal (Code D) and recovery (Code R) activities are presented in Table 4.2. The storage of waste DM prior to collection may require a waste authorisation. However, temporary storage of waste at the place of production for a period not exceeding six months is exempt from requiring a waste authorisation.

If it is unclear as to what authorisation is required, a request can be made to the EPA during the preliminary stages of the project in accordance with Article 11 of the Waste Management (Facility Permit and Registration) Regulations. The EPA may consult with a local authority in reaching its determination. In the Article 11 on-line application form, the proposed DM beneficial use should be clearly defined. This application process is free. The stakeholder will receive notification from the EPA informing the requester of its determination within 15 working days of receipt of a completed request. Depending on the complexity of the information provided, the EPA may request further detail on the application. An online Article 11 application may be completed at: http://art11.epa.ie/Article11/ (EPA, 2013). If the DM is classified as a resource rather than a waste, then the regulatory process is simplified with potentially significant project cost savings.

Table 4.2 Disposal and Recovery Codes as per EU Waste Framework Directive (2008/98/EC) and Eurostat (2010)

Codes		Description
		DISPOSAL
D2	**Land Treatment**	Spreading of non-hazardous waste on land, often followed by the incorporation of the waste into the soil, which does not result in benefit to agriculture or other ecological improvements; e.g. disposal of dredging sludge.
D4	**Surface Impoundment**	The deposit of waste in natural or engineered ponds, pits or lagoons (impoundment); impoundment of dredging sludge.
D6	**Release to Waters**	Deposit of non-hazardous dredging sludge and other non-hazardous sludge in surface water including the bed and the subsoil.
		RECOVERY
R10	**Land-spreading**	Land treatment resulting in benefit to agriculture or ecological improvement

In the case of environmental enhancement and some specific engineering uses of non-hazardous DM, e.g. land reclamation, coastal protection, beach nourishment, flood defences and sediment cell maintenance, Article 2(3) of the EU Waste Framework Directive indicates that such beneficial use of non-hazardous DM may be excluded from the scope of the Directive to the extent that its use is covered by other community legislation (based on the following from Article 2):

"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."*

If the DM is classed as hazardous waste, it cannot be excluded from the scope of the Directive. If the DM is classed as non-hazardous waste, it must be proven that the relocation inside surface waters is for the specific purposes listed (managing waters and waterways or preventing floods or mitigating the effects of floods and droughts or land reclamation) in order for it to be excluded.

The general issue of waste as a resource has been addressed in Clause 19 of the Waste Framework Directive (2008) which states that "The definitions of recovery and disposal need to be modified in order to ensure a clear distinction between the two concepts, based on a genuine difference in environmental impact through the substitution of natural resources in the economy and recognising the potential benefits to the environment and human health of using **waste as a resource**. In addition, guidelines may be developed in order to clarify cases where this distinction is difficult to apply in practice or where the classification of the activity as recovery does not match the real environmental impact of the operation".

4.3 Guidance on DM Beneficial Use Legislative Process

Table 4.3 presents a **draft** guide to the potential legislative process that may be associated with different beneficial uses of DM. Figure 4.1 presents a **draft** decision process diagram for determining what type of authorisation may be required for the engineering use of DM. Figures 4.2 and 4.3 present similar **draft** diagrams for environmental enhancement and agricultural and product uses of DM respectively.

It should be noted that this legislative guidance is not definitive and potential applicants for any of the authorisations referenced in this guidance are responsible to ensure they meet their statutory obligations under Irish and EU law.

Table 4.3 Relevant Legislation by Beneficial Use Type

	Engineering Uses					Environmental Enhancement			Agricultural/Product Uses				
LEGISLATION	Beach Nourishment	Land Reclamation	Landfill Cover	Coastal Protection	Offshore Coastal Protection (Berms)	Wetland Habitat	Sediment Cell Maintenance	Mine/Quarry Fill Material	Landfill Liner	Manufactured Topsoil	Concrete manufacture	Brick Production	Road Sub-Base
Foreshore Act	✓	✓		✓	✓	✓	✓						
Planning Permission	✓	✓		✓	✓	✓	✓						
Waste Management Acts		✓	✓			✓		✓	✓	✓	✓	✓	✓
Article 5 & 6 EU Directive 2008/98/EC on Waste Management			✓					✓	✓	✓	✓	✓	✓
Waste Management Collection Permit Regulations		✓	✓					✓	✓	✓	✓	✓	✓
Landfill of Waste			✓						✓				
Directive on Environmental Quality Standards	✓	✓		✓	✓	✓	✓						
Fisheries Act	✓	✓		✓	✓	✓	✓						
Water Framework Directive	✓	✓		✓	✓	✓	✓						
Marine Strategy Framework Directive	✓	✓		✓	✓	✓	✓						
EC Quality of Shellfish Waters Regulations 2006	✓	✓		✓	✓	✓	✓						
Birds and Natural Habitats Regulations 2011	✓	✓		✓	✓	✓	✓	✓					
Bathing Water Directive[1]	✓												
Quality of Salmonid Water Regulations 1988.[2]													
EC Environmental Objectives (Surface Water) Regulations 2009[3]													

[1] Specific Beneficial Use Projects may impact on the Quality of Bathing Waters

[2] Specific Beneficial Use Projects may impact on migrating Salmonid populations

[3] Specific Beneficial Use Projects may impact on Surface Waters

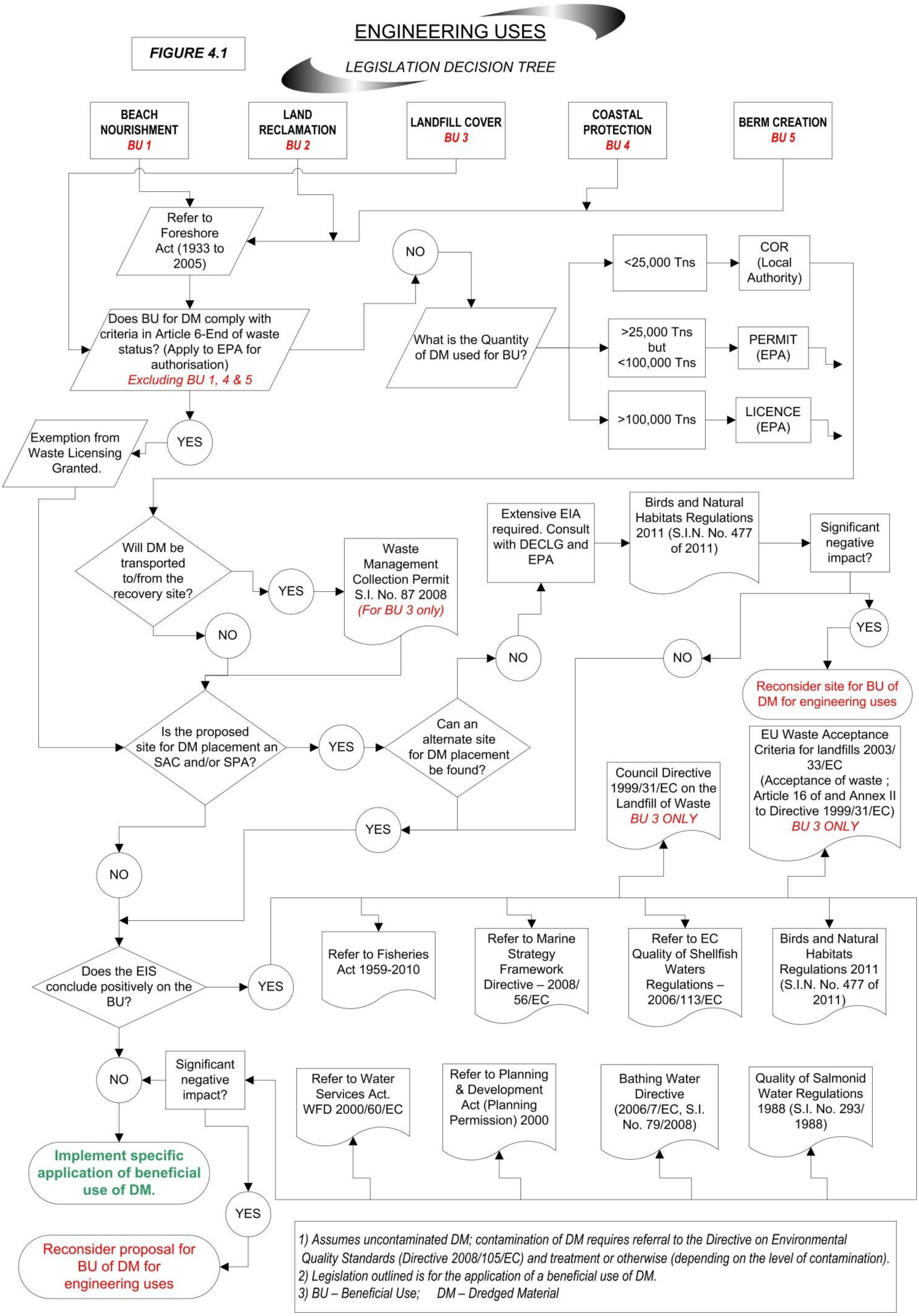


FIGURE 4.1
ENGINEERING USES
LEGISLATION DECISION TREE
BEACH NOURISHMENT BU 1
LAND RECLAMATION BU 2
LANDFILL COVER BU 3
COASTAL PROTECTION BU 4
BERM CREATION BU 5
Refer to Foreshore Act (1933 to 2005)
Does BU for DM comply with criteria in Article 6-End of waste status? (Apply to EPA for authorisation)
Excluding BU 1, 4 & 5
NO
What is the Quantity of DM used for BU?
<25,000 Tns
COR (Local Authority)
>25,000 Tns but <100,000 Tns
PERMIT (EPA)
>100,000 Tns
LICENCE (EPA)
YES
Exemption from Waste Licensing Granted.
Will DM be transported to/from the recovery site?
YES
Waste Management Collection Permit S.I. No. 87 2008
(For BU 3 only)
NO
Extensive EIA required. Consult with DECLG and EPA
Birds and Natural Habitats Regulations 2011 (S.I.N. No. 477 of 2011)
Significant negative impact?
YES
Reconsider site for BU of DM for engineering uses
NO
NO
Is the proposed site for DM placement an SAC and/or SPA?
YES
Can an alternate site for DM placement be found?
YES
Council Directive 1999/31/EC on the Landfill of Waste
BU 3 ONLY
EU Waste Acceptance Criteria for landfills 2003/33/EC (Acceptance of waste ; Article 16 of and Annex II to Directive 1999/31/EC)
BU 3 ONLY
NO
Does the EIS conclude positively on the BU?
YES
Refer to Fisheries Act 1959-2010
Refer to Marine Strategy Framework Directive – 2008/56/EC
Refer to EC Quality of Shellfish Waters Regulations – 2006/113/EC
Birds and Natural Habitats Regulations 2011 (S.I.N. No. 477 of 2011)
NO
Significant negative impact?
Refer to Water Services Act. WFD 2000/60/EC
Refer to Planning & Development Act (Planning Permission) 2000
Bathing Water Directive (2006/7/EC, S.I. No. 79/2008)
Quality of Salmonid Water Regulations 1988 (S.I. No. 293/1988)
Implement specific application of beneficial use of DM.
YES
Reconsider proposal for BU of DM for engineering uses
1) Assumes uncontaminated DM; contamination of DM requires referral to the Directive on Environmental Quality Standards (Directive 2008/105/EC) and treatment or otherwise (depending on the level of contamination).
2) Legislation outlined is for the application of a beneficial use of DM.
3) BU – Beneficial Use; DM – Dredged Material

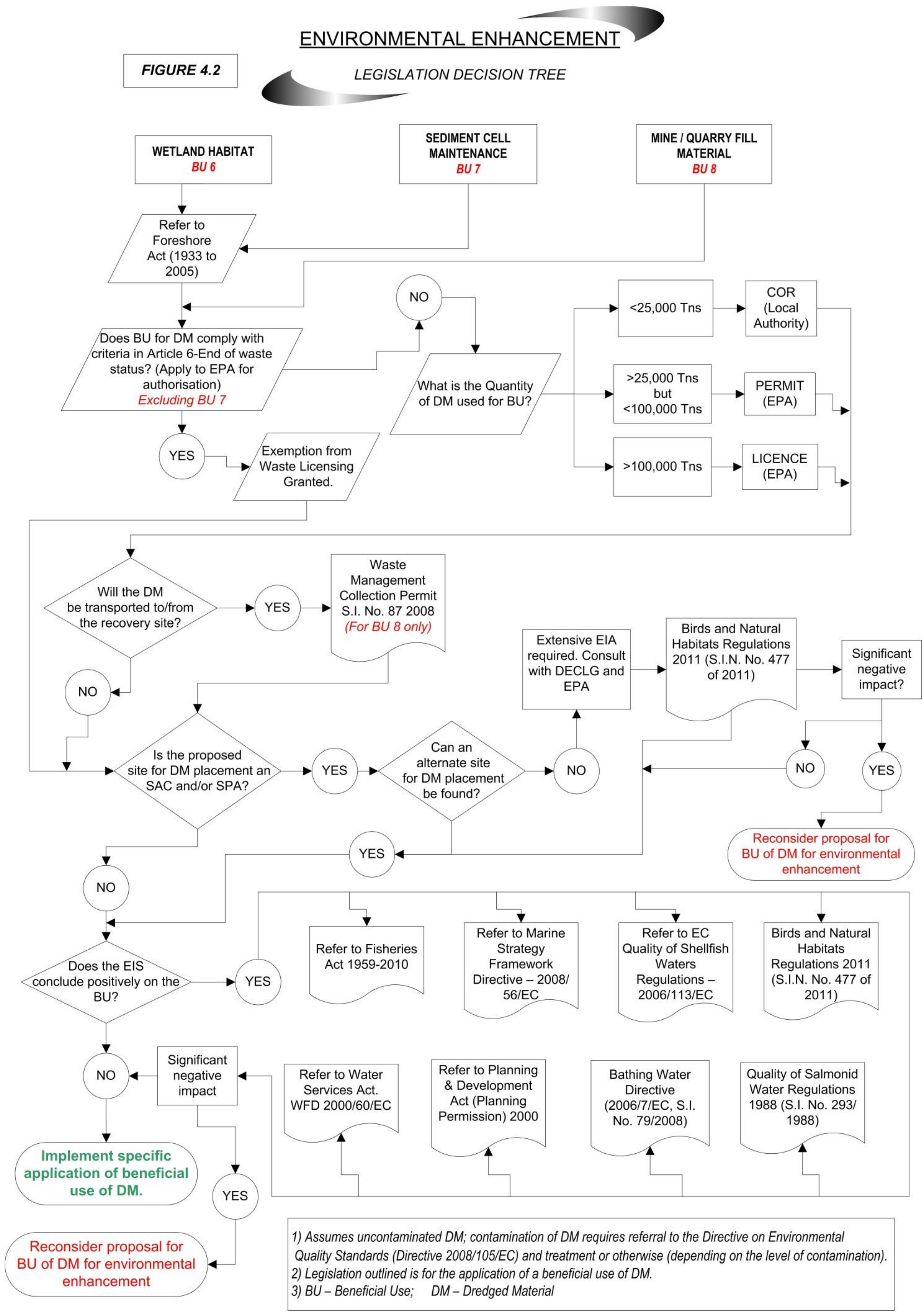
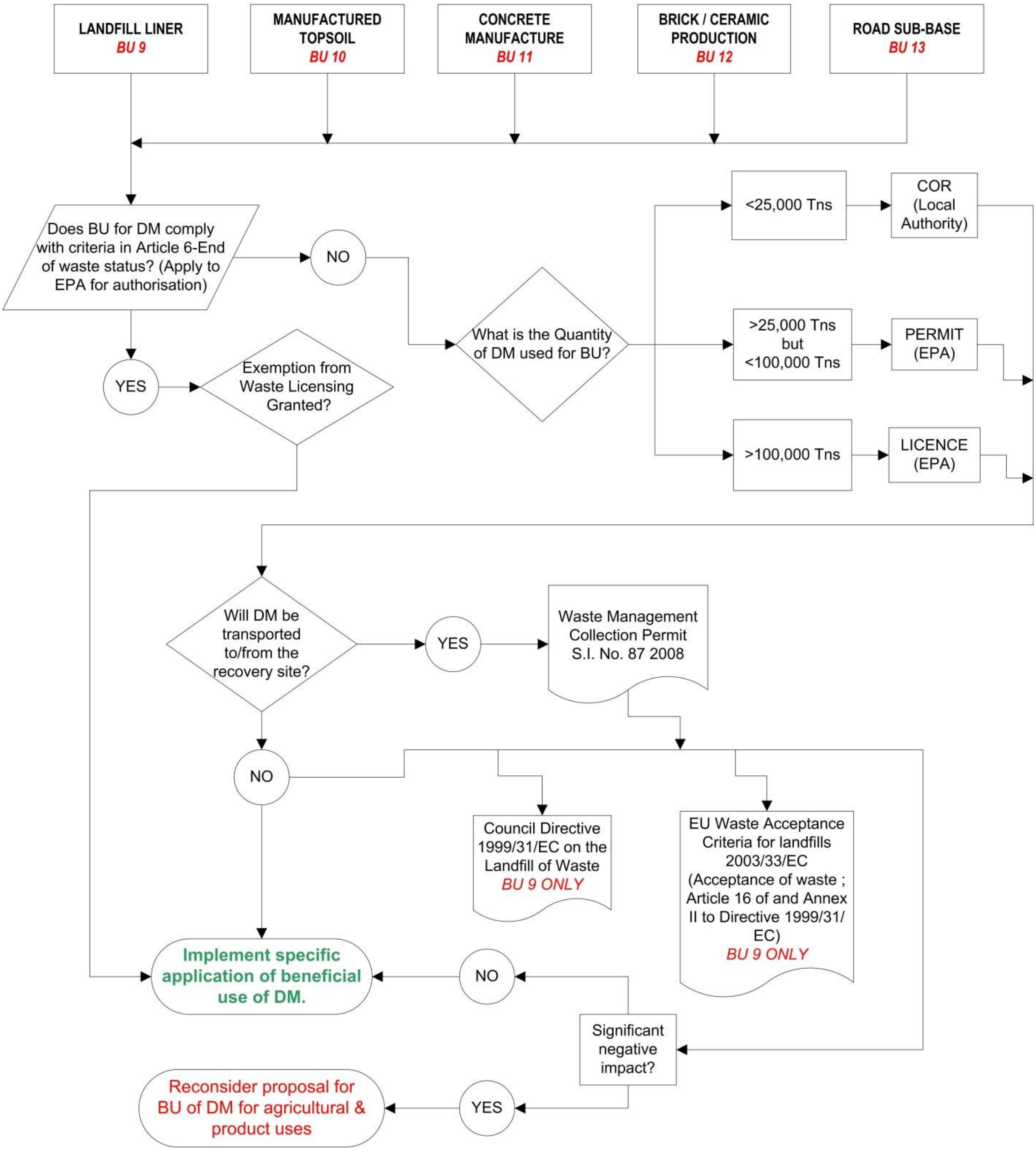

ENVIRONMENTAL ENHANCEMENT
FIGURE 4.2
LEGISLATION DECISION TREE
WETLAND HABITAT
BU 6
SEDIMENT CELL MAINTENANCE
BU 7
MINE / QUARRY FILL MATERIAL
BU 8
Refer to Foreshore Act (1933 to 2005)
Does BU for DM comply with criteria in Article 6-End of waste status? (Apply to EPA for authorisation)
Excluding BU 7
NO
YES
Exemption from Waste Licensing Granted.
What is the Quantity of DM used for BU?
<25,000 Tns
>25,000 Tns but <100,000 Tns
>100,000 Tns
COR (Local Authority)
PERMIT (EPA)
LICENCE (EPA)
Will the DM be transported to/from the recovery site?
YES
Waste Management Collection Permit S.I. No. 87 2008
(For BU 8 only)
NO
Is the proposed site for DM placement an SAC and/or SPA?
YES
Can an alternate site for DM placement be found?
NO
Extensive EIA required. Consult with DECLG and EPA
Birds and Natural Habitats Regulations 2011 (S.I.N. No. 477 of 2011)
Significant negative impact?
NO
YES
Reconsider proposal for BU of DM for environmental enhancement
YES
NO
Does the EIS conclude positively on the BU?
YES
Refer to Fisheries Act 1959-2010
Refer to Marine Strategy Framework Directive – 2008/56/EC
Refer to EC Quality of Shellfish Waters Regulations – 2006/113/EC
Birds and Natural Habitats Regulations 2011 (S.I.N. No. 477 of 2011)
NO
Significant negative impact
Refer to Water Services Act. WFD 2000/60/EC
Refer to Planning & Development Act (Planning Permission) 2000
Bathing Water Directive (2006/7/EC, S.I. No. 79/2008)
Quality of Salmonid Water Regulations 1988 (S.I. No. 293/1988)
Implement specific application of beneficial use of DM.
YES
Reconsider proposal for BU of DM for environmental enhancement
1) Assumes uncontaminated DM; contamination of DM requires referral to the Directive on Environmental Quality Standards (Directive 2008/105/EC) and treatment or otherwise (depending on the level of contamination).
2) Legislation outlined is for the application of a beneficial use of DM.
3) BU – Beneficial Use; DM – Dredged Material

FIGURE 4.3

AGRICULTURAL & PRODUCT USES

LEGISLATION DECISION TREE



1) Assumes uncontaminated DM; contamination of DM requires referral to the Directive on Environmental Quality Standards (Directive 2008/105/EC) and treatment or otherwise (depending on the level of contamination).
2) Legislation outlined is for the application of a beneficial use of DM.
3) BU – Beneficial Use; DM – Dredged Material

5. Case Study

Dredging Site

A small harbour, under the jurisdiction of the local Harbour Commissioners, is located in a semi-enclosed tidal bay with a marina and 200m long deep sea pier. The Harbour Commissioners propose to extend the marina with wave protection provided by a rubble mound breakwater structure. Capital dredging will be required as part of this harbour expansion project.

One specific semi-isolated area within the bay is designated as Special Areas of Conservation (SAC) under the Birds and Natural Habitats Regulations.

Maintenance dredging of the harbour is conducted irregularly with an average volume of 10,000m^3 of DM removed approximately every 3 years. Several larger capital dredging projects have been undertaken in the past at the harbour due to initial expansion works and increasing the capacity of the shipping berths. The DM has been disposed at a licensed dumping at sea site located approximately 10km sail distance from the harbour.

It is estimated that the proposed new dredging works will require the removal of approximately 165,000m^3 of DM.

The dredging site contains both fine and coarse sediment material.

The bay is surrounded by a number of nearby beaches, with the main recreational sandy beach experiencing coastal erosion; a small groyne field was constructed on the beach some years ago to counteract the impacts of the erosion.

The bay is characterised by a number of tidal mud flats, some of which are also experiencing erosion.

DM Management Process

DM Characterisation
The physical and chemical characteristics of the DM were determined. A pre-dredge survey plan was prepared (Fig. 2.1). In accordance with best practice, eight sampling stations were established for the proposed dredging area. Direct sampling techniques were applied using a sediment grab sampler (Table 2.2, Fig. 2.3) and a sediment corer (Table 2.3, Fig. 2.3) to a depth of 3m as existing borehole data from the site showed that a surficial silt layer rarely exceeding 2.5m in depth. The site investigation showed a clear definition between the surficial silt and underlying sand stratum.

The overall physical test results indicated the following (Table 2.5):

- % Gravel (>2mm) = 1%
- % Sand (63µm-2mm) = 56%
- % Silt/Clay (<63µm) = 43%

Sediment samples were also taken at the main recreational beach and tested. The results indicate that the sediment size distribution is similar to that of the sandy material to be dredged and that the colour and texture is also similar.

Chemical testing was undertaken by an accredited laboratory and the test results indicated that the material was uncontaminated and complied with Ireland's Action List for Dumping at Sea (Table 2.6). Testing for additional chemical properties was also undertaken (Table 2.7) and indicated suitable levels for the standard chemical properties.

The physical and chemical characterisation process undertaken was considered sufficient to fully assess the DM and biological characterisation of the DM was not required.

DM Management Options & Assessment
A range of DM management options were identified (Table 3.2) and considered for the site. An initial desk top analysis was undertaken yielding the preliminary conclusions as outlined below. The DM management options identified in bold font were considered to be the most feasible requiring further more detailed investigation.

DM Management Option	Comments
Beach Nourishment	Sandy material available, eroding beach nearby, technically feasible
Land Reclamation	No current demand to reclaim, raise (due to flooding) or improve land in the locality
Landfill Cover	No landfill site located within an economic distance of the dredging site
Coastal Protection	No rock being dredged thus no rock material that might be suitable for the rubble mound armour protection for the breakwater. Material mix potentially suitable for geotubes filled with DM to form the core of the proposed breakwater structure, potentially technically feasible but would require extensive pilot scale and design work.
Offshore Berm	Not applicable at this harbour site in a semi-enclosed bay
Wetland Creation	Degraded wetland areas were not identified in close proximity to the DM site
Sediment Cell Maintenance (specific to sediment maintenance in the vicinity of tidal mudflats)	General sediment cell maintenance is not deemed appropriate due to the presence of an SAC. However only one specific area within the bay is designated as an SAC, and the clean uncontaminated fine grained DM has the potential to be targeted to be used to feed the eroding tidal mudflats (as a form of tidal mudflat enhancement/sediment cell maintenance in a specific area).
Fill for Quarries/Mines	No suitable sites located within an economic distance of the dredging site
Upland Habitat Creation	Potential upland habitat areas were not identified at the initial study stage
Concrete Manufacture	No concrete manufacturer located within an economic distance of the dredging site
Road Sub-Base Construction	Technology at an early stage of development requiring significant additional research and pilot scale work before it would become potentially feasible for this site.
Landfill Liner	No landfill site located within an economic distance of the dredging site
Manufactured Topsoil	Regular supply of maintenance DM would be required as feedstock for the process.
Production of Ceramics/Bricks	Regular supply of maintenance DM would be required as feedstock for the process.
Disposal at Sea	Licensed disposal site available, technically feasible, no beneficial use of DM

The DM management options identified were considered to be technically feasible and may be summarised as follows:

DM Management Option No. 1: Full disposal of the DM at sea.
This approach has previously been practiced at this site, however it does not provide a beneficial use for the DM and involves disposal of the coarse grained material for which a number of beneficial uses could be found.

DM Management Option No. 2: Beach Nourishment for Sandy Material & Disposal at Sea or Mud Flat Replenishment for Fine Grained Material
The beach nourishment option was considered suitable for the coarse grained sandy DM for the nearby beach; the particle size distribution and colour and texture of the sandy DM and the local beach material are similar. However the fine grained fraction (which can be dredged separately to the sand) is not suitable as beach nourishment material and requires an alternative management approach. Two potential DM management approaches (two sub-options) are proposed:

(a) Disposal of the fine grained fraction at sea at the current licensed disposal site.
or
(b) Placement of the fine grained fraction of the DM in the vicinity of the eroding tidal mud flats as a source of supply material for the mudflats (as the material is fine grained and uncontaminated and the eroding mudflats are not within the SAC).

An economic analysis indicates the feasibility of this DM management option; sub-option (a) involves a reduced DM volume for dumping and sub-option (b) involves full reuse of material. A CO_2 emission analysis indicates reduced CO_2 emission levels due to the reduced trips to the dumping site for sub-option (a) and no sea dumping for sub-option (b).

DM Management Option No. 3: Use of DM as fill for geotubes to form the core of the proposed rubble mound breakwater
The use of geotubes to form the core of the proposed breakwater structure is technically feasible as the sand content of the DM is approximately 56% which exceeds the recommended minimum of 40% sand sufficient to allow the geotubes to be used as a structural core. This DM management approach allows both the coarse and fine grained DM to be beneficially used.

An economic analysis was undertaken on the use of geotubes filled with DM. The results of the analysis indicated that the use of geotubes in the core of the breakwater as an alternative to quarry run core material in a traditional breakwater was economically feasible and provided a cost saving. A CO_2 emission analysis was also undertaken of the proposed use of geotubes. The results of this analysis indicated that lower CO_2 emissions for the geotube DM approach, relative to the construction of a traditional breakwater, due to the significant reduction in the transport of quarry run core material from the source quarry to the harbour site.

Conclusion

DM Management Option No. 1 will not be pursued as alternatives exist which are technically, economically and environmentally feasible and involve the reuse of some of all of the DM.

The following sections present the approach taken for both Option Nos. 2 & 3 in terms of Applicable Legislation/Permitting and Beneficial Use of DM Application.

Note: The information presented is preliminary in nature; detailed study and design is required prior to implementation of a specific beneficial use for DM at a particular site.

Selected DM Management Option No. 2

Applicable Legislation

All relevant legislation must be reviewed including general environmental legislation in addition to the regular dredging and waste legislation.

A licence application was made under the Foreshore Act for the construction of the breakwater and the proposed dredging and associated beach nourishment works. A submission was made to the Marine Licensing Vetting Committee (MLVC). In parallel planning permission was sought from the Local Authority under the Planning and Development Act. Both the Foreshore Licence and the planning permission were granted. An Environmental Impact Assessment (EIA) was undertaken at the preliminary stages of the project as recommended by the planning authority. The Environmental Impact Statement (EIS) concluded that no negative impacts to the local ecosystem or environment would arise from the dredging and associated works and the construction of the rubble mound structure.

Sub-option (a): An application was made to the EPA under the Dumping at Sea Act for disposal of the fine grained fraction at the existing licensed disposal site; a Dumping at Sea Permit was issued by the EPA.

or

Sub-option (b): Sediment Cell Maintenance/Tidal Mudflat enhancement involves placement of the fine grained DM in the vicinity of the eroding mudflats. In this case the license application under the Foreshore Act included the sediment cell maintenance/tidal mudflat enhancement proposal.

After consultation with the Department of Environment, Community and Local Government (DECLG) and the Department of Agriculture, Food and the Marine (DAFM) regarding any potential impacts on water quality or marine wildlife and benthic communities in the area, in conjunction with the relevant environmental legislation, permission was granted for the project.

Beneficial Use Application

A detailed design of the proposed beach nourishment plan was prepared including detailed wave model studies for the site. The bays between the existing groynes on the beach are to be nourished with sand. The design includes for some level of overfill on the beach to reflect the subsequent loss of fine material. The DM is dredged, in this case, using a hopper dredger and transferred via a floating pipeline onto the beach where it is discharged as beach nourishment.

Sub-option (a): The fine grained material is dredged using a trailing suction hopper dredger with sailing and disposal/dumping at the licensed dumping site.

or

Sub-option (b): The fine grained material is dredged using a hopper dredger and transferred via a floating pipeline and diffuser where it is accurately deposited in the vicinity of the tidal mudflats. Modelling studies undertaken indicate that placement of the DM in specific areas adjacent to the mudflats allow feeding/nourishment of the mudflats without significant transport of the sediment to other areas within the bay and any sediment transport into the semi-isolated SAC.

Selected DM Management Option No. 3

Applicable Legislation

All relevant legislation must be reviewed including general environmental legislation in addition to the regular dredging and waste legislation.

The geotube cored rubble mound structure is located near to the shoreline and therefore requires a licence under the Foreshore Act. A submission was made to the Marine Licensing Vetting Committee (MLVC). In parallel planning permission was sought from the Local Authority under the Planning and Development Act. Both the Foreshore Licence and the planning permission were granted. An Environmental Impact Assessment (EIA) was undertaken at the preliminary stages of the project as recommended by the planning authority. The Environmental Impact Statement (EIS) concluded that no negative impacts to the local ecosystem or environment would arise from the dredging and construction of the rubble mound structure with a geotube core.

Whilst it may not be a requirement for the project an Article 11 form was submitted to the EPA seeking clarification on whether the DM could be exempt from waste licensing and regulation as it would be used for a specific beneficial purpose and will not lead to overall adverse environmental or human health benefits, therefore achieving end-of-waste status. Exemption from waste licensing was granted meaning the DM could be classified as a raw material rather than a waste; hence no waste management permits or licensing was necessary.

After consultation with the Department of Arts, Heritage and the Gaeltacht through the National Parks and Wildlife Service and the Department of Agriculture, Food and the Marine (DAFM) regarding any potential impacts on water quality or marine wildlife and benthic communities in the area, in conjunction with the relevant environmental legislation, permission was granted for the project.

It should be noted that in this case where no DM is dumped at sea that a Dumping at Sea permit is not required.

Beneficial Use Application

A detailed design of the rubble mound structure was completed based on best practice design. As the use of geotubes to form the core of the breakwater is a new and innovative approach relative to traditional quarry run core material detailed model studies, including physical model studies, were completed to ensure a high level of confidence in the final design.

As recommended by the specialist geo-synthetic contractor consulting on the project a small cutter suction dredger was chosen to recover the DM from the site, six to eight inch pipe size was used to ensure optimum fit to the inlet ports of the geotubes. Continuous filling of the geotubes from the dredger was prioritised as an essential part of the project to ensure the geotubes reached their design height. It was noted that failure to achieve this could result in consolidation of the DM within the geotube which may deform the final shape.

The breakwater design replaces the traditional quarry run core material with the filled geotubes. The geotubes were placed in position, stacked and filled with seawater prior to the DM being pumped into the geotubes to help retain the desired shape and slope and reduce the risk of consolidation within the geotubes. Dewatering and filtration of the DM in the geotube structures occurs over time. The geotubes were then covered with a geotextile, rock underlay and a rock armour layer as per standard breakwater design and construction best practice. It is estimated that replacing the quarry run core with geotubes resulted in a significant cost saving.

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Appendix A Additional Information

Table A.1 Recommended Common Guidelines for the Characterisation of DM

Author	Title	Summary	Source/Website
OSPAR Commission (2009)	Guidelines for the Management of Dredged Material	• Detailed DM characterisation and analysis • Normalisation of contaminant concentrations	http://www.dredging.org/documents/ceda/downloads/environ-ospar-revised-dredged-material-guidelines.pdf
CEFAS (2002)	Guidelines for the conduct of benthic studies at aggregate dredging sites	• Planning, design & conduct for surveys • Sampling - best practices	www.cefas.defra.gov.uk/media/477907/mepf-benthicguidelines.pd
PREMIAM Project – DEFRA (2011)	Post-incident monitoring guidelines	• Monitoring of contaminated sediments at sea • Managing contaminated samples	http://www.scotland.gov.uk/Topics/marine/marine-environment/cleanseas/premiam
IMO – International Maritime Organisation (2005)	Waste Assessment Guidelines Training Set Extension for the Application of Low-technology Techniques for Assessing Dredged Material	• DM characterisation overview • Waste Assessment Guidance (WAG) • Case studies	http://www.imo.org/blast/blastDataHelper.asp?data_id=30961&filename=WAGTE-Vers1.0.pdf
MALSF – Marine Aggregate Levy Sustainability Fund (2011)	Guidelines for the Conduct of Benthic Studies at Marine Aggregate Extraction Sites 2nd Edition	• EIA guidance for dredging projects • Planning and design of surveys	http://www.cefas.defra.gov.uk/media/477907/mepf-benthicguidelines.pdf
Marine Institute of Ireland (2006)	Guidelines for the assessment of dredge material for disposal in Irish waters	• SQGs for DM • Quality control of sampling and analysis of DM	www.marine.ie

Table A.2 Appropriate Characterization Tests for Chemical Properties of DM to Determine Suitability for Beneficial Uses (DOER, 1999)

Test	**Source** (See DOER (1999) for detail)
pH	ASA 1996 :Ch 16; CSSS: 16.2.1
Calcium Carbonate Equivalents	ASA 1996:Ch 16; CSSS 14.2 and 44.6
Cation Exchange Capacity	ASA 1996: Ch 40; CSSS 19.4
Salinity	ASA 1996: Ch 14; CSSS:18.2.2
Sodium	ASA 1996: Ch 19
Chloride	ASA 1996: Ch 31
Sodium Adsorption Ratio (SAR)	CSSS: 18.4.3
Electrical Conductivity	ASA 1996: Ch 14
Total Organic Carbon	ASTM D2974; D2974-87; ASA 1982: 29-4.2; CSSS 44.3
Carbon:Nitrogen Ratio	Analyses 19, 23, and 25 in this table
Total Kjeldahl Nitrogen	EPA-CRL-468
Ammonium Nitrogen	EPA-CRL-324
Nitrate-nitrogen	EPA-SW846-9200
Nitrite-nitrogen	EPA-SW846-9200
Total Phosphorus	EPA-CRL-435
Orthophosphorus	EPA-CRL-435
Potassium	ASA 1996: Ch 19
Sulfur	ASA 1996: Ch 33
Diethylene Triamine Pentaacetic Acid (DTPA) Metals	ASA 1982: 19-3.3; CSSS:1.3;
Total Metals *	EPA-SW846-200.9; ASA 1996: Ch 18-30
Pesticides (chlorinated)	EPA-SW846-8080
Polynuclear Aromatic Hydrocarbons (PAHs)	EPA- SW846-8270
Polychlorinated Biphenyls (PCBs), Congeners	EPA-CRL-8081
Dioxins	EPA-SW846-8290 and 1630
Leachate Quality Test	
Surface Runoff Quality	

Notes: * ***Metals = arsenic, cadmium, chromium, copper, lead, mercury, silver, nickel, and zinc; Use EPA 1986 Method 245.6 for mercury determinations.***
Methods:
ASA = American Society of Agronomy/Soil Science Society of America
CSSS = Canadian Society of Soil Science
ASTM = American Society

Country	DM Management Strategy and Practice
The Netherlands	Annual DM production of 25-30 million m^3, with an annual average budget of €130 million, most of which is spent on maintenance dredging at the Port of Rotterdam. • Prioritise dredging activities with largest benefits and quantify economic and social revenues. • Introduction of subsidies for dredging in urban areas and financial incentives for maintenance dredging. • Adaptation of DM legislation to make it more coherent, simple and suitable to achieve policy targets. ***Example Case Study*** *Limburg, Zeeland: maintenance project in canals with contaminated silty-sand DM. Treatment and beneficial use of 50% of DM by ripening, sand separation and immobilisation.*
Germany	Annual DM production of approximately 46 million m^3, 76% of which is from maintenance dredging in coastal areas. • Established a Working Group on Coastal Dredging (AKN)-to define management practices for maintenance dredging and improve economic efficiency of equipment and machinery. • Large scale contaminated treatment plant (METHA) in Hamburg. Mechanical separation and dewatering of CDMS. ***Example Case Study*** *Contaminated maintenance DM from Bremen Harbour used for brick production, containment layer in landfills and the production of Light Weight Aggregates (LWA).*
Norway	Less than 100,000 m^3 is dredged annually but there are considerable issues with contaminated sediments. • Norwegian Pollution Control Authority (SFT) established to monitor and evaluate CDMS. • Policy to advance through pilot projects, research, monitoring and establishment of a national council to address sediment issues. • Impose obligation on polluters to conduct the necessary clean-up required ***Example Case Study*** *Sandefjord Seaport/bay- Dewater CDMS using Geotubes deposited locally on seabed to act as a barrier. This is covered over with geotextile and clean sand.*
Belgium	The main region for dredging activities is Flanders – annual DM production of 6.3 million m^3. • Introduction of TRIADE approach to DM classification; 4 pollution classes ranging from no pollution (class 1) to severe pollution (class 4). • Spreading of DM on rivers, canals and waterways to enhance navigable areas. • Flemish waste regulations (VLAREA) allow classification of suitable DM (after analysis) as “secondary raw material”; it is no longer considered a waste allowing for easier beneficial use application of DM. ***Example Case Study*** *2.5 million m^3 of dry contaminated DM spread over 13 treatment facilities where it is dewatered and treated biologically to remove contaminants. The remaining clean sediment (sand and fine aggregates) is certified by Flemish waste agency (OVAM) as either ‘soils’ or ‘building material’ for beneficial use.*
France	Annual volume of DM production is approximately 56 million m^3; 89% of which comprises of marine sediments generated from the 6 main ports. • Developed the GEODRISK method of DM characterisation; gives geochemistry of DM and also identifies potential hazards. • History of implementing a range of different beneficial uses for DM including: land improvement, agricultural fill material, beach nourishment, coastal erosion control, construction material and topsoil. ***Example Case Study*** *Charentes, maintenance DM used as beach nourishment to improve coastal regime and enhance recreational opportunities.*
Italy	Approximate annual national dredging requirement of 6 million m^3. • National policy of viewing DM as a ‘resource’ instead of a ‘waste’. • National Program of remediation and environmental recovery of contaminated DM. • Testing of treatment technologies for contaminated sediments in order to identify environmentally sustainable management options.

	Example Case Study *Confined Disposal Facility (CDF) for containment of CDMS in the harbour of La Spezia. Level of contamination required a 1m thick lining of impermeable material to the sides and bottom of the CDF.*
United States	Approximate annual national dredging requirement of 200-300 million m^3 of DM. • Established National and Regional Dredging Teams (USEPA & USACOE's & RDT's) to facilitate communication, coordination, and resolution of national dredging issues. • Extensive and detailed national dredging management programme overseen by the EPA and DMMO (Dredged Material Management Office). • Published "Beneficial Use Planning Manual" which presents a framework for identifying, planning, and financing beneficial use projects in the US. • Committed to implementing beneficial uses of DM over the last decade under the "Action Agenda – 2003 to 2013" outlying the issues and principles of good DM Management. ***Example Case Study*** *The LTMS (Long-Term Management Strategy) of the San Francisco Bay RDT has developed several beneficial use programs for DM and aims to use 40% of all DM beneficially in the long term. Current beneficial uses include: landfill daily cover, beach nourishment, sand for use by aggregate companies, and construction fill in separately approved upland or aquatic fill projects (for both material that is clean and that is unsuitable for aquatic disposal).*

Table A.3 Brief summary of some National Strategy and Practice for DM Management in the EU & the United States (Palumbo, 2007; SedNet, 2007; USEPA & USACOE, 2007; USACE & USEPA, 2007)

Country	Summary of DM Legislation/Regulations
UK	• Main National Agency dealing with DM disposal and re-use is the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) • Regulatory agency is the Marine Management Organisation (MMO) • Separate license required for sampling of seabed in addition to any dredging licensing granted • Main legislative instrument governing DM re-use is the Environmental Permitting Regulations (2010) but does not provide specific guidance on DM • The Contaminated Land: Applications in Real Environments (CL:AIRE) code of practice (2008) outlines regulations for re-use of suitable DM on land • CIRIA currently developing guidance document on the re-use and disposal of dredged material to land with a focus on legislation and regulation governing DM
The Netherlands	• National guidelines in place outlining the different pathways for handling DM based on National policy and strategy for DM. • DM still generally regarded as a 'waste material', however, certain categories of DM are exempt from waste regulations. • Dutch Building Materials Decree has been adapted for several parameters leading to simplified application of suitable DM in construction etc. • Prioritisation of the EU Water Framework Directive; DM is incorporated in the water legislation
Germany	• No specific National documentation on DM disposal options • DM regulated by various laws for water, waterways, soil and waste • Directive for Dredged Material Management in Federal Coastal Waterways (HABAK); incorporates majority of coastal DM – gives guidance on testing, evaluation and disposal of DM
Norway	• Government report released in 2002 entitled "Protecting riches of the sea" outlined strategic plans to protect and improve the marine environment. • No specific guidance on DM/sediment management. • Dependent on guidelines established in OSPAR Convention (1992).
Belgium	• Waste legislation and strategies can vary in each designated region; Brussels, Walloon or Flanders. • Flemish legislation for waste prevention and management (VLAREA) established concise set of guidelines/rules for beneficial use of DM; periodically updated since 2004 • DM still considered a waste in the first instance; after analysis it may be categorised as "secondary raw material" and is no longer considered a waste. • Established public waste products organisation (OVAM) which controls the entire process of applying for DM to be used beneficially as a construction material
France	• Still heavily dependent on the International regulations established in the OSPAR Convention (1992) for guidance on DM management • No specific national legislation directly related to DM • Various Decrees in French law encompassing DM as a waste for disposal • Special measures must be taken to beneficially re-use DM in accordance with current French Law
Italy	• Legislative Decree 152/99 states that disposal of DM may only be approved once alternatives for beneficial use cannot be implemented • Contaminated DM addressed under national laws and Ministerial Decrees. • Ministry of the Environment established national research organisation to define DM characterisation (ICRAM)

Table A.4 Summary of some relevant DM legislation and regulations for a selection of EU states (Palumbo, 2007; CEFAS, 2009)