



Department  
for Environment  
Food & Rural Affairs

# Sampling and Analysis methods for contaminated sediments

## Work Package 1C Report

July 2017



Joint Water Evidence Programme

# **Sampling and Analysis methods for contaminated sediments Work Package 1C**

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# REPORT

## Sampling and Analysis methods for contaminated sediments

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## 1 Introduction

The scope of Work stream 'A' (Work packages 1A to 5A) is to design and cost further investigation to fill gaps in sediment quality information, or to produce a contaminated sediments investigation and assessment methodology for operational staff. This requires an in-depth understanding of the currently available guidance and practice in sediment sampling and analysis within the UK. Work package 1C (WP1C) was therefore commissioned to investigate this within both Government organisations and commercial laboratories.

A tiered approach was agreed with the Project Board:

- **Phase 1(a):** arrange a conference call between representatives from the Project Board, Royal HaskoningDHV, the Centre for Environment, Fisheries and Aquaculture Science (Cefas) and the Environment Agency's National Laboratory Services (NLS) to discuss current practice.
- **Phase 1(b):** if required, arrange a second conference call with other relevant organisations should it be believed that further relevant information could be obtained (e.g. Canal and Rivers Trust (C&RT) (or their dredging contractor, Land and Water Services), representative commercial laboratories (e.g. Fugro-EMU Ltd, ALcontrol, Chemtest, etc.).
- Provision of an initial assessment of whether there are gaps in the knowledge required for the wider project, and if so collate a list of documents for further review.
- **Phase 2:** Review documentation highlighted and agreed in Phase 1 to establish differences in current practices and suggest options for standardising or developing methodologies or guidance documents (this would be a separate project).

WP1C therefore aims to answer the following key questions, as requested by the Project Board:

- What is current practice in the UK (e.g. within Environment Agency and C&RT projects)?
- What constitutes best practice within Europe?
- Is current UK practice consistent with European best practice?
- What are the advantages and disadvantages of current UK and European sampling techniques?

The findings and recommendations from WP1C will feed into WP5A.

## 2 Current best practice methodologies and standards used for analysis of contaminated sediments

Phase 1a of WP1C consisted of a teleconference held on 23 November 2015 between representatives from the Project Board, Royal HaskoningDHV, Cefas and NLS. Minutes of the meeting are provided in **Annex A**. A summary of the key findings is presented in the following sections.

### 2.1 Centre for Environment, Fisheries and Aquaculture Science (Cefas)

Cefas are the primary scientific advisor to the Marine Management Organisation (MMO) and Natural Resources Wales (NRW) and provide advice on dredge disposal marine licence applications made under the requirements of the Marine and Coastal Access Act 2009 (as amended)<sup>1</sup> (MCAA 2009). Cefas also undertake the majority of marine sediment analysis in support of marine licence applications from their Lowestoft laboratories, though laboratories other than Cefas are also able to undertake such analyses as long as certain criteria are met (as outlined on the MMO's website<sup>2</sup>).

The Cefas laboratory has accredited status and certification under ISO 17025. It also participates in the European-wide proficiency testing scheme, Quality Assurance for Marine Environmental Monitoring in Europe (QUASIMEME<sup>3</sup>) and the National Marine Biological Analytical Quality Control Scheme (NMQAQC<sup>4</sup>) and the Biological Effects Quality Assurance In Monitoring programme (BEQUALM<sup>5</sup>).

#### 2.1.1 Sampling

Cefas provide advice to marine licence applicants and the MMO on the number of samples needed and contaminants of concern based on existing knowledge. The assessment framework is driven by the requirements of the 'OSPAR Guidelines for the Management of Dredged Material at Sea' and includes guidance on the number of samples required and what they should be tested for. The OSPAR guidance on number of samples is based on the volume of material to be dredged.

Cefas currently send out sampling containers to applicants along with a sampling specification. All sampling is undertaken by applicants and not observed by MMO/Cefas. However, Cefas specify where and how samples must be taken and handled. For example, for 'maintenance dredging'<sup>6</sup>, where Cefas are reasonably certain of the levels of contaminants which may or may not be present in recent sediment deposits, only samples from the surface of the sediment are required. For 'capital dredging'<sup>7</sup>, which involves removal of materials which have not previously been dredged within the last 10 years, core samples would usually be specified to characterise any subsurface contamination. For a complex port location, the sampling plan would likely be equally complex to allow adequate characterisation of those sediments present and reflect known uses of individual berths, both current and historic (e.g. for ship repair).

<sup>1</sup> as amended by The Marine and Coastal Access Act 2009 (Amendment) Regulations 2011.

<sup>2</sup> <https://www.gov.uk/guidance/marine-licensing-sediment-analysis-and-sample-plans#laboratory-capability>

<sup>3</sup> <http://www.quasimeme.org/>

<sup>4</sup> <http://www.nmbaqcs.org/>

<sup>5</sup> <http://www.bequalm.org/about.htm>

<sup>6</sup> 'Maintenance dredging' is undertaken to keep channels, berths and other areas at their designed depths. It involves removing recently accumulated sediments such as mud, sand and gravel. To be classed as maintenance dredging the activity must take place where:

- the level of the seabed to be achieved by the dredging proposed is not lower than it has been at any time during the past 10 years, and;
- there is evidence that dredging has previously been undertaken to that level (or lower) during that period.

<sup>7</sup> 'Capital dredging' is generally undertaken to create or deepen navigational channels, berths or trenches or to remove material unsuitable for the foundation of a construction project. It involves the removal of consolidated sediments.



It is not currently common practice to resample after dredging has been undertaken, though this may be done where it is known that the dredge would not remove all contaminated sediments present.

The same principles for managing potentially contaminated sediments in dredging have also been applied to some construction projects for which marine licence applications have been made, however this is not that common where dredging is not also proposed as an activity.

### 2.1.2 Analysis

Assessment methodologies required for dredged material are outlined in 'Technical Annex I' of the OSPAR guidelines. Analysis data is used for assessment purposes and also to calculate the input of contaminants to the marine environment of the OSPAR region. OSPAR analytical techniques require the use of the <2mm sediment fraction (sands, silts and clays according to the commonly used Wentworth<sup>8</sup> scale) to assess the full amount of contaminant input.

The '*Aquatic Environmental Protection: Analytical Methods*' series of publications form the basis of analysis methods used by the Cefas laboratory, though some of these are currently under review (e.g. TBT). Those believed to be most relevant to the current study are listed below:

- **AEPAM 4:** The determination of total tin and organotin compounds in environmental samples.
- **AEPAM 6:** Methods of analysis for chlorinated hydrocarbons in marine and other samples.
- **AEPAM 11:** Methods for analysis for trace metals in marine and other samples.
- **AEPAM 12:** Methods for analysis for Hydrocarbons and Polycyclic Aromatic Hydrocarbons (PAH) in marine samples.
- **AEPAM 13:** Review of Standard Operating Procedures (SOPs).

For analysis of trace metals in dredged materials, the Cefas laboratory follow those methods outlined in Section 11 of AEPAM 11 (*'Preparation of effluent and dredged material samples for the determination of trace metals'*). This states that a nitric acid/hydrogen peroxide method was adopted in 1983 instead of nitric acid or *aqua regia* (a mixture of hydrochloric and nitric acid) methods as "*it was considered to be easier to use with no loss in performance and to give a better approximation to a total digest*" (Jones and Laslett, 1984).

Alternative digestion techniques, such as the use of hydrofluoric acid (HF), are also discussed in other sections of AEPAM11. Such techniques allow for the total metals content of sediments (i.e. total digestion) to be determined for use in marine monitoring programmes. This also allows for normalisation of samples to discriminate between 'background' and 'anthropogenic' concentrations of trace metals in samples.

## 2.2 National Laboratory Services (NLS)

The NLS was originally part of the National Rivers Authority and currently operates as a business unit of the Environment Agency. NLS laboratories are accredited to EN ISO 17025 and participate in QUASIMEME.

The NLS is accredited for MCERTS, the Environment Agency's Monitoring Certification Scheme for the monitoring of emissions to air, land and water. NLS has also recently been accredited for undertaking sediment analysis in support of marine licence applications in England.

<sup>8</sup> Wentworth, C.K. (1922) A grade scale for clastic sediments. *Journal of Geology* **30**, 377-392.

### 2.2.1 Sampling

NLS do not provide sampling advice to applicants, however as the main laboratory providing analytical services for the Environment Agency, the Operational instruction for sample taking (010\_07 – ‘Sediment sampling in water for chemical and particle size analysis’) is available. For freshwater for example, a single sediment sample is usually requested for analysis by the Environment Agency.

### 2.2.2 Analysis

The NLS Leeds laboratory undertakes analysis on all sediment/solid matrices and also provides guidance on MCERTS for soils.

For metals digestions in freshwater and marine sediment samples both of these are undertaken on the whole dried sample and digested using *aqua regia*. For freshwater sediments this is undertaken at atmospheric pressure on a hot block (digi-prep system) and analysed by either ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry) or ICP-MS (Inductively Coupled Plasma Mass Spectrometry) dependent on the detection limit required. For marine sediments digestion is at pressure in a microwave vessel and again heated. Subsequent analysis is by ICP-MS.

NLS do not believe there is any major difference in the required handling of ‘terrestrial’ or ‘marine’ samples. The methods of analysis selected for each sample can be either for ‘dried’ or ‘as received’. If analysis is undertaken ‘as received’ results are reported on a dry weight basis to compensate.

Unless specified by a client, freshwater sediment analysis is undertaken on the whole sample (i.e. it is not separated), therefore this technique could not be compared if Cefas only undertook analysis on the <2mm fraction.

Though techniques for sample digestion are applicable to both freshwater and marine sediment samples analysed by NLS, it was recognised that there is a difference with Cefas techniques when the marine licencing digest for metals (nitric acid) as this was designed not to digest the whole of the sediment but to get out the maximum feasibly available amount.

### 3 Other operators

#### 3.1 Canal and Rivers Trust (C&RT)

A telecon was held on 17 May 2016 with Nick Smith, National Waste Management Surveyor with the C&RT. C&RT was formed from its predecessor British Waterways in 2012 and manages a network of approximately 3,000 km of waterways.

##### 3.1.1 Freshwater

###### Dredging

Sedimentation within the canal network is slow and C&RT do not generally need to dredge to the bottom of the canals/waterways. Where C&RT need to undertake dredging within their network, their contractor Land and Water Services is required to take sediment samples and have the samples analysed for a suite of potential contaminants. The frequency of sampling is based on length of waterway (km) or volume (m<sup>3</sup>) of dredged material to be removed. There are occasional differences in the results of analysis from more detailed sampling and analysis effort compared with known background information, though often the two are often very similar with no significant change identified.

The main regulatory driver for reuse of dredged material is the Waste Framework Directive and its implementing legislation and guidance.

The fate of dredged material is influenced by the quantity of material to be dredged and also whether C&RT owns the banks of the waterway to be dredged. If the sediments are shown to be acceptable both physically and chemically (and do not contain other man-made materials/debris), then it is likely that they would be placed on the existing banks of the watercourse.

In rural areas, C&RT may also spread dredged material on agricultural land subject to landowner approval with the same requirements regarding lack of the presence of man-made debris and quality of material. In urban areas, material most frequently goes to a suitable landfill site as it often contains a lot of man-made material/debris.

Guidance produced by the Association of Inland Navigation Authorities (AINA) entitled '*Good practice guide - Sustainable management of dredged material from inland waterways*'<sup>9</sup> is used by C&RT.

###### Permitting

Contractors work under the Environment Agency's 'Standard Rule Permit' system (e.g. 'Standard rules SR2010No4: Mobile plant for land spreading'<sup>10</sup>) and submit an 'Application for Deployment' to the Environment Agency each time they wish to spread dredged material on land to demonstrate that it is a benefit. This includes an assessment of chemical composition, including nutrient levels. Depending upon the results, materials may need to be mixed in with underlying soils. The generic risk assessment spreadsheet associated with SR2010No4 is used to characterise the material and classify it for reuse/disposal.

With regards to placement of dredgings on the banks of watercourses, the C&RT are often able to rely upon 'Waste Exemption D1: depositing waste from dredging inland waters'<sup>11</sup>. Over a 12 month period this allows up to 50m<sup>3</sup> of dredgings to be deposited for each metre of land on which the material is deposited.

<sup>9</sup> [http://www.aina.org.uk/docs/good%20practice%20guides/AINA\\_%20WDGMay2013v5.pdf](http://www.aina.org.uk/docs/good%20practice%20guides/AINA_%20WDGMay2013v5.pdf)

<sup>10</sup> <https://www.gov.uk/government/publications/sr2010-no4-mobile-plant-for-land-spreading>

<sup>11</sup> <https://www.gov.uk/guidance/waste-exemptions-disposing-of-waste>

The material must be deposited either on the banks of the waters from where it was dredged, or on land adjoining the water from where it was dredged (as long as this can be undertaken mechanically).

C&RT previously followed guidance published in a CIRIA report from 1996<sup>12</sup> which reviewed the deposition of dredged material to land, dredging activities and techniques for sampling/sediment characterisation. C&RT believe that the more recent AINA Good Practice Guide (AINA, 2013) is the most recent source of information, which could be modified / updated to reflect new legislation and reference any other new requirements as appropriate.

### Sampling

A sampling exercise was previously undertaken (funded by the then Department of Environment) which involved taking surface sediment samples across the canal/waterway network at approximately 2km intervals by deploying a simple bucket on a rope which was dragged across the sediment surface to recover a sample. This gave a representative sample which was then put into a pot for analysis.

Other sampling techniques adopted include use of a pole with a scoop attached; however this is limited to sampling closer to the banks. Boat-deployed sampling equipment has been used occasionally, though actual sediment samples are still taken using the bucket technique or directly from a dredge bucket if applicable. Grabs and core sampling have been undertaken where more accurate results are required for a particular location or purpose (e.g. regulatory driver), but this is not common. Window sampling techniques have also been used in the past, however this was not considered to provide representative results.

Sampling activities are undertaken by C&RT Environmental Scientists and follow the relevant C&RT operating procedures to ensure sampling equipment used is clean, recovered samples are mixed to provide a representative sample and sample pots are filled adequately and labelled appropriately. The sampling process undertaken is considered to be adequately representative and allows the C&RT to identify areas of potential contamination. This was believed to have worked well in a case in a waterway in Scotland where elevated mercury levels were detected and the source identified through increased sampling/analysis effort

### Analysis

C&RT have historically used ADAS laboratories for analysis of dredged material, although C&RT now generally use Environmental Sampling Group (ESG) for such analyses unless they are unavailable.

C&RT have a standard suite of determinands that have been developed over the years (e.g. metals, hydrocarbons, etc.) however each dredge is looked at on a project-by-project basis and other determinands may be added to the suite if appropriate (e.g. dioxins).

C&RT has also undertaken forensic analysis when attempting to determine the source of hydrocarbons (e.g. from coal in the canals), with procedures following those outlined in the Environment Agency's waste classification technical guidance (Technical Guidance WM3<sup>13</sup>), but is uncertain how well this works for sediments as opposed to soils.

Such work can help to demonstrate that the contaminants present may not be the most hazardous (e.g. carcinogenic) and that they would pose little or no risk if the material was to be placed on the banks. Therefore as long as the Standard Rule Permit process has been followed appropriately, the Environment

<sup>12</sup> CIRIA (1996) *Guidance on the disposal of dredged material to land*, CIRIA Report R157

<sup>13</sup> <https://www.gov.uk/government/publications/waste-classification-technical-guidance>

Agency may produce a regulatory assessment statement which allows for some 'hazardous' material to be placed onto the banks as well as 'non-hazardous' material.

Regarding the C&RT standard analytical suite, the following is taken from the AINA Good Practice Guidance (AINA, 2013):

*"The Canal & River Trust uses this suite of tests as a basic screen for analysing sediments; additional parameters are added based on local knowledge or if it is suspected that other contaminants might be present. Other types of tests and methods of analysis are used as necessary for determining the suitability of sediments for certain types of use, recovery or disposal e.g. WAC [Waste Acceptance Criteria] testing for disposal at landfills, nutrients for spreading to agricultural land and leachate testing where sediments with elevated levels of contaminants are being considered for bankside disposal."*

Table 3.1 Canal & River Trust Standard Sediment Screening Suite

Number	Parameter	Number	Parameter
1	Air dried solids	11	Molybdenum (total)
2	pH	12	Selenium (total)
3	Cadmium (total)	13	Sulphide (total)
4	Chromium (total)	14	Phenols (total monohydric)
5	Copper (total)	15	Cyanide (total)
6	Nickel (total)	16	Barium (total)
7	Lead (total)	17	Boron (total)
8	Zinc (total)	18	PAH (16 EPA speciated & Total)
9	Arsenic (total)	19	Soil Organic Matter Content (%)
10	Mercury (total)	20	Extractable Petroleum Hydrocarbons (EPH) GC FID C10-C40 plus banding

### 3.1.2 Marine

#### Dredging

The C&RT are Statutory Harbour Authority (SHA) in a number of areas around the country, including for the impounded dock at Sharpness in Gloucestershire and on the River Ouse in Yorkshire (which is tidal below Naburn Locks, south of York). They are also Harbour Master at London Docklands and also in relevant areas in Liverpool Docks (e.g. water space and pontoons in Albert Dock).

As SHA the C&RT can rely upon an exemption for the requirement for a marine licence under Section 75 of the MCAA 2009 (as amended) 'for certain dredging activities'. Where this exemption is relied upon, C&RT may use ESG laboratories to demonstrate to the MMO that the sediments are not 'hazardous waste' (as required under Article 2A(c) of Section 75).

When C&RT need to dredge in the marine environment, they frequently use Water Injection (WI), plough or suction techniques to redistribute the material within the local marine environment. Where dredged material is recovered, it is normally disposed of to landfill. Dredged material is not transported to a licensed sea disposal site, though is sometimes redistributed into tidal waters using agitation or suction/pumping techniques.

C&RT also work in Wales and use the same approach for sampling and analysis as in England, though recognising the different legislative requirements of National Resources Wales (NRW).

### Sampling

Where sampling is required in relation to a marine licence application, C&RT follow Cefas guidance for sample collection and storage.

### Analysis

The same standard analytical suite is applied to marine waters as well as freshwaters. The same laboratories (e.g. ESG) and analytical techniques are generally followed; however C&RT have submitted samples to the Cefas laboratories for analysis where it has been necessary in support of a marine licence application (e.g. for dredging works at Hull Marina, the tidal River Ribble near Preston and also areas on the Thames including Canary Wharf/Docklands, Limehouse Basin, etc.).

ESG plans to apply to become an MMO-validated laboratory for marine licence applications. It is understood that ESG may be a back-up for the Cefas laboratory if they cannot undertake the work themselves (e.g. due to workloads).

## 3.2 Commercial Laboratory - Fugro-EMU

A teleconference was held with Chris Wilson, Laboratory Services Manager (Edinburgh) at Fugro EMU Limited Laboratories who specialise in the provision of marine analytical services and operate from three locations in Portchester, Great Yarmouth and Edinburgh. As part of their work, Fugro-EMU undertake marine sediment sampling and analysis for a variety of public and private bodies across many industry sectors.

Fugro-EMU are one of a series of laboratories which have been approved by Marine Scotland for the provision of marine sediment analysis services in support of marine licence applications. Fugro-EMU also plan to become an MMO-validated laboratory for the provision of similar services in support of marine licence applications in England. Currently most analysis work is related to the characterisation of marine sediments rather than specifically for offshore disposal, though this has also been undertaken previously.

### 3.2.1 Sediment laboratory techniques

Fugro EMU's ISO17025:2005 accredited sediment laboratory provides analytical facilities for marine and freshwater sediments and participates in the FAPAS LEAP<sup>14</sup> and NMBAQC inter-laboratory proficiency schemes. The analysis services include<sup>15</sup>:

- Particle Size Analysis (Wet and Dry Sieving) - analysing particles in the range of 63000 - <0.063 µm. (BS1377: Parts 1 - 2: 1990 and NMBAQC method).
- Particle Size Analysis (Laser Diffraction) using a Malvern Mastersizer 2000 – analysing particles within the range of 2000 - 0.02 µm (BS ISO 13320: 2009 and the NMBAQC method).
- Total Suspended Sediment (Based on HMSO Methods 1980 and BS EN 872: 2005).
- Loss on Ignition / Organic Content (BS1377: Part 3: 1990).
- Hydrogen Peroxide Pre-treatment of Organic Matter.

### 3.2.2 Chemical analysis laboratory techniques

Fugro EMU's ISO17025:2005 accredited chemical laboratory services cover the analysis of contaminants within sediments using a variety of techniques including Accelerated Solvent Extraction (ASE), Fourier Transform Infra-Red Spectroscopy (FTIR), Gas Chromatography with Flame Ionisation Detection (GC-FID), Gas Chromatography with Electron Capture Detection (GC-µECD) or Gas Chromatography with

<sup>14</sup> <http://fapas.com/proficiency-testing-schemes/leap/>

<sup>15</sup> <http://www.fugroemu.com/services/laboratories/sediment-laboratory/sediment-testing/>

Total Conductivity Detection (GC-TCD), and Gas Chromatography-Mass Spectrometry (GC-MS). Where analysis is not undertaken in-house, Fugro EMU will also sub-contract to other laboratories

The following contaminants are frequently analysed for<sup>16</sup>:

- Total Hydrocarbon Content (THC) - Including Speciated Aliphatics) by GC-FID (UK Accreditation Service; UKAS).
- Benzene, toluene, ethylbenzene and xylenes (BTEX), volatile organic compounds (VOCs) by Headspace GC-MS.
- Polycyclic Aromatic Hydrocarbons (PAHs) (US Environmental Protection Agency (USEPA) 16 and alkylated-PAH).
- Halogenated Organics by GC- $\mu$ ECD and GC-MS (including polychlorinated biphenyls (PCBs)).
- SVOC (Qualitative / Quantitative).
- Organotin Compounds as mono- / di- / tri-butyl tin (MBT / DBT / TBT) by GC-MS.
- Characterisation of Dredge Material for Disposal at Sea (Cefas / Marine Scotland Guidance).
- Alkylphenols and Alkylphenol Ethoxylates by GC-MS.
- Volatile Organic Acids by GC-MS.

The laboratory prepares suitable sampling kits for a variety of analyses, including for dredged material. Sediment quality analyses undertaken include the following:

- Trace and Heavy Metals.
- PCBs.
- PAHs.
- Total Petroleum Hydrocarbons (TPH).
- Organotins.
- Particle Size Distribution.
- Total Organic Carbon.

<sup>16</sup> <http://www.fugroemu.com/services/laboratories/chemistry-analytical-services/>

## 4 Initial assessment of gaps in knowledge and list of documents for further review

### 4.1 Initial assessment

It has become apparent from the initial stages of this project that little standardisation between techniques for the sampling and analysis of contaminated sediments exists between the marine and freshwater requirements. Whilst certain legislative drivers have led to a standardisation of requirements for marine sediment sampling (specifically in relation to the determination of analyses in support of marine licence applications), no such standardisation appears to be present for freshwater sediment sampling and analysis. The main drivers in this instance appear to be related to the requirements of the Waste Framework Directive and the ultimate fate of the sediment (e.g. dredged material) in question.

In summary, the following areas appear to be the main 'gaps' in current knowledge and understanding:

- Standardisation of sampling techniques (methods used, etc.), sediment size fraction, sample treatment, analytical techniques for different types of contaminants;
- Guidance in sampling techniques and analysis methods most suitable for the freshwater/fluvial environment.

It is recognised however that it may not be possible to standardise 'across the board', and that site specific requirements will always influence the selection of the most appropriate sampling and analytical protocols. It is also recognised that standardisation across the freshwater and marine environments may also be an area with some difficulties.

### 4.2 Documents identified

Following discussions with practitioners in Phase 1(a) and 1(b), the following documents and information resources were highlighted for further review:

Table 4.1 Documents identified for further review

Document	Info	Outline	Page
1 Cefas Aquatic Environmental Protection: Analytical Methods (AEPAM)	Analytical methods	As outlined on page 3 of this report.	-
2 CSEMP Green Book Regional Assessment of Hazardous Substances in Coastal and Offshore Marine Environments: 1999-2009	Analytical methods	Background concentration assessment criteria PSA Analysis Chemical Analysis Metals Analysis Statistical Analysis	21 24 25 28 30
	Sampling	Sediment, fish and mussel sampling methods	23
3 CESMP Green Book Greenbookappendicesv15	Sediment sampling	Subtidal sediment sampling Physico-chemical sample collection Physico-chemical sample preparation	8 9 15
	Analytical methods	Analysis of trace metals Analysis of trace organics Determination of trace contaminants in water samples	16 18 28



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4	02-16e_agreement_jamp_gl_contaminants_in_sediments	Sediment sampling	Monitoring programme design Sampling equipment	6-8
	JAMP Guidelines for Monitoring Contaminants in Sediments	Analytical methods	Procedures Analysis of PCBs in sediments Analysis of PAHs in sediments Analysis of TBT in sediments Analysis of metals in sediments	10 14 27 43 70
5	14-06e	Sediment sampling	Sampling programme for dredging	7
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6	20051201 MV Final Report	Analytical methods	Decision hierarchy for sediment management Using SQGs to evaluate sediment quality	14 39
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7	Association of Inland Navigation Authorities (AINA)	Sediment sampling	Waste exemptions under EPR 2010 Characterising dredgings – sample strategy Remediation options Particle size separation (soil washing) Legislation overview	10 16 27 28 34
	AINA_WDGMay2013v5  Good Practice Guide: Sustainable management of dredged material form inland waterways. www.aina.org.uk			
8	AE0257 (Cefas) Natural regional variation	Sediment sampling	Core samples	6
		Analytical methods	Modelling	6
9	C2641 final draft report	Analytical methods	Introduction Sediment assessment scheme Assessment of availability for chemical contaminants Comparison between Canadian and Cefas	6 8 15 22
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10	EA Final Report 2002  Review and recommendations of methodologies for the derivation of sediment quality guidelines	Analytical methods	Sediment quality guidelines developed in the UK	18
11	EA Technical Guidance WM3 (2015) Appendix D: Waste Sampling	Sediment sampling	Select the sampling approach; types, patterns, quantities	174 – D18

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13	London Convention dredged material assessment guidelines	Analytical methods	Chemical & biological characterisation of sediments	6
14	London Convention guidelines for sampling and analysis of dredged material	Analytical methods	List of analytes Sample handling and storage Analytical parameters	13 33 36
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15	MOU_ and MOU Guidance merge final  MOU between the Environment Agency and British Waterways for the use of hydrodynamic dredging techniques in inland and estuarine waters in England and Wales	Sediment sampling	Sediment contamination	19
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16	OSPAR (2008) p00363e_action_level  OSPAR Commission, 2008: Overview of Contracting Parties' National Action Levels for Dredged Material	Analytical methods	Overview of existing and revised UK action levels	12
			Approaches for Deriving National Action Levels Concentration ranges for dumping at sea Licensing procedures	16 18 23
17	Rpt_13-11-2013-02939-01-E	Sediment sampling	Lateral distribution of contaminants in sediments Challenges with field data collection Field sampling strategies	35 83 85
		Analytical methods	Sediment Quality Triad approach Quantifying risk to receptors	88 97
18	SEDNET (2011)  Assessment Criteria for Dredged Material with special focus on the North Sea Region	Sediment sampling	Sampling strategies in Europe; Germany The Netherlands Belgium Ireland Norway Spain	5 8 9 18 20 24
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	SCHER: Opinion on the Chemicals and the Water Framework Directive: Technical Guidance for Deriving Environmental Quality Standards			
20	Sample Request Letter	Sampling methods	Sample Request letter / Procedure for taking samples of material to be dredged, using glass jars and metal scoops'  OSPAR sampling guidance	1
	CEFAS Sustainable Environmental Advice for Licensing (SEAL) Team			
21	Marine Management Organisation (MMO)	Sediment sampling	Advice on sample and analysis plans in support of marine licence applications.	Web
	Marine Licensing: sediment analysis and sample plans. <a href="https://www.gov.uk/guidance/marine-licensing-sediment-analysis-and-sample-plans">https://www.gov.uk/guidance/marine-licensing-sediment-analysis-and-sample-plans</a>			
22	Marine Management Organisation (MMO)	Analytical methods	Analysis procedures to be followed in support of marine licence applications.	Web
	Marine licensing: physical and chemical determinands for sediment sampling. <a href="https://www.gov.uk/government/publications/marine-licensing-physical-and-chemical-determinands-for-sediment-sampling">https://www.gov.uk/government/publications/marine-licensing-physical-and-chemical-determinands-for-sediment-sampling</a>			
23	Edwards, T.K. and Glysson, G.D. (1999)	Sampling methods	Sediment sampling equipment Sediment sampling techniques	4 35
	Field Methods for Measurement of Fluvial Sediment (Chapter C2). [In] USGS Techniques of Water Resources Investigations of the US Geological Survey. Book 3: Applications of Hydraulics.			
24	EPA Sediment Sampling SOP #2016, 11/17/94, Rev 0.0	Sediment sampling	Sample preservation, containers, handing and storage Equipment Procedures, sample collection Figures of sampling techniques	1 2 3 App A
25	Horowitz, A.J. (1991)	Sampling methods	Sampling Sediments, programme design.	92
	A Primer on Sediment-Trace Element Chemistry (2nd Edition). USGS Open-File Report 91-76.			
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26	Emerging contaminants in lake sediments	Sampling methods	Sediment core sample collection and preservation	977
	Screening of lake sediments for emerging contaminants by liquid chromatography atmospheric pressure photoionization and electrospray ionization coupled to high resolution mass spectrometry	Analytical methods	Liquid chromatography tandem high resolution mass spectrometric detection	978
27	BGS Normal background concentrations	Analytical methods	Spatial variability in contaminant distributions Methodology for determining normal background concentrations	10
	Normal background concentrations (NBCs) of contaminants in English soils: Final project report			16
28	Sednet criteria for CoCs	Sediment sampling	Development of contaminant monitoring guidelines	223
	Synthesis of the SedNet Work Package 3 Outcomes			
29	Woodhead et al., 1999	Sediment sampling	Materials and methodology	773
	Polycyclic aromatic hydrocarbons in surface sediments around England and Wales, and their possible biological significance	Analytical methods	Analysis by high performance liquid chromatography	774
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30	Contaminated sediment remediation guidance for hazard waste sites	Analytical methods	General PCB Contaminant information	2-4 p38
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31	Handbook for Sediment Quality Assessment Environmental Trust	Sediment sampling	Monitoring Programs and Sampling	7
		Analytical methods	General sediment quality parameters Sediment Contaminants	22 24
32	Edwards and Glysson 1970	Sediment sampling	Bed material samplers	19
			Sediment sampling techniques	35

### 4.3 Next steps

A number of documents have been identified which contain potentially relevant information on existing sampling and analysis techniques adopted both in the UK and Europe/overseas. The documentation identified has been reviewed further to determine existing sampling and analysis techniques and the findings are presented in the following sections of this report.

## 5 Phase 2

### 5.1 Introduction

Gaps and uncertainties in the sediment quality analysis data available were discussed in Work Package 1A (WP1A). These included:

- Limited spatial distribution (data available for some areas but not the whole of England);
- Limited range of contaminants (some potential contaminants of concern have been measured routinely, but for others there are little or no data available); and,
- Variability in sampling, sample preparation (e.g. particle size fraction analysed) and analytical methods, making direct comparison between results tentative.

Phase 2 of this work package presents a review of the documentation on sediment sampling strategies, methods and analysis techniques from the source list identified and agreed at the end of Phase 1 (Table 4.1). The aims of this review are to identify differences and similarities in practices currently adopted by different organisations, and suggest options for standardising procedures or developing methodologies or guidance documents (which would comprise a separate project).

The review will target key stages of freshwater and marine in-situ sediment contamination investigation, from sediment sampling to analysis, covering a range of equipment and analytical methodologies. The documentation covers a range of case studies across Europe, Australia and the United States and covers the following topics:

- Sampling strategies – **Section 5.2**.
- Sampling equipment – **Section 5.3**.
- Analytical techniques – **Section 5.4**.

### 5.2 Sampling strategies

The documents identified for further attention in **Section 4.2** have been reviewed and key relevant information is summarised in the text boxes presented in **Sections 0** (for freshwater environments) and **5.2.2** (for marine and estuarine environments).

### 5.2.1 Freshwater environments

#### BOX 1 Environment Agency 'Best Practice Leaflet' for 'Sampling Strategies, Analysis and Interpretation'

An Environment Agency 'Best Practice Leaflet' for 'Sampling Strategies, Analysis and Interpretation' is presented in Appendix 12 to the AINA guidance document (AINA, 2013). The leaflet, which was prepared by RPS, provides an overview of sample plans. The guidance is targeted at staff undertaking sampling of *in situ* sediment in watercourses prior to carrying out dredging activities and recognises that the generic best-practice principles provided should be adapted to specific site conditions as exact requirements will differ for each site.

A sampling plan should be specific to the site to take into account local conditions such as access and channel navigation. The main purpose being to identify the location, depth and number of samples that are required to adequately characterise the material and determine whether the material can be reused/recycled or sent for disposal.

As a general rule, samples should be taken from points that are representative, and at regular intervals within the area. Additional samples should be taken adjacent to areas of known or suspected contamination in order to define the nature and extent of contamination

The number of samples required will be different for each site and dependent on the method of sediment collection. A number of factors should be taken into account when calculating the number of samples required;

- Location of the site i.e. urban areas are more likely to be contaminated than rural areas;
- Potential sources of contamination i.e. reported pollution incidents, current and historical land uses;
- The area and depth i.e. the greater the area and depth to be investigated, the more samples required;
- Sediment type and variability i.e. the less homogenous the material the more samples are required; and
- Details of previous relevant and site-specific investigations.

**BOX 2 Horowitz, 1991. *A Primer on Sediment-Trace Element Chemistry (2nd Edition)*. US Geological Survey (USGS) Open-File Report 91-76.**

*Sampling strategies*

The decisions on how, when, and where to sample must be based the aims of the survey, also, a thorough knowledge of local hydrological (e.g., flow regimes) and geological conditions (e.g., information on local rock types) is necessary (Horowitz, 1991). For instance, selection of sampling locations in rivers can have a major impact upon the results obtained, i.e. higher contamination concentration in depositional environments such as pools and lower concentrations in transport dominated environments such as riffles. There is therefore a need to standardise the locations from which samples are collected. Several potential sampling strategies are recommended:

- Simple random sampling: Very effective in homogeneous areas, but may not be in heterogeneous areas. Commonly applied when no details about local conditions are available.
- Stratified random sampling: A heterogeneous area is divided into homogeneous zones, within which samples are randomly located. Requires some understanding of baseline conditions.
- Systematic sampling: Samples are collected at a predetermined interval, with initial sampling site selected randomly. Very easily applied to different freshwater systems, but can produce biased results.
- Fixed transect sampling: Samples are collected at predetermined sites (not necessarily at fixed intervals). Preselection of sites can make trends difficult to infer.

*Sampling the sediment column*

Generally, sampling of *in situ* bed sediment is divided into two distinct categories:

- Surficial sampling; and
- Sampling at depth.

In certain cases, either sample type may be appropriate depending on investigation goals. Surficial samples typically are used for the determination of trace element-spatial distributions and reconnaissance surveys and are generally limited to the collection of only the upper 1 to 3 cm of the sediment column. Sampling sediments at depth typically is used to determine temporal trace element-trends, establish local trace element-baseline levels, and/or establish historical changes in sediment-associated trace element concentrations (Horowitz, 1991).

*Grain size requirements*

Since the relationship between particle size, surface area and concentration of many sediment-associated contaminants is well documented, it is important to collect and analyse a consistent grain size fraction. The fine fraction (i.e. sands, silts and clays with a diameter of <2mm) is generally recommended, although the <63µm fraction (silts and clays) is recommended where suspended sediments are of interest or concern.

**BOX 3 British Geological Survey (BGS) - G-BASE Field Procedures Manual**

The Geochemical Baselines Survey of the Environment (G-BASE) project is a systematic high-resolution survey to establish a geochemical baseline across the United Kingdom. The collection of drainage samples from active stream channels for geochemical mapping is now a well-established procedure that has readily been adapted for environmental studies. The methods involved include the collection of stream sediments, waters and panned heavy mineral concentrates for inorganic chemical analysis. This strategy has been adapted and used in many different environments around the world. Detailed sampling strategies are discussed in Johnson *et al.* (2008).

The main recommendations of this guidance document are that:

- One sampler should walk 50-100 m upstream (along the bank) of the intended site to check for any localised contamination, prior to initiating sample collection. Samples should be located >75m upstream of potential contamination sources, including tributary inputs, field drains, bridges, roads and livestock access points.
- Samplers should seek to sample typical flow regimes (i.e. parts of a reach that represent the most common or prevailing conditions for that reach) rather than sites which favour depositional sorting.
- Samples should always be collected from an active area of the stream bed, rather than a low energy slack water area in the channel margins. This will ensure that they are representative of the material that is currently being actively transported within the watercourse from the upstream catchment.
- Samples should ideally be located centrally placed\* in the stream to minimise the potential for contamination from any bank fall material (**Figure 5.1**).

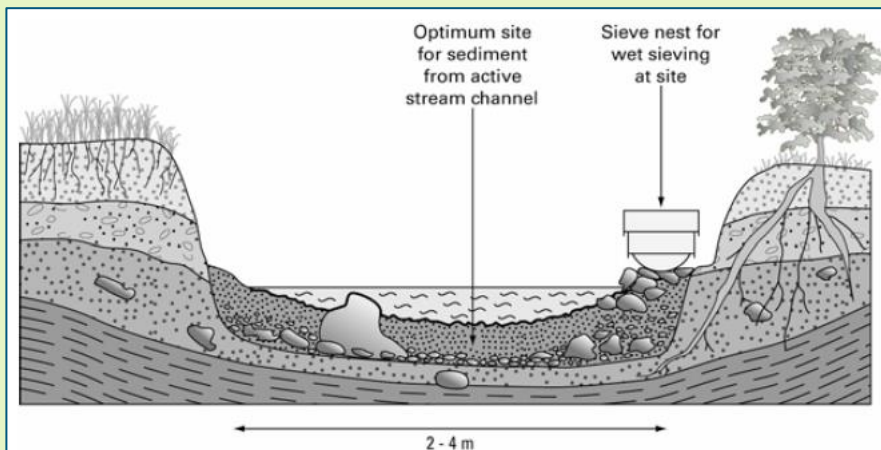


Figure 5.1 A typical sediment sampling site from a stream

*\*Although it should be noted that the centre of the channel is not always the area of swiftest flows. This zone, known as the thalweg, is located centrally in straight reaches, but moves towards the outside of the bend as the river meanders.*



## 5.2.2 Marine and estuarine environments

### BOX 4 Port of London Authority (PLA) - sediment sampling guidance

The PLA's sampling guidance is referred to as a good example, as is CIRIA's 'Guidance on the disposal of dredged material to land (1996)', which is based on the OSPAR guidelines (AINA, 2013). The latter is more appropriate for large scale dredging schemes. Table 5.1 outlines the recommended number of samples taken depending on the quantity of sediment to be dredged as outlined by the Port of London Authority. Note that the actual number of samples required is site specific.

- The full suite of determinants should be tested for (Appendix A).
- Bulk samples (where samples are combined with samples) will not be accepted.
- Although sample sites will have been selected with regard to local infrastructure, the sampling process should be carried out with full appreciation of the pipelines, tunnels, mooring and any other sensitive infrastructure at the site.
- The sample sites have been selected at positions which are most representative of where most material is to be removed.

Table 5.1 Recommended sampling strategy (taken from PLA cited in AINA, 2013)

Quantity of sediment to be dredged (m <sup>3</sup> )	Time since last dredged		
	<3 years	4-10 years	>10 years
<3,000	1	2	3 (surface only)
3 – 10,000	2	3	5 (surface and dredge depth)
10,000 – 50,000	3	4	6 (surface, dredge depth & midway)
50,000 – 100,000	4	5	8 (surface, dredge depth & midway)
100,000 – 200,000	5	6	10 (surface, dredge depth & midway)
>200,000	Determined on individual basis		

### BOX 5 Trial of Proposed Tiered Framework for the Assessment of Sediment Quality

The report produced for the Environment Agency by Cefas in 2005 entitled '*R&D SC050066 - Trial of Proposed Tiered Framework for the Assessment of Sediment Quality*' addressed the Agency's needs to be able to assess the potential impacts of contaminants in sediment on the health of aquatic ecosystems (Environment Agency, 2005). This report contained useful information on the potential design of suitable sampling schemes for sediment assessment purposes (number, amount, location) in a cost-effective manner whilst not biasing the result of the final assessment undertaken. Systematic, random or targeted sampling techniques are discussed, along with the requirement to recognise specific pressures/activities (either point source or diffuse) which may influence the numbers or locations or samples to be collected.

The spatial area over which the assessment is to be undertaken is also important in determining the number of samples which should be collected, with the required confidence levels balanced against the cost and purpose of the assessment (Environment Agency, 2005). For example, for sampling of materials to be dredged, Environment Australia use targeted sampling of hotspots in addition to general sample number guidance depending upon the volume of materials to be dredged. For small and medium-sized site, or where contamination profiles were known to be fairly uniform, the site is treated as a single site. For larger sites (i.e. >500,000 m<sup>3</sup>), or those with a more variable sediment composition, the area would be stratified into separate sites (depending upon the known contamination pattern) and each site sub-sampled separately (Environment Agency, 2005).

**BOX 6 A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater, Estuarine and Marine Ecosystems in British Columbia**

McDonald and Ingersoll (2002) have published comprehensive information on the design of sediment sampling strategies for in-situ sediment contamination investigations in marine and estuarine environments. A sediment sampling plan is defined as a preliminary site investigation (PSI) which would then be followed up by a detailed site investigation (DSI) consisting of a focussed sampling programme. A detailed site investigation is required at marine or estuarine sites if the results of the preliminary site investigation (PSI; which is conducted using sediment chemistry data) indicate that sediments are sufficiently contaminated to impair the beneficial uses of the aquatic ecosystem (i.e., pose unacceptable risks to sediment-dwelling organisms, aquatic dependent wildlife, and/or human health).

The information collected and compiled during the PSI should be used to design the DSI. The PSI is conducted to evaluate the nature, magnitude, and extent of sediment contamination at the site, the results of which provides information needed to identify which substances occur in sediments at potentially harmful levels [e.g., in excess of sediment quality criteria (SQC) or similar values), describes the range of concentrations of priority substances, and identifies the locations that contain elevated levels of sediment-associated chemicals of potential concern (COPCs). Importantly, the PSI should constitute a literature review to provide essential background information on the site, such as the location of contaminant discharges and spills, historic activities, and land uses at the site.

While the results of chemical analyses of environmental samples provide important information for assessing the risks that contaminated sediments pose to human health and environmental receptors, other types of data should also be collected during the DSI to confirm the results of such assessments and to provide multiple lines of evidence for assessing risks to ecological receptors. Specifically, data from toxicity tests (including whole-sediment and pore-water tests), benthic invertebrate community assessments, and fish community assessments can provide important information for evaluating the effects of contaminated sediments on aquatic organisms. In addition, bioaccumulation assessments can be used to assess the potential effects of COPCs that tend to bioaccumulate in the food web and, in so doing, pose risks to aquatic-dependent wildlife and/or human health. In designing the DSI, it is important to remember that the weight-of-evidence required needs to be proportional to the weight of the decisions that are likely to be made at the site (Wenning and Ingersoll 2002).

The second step in the design of a DSI sampling plan is to develop a sampling grid (i.e., identify the location of sampling sites). The DSI needs to provide information on the specific areas, depths, and magnitude of contamination at the site and in nearby areas. A biased sampling design is preferred for the DSI because it can be used to focus sampling effort on the areas that are most likely to be contaminated (i.e., by conducting targeted sampling to delineate the location and extent of hot spot areas). Intensive sampling should be conducted in the vicinity of the sediment hot spots that were identified to confirm the results of the PSI, to determine the areal extent of contamination at each hot spot, and to identify gradients in contaminant concentrations. Outside these hotspots random sampling should be used to investigate the potential for contamination in other areas.

Importantly, the DSI sampling program should be designed to determine the concentrations of contaminants of potential concern (COPCs) in both surficial (i.e., 0 to 10 cm) and deeper sediments. Sampling of deeper sediments is essential in order to characterise sediment quality conditions within the biologically-active zone (0 to 100 cm) and in areas that could become more biologically active if surficial sediments were removed. The sampling plan should identify the location and depths of each site that will be sampled, with decision criteria also provided in the event that sampling certain sites is not feasible. As the mobilization/demobilization costs associated with sediment sampling can be substantial, it may be prudent to collect and archive samples from additional locations during the DSI. This makes it possible to, for example, analyse samples collected 10 m from a hot spot if the samples collected 5 m from that hot spot show significant contamination. In this way, the costs associated with chemical analyses can be minimized.

**BOX 7 A Handbook for Sediment Quality Assessment**

A Handbook for Sediment Quality Assessment (Simpson et al., 2005) has been produced outlying guidance for sampling program design in collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The document corroborates with the approach taken by Simpson and Ingersoll (2002) above. The sampling programme design stage process involves defining the issue, defining the information requirements, collating available information, and then developing some preliminary system understanding, usually in the form of a conceptual process model. The design of a sampling program for sediments must take into account the fact that sediments are quite heterogeneous, both chemically and physically. Contaminant distribution will be very much grain size dependent. When designing a monitoring programme for sediment contamination investigation, the frequency of sampling may be dictated by the rate of sedimentation. Sedimentation rates in water bodies typically vary from a few millimetres to 1-2 cm/year; sampling depths will need to account for this (Simpson et al., 2005).

Random sampling involves the selection of sites randomly in order to provide an unbiased assessment of the condition of the sediments within a water body. The use of random sampling designs has a greater ability to miss key sites that are necessary to develop relationships among variables, e.g. estimation of benthic response or contaminant concentration, in relation to a known contaminant discharge point. Random selection of stations may not include a sufficient number of key sites as many sites will be well removed from the contaminant source. To overcome these problems with random sampling designs, random stratified designs are preferred, with sampling locations at increasing distances from the point source, in the case of a discharge. The spatial heterogeneity (both horizontal and vertical) must be taken into consideration. Sampling should involve replicate samples to determine localised heterogeneity. Vertical heterogeneity can be readily assessed from core samples and, for this purpose, they are preferable to surface grab samples. Sediment deposition in a water body will not necessarily occur uniformly, but will be dictated by flow. Scouring of bottom sediments is common in the channels of fast flowing rivers, while deposition will occur in low flow regions.

Targeted sampling requires existing information, and the selection of sites based on this knowledge. In targeted sampling designs, sites are selected based on prior knowledge of other factors, such as contaminant sources, substrate types, water depths, tidal influences, and anthropogenic activities. Targeted sampling designs can often be quickly implemented and offer much more flexibility than statistically-based (random) sampling designs. Data from targeted sampling cannot, however, be easily used to make predictions of contamination at other sites (stratified random sampling is better for this purpose).

**BOX 8 OSPAR Guidelines for the Management of Dredged Material**

Regarding marine sediments, under the requirements of the OSPAR guidelines (OSPAR, 2014), advice is provided on the sampling required to characterise any area which may be dredged. These guidelines also make reference to the IMO's 'Guidelines for the Sampling and Analysis of Dredged Material Intended for Disposal at Sea' (IMO, 2005) to ensure both OSPAR and London Convention requirements are met.

The OSPAR guidelines require the distribution and depth of sampling undertaken to reflect the area and volume to be dredged and the expected variability in the horizontal and vertical distribution of contaminants. Core samples are recommended where the depth of dredging and expected vertical distribution of contaminants suggest that this is warranted. In other circumstances, grab sampling will usually be sufficient (OSPAR, 2014).

The number of separate sampling stations required to obtain representative results, assuming a reasonably uniform sediment distribution in the area to be dredged, is provided in Table 5.2. The number of sample stations should take account of the exchange characteristics of the area; more samples may be required in enclosed and semi-enclosed areas and less in open areas.

Table 5.2 OSPAR recommended number of separate sampling stations (OSPAR, 2014).

Quantity of sediment to be dredged (m <sup>3</sup> )	Number of sampling 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 <sup>3</sup>

The MMO requires these guidelines to be followed for the purposes of marine licensing where the disposal of dredged material at sea is proposed, and Cefas will advise on a suitable sampling and analysis plan where required. As allowed under the OSPAR guidelines, it may be possible to 'bulk' samples where they are clearly homogenous with respect to sediment texture, providing there are no significantly different contaminant concentrations in sub-samples and mean contaminant levels can still be determined.

### 5.2.3 Developing a sampling strategy

The review of the selected literature has demonstrated that the following key points need to be considered when developing an investigation into in-situ contamination in the freshwater, estuarine and marine environments:

- What is the driver/objective of the proposed study/sampling requirement (e.g. legislative requirement, pro-active intervention, etc.)?
- What potential substances/contaminants of concern are to be investigated?
- Where is/are the site(s) located?
- What/where are the main potential receptors of concern?

#### A systematic approach to sampling

Once the purpose of the proposed study has been defined, it is then necessary to follow a logical step-wise approach to planning the study to ensure that it meets its stated objectives. A potential approach is outlined below:

1. Review of previously held/obtained information, historical data sources (if available).
2. Development of a Conceptual Site Model (CSM) or Preliminary Site Investigation (PSI), taking into account all relevant information.
3. Location/access: is the site easily accessible (by vehicle or on foot), or will specialist transport be required (e.g. vessel)?
4. Investigation of potential landowner permission/consents required to undertake sampling in target location.
5. Target sediments (e.g. sediment types if known, requirement for surface samples and/or subsurface samples).
6. Number of samples/replicates required. Are reference sites also required to allow for comparison between areas of concern/background?
7. Intervals between sample locations (e.g. if a large area to be characterised/variable sediment types are expected).
8. Targeted (e.g. grid) or random (e.g. stratified) sampling approach? Do the results need to be statistically comparable?
9. Cost-effectiveness: Is the proposed sampling effort appropriate for the purpose to be achieved (e.g. targeting of known 'hotspots' or wider site characterisation)? Will the 'weight of evidence' obtained achieve the goals of the study?
10. Have all potential costs been factored into the planning of the survey (e.g. transport/vessel hire, sampling equipment/storage, analysis costs for numbers of samples/replicates to be obtained, etc.)?

A variety of targeted and systematic sampling strategies are described in the literature, each with their own advantages, disadvantages and broad applicability to different parts of the water environment. A simple grid approach can be usefully adopted for sampling effort around known 'hotspots', to both define their areal extents and any contaminant gradients which may exist. Random sampling outwith these areas could provide useful information on contamination within the wider area. Although this approach is universal in its applicability, it may be more limited in rivers and streams where a catchment rather than reach based assessment is required. Where inputs from tributaries and localised contamination sources in a catchment are of concern, a more systematic sampling strategy is likely to be required.

When planning a sampling campaign within freshwater/estuarine environments, it is important to take into consideration the potential for river flows to influence sediment deposition rates as this may affect the previously selected sample locations. For example, higher levels of contamination could be expected to occur within depositional environments, such as pools, rather than in higher energy transport-dominated areas. This may therefore lead to a need to standardise samples if a wider overview of sediment quality within a certain area was required.

The depth of samples required will also influence the planning and costs associated with sampling. Often, such sampling may be limited to the biologically active zone of sediments (e.g. top 150mm for tidal waters, top 35mm for fresh waters<sup>17</sup>). However, where materials are to be removed from deeper *in-situ* (e.g. for dredging and disposal), it will likely be necessary to obtain sediment samples from much deeper in the

<sup>17</sup> Environment Agency & British Waterways, 2011

profile to allow an adequate sediment quality characterisation to be made. In such cases it may however be possible to 'bulk' samples which appear to be similar in appearance with no obvious differences in contamination levels.

Taking advantage of geographical location to minimise sampling effort is considered to be a sensible way in reducing costs and time, such as the sampling of sediments from rivers or streams near to any confluence, to allow for characterisation of conditions which may be occurring further upstream and which may be more difficult/costly to access (although an allowance for adequate mixing distances will need to be taken into account). This is the approach recommended by the BGS's 'Geochemical Baselines Survey of the Environment' (G-Base) field procedures manual.

Sampling locations for any proposed survey will ultimately be based upon the objectives of the survey. It may not always be possible to obtain a sample from the preferred/planned location for a number of reasons (e.g. restricted access, private land, etc.), in which case suitable alternatives should be sought. Current Environment Agency guidance states that for 'routine' sampling locations, samples taken from freshwater environments can be classed as representative of the previous sample location where the new sample is obtained no further than two channel-widths upstream or downstream of the previous location. In the marine environment, should an alternative site be required, it is recommended that the sample location tries to obtain a similar substrate type as close as possible to the original sample site (e.g. within 50m). For 'non-routine' sites, the site of sampling is influenced by access/safety considerations, and the presence of suitable sediment types.

A CSM for the site in question is therefore key to the successful design of a sampling strategy, with both the CSM and strategy required to be site and task specific to ensure the sediment assessment is appropriate for the purposes of the investigation. It is therefore not possible to produce a 'one size fits all' approach to numbers and location of samples to be collected, beyond general guidance that both targeted and random sampling schemes should be employed, with the use of 'site stratification' where the size of the site or other information indicate that this would be appropriate (Environment Agency, 2005 – see Box 1).

## 5.3 Sampling equipment

### 5.3.1 Introduction

The following sections outline sediment sampling techniques recorded in existing literature and guidance in relation to both surface and sub-surface sampling techniques.

### 5.3.2 Site-specific considerations

The selection of suitable sampling equipment for any sampling project will be dictated by a number of variables, as outlined in the Environment Agency's 'Operational Instruction 010\_07':

- The reason for/purpose of sampling.
- The location of the sample site(s).
- The ease of access to the site/substrate
- The physical nature of the substrate.
- The depth of sediment/substrate to be sampled.
- The depth/flow of water anticipated at the site, including tidal conditions (if applicable).

Consideration of equipment suitable for obtaining samples from *in-situ* contaminated sediments will include the layers of sediment to be sampled. For example, in intertidal areas or very shallow water it may be possible to undertake 'manual' sampling (i.e. not using a 'remote' grab or corer but hand-held scoop to transfer the sediment to a suitable receptacle directly). Where a remote grab or similar must be used, consideration will also need to be given to controlling the deployment of such equipment to reduce the potential for pressure waves disturbing surface sediments.

An overview of sampling equipment and applicability is provided in (**Table 5.3**).

Table 5.3 Outline of sediment samplers in this report and their applicability to sediment type(s)

Equipment	Type	Applicability	
		Sediment Type	Sample
Birge-Ekman	Grab	Small and bulk samples of soft clay, mud, silt, silty-sand	Surface sediment
Van Veen	Grab	Bulk samples of indurated or soft clay, mud, silt sand, gravel	Surface sediment
Ponar	Grab	Bulk samples of indurated or soft clay, mud, silt, sand, gravel	Surface sediment
US BM-54	Cable and reel	Small samples of soft clay, mud, silt and silty-sand	Surface sediment
US BMH-53	Hand-held	Small samples of soft clay, mud, silt and silty-sand	Surface sediment
US BMH-60	Hand-held	Small samples of soft clay, mud, silt and silty-sand	Surface sediment
US RBMH-80	Hand-held	Small samples of soft clay, mud, silt and silty-sand	Surface sediment
Box Corer	Corer	Short length (1m <sup>2</sup> ) undisturbed cores in soft fine-grained clay to coarse grained sand	Surface/Sub-surface sediment
Gravity Corer	Corer	Short to medium length cores in soft fine-grained clay to fine-grained sand	Sub-surface sediment, up to 1.8m
Piston Corer	Corer	Medium to very long length samples of soft fine-grained clay to medium-grained sand	Sub-surface sediment, up to 18m
Vibrocorer	Corer	Medium to long-length cores in soft fine-grained clay to indurated coarse-grained sand	Sub-surface sediment, up to 12m

### 5.3.3 Surface sediment sampling techniques

As outlined in **Table 5.3**, several different types of sampling equipment can be used to collect surface sediment samples. These can be grouped into two broad categories:

- Grab samplers such as the Birge-Ekman, Van Veen and Ponar samplers (**Appendix A1**).
- Hand held samplers such as the US BMH-53, US BMH-60 and US RBMH-80 samplers (**Appendix A2**) and more rudimentary equipment such as scoops, trowels and shovels.

Grab samplers are frequently recommended for use in the collection of surface sediments due to their ease of handling and operation and their versatility for collecting a range of sediment substrates. They are also preferred for the collection of all submerged surface sediment samples because they minimise the loss of finer sediment (i.e. the size fractions that are typically most important for sediment associated contaminants) in flowing water. Furthermore, grab samplers typically retain the integrity of the collected sediment; thereby avoiding disruption of the sediment's structure that could distort its chemical and physical characteristics (Simpson et al., 2005).

If sediments are collected from areas exposed at low tide, or from exposed sediments in a river channel (e.g. on lateral or medial bars), a trowel, shovel or other hand-held sampler may be appropriate, particularly if there is potential for cross-contaminating the sample given its surfaces (e.g. metallic or plastic). In the case of deeper rivers, ponds, or lakes, samples are usually collected with some type of grab sampler.

Note that corers (see **Section 5.3.4**) are not typically used for spatial surveys based on surficial sediment samples, especially in shallow, wadeable aquatic environments. This is because a major disadvantage of most corers is the extremely small area of the bed that is actually sampled. Thus, many more core samples than grab samples usually are required to provide an adequate bottom sediment sample (Horowitz, 1991).

The quantities of sediments that require collection will depend on the analyses and tests to be undertaken. Generally, 2 kg of sediment from each sites should be sufficient for analyses of most contaminants (e.g. 1 kg for elutriate tests, 250 g for organics, 59 g for each of metals, AVS, analysis of particle size and other physical properties), and for toxicity tests (3x 50-100 g/species) (Simpson et al., 2005). Both grab samplers and hand-held samplers are capable of collecting sufficient sample size.

Experience gained by the C&RT has shown that for the purposes of maintaining freshwater canals and waterways under their management, rudimentary sampling practices have been sufficient to gain regulatory approvals for the spreading of dredged materials on agricultural land, placement of materials on the banks of the waterway being dredged, or as a last resort to a licenced landfill. The sampling methods are not complex, and may result in the loss of finer fractions surface sediments to be dredged, and unless a known hotspot area exists there does not appear to be a driver which would alter this current practice. This is in contrast to sampling of marine sediments, where sampling of undisturbed surface sediments (e.g. typically the upper few centimetres) is standard practice. For example, Cefas sampling guidance to marine licence applicants states that 'surface samples should be taken from the upper layer of in-situ sediment using a non-metallic / stainless steel scoop' (Cefas, 2015).



### 5.3.4 Sub-surface sediment sampling techniques

Sub-surface sediment samples provide an indication of the spatial (vertical and horizontal) variation in sediment properties and the distribution of contaminants. This is often useful for three dimensional mapping of contaminants for defining volumes of contaminated sediment for dredging, and for determining the historical “signal” of contamination in in situ sediments. Vertical sampling of a sediment column invariably involves the use of some type of coring device (**Table 5.3**). These tend to fall into three major categories:

- Gravity corers.
- Piston corers.
- Vibrocorers.

Gravity corers, use the force of gravity to penetrate into the sediment column and obtain a sample. Generally, the heavier the corer, the greater the degree of penetration. These devices also require a minimum amount of water depth to achieve sufficient velocity to obtain maximum penetration (Horowitz, 1991). There are a range of different types of gravity corer, with variable column length, barrel dimensions and construction. Free fall gravity corers can be used directly in soft sediment with little or no water cover, although they can also be used by divers to collect small cores (<1 m) at greater water depth (Simpson et al., 2005). Standard gravity corers are typically attached to a line to collect longer cores in submerged fine grained (<2mm) sediments. Box corers (<1 m depth) are a type of gravity corer that are particularly useful for collecting larger volumes of sediment from a given depth (allows sediment for all tests to be collected from one sample), and for collecting sediments for pore water extraction and characterisation (Simpson et al., 2005).

Piston corers incorporate a piston within the corer barrel. The piston creates a vacuum, which reduces resistance and allows the barrel to penetrate further into the deposits. These corers are typically attached to a line to collect longer cores in submerged sediments (clays to medium sand sized particles). They are particularly effective at collecting long, relatively undisturbed sediment cores (Horowitz, 1991).

Vibrocorers or percussion corers) are powered devices that actively force a thin walled barrel through the sediment. They can be powered by electric motors, compressed air or small petrol engines. Vibrocorers yield excellent sample integrity and are recommended for the collection of deep cores (up to 12 m), or where sediment consists of very compacted or large-grained material (e.g. gravel). However, the vibrations that they generate to help them penetrate sediments can result in much greater sample disturbance in comparison to piston corers (Horowitz, 1991).

### 5.3.5 Sample quality assurance

#### Overall approaches

Analytical Quality Control (AQC) is an essential part of any investigation into chemical contamination in in situ sediments. There are two broad approaches to AQC that are described in the literature (e.g. Ramsey, 1997; Thompson, 1992):

- A “top down” approach, which involves inter-laboratory trials to estimate total measurement uncertainty. The same sample is analysed at different laboratories, all using the same technique. The scatter of results can be used to estimate the overall uncertainty associated with each measurement.
- A “bottom up” approach, which involves the identification and minimisation of all potential sources of uncertainty involved in the sampling and analytical procedure to be undertaken at a single laboratory.

Both approaches use repeat samples and external standards to verify results and quantify uncertainty. However, the “bottom up” approach cannot estimate factors such as variation introduced by laboratory temperature. Although the comprehensive “top down” approach to AQC is therefore likely to provide the most satisfactory results, it is frequently unfeasible due to resource requirements and associated expense. A robust “bottom up” approach is therefore more frequently adopted.

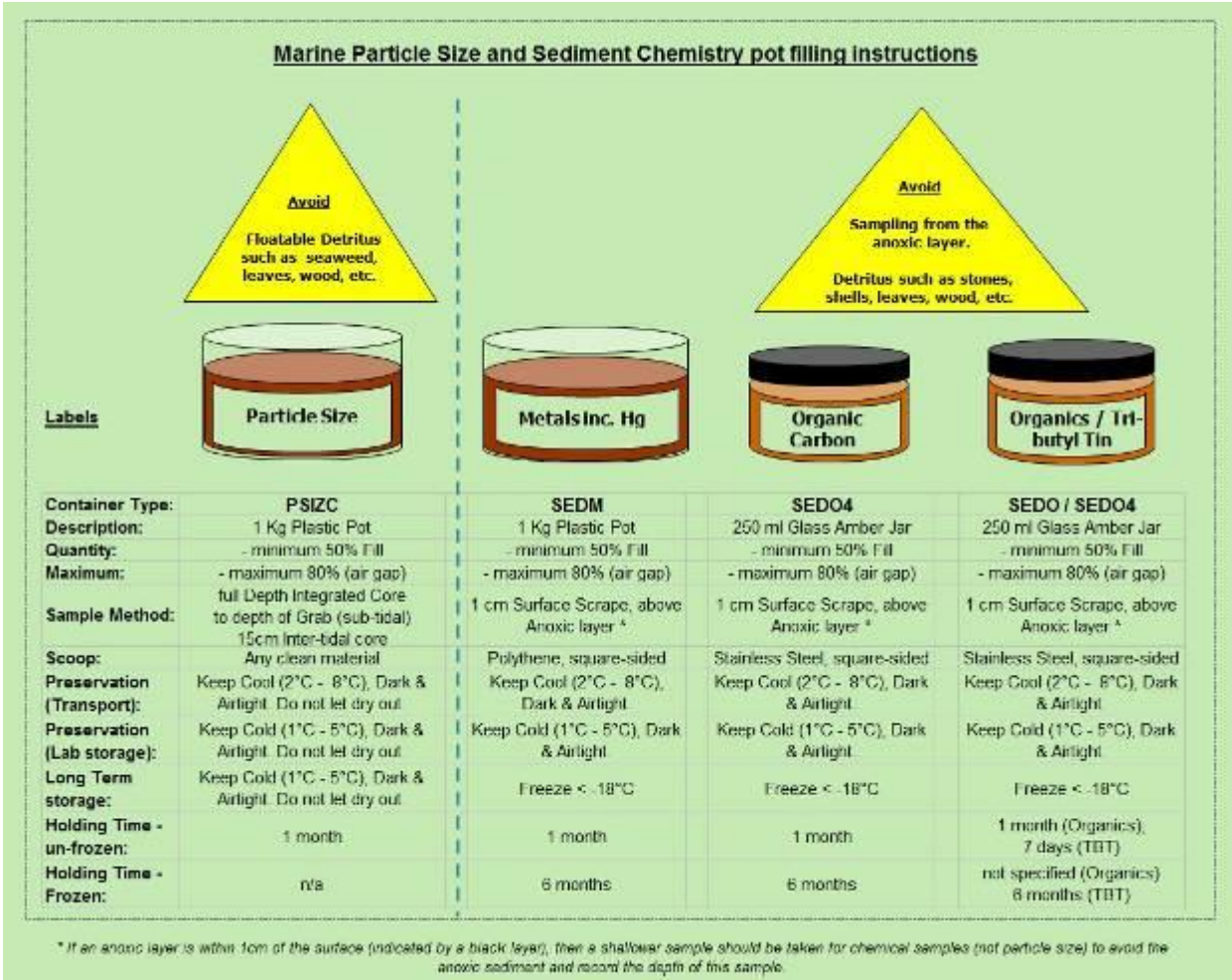
#### Approaches during sample collection

Quality assurance during sample collection is an important part of any AQC procedure, and is especially important as part of a “bottom up” approach due to the large potential contribution of sample variation to the total uncertainty associated with any measurement (Ramsey, 1997).

Various procedures have been established to help minimise sampling uncertainty (e.g. Environment Agency, 2008, cited in AINA, 2013; BGS, 2005), providing details of recommended sampling equipment (including cleaning procedures to be used between samples), labelling, preservation and storage procedures (**Figures 5.1**). These procedures typically recommend the following standard methods:

- Use of suitably trained personnel to undertake sampling, preferably using MCERTS accredited methods where possible.
- Amalgamation of small spot samples within a specified radius (e.g. 1 – 5 m) of the selected sampling point to create a single sample.
- Collection of duplicate samples within a specified distance (e.g. 25m) of the original sample for a set proportion of sample points (e.g. one in every 10, 50 or 100 depending upon total number of samples). This is particularly useful for estimating sampling uncertainty.
- Production of replicate subsamples from within a single sample for subsequent analysis. This is useful for estimating analytical uncertainty.

Figure 5.1 Environment Agency - specific sampling requirement for different analyses<sup>18</sup>



<sup>18</sup> Environment Agency Operational instruction 010\_07 - Sediment sampling in water for chemical and particle size analysis.

## 5.4 Sediment analysis techniques

### 5.4.1 Sample and analysis plan

The procedures that will be used to identify and quantify the chemical substances in sediment samples should be described in a sampling and analysis plan (MacDonald and Ingersoll, 2002). As a first step, a list of substances for chemical analysis should be compiled using the results of any preliminary site information and other considerations (e.g. substances of particular concern, or substances used to calculate mean SQC-quotients). This list should also include the sediment quality variables that provide information for interpreting the resultant sediment chemistry data, notably:

- Physical properties such as analyses for particle size, dry matter content and organic matter content.
- Physico-chemical properties such as analyses for pH, redox and sediment oxygen demand.
- Visual properties of the sample and its contents such as observations of colouration, oily films and paint flecks.

In addition, the water quality variables that need to be measured to support interpretation of the sediment quality data should be identified (e.g. bottom water dissolved oxygen (DO) and salinity, pore water salinity, hydrogen sulphide, pH, and total ammonia). The preferred analytical method for each analyte can also be specified in the sampling plan. Existing background information of the site will provide information on the likely contamination present. For example, information from a variety of sources indicates that sediments in aquatic ecosystems throughout North America are contaminated by a wide range of toxic and bioaccumulative substances, including metals, PAHs, PCBs, OC pesticides, a variety of semi-volatile organic chemicals (SVOCs), and polychlorinated dibenzo-p-dioxins and furans (PCDDs and PCDFs) (MacDonald and Ingersoll, 2002).

### 5.4.2 Sample preparation

A large volume of guidance on sample preparation for in situ sediments collected from surface waters is provided in the academic literature (e.g. Grimshaw, 1989; Gill, 1997) as well as more practically-focussed guidance from regulators (e.g. USEPA, 1994). These references set out detailed procedures for the post-collection handling of samples, and recommend laboratory-based techniques for aspects such as drying, disaggregation and wet or dry sieving to obtain the most appropriate size fraction for analysis. Typical procedures include:

- Cooling of samples (e.g. at 4°C) until they can be further prepared.
- Air drying or oven drying samples at a low temperature (e.g. 40°C for 24 hours) to avoid the loss of volatile substances.
- Gentle disaggregation of samples using a pestle and mortar, to break up amalgamations of material but avoid breaking down individual particles.
- Thorough homogenisation (mixing) to ensure that a representative subsample for further analysis can be obtained.
- Use of wet or dry sieving techniques to obtain the appropriate size fraction for analysis.

These procedures also recommend that all equipment used during sample preparation is composed of stainless steel, plastic or other suitable material (e.g. Teflon) that will not lead to cross-contamination of the samples (e.g. the use of brass sieves can introduce copper and zinc to the sediment sample). Furthermore, procedures for cleaning equipment between samples are also specified, for example through the use of deionised water or a dilute acid solution to decontaminate all equipment.

### 5.4.3 Laboratory analysis

There are a wide range of different laboratory techniques that can be used to analyse contaminant concentrations in in situ sediment samples. Analytical techniques used to measure concentrations of sediment-associated contaminants typically fall into two broad categories (Gill, 1997):

- Those that require dissolution of sediment samples and analysis of the resulting solutions (solution methods).
- Those that require the direct analysis of solid material (direct methods).

Dissolution techniques are more commonly applied than direct methods, since they are easy to standardise and have a relative lack of matrix effects. There are a wide variety of dissolution methods, which can be grouped into two categories:

- Total extraction techniques, which dissolve the entire sample, including elements within the crystal lattice of silicate minerals. These typically require the use of hydrofluoric acid in conjunction with another strong mineral acid (e.g. Chow and Sanzalone, 1992). Total extractions provide a measure of the total concentration of a particular substance in a sediment sample.
- Partial extraction techniques, which dissolve substances sorbed onto mineral particulates, but do not dissolve elements bound within mineral grains. These techniques typically rely on weaker acids such as nitric acid, hydrochloric acid or *aqua regia*. Partial extractions are generally thought to be more representative of bioavailable contaminants than total extractions, and are thus generally recommended for environmental studies (Walsh et al., 1997).

There is no definitive guidance for the selection of analytical technique that should be used for different substances within in situ contaminated sediments. The selection of specific analytical techniques is dependent upon a range of factors, including:

- The type of substances that need to be analysed. The majority of techniques are able to analyse a range of substances, but these are typically confined to a single “family” of chemicals (e.g. metals, nutrients, hydrocarbons, pharmaceuticals). It should also be noted that some techniques are more appropriate for specific substances than others.
- The end use of the resulting analytical data and any associated procedures necessary to comply with specified / prescribed quality management systems, accreditation systems, analytical methods, etc. For example, comparison against sediment quality criteria to inform licensing of the sediment’s reuse or exempted / permitted disposal, or to inform bench testing for identifying suitable sediment remediation techniques.
- The expected range of concentrations of these substances, and the upper and lower detection limits of the laboratory equipment. For example, some techniques may not be sufficiently sensitive to determine low concentrations of a substance, while others may be too sensitive to accurately measure high concentrations without the need for further dilution.
- The amount of sample required for analysis versus the amount of sample available.
- The availability of specific equipment within a particular laboratory.

It should be noted that, although international standards (particularly for marine sediments) may set out criteria for sediment sampling and analysis, there can be differences in the way in which these criteria are interpreted. An example for marine sediments is provided in the box overleaf.

### Guidance for analysis of marine sediments

Once the purpose of the proposed study has been defined, it is then necessary to follow a logical step-wise approach to planning the study to ensure that it meets its stated objectives. A potential approach is outlined below:

Technical Annex I of the OSPAR Guidelines (OSPAR, 2014) outlines the analytical requirements necessary for dredged material assessment. This includes analysis of both physical (Tier 1) and chemical (Tier 2) properties. The Annex references the Joint Assessment and Monitoring Programme (JAMP) 'Guidelines for Monitoring Contaminants in Sediments (Agreement 2002/16)', which outlines detailed analytical requirements for each contaminant of concern.

From review of the document 'High Level Review of Current UK Action Level Guidance' (MMO, 2015) it is apparent that, within the OSPAR region, there are significant differences in approach by Contracting Parties to the analysis of marine sediments in the context of disposal of dredged material to sea. For example, regarding the sediment fraction typically analysed for metals, certain countries (e.g. UK, Denmark, France, Ireland, Netherlands and Norway) analyse the <2mm fraction, whereas other countries (e.g. Belgium and Spain) analyse the <63µm fraction, whilst Germany analyses the <20µm fraction. Contamination extraction techniques for metals also differ between Total HF (hydrofluoric acid) and Partial HNO<sub>3</sub> (nitric acid) for certain contracting parties.

Given that the finer fractions of sediments are likely to contain higher proportions of contaminants when compared with coarser-grained sediments, it is therefore not possible to directly compare sediment contamination data between OSPAR countries who analyse different sediment fractions and use different extraction techniques. There are also no reliable methods to adjust the data to make it comparable between nations, with reliable comparisons only possible where sediment fraction size and the same extraction technique (or ones demonstrated to provide similar results) are adopted (MMO, 2015).

For the analysis of marine sediments (particularly in relation to disposal of dredged material to sea), the devolved administrations of the UK have implemented processes which meet the requirements of both the OSPAR Convention and the London protocol, though as has been discussed, this does not automatically mean that data are comparable between all Contracting Parties. It has also become apparent that sampling methodologies may also differ between CP's, with anecdotal evidence from Dutch dredging contractors that grab sampling is not permitted due to loss of fines and disturbance of sediments during sampling (Alison Hallas, pers. comm.). However, in the UK the regulatory authorities believe that this technique provides acceptable sample quality as long as the sampling equipment has been correctly deployed (Chris Vivian, pers. comm.).

The PLA specifies that the entire sediment fraction should be analysed for water injection, plough and bed levelling dredging activities on the Thames<sup>19</sup>. Limits of detection specified are also different from those specified by the MMO20, being an order of magnitude greater in some cases (e.g. trace metals), making it not possible to directly compare results obtained through these requirements.

<sup>19</sup> <http://www.pla.co.uk/Environment/Appendix-A-Contaminant-analysis-Water-Injection/Plough-Dredging-and-Bed-Levelling>

<sup>20</sup> <https://www.gov.uk/government/publications/marine-licensing-physical-and-chemical-determinands-for-sediment-sampling/chemical-determinands>

## 6 Conclusions and recommendations

### 6.1.1 Summary of findings

Phase 2 of this report has demonstrated that there is a wide range of guidance available for planning sediment sampling, collecting sediment samples in the field and analysing samples in the laboratory in the freshwater and marine environments.

However, this guidance is not definitive, and although specific sampling strategies, collection techniques and analytical procedures are recommended, there is not necessarily a consensus between different pieces of guidance. This is further complicated by the sometimes differing requirements of the drivers behind investigations of in situ contaminated sediments (e.g. legislation and the need to demonstrate compliance with different sets of sediment quality standards), and the physical differences apparent in different parts of the water environment (e.g. due to variations in factors such as hydrology and geomorphology).

This lack of standardisation can be problematic when results are considered at a national or even catchment scale, because datasets collected with different aims and using different analytical techniques cannot necessarily be directly compared to each other. For example, sediment samples composed of different grain size fractions, collected from different parts of a river channel bed and analysed using different laboratory techniques will not be directly comparable.

There is therefore a need for standardisation and the development of a single approach (or set of approaches) that can be used to ensure that future sediment analysis results can be considered in a strategic manner (e.g. environmental monitoring, record-keeping).

### 6.1.2 Recommendations for standardisation of sampling and analysis methodologies and guidance

In most circumstances there will be a requirement for routine sampling and analysis to be undertaken (e.g. for regular monitoring regimes, or the characterisation of dredged material for reuse/disposal, etc.). In these instances, well-established protocols and procedures are available to ensure that sample collection and subsequent analysis are scientifically robust and appropriate for the purposes for which they have been collected.

In other circumstances, such as site-specific or bespoke requirements, there are many alternative methods available for sediment sampling and subsequent analysis, depending upon the objectives of the investigation and also the potential fate of the material being analysed. The potential fate of the material in question will also be heavily influenced by the results of any sampling and analysis undertaken, which in turn will often be determined by the proposed intervention option. This can therefore result in a circular argument, making it extremely difficult to produce a definitive 'route-map' for operatives to follow in every potential scenario envisaged.

Whether the scenario in question is considered to be routine or non-routine in nature, the ability to undertake sampling and analysis of *in-situ* contaminated materials in a consistent and scientifically robust manner will be crucial in the development of any future guidance. As a minimum, applicable standards should be met for any project which proposes the sampling and analysis of *in-situ* contaminated sediments for any reason.

As outlined in the WP1A report, the following recommendations are also applicable to WP1C:

- A standardised framework for sample collection, analysis and reporting should be developed by organisations undertaking sampling, particularly for regional or national sampling projects.
- Further areas where standardisation is necessary include digestion procedure and analytical techniques; if these methods cannot be standardised then accuracy results obtained from analysing standard reference material should be reported. When reporting results, data should be stored in a clear and simple format that is easily understood by a third party.
- Development of a set of national guidelines for sediment sampling, to ensure that contamination is identified in a coherent and comprehensive way. These should include recommendations for sample collection from a range of sedimentary environments, ideally to include suspended sediments, active bed sediments, deposits from palaeochannels and other depositional hollows and floodplain cores.

The following example of a possible 'decision making framework' (**Table 6.1**) is based upon the 'Conceptual Model for In situ contaminated sediments' as developed under Work Package 1A.



Table 6.1: Example decision-making framework for the selection of appropriate sampling and analysis techniques for in-situ contaminated sediments in England - Dredging

Key parameters	Potential decision-making framework for the selection of appropriate sampling and analysis techniques				
Activity/Purpose for sampling and analysis	Dredging and excavation (e.g. including navigational and non-navigational such as clearance, environmental, etc.)				
In-situ environment	Freshwater			Marine/estuarine	
Potential use/fate of materials	Reuse (e.g. on banks of watercourse)	Land spreading (e.g. agricultural)	Onshore disposal	Onshore disposal	Disposal at sea / beneficial use
Applicable standards/guidance	<ul style="list-style-type: none"> <li>Revised Waste Framework Directive.</li> <li>'Waste Exemption D1: depositing waste from dredging inland waters'.</li> <li>AINA, 2013 Good Practice Guide.</li> </ul>	<ul style="list-style-type: none"> <li>Revised Waste Framework Directive.</li> <li>'Standard Rules Permit SR2010No4: Mobile plant for land spreading'.</li> <li>AINA, 2013 Good Practice Guide.</li> </ul>	<ul style="list-style-type: none"> <li>Revised Waste Framework Directive.</li> </ul>	<ul style="list-style-type: none"> <li>Revised Waste Framework Directive.</li> </ul>	<ul style="list-style-type: none"> <li>OSPAR Convention and Guidelines (Technical Annex I).</li> <li>London Convention and Protocol.</li> <li>MMO/Cefas sampling and analysis plan.</li> <li>PLA sample plan if within tidal Thames.</li> </ul>
Sampling equipment	Remote sampling equipment: <ul style="list-style-type: none"> <li>Bucket/grab for surface samples.</li> <li>Corer for depth samples (if required).</li> </ul>	Remote sampling equipment: <ul style="list-style-type: none"> <li>Bucket/grab for surface samples.</li> <li>Corer for depth samples (if required).</li> </ul>	Remote sampling equipment: <ul style="list-style-type: none"> <li>Bucket/grab for surface samples.</li> <li>Corer for depth samples (if required).</li> </ul>	Remote sampling equipment: <ul style="list-style-type: none"> <li>Grab for surface samples.</li> <li>Corer for depth samples (if specified).</li> </ul>	Remote sampling equipment: <ul style="list-style-type: none"> <li>Grab for surface samples.</li> <li>Corer for depth samples (if specified as required by regulators).</li> </ul>
Sample collection and storage	EA Operational instruction 010_07	EA Operational instruction 010_07	EA Operational instruction 010_07	Cefas guidance on sample collection and storage	Cefas guidance on sample collection and storage
Sediment fraction analysed	<ul style="list-style-type: none"> <li>&lt;2mm sediment fraction (sands, silts and clays).</li> </ul>	<ul style="list-style-type: none"> <li>&lt;2mm sediment fraction (sands, silts and clays).</li> </ul>	<ul style="list-style-type: none"> <li>&lt;2mm sediment fraction (sands, silts and clays).</li> </ul>	<ul style="list-style-type: none"> <li>&lt;2mm sediment fraction (sands, silts and clays).</li> </ul>	MMO/Cefas <ul style="list-style-type: none"> <li>&lt;2mm sediment fraction (sands, silts and clays).</li> </ul> PLA <ul style="list-style-type: none"> <li>Whole sediment sample (all fractions).</li> </ul>
Typical analytical suite	Typical suite: Solids; pH; trace metals, phenols, PAHs, organic matter content, extractable TPHs etc.  <u>Reuse on banks only:</u> Leachate testing for sediments with elevated levels of contaminants.	As for typical suite, plus: <ul style="list-style-type: none"> <li>Nutrient levels for spreading to agricultural land.</li> </ul>	WAC testing criteria: <ul style="list-style-type: none"> <li>Full WAC suite - if material is 'hazardous' and to be disposed of at a Hazardous Landfill</li> <li>Inert WAC suite - if material is 'non-hazardous' and to be disposed of at an inert landfill.</li> </ul>	WAC testing criteria: <ul style="list-style-type: none"> <li>Full WAC suite - if material is 'hazardous' and to be disposed of at a Hazardous Landfill</li> <li>Inert WAC suite - if material is 'non-hazardous' and to be disposed of at an inert landfill.</li> </ul>	<ul style="list-style-type: none"> <li>PSA.</li> <li>Trace metals (e.g. As, Cd, Cr, Pb, Cu, Ni, Zn).</li> <li>Organotins (e.g. TBT, DBT).</li> <li>THCs.</li> <li>PAHs.</li> <li>PCBs (ICES 7).</li> </ul>
Typical LoDs	Awaiting info from C&RT - EGS	As defined in RB09 (the 'fertiliser manual') <sup>21</sup> .	As defined in WAC testing guidance <sup>22</sup> .	As defined in WAC testing guidance.	<ul style="list-style-type: none"> <li>As defined by MMO and Cefas<sup>23</sup>.</li> <li>As defined by PLA<sup>24</sup></li> </ul>
Other requirements	Pre-treatment by dewatering	Pre-treatment by dewatering	Pre-treatment by dewatering	Pre-treatment by dewatering	-

<sup>21</sup> <http://www.ahdb.org.uk/projects/CropNutrition.aspx>

<sup>22</sup> [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/321207/Sampling\\_and\\_testing\\_of\\_waste\\_for\\_landfill.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/321207/Sampling_and_testing_of_waste_for_landfill.pdf)

<sup>23</sup> <https://www.gov.uk/government/publications/marine-licensing-physical-and-chemical-determinands-for-sediment-sampling/chemical-determinands>

<sup>24</sup> <http://www.pla.co.uk/Environment/Appendix-A-Contaminant-analysis-Water-Injection/Plough-Dredging-and-Bed-Levelling>

## Appendix A: Description of sampling equipment

DRAFT

## A1 Grab samplers

There are numerous grab sampling devices, of various design, that have different advantages and disadvantages depending on the nature of the sediment to be sampled (e.g., coarse versus fine), the water depth, the amount (mass) of sediment required, the size of the area to be sampled, local energy conditions (e.g., sampling in a rapidly flowing stream versus sampling in a relatively quiescent lake), sampling platform (e.g., a boat versus sampling from a bridge) and the availability of lifting equipment (e.g., hand-operated versus crane- or winch-operated).

Generally, the selection of a particular type of grab for the collection of a sediment-trace element sample is dependent on evaluations against four criteria: 1) degree of physical disturbance during sampling, especially while the device is being lowered to collect a sample (due to the 'bow or pressure wave' created by the device which can disperse fine-grained sediment or flocs at the sediment-water interface); 2) loss of material, especially fine-grained sediments, during recovery of the sampler through the water column ('washout'); 3) the efficiency of the grab for collecting sediments of varying textures (e.g., grain size, degree of induration); and 4) potential for sample contamination.

For example, anecdotally it is understood that Dutch dredging contractors have indicated that grab sampling is not permitted for sediment sampling for dredge disposal due to loss of fines and disturbance of sediments during sampling (Alison Hallas, *pers. comm.*). However, in the UK the regulatory authorities believe that this technique provides acceptable sample quality as long as the sampling equipment has been correctly deployed (Chris Vivian, *pers. comm.*).

The Birge-Ekman grab sampler is suitable for sampling soft sediments in shallow, quiescent rivers and lakes (Figure A1). Small or lightweight designs may be operated by hand line while wading whilst larger models will be operated by winch from a boat.

The Van Veen grab sampler is more versatile for collecting sediments with a range of sediment properties, and is generally operated by winch from a boat (Figure A2).

Both the Birge-Ekman and Van Veen samplers permit relatively non-disruptive sampling. However, Birge-Ekman samplers are not recommended for use in strong currents or high waves as they are less stable than Van Veen samplers during sediment penetration.

An example of a handline sampler is the Ponar sampler (Figure A3). This is a clam-shell type sampler, consisting of two quarter-cylinder sections hinged together at the top. This sampler is particularly effective where bottom sediments consist of unconsolidated fines with no armouring present. Some protection against erosion of the captured sediment is provided by an overlapping lip on the bottom and sides. However, a watertight seal does not exist, so care must be exercised when raising the sampler to the surface.

The U.S. Geological Survey (USGS) has published a series of manuals describing procedures for planning and conducting specialised work in water-resources investigations. The cable-and-reel suspended BM-54 sampler can be used for sampling bed material of streams and lakes of any reasonable depth, except for streams with extremely high velocities (Figure A4). The spring is powerful enough to obtain a sample from a bed of very compacted sand.



Figure A1 Birge-Ekman grab sampler in armed position (sourced from Hydro Bios, 2016)



Figure A2 Van Veen grab sampler in armed and triggered positions (sourced from KC Denmark Research Equipment, 2016)



Figure A3 Ponar grab sampler

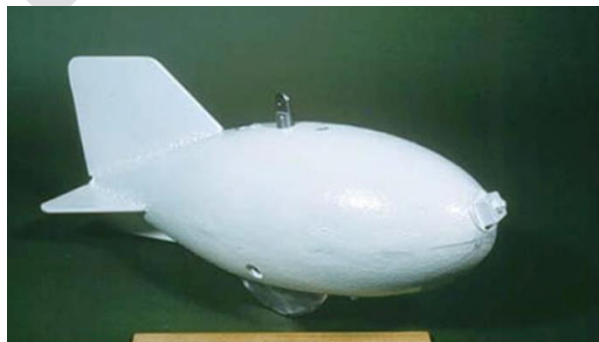


Figure A4 US BM-54 sampler

## A2 Hand-held samplers

Three types of instruments for hand sampling of bed material finer than medium gravel have been developed for general use (Edwards and Glysson 1970).

The BMH-53 is designed to sample bed material in wadable streams (Figure A5). In soft cohesive beds, this technique generally provides shallow cores with a minimum of distortion, from which sediment variations with depth and subsamples can be obtained.

The bed material of some wadable streams or lakes can be sampled with the US BMH-60 (Figure A5). Because of its light weight, it is useful only in streams of moderate depths and velocities. The bed material must be moderately firm and contain little or no gravel.

Another bed-material hand-sampling instrument available for general use is designated BMH-80 (Figure A6). This sampler is used to sample the bed of wadable streams. The sampling mechanism is a semi-cylindrical bucket, resembling the BMH-60 bucket assembly, which is operated by positioning the lever on the handle to open or close the bucket. When the bucket is closed and a sample volume of approximately 175cm<sup>3</sup> of bed material is captured, the closure is sufficiently sealed to prevent erosion of the sample while the instrument is lifted through the water column.

The Geochemical Baselines Survey of the Environment (G-BASE) project outlines a detailed sampling methodology utilising a trenching tool (shovel) and sieve nest (Figure A7). The procedures can be found in a step-by-step guide within Johnson et al. (2005; 2008). Firstly, the uppermost (10 to 20 cm) heavily oxidised sediment is removed with the shovel. The coarser sediment below is then loaded onto the top sieve. Excess water should be drained off and any large clasts removed before placing the material into the top sieve. It will normally be necessary to dig 15 - 25 kg (wet weight) of material to provide a sufficient final sample weight.



Figure A5 US BMH-53 (L) and US BMH-60 (R)

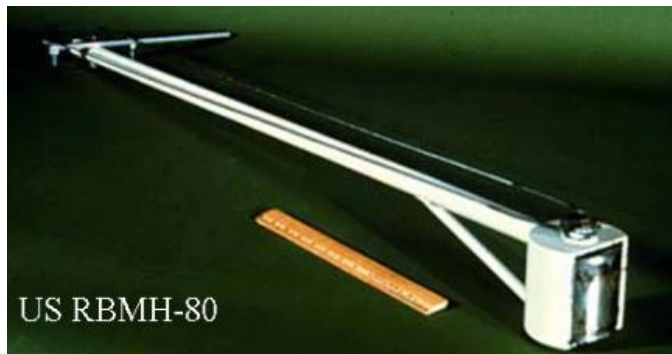


Figure A6 US RBMH-80 hand-held sampler

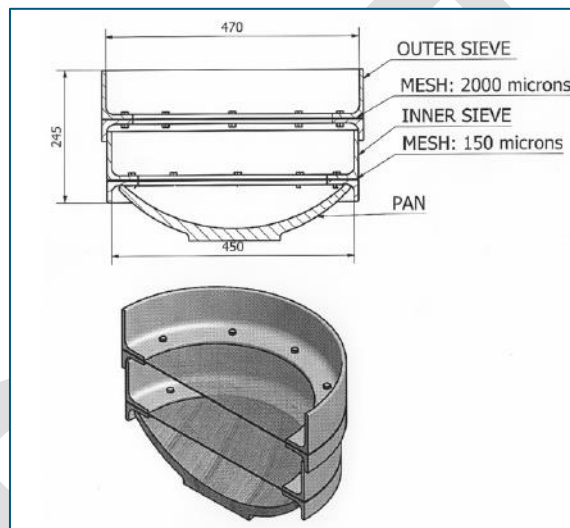


Figure A7 Diagram of a nester sieve set used for stream sediment sampling (Johnson *et al*, 2008).