

**Cefas contract report: SLAB5**

## **Dredged Material Disposal Site Monitoring Around the Coast of England: Results of Sampling (2012)**

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## Executive Summary

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- This report presents the scientific findings and monitoring implications of dredged material disposal site monitoring under SLAB5 around the coast of England during 2012.
- The main aims of this report are to aid the dissemination of the monitoring results, to assess whether observed changes are in line with those expected, to compare the results with those of previous years (where possible) and to facilitate our improved understanding of the impacts of dredged material disposal at both a site-specific and a national (i.e., non site-specific) level.
- Parameters monitored varied between sites (governed by site-specific issues) but included multibeam and sidescan sonar acoustic techniques, sediment particle size assessments, sediment organic carbon and nitrogen content determination, the study of macrofaunal assemblages and the assessment of a range of sediment contaminants including tributyl tin (TBT), polycyclic aromatic hydrocarbons (PAHs), organohalogens (e.g., organochlorine pesticides, brominated flame retardants) and trace metals.
- A significant proportion of the work undertaken during 2012 focussed on improving our understanding of the physical and chemical characteristics of contaminated dredged material (CDM) disposed and capped at Souter Point during 2004/5, and on determining the current integrity of the overlying sediment cap.
- Work pertaining to sediment particle tracking following deposition to three sites within the Mersey Estuary was conducted via modelling approaches, sub-contracted to NOC, Liverpool.
- The implications of these findings for each site are discussed with respect to the need for subsequent monitoring under SLAB5. However, it should be remembered that these data do not represent the sole basis of such final decisions regarding future monitoring; in addition, up-to-date intelligence regarding potential changes to the disposal regime and/or concerns raised from any stakeholders are all embraced within the selection process for disposal site monitoring under this project.

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## **1. INTRODUCTION**

### 1.1 Regulation of disposal activity in England

Until recently, the deposit of substances and articles in the sea, principally the disposal of dredged material, was controlled by a system of licences issued under Part II of FEPA. However, the responsibility for the licensing function in England and Wales on 1<sup>st</sup> April 2010 transferred from the Marine and Fisheries Agency to the Marine Management Organisation (MMO) for England and to the Welsh Government for Wales. The marine licensing provisions of the Marine and Coastal Access Act 2009 that came into force on 1<sup>st</sup> April 2011 have thus taken over from Part II of FEPA for the licensing function in England and Wales.

In licensing the disposal of dredged material at sea, numerous conditions associated with the relevant national and international agreements (e.g., the London Convention 1972 (LC72) and London Protocol of 1996 (LP96), the OSPAR Convention, the Environmental Impact Assessment Directive (97/11/EEC), the Habitats and Species Directive (92/43/EEC), the Wild Birds Directive (79/409/EEC), and the Water Framework Directive (WFD, 2000/60/EC)), must be considered to determine whether likely impacts arising from the dredging and disposal are acceptable (MEMG, 2003). Criteria considered under the various conventions and directives include the presence and levels of contaminants in the materials to be disposed of, along with perceived impacts on any sites of conservation value in the vicinity of disposal. Additional potential beneficial usage of the materials must be considered prior to a disposal consent being issued (MEMG, 2003).

One of the roles of Cefas is to provide scientific advice to the MMO on the suitability of the material for sea disposal at the application stage and, once a licence is granted, to check that disposal licence conditions are met and that no unexpected effects occur. Advice on the licensing of dredged material disposal at sea is provided by Cefas' Regulatory Assessment Team (RAT), work conducted under SLAB5 helps underpin the scientific rationale for such advice (see Section 1.3).

### 1.2 Disposal sites around England

There are approximately 150 sites designated for dredgings disposal around the coast of England, not all of which are used in any one year. While the majority of these are located on the coast of the mainland, generally within a few miles of a major port or estuary entrance, a significant number are positioned within estuaries (e.g., Humber) or on intertidal mudflats as part of beneficial use schemes (Bolam et al., 2006).

In total, approximately 40 million wet tonnes are annually disposed of to coastal sites around England, although this can vary from 28 to 57 million wet tonnes (for the period between 1986 and 2010). Individual quantities licensed may range from a few hundred to several million

tonnes, and the nature may vary from soft silts to boulders or even crushed rock, according to origin, although the majority consists of finer material (Bolam et al., 2006).

### 1.3 Overview of Cefas / MMO MoU contract No. SLAB5 'Monitoring of dredged material disposal sites'

In England, SLAB5 is one of several contracts funded by the MMO under a non-R&D MoU. The project provides field evaluations ('baseline' monitoring and 'trouble-shooting' surveys) at dredged material disposal sites round the coast of England. A major component of the project is, therefore, the commissioning of sea-going surveys at targeted disposal sites. Such field evaluations under SLAB5 are designed to ensure that:

- environmental conditions at newly designated sites are suitable for the commencement of disposal activities;
- predictions for established sites concerning limitations of effects continue to be met; and,
- disposal operations conform with licence conditions.

The outcomes of such surveys contribute directly to the licensing/enforcement process by ensuring that any evidence of unacceptable changes or practices is rapidly communicated and acted upon. As such, there are inherently strong links and ongoing discussions between the approaches and findings of this project with the work carried out by Cefas' Regulatory Assessment Team (RAT). One of the key roles of the latter is to advise the licensing authority (i.e., the MMO) of the appropriateness of current licences and the suitability of any new licence applications. The scientific outcomes of work undertaken within SLAB5 are circulated to the Cefas RAT *via* a number of routes including peer-reviewed publications (including both activity-specific and site-specific findings), internal documents, direct discussions and internal and external presentations. The production of this report, within which a summary of the annual findings is presented (Section 2), forms an important element of such scientific communication. It is not the purpose of this report to present a detailed appraisal of the processes giving rise to impacts at a particular site (this is more the role of, for example, peer-review outcomes or specifically-requested reports) but to encapsulate the essence of the impacts associated with this activity in its entirety round the coast of England (see Section 1.5).

### 1.4 Sites monitored

To aid with determining which disposal sites should be selected for sampling in any one year, Cefas has derived a tier-based approach that classifies a number of possible issues or environmental concerns that may be associated with dredged material disposal into a risk-based framework (Bolam et al., 2009; Birchenough et al., 2010). The issues that pertain to a

particular disposal site, and where these lie within the tiering system (i.e., their perceived environmental risk) depict where that site lies within the tiered system. This ultimately determines whether that site is considered for sampling during a particular year. It is intended that this approach should increase the transparency of the decision-making process regarding disposal site selection for SLAB5 monitoring, i.e., it establishes a model for site-specific decisions regarding sampling.

A tiered survey design and site assessment system, therefore, facilitates the prioritisation of dredge material disposal sites in terms of the need for, and the scale of, monitoring required at each site. In practice, this method will provide a scientifically valid rationale for the assessment of risks associated with relinquished, current and proposed disposal sites to the surrounding environment and amenities.

The disposal sites targeted for Cefas monitoring during 2012 are listed in Table 1.1. These sites were identified following consultation between Cefas case officers within the RAT and Cefas scientists in a number of key disciplines (e.g., benthic ecology, sediment contaminants). Additionally, these sites have been selected based on information from dredged material licence applications, consultation with the MMO and through concerns identified by stakeholders including conservation agencies and the general public.

*Table 1.1. Dredged material disposal sites targeted for monitoring under SLAB5 during 2012.*

	<b>Geographical location around English coast</b>	<b>Code</b>	<b>Prioritisation assessment: Tier</b>
North Tyne	Northeast	TY070	1
Souter Point	Northeast	TY081	1
Inner Tees	Northeast	TY160	1
Goole Reach	East	HU041	1
Inner Gabbard East	Southeast	TH056	2
Mersey	Northwest	IS110, IS120, IS128	2

### 1.5 Aims and structure of this report

This report does not aim to present a critique of the processes leading to observed changes at dredged material disposal sites around the coast of England. Such appraisals are conducted *via* other reporting routes, either *via* discussions with Cefas case officers, presentations and subsequent publications at national and international conferences, and *via*

papers in peer-reviewed journals (e.g., Bolam and Whomersley, 2005; Bolam et al., 2006; Birchenough et al., 2006; Bolam et al., 2011; Bolam et al., 2014). The aims of this report are:

- To present the findings of the results of sampling undertaken during 2012 under SLAB5, thereby aiding the dissemination of the findings under this project;
- To indicate whether the results obtained are in line with those expected, or whether subsequent investigations should be conducted;
- Where possible, to assess the 2012 results in line with those of previous years to provide a temporal assessment (see Bolam et al., 2009, 2011 and 2012 for reports of previous years' monitoring);
- To facilitate our improved understanding of the impacts of dredged material disposal at both a site-specific level and a national level; and,
- To promote the development of scientific (or other) outputs under SLAB5.

Within earlier SLAB5 reports (e.g., Bolam et al., 2009; 2011), an appraisal of the findings of each data component (e.g., acoustics, sediment granulometry, macrofauna, contaminants) for each site was presented followed by a summary of the implications of such information for subsequent monitoring under SLAB5. Due to the inherent length of the former, the key outcomes of the report were perhaps not sufficiently prominent for the reader. Thus, in accordance with last year's report (Bolam et al., 2012), the conclusions for each site are contained within a new section within the present report (i.e., Section 2, below); the presentation of all the scientific data has remained as previously presented but has been transferred to an appendix (Appendix 2). For background information regarding each disposal site monitored during 2012, the reader is directed towards this appendix. Appendix 1 contains, as per the previous reports, information regarding the analytical and numerical methods used during the assessments of sediment contaminants (the reader may need to consult these whilst appraising Section 2).

## **2. CONCLUSIONS AND IMPLICATIONS FOR FURTHER MONITORING**

The main findings of the monitoring data for each site are presented within this section (see Appendix 2 for more detail), together with their implications regarding the need for subsequent monitoring under SLAB5. However, it should be noted that these data do not represent the sole basis of such final decisions regarding monitoring; up-to-date intelligence regarding potential changes to the disposal regime and/or concerns raised from any stakeholder are all embraced within the selection process for disposal site monitoring under this project. Thus, the recommendations for monitoring presented here for each site, although representing a major component of the decision-making process, may or may not be altered by other site-specific factors.

### 2.1 North Tyne (TY070)

Monitoring at the North Tyne dredged material disposal site has been conducted under the auspices of SLAB5 for a number of years. As such, a good understanding of the spatial variation of the biology (macrofauna), sediments and contaminants following disposal activity at this site has been acquired. Temporal data previously attained for the macrofauna suggested that impacts are consistently localised and, as such, the biota was not the subject of monitoring under SLAB5 during 2012.

Sediment monitoring at North Tyne during 2012 indicated that polycyclic aromatic hydrocarbon concentrations (PAHs) remain elevated. Concentrations of all 11 stations sampled exceeded the effect range low (ERL) for low molecular weight (LMW) PAHs, and values for all stations except four exceeded the effect range median (ERM) for LMW PAHs. Six stations possessed sediments which exceeded the ERL for high molecular weight (HMW) PAHs although the ERM concentration for HMW PAHs was not breached at any station.

Regarding organohalogenes (OHs), concentrations of chlorobiphenyls (CBs) were mostly below Cefas AL1 and most stations displayed a 'good' environmental status for ICES 7 CBs under OSPAR guidelines. Four stations displayed 'bad' environmental status for CB118 and one station (inside the disposal site boundary) was regarded as 'bad' status for CB52, CB118, CB101 and thus 'bad' status overall. There is no indication of any temporal trend in OH concentrations at North Tyne: some stations showed elevated levels in 2012 while others showed decreased concentrations.

While intelligence regarding potential future changes to the disposal regime must be utilised, monitoring data acquired during 2012, when appraised together with those data from previous years, indicate that further monitoring of PAH and OH contaminants is required, although not on an annual basis.

### 2.2 Souter Point (TY081)

Monitoring at Souter Point dredged material disposal site has been conducted annually for a number of years under SLAB5, aiming primarily to determine the physical integrity of the cap placed over the contaminated sediment and ensuring that impacts of ongoing disposals are limited to within the vicinity of the disposal site. A number of complementary approaches (e.g., grabbing, coring, acoustics, sediment profiling imagery (SPI)) have been adopted at this site to achieve these aims. However, the Nioz core has a sediment penetration limit of approximately 30cm and, thus, there has always been the potential that previous monitoring has not penetrated into the capped contaminated dredged material (CDM).

In 2012, the focus of sampling at Souter Point was to gain increased confidence in the assessment of cap thickness. Following an acoustic survey, 27 stations were sampled using a vibrocorer which provided intact sediment cores up to 2 m into the sediment matrix. These cores, following careful sub-sectioning, allowed a contemporary assessment of the location and depth of the CDM. The CDM showed high levels of some contaminants (TBT, Cd, Zn and PAHs): these contaminants are thus capable of distinguishing the signatures of the CDM from non-CDM material. CDM was found at a total of 16 of the 27 stations sampled, three of these being located outside the initial CDM placement licensed boundary. The data showed that, while CDM was covered by sufficient amount of sediment overburden at most stations, the current cap thickness was noticeably less at some stations (15-18 cm being the thinnest cap): an appraisal of the temporal bathymetric data indicated that these stations coincided with regions of natural sediment erosion.

The data acquired at Souter Point during 2012 have provided important intelligence concerning the concentrations of contaminants of the CDM *in situ* and the contaminant groups capable of determining CDM from non-CDM sediments: this will be of future use in subsequent monitoring efforts. While monitoring of cap thickness in the southeastern corner of the capping area may be regarded as prudent, remedial action for this site would be to direct ongoing maintenance deposits in this region, thereby reducing the potential of the CDM reaching the sediment-water interface (licence conditions included the requirement for a cap thickness of at least 60 cm).

### 2.3 Inner Tees (TY160)

Analogous to the situation for North Tyne and Souter Point, SLAB5 monitoring at the Tees disposal site has been conducted annually for a number of years and, as such, we have a good temporal dataset to draw upon when making contemporary assessments.

Ongoing disposal activity to the Inner site has resulted in data acquired being typical of a site receiving maintenance dredged material. The temporal bathymetric data revealed no distinct changes from previous years other than the expected increase in material within the site. Sediments from all sampling stations were found to exceed the ERL and ERM for LMW PAHs. The ERL for the HMW PAH was breached at all stations except IND4, IND5 and IT5, which are located in the northern half of the disposal site. No station exceeded the ERM for the HMW PAHs. There was no disposal activity to Inner Tees during 2011-12, which could account for the lower concentrations seen at most of the disposal sampling points. TBT (which has previously been shown to be low at Tees) and OH concentrations were not assessed in 2012.

Subsequent monitoring should focus on assessments of contaminant concentrations at the Inner Tees site, unless disposal activity to the Outer Tees site has, is or likely to, be resumed.

#### 2.4 Goole (HU041)

The monitoring conducted along the River Ouse which spans from the west of Goole Reach to the east of Whitgift Bight has again demonstrated that TBT concentrations remain low. TBT concentrations were below limit of detection at all 13 sampling stations: two stations had previously exhibited concentrations above detectable limits in 2011. PAH levels remain fairly static: decreasing at some stations (particularly those upstream stations) and increasing at others (especially those surrounding Whitgift Bight disposal site). The ERL for LMW PAHs was exceeded at all stations except G4, G6, G12 and G13, where the summed PAH concentrations were less than  $3,600 \mu\text{g kg}^{-1} \text{ dw}$ . The ERM for LMW PAHs was exceeded only at G5, G8 and G11. The ERL for HMW PAHs was also exceeded at G5, G8, and G11. G11 was the only station to breach the ERM for HMW PAHs.

Monitoring of TBT is no longer necessary and, although PAH concentrations are still of significance in this area, monitoring of these contaminants may be conducted at a lower temporal intensity than annually. Future monitoring should also resume the inclusion of OHs where recent data indicate that source material possesses high concentrations of brominated flame retardants.

#### 2.5 Inner Gabbard East (TH056)

The acoustic-based monitoring previously conducted at the Inner Gabbard East (IGE) site in 2009, 2010 and 2011 has provided important data from which assessments regarding granulometric and bathymetric changes can be made and, consequently, indications regarding the fate of material deposited. Additional acoustic data attained in 2012 for IGE and its environs revealed that the centre of the disposal site has a lower acoustic return than that of the surrounding seabed sediments with areas of higher backscatter strength bordering. These data imply that disposal activity is currently being contained within the licensed disposal site boundary. Additionally, there has been very little change in the distribution of the detected disposal material. The observation that disposed material accumulates within the site supports *a priori* expectations for the site as being non-dispersive: unlike some other sites, such accumulation is not regarded as a problem due to its depth (approx. 55 m deep).

These data imply that the large deposit recently received at IGE has predominantly been contained within the IGE boundary. Annual monitoring of the site can, therefore, be ceased and no monitoring is warranted unless new or proposed large deposits are considered.

## 2.6 Mersey (IS110, IS120, IS128)

A modelling study was undertaken to improve our understanding of the fate of material deposited to three disposal sites (IS110, IS120 & IS128) within the Mersey Estuary. Five scenarios were modelled to investigate the behaviour of two sediment mixes (1:1 and 7:3 silt:medium sands respectively) and three disposal tonnages (10, 50 and 1500 tonnes) at each site. The results, therefore, allow us to address key questions regarding the outcomes of potential variations to licence condition such as disposal volumes, frequencies, types, tidal conditions, etc.

The study indicated that the majority (> 83%) of each sediment class deposited at each location remains within the Mersey Estuary. Slowly releasing the material over a period of time, depositing sediment at different states of the tide or increasing the deposit thickness on the bed (reducing the area of deposit or increasing volume disposed over a time) will have little influence on the long-term transport. Releasing the particles at different times within the tidal flow (slack water before ebb or maximum ebb flow) may slow the net transport but only by the net movement during that tidal cycle. Finally, there is a risk that maintenance dredging of the docks will need to increase in response to the migration of disposed sediment towards the inner estuary shorelines.

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#### **4. References** (including those cited in the Appendices)

Allchin, C.R., Kelly, C. & Portman, J.E., 1989. Aquatic Environmental Protection: Analytical Methods, MAFF Directorate of Fisheries Research, Lowestoft, (6), 25pp.

de Boer, J., Allchin, C.R., Law, R.J., Zegers, B.N. & Boon, J.P. 2001. Method for the analysis of polybrominated diphenylethers in sediments and biota. *Trends in Analytical Chemistry* 20: 591 - 599.

Birchenough, S.N.R., Boyd, S.E., Coggan, R.A., Foster-Smith, R., Limpenny, D.S., Meadows, W.J. & Rees, H.L., 2006. Lights, Camera, Acoustics: assessing macrobenthic communities at a dredged material disposal site off the North East Coast of the UK. *Journal of Marine Systems*, 62: 204-216.

Birchenough, A., Bolam, S.G., Bowles, G.M., Hawkins, B. Whomersley, P. & Weiss, L., 2010. Monitoring of dredged material disposal sites at sea and how it links to licensing decisions. Proceedings from PIANC MMX, Liverpool, May 2010.

Blott, S.J. and Pye, K. (2001) GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms* 26, 1237-1248.

Bolam, S.G., Whomersley, P. 2005. Development of macrofaunal communities on dredged material used for mudflat enhancement: a comparison of three beneficial use schemes after one year. *Marine Pollution Bulletin* 50: 40-47

Bolam, S.G., H.L. Rees, P. Somerfield, R. Smith, K.R. Clarke, R.M. Warwick, M. Atkins & E. Garnacho, 2006. Ecological consequences of dredged material disposal in the marine environment: a holistic assessment of activities around the England and Wales coastline. *Marine Pollution Bulletin* 52: 415-426

Bolam, S.G., Mason, C., Bolam, T., Whomersley, P., Birchenough, S.N.R, Curtis, M., Birchenough, A., Vanstaen, K., Rumney, H., Barber, J., Law, R., Aldridge, J, Nye, V. and

Griffith, A. 2009. Dredged Material Disposal Site Monitoring Across England and Wales: Results of Sampling Under SLAB5 (2008-09). SLAB5 Project Report, Cefas, Lowestoft, UK.

Bolam, S.G., Mason, C., Bolam, T., Whomersley, P., Birchenough, S.N.R, Curtis, M., Birchenough, A., Rumney, H., Barber, J., Rance, J., Law, R. & Griffith, A., 2011. Dredged material disposal site monitoring around the coast of England: results of sampling (2009). SLAB5 Project Report, Cefas, Lowestoft, UK.

Bolam, S.G., Mason, C., Bolam, T., Birchenough, S.N.R, Rumney, H., Barber, J., Rance, J., McIlwaine, P., Bastreri, D. & Law, R.L.J., 2012. Dredged Material Disposal Site Monitoring Around the Coast of England: Results of Sampling (2011). SLAB5 Project Report, Cefas, Lowestoft, UK.

Bolam, T., Barry, J., Law, R.J., James, D., Bolam, S.G., 2014. A temporal and spatial assessment of TBT concentrations at dredged material disposal sites around the coast of England and Wales. *Marine Pollution Bulletin* 79: 326-332

Bolanos, R., Brown, J.M., Amoudry, L.O. and Souza, A.J., 2013. Tides, river and wind influence on the circulation in a macrotidal estuary. *Journal of Physical Oceanography*, 41(1): 29-50.

Brown, J.M., Amoudry, L.O., Souza, A.J. & Rees, J. 2013. Particle tracking in the Mersey Estuary. National Oceanography Centre Research & Consultancy Report No. 40, 34pp.

Cefas, 2005. Background levels and the anthropogenic component, of naturally-occurring elements in marine sediments subject to dredging and disposal. Final report of Defra-funded project AE0257, Cefas, Burnham-on-Crouch, Essex.

Cefas, 2011. Regional trace metal baselines for determining trace metal enrichment at disposal site assessment in England and Wales. Final report for project ME5403 Module 10, Cefas, Lowestoft, UK.

Gorham-Test, C., 1998. Regional Environmental Monitoring and Assessment Program: Galveston Bay 1993. US EPA report no EPA/906/R-98/002. 51 pp.

Kelly, C.A., Law, R.J. & Emerson, H.S. 2000. Methods of analysing hydrocarbons and polycyclic aromatic hydrocarbons (PAH) in marine samples. Science Series, Aquatic Environment Protection: Analytical Methods, CEFAS, Lowestoft, (12), 18pp.

Long, E.R., Field, L.J. & MacDonald, D.D. 1998. Predicting toxicity in marine sediments with numerical sediment quality guidelines. *Environmental Toxicology and Chemistry*, 17(4): 714 – 727.

MacDonald, D.D., DiPinto, L.M., Field, J., Ingersoll, C.G., Long, E.R. & Swartz, R.C. 2000. Development and evaluation of consensus-based sediment effect concentrations for polychlorinated biphenyls (PCBs). *Environmental Toxicology and Chemistry* 19: 1403-1413.

MEMG, 2003. Group Co-ordinating Sea Disposal Monitoring. Final Report of the Dredging and Dredged Material Disposal Monitoring Task Team. Science Series, Aquatic Environment Monitoring Report, CEFAS, Lowestoft, (55): 52pp.

OSPAR, 2006. Agreement on background concentrations for contaminants in seawater, biota and sediment. OSPAR Agreement 2005-6.

OSPAR Commission, 2008. Co-ordinated Environmental Monitoring Programme – Assessment manual for contaminants in sediment and biota ISBN 978-1-906840-20-4, Publication Number No. 379/2008.

Pye, K. and Blott, S.J., 2010. Geomorphology of the Sefton coast and sand dunes. In: *Sefton's Dynamic Coast*, Proceedings of the conference on coastal geomorphology, biogeography and management 2008. Eds. Worsley, Lymbery, Holden and Newton, 131-160.

Ridgway, J., Breward, N., Langston, W.J., Lister, R., Rees, J.G. & Rowlatt, S.M., 2003. Distinguishing between natural and anthropogenic sources of metals entering the Irish Sea. *Applied Geochemistry*, 18(2): 283 - 309.

Rowlatt, S.M. & Lovell, D.R. 1994, Lead, zinc and chromium in sediments around England and Wales. *Marine Pollution Bulletin*, 28 (5): 324 – 329.

Sly, P.G., 1966. Marine geological studies in the Eastern Irish Sea, with special reference to sedimentation in Liverpool Bay and the River Mersey: PHD thesis Liverpool University.

Souza, A.J. and Lane, A., 2013. Effects of freshwater inflow on sediment transport. *Journal of Operational Oceanography*, 6(1): 27-31.

Stewart, L.K., Kostylev, V.E., Orpin, A.R., 2009. Windows-based software for optimizing entropy-based groupings of textural data. *Computers & Geosciences*, 35, 1552–1556.

Van Rijn, L.C., 1993. Principles of Sediment Transport in Rivers, Estuaries and Coastal Seas, Aqua Publications.

**APPENDICES**

## **Appendix 1. Assessment methods for sediment contaminants**

### **1.1 TBT**

#### 1.1.1 Methodology

The sediment samples were collected in hexane-rinsed glass jars and were frozen immediately after collection. The samples were collected for organics analyses, mainly organotins (TBT and DBT), organohalogens and hydrocarbons analyses. The whole (wet) sediment sample is homogenised then sub-sampled for the determination of the total solid content and for organotins analysis.

Sample extraction is initially carried out by alkaline saponification, the organotins compounds are then converted into their hydrides forms with the addition of sodium borohydride. The organotin hydrides are finally back-extracted into hexane by liquid-liquid extraction. Analysis is undertaken using a Gas Chromatography-Flame Photometric Detector (GC-FPD) and quantification is conducted using external calibration. A certified reference material is run within each sample batch for quality control. Results are reported in mg kg<sup>-1</sup> (ppm) dry weight (dw).

#### 1.1.2 Method used for assessment

In this report, since the method is similar to that used for the dredged materials analysis, direct comparison can be made and therefore we assess the organotins data against the actions levels used by the Regulatory Assessment Team (Table A1.1.1). In general, contaminant levels in dredged material below Action Level 1 are of no concern and are unlikely to influence the licensing decision. However, dredged material with contaminant levels above Action Level 2 is generally considered unsuitable for sea disposal. The latter situation most often applies only to a part of a proposed dredging area and so that area can be excluded from disposal at sea and disposed of by other routes e.g. landfill. Dredged material with contaminant levels between Action Levels 1 and 2 requires further consideration and testing before a decision can be made.

*Table A1.1.1. Actions levels for organotin compounds.*

ACTION LEVELS	Action Level 1 (mg/kg)	Action Level 2 (mg/kg)
Organotins; TBT/ DBT/ MBT	0.1	1

## 1.2 PAHs

### 1.2.1 Methodology

Sediment samples, collected in glass jars, were frozen immediately after collection and not defrosted until required for analysis. Each homogenised wet sediment sample was extracted using alkaline saponification followed by liquid/liquid extraction. A sample of sediment was taken for a total solids determination as all results are reported on a dry weight (dw) basis. The sample extract was then passed through an alumina chromatography column in order to remove polar compounds, concentrated to 1 ml and sealed in a vial. A suite of alkylated and parent PAH were then determined using coupled gas chromatography/mass spectrometry (GC/MS). Quantification was by means of deuterated internal standards added prior to digestion, with analytical quality control samples being run within each sample batch. Full details can be found in Kelly *et al.* (2000).

### 1.2.2 Method used for assessment

Cefas currently has action level limits for contaminants such as trace elements and PCBs but none currently exist for PAHs. Reviews of what has been investigated in other countries has indicated that the most promising of the currently available co-occurrence methods is the Effects Range Low/Effects Range Median (ERL/ERM) methodology which is founded on a large database of sediment toxicity and benthic community information (Long *et al.*, 1998).

The ERL/ERM methodology derives SQGs representing, respectively, the 10<sup>th</sup> and 50<sup>th</sup> percentiles of the effects dataset and can be derived for individual PAH compounds. In a regulatory context, where SQGs are to be used as informal (non-regulatory) benchmarks to aid in the interpretation of sediment chemistry (Long *et al.*, 1998), this becomes complicated where a large number of individual PAH and groups (for alkylated PAH) are determined, as is usually the case. This has led to separate ERL/ERM derived SQGs being set for “Low molecular weight PAHs” and “High molecular weight PAHs” (Gorham-Test, 1998). In this context;

LMW PAHs include 2- and 3-ring PAH compounds;

- naphthalene
- monomethyl naphthalenes
- acenaphthene
- acenaphthylene
- fluorene
- phenanthrene
- anthracene

HMW PAHs include the 4- and 5-ring PAH compounds;

- fluoranthene
- pyrene

- benz[a]anthracene
- chrysene
- benzo[a]pyrene
- dibenz[a,h]anthracene

Although a wider suite of PAH is determined routinely for both licensing and monitoring purposes, these can be considered as toxicity markers for the PAH as a whole. The ERL and ERM concentrations applied are given in Table A1.2.1.

*Table A1.2.1. ERL and ERM concentrations for LMW and HMW PAHs in sediments. The limits for LMW PAH are lower than those for HMW PAH as they carry a higher acute toxicity.*

<b>PAH compounds</b>	<b>ERL (<math>\mu\text{g kg}^{-1}\text{ dw}</math>)</b>	<b>ERM (<math>\mu\text{g kg}^{-1}\text{ dw}</math>)</b>
LMW PAH	552	3,160
HMW PAH	1,700	9,600

### 1.3 Organohalogenes

Full details of the analytical methodology are given in Allchin *et al.* (1989) and de Boer *et al.* (2001).

#### 1.3.1 Sample extraction

Sediment samples were air dried and sieved (< 2 mm) in a controlled environment. 10 g of dried sediment were mixed with sodium sulphate, transferred to a glass *Soxhlet* thimble and topped with 1 cm of sodium sulphate.  $^{13}\text{C}$ -labelled BDE209 was added as internal standard to all samples prior to the extraction step. Samples were extracted over a 6 h period using 50:50 hexane:acetone, with an average of 9 - 10 cycles  $\text{h}^{-1}$ . Sulphur residues were removed at this stage with copper filings added to the reflux flask.

#### 1.3.2 Sample extract clean-up

An aliquot of the *Soxhlet* extract was cleaned up and fractionated using alumina (5% deactivated) and silica (3% deactivated) columns, respectively. The silica column fractionation results in two fractions, the first fraction containing polychlorinated biphenyls (PCBs) and BDE209, the second fraction containing polybrominated diphenylethers (PBDEs), with organochlorine pesticides (OCs) split across the two fractions.

#### 1.3.3 Analysis of PCBs and OCs by GC-ECD

After addition of internal standard CB53, PCB and OC concentrations were determined with an Agilent 6890 GC with  $\mu\text{ECD}$ , with separate injections for PCBs and OCs. The separation of

analytes was performed on a 50 m × 200 µm, 0.33-µm-film-thickness DB-5 capillary column (J&W). The carrier and ECD make-up gas were hydrogen (32.2 psi constant pressure, initial velocity 50 cm/s) and argon/methane (95:5), respectively. The initial oven temperature was 90°C, held for 2.00min, then increased to 165°C at 15°C/min, to 285°C at 2°C/min, and finally held for 23 min. The injector temperature and detector temperature was 270°C and 300°C, respectively. A 1 µl extract was injected in splitless mode with a purge time of 2 min.

#### 1.3.4 Analysis of PBDEs by GC-MS

After addition of internal standard CB200, BDE congener concentrations were determined with an Agilent 6890 GC with 5973 MS in electron capture negative ionisation (ECNIMS) mode. The separation of analytes was performed on a 50 m × 250 µm, 0.25-µm-film-thickness DB-5 capillary column (J&W). The carrier gas was helium (30 psi constant pressure, average velocity 40 cm/s) and the reagent gas was methane (40 psi). The initial oven temperature was 90°C, held for 2.00min, then increased to 200°C at 30°C/min, to 295°C at 2.5°C/min, and finally held for 31.33 min. The injector temperature and detector temperature was 270°C and 200°C, respectively. A 2 µl extract was injected in splitless mode with a purge time of 2 min.

#### 1.3.5 Analysis of BDE209 by GC-MS

BDE209 concentrations were determined with an Agilent 6890 GC with 5973 MS in NCI mode. The separation of analytes was performed on a 15 m x 250 µm, 0.1-µm-film-thickness DB-1 capillary column (J&W). The carrier gas was helium (1.3ml/min constant flow, average velocity 59 cm/s) and the reagent gas was methane (40 psi). The initial oven temperature was 90°C, held for 1.00min, then increased to 200°C at 25°C/min, to 295°C at 10°C min<sup>-1</sup>, and finally held for 20 min. The injector temperature and detector temperature was 250°C and 200°C, respectively. A 2 µl extract was injected in pulsed splitless mode with a 20psi pulse until 1 min and a purge time of 2 min.

#### 1.3.6 Quantitation methods

The identification of PCBs and OCs was based on the retention time of individual standards in the calibration mixtures. Quantitation was performed using internal standards and 7 calibration levels (range 0.5 – 100 ng ml<sup>-1</sup>). The PCB standard solutions contained the following 27 compounds in *iso*-octane (IUPAC designations): Hexachlorobenzene; *p,p'*-DDE; CB101; CB105; CB110; CB118; CB128; CB138; CB141; CB149; CB151; CB153; CB156; CB158; CB170; CB18; CB180; CB183; CB187; CB194; CB28; CB31; CB44; CB47; CB49; CB52; CB66. The OC standard solutions contained the following 6 compounds in *iso*-octane: alpha-HCH; beta-HCH; gamma-HCH; dieldrin; *p,p'*-TDE; *p,p'*-DDT.

Quantitation for PBDEs was performed using internal standards and 8 calibration levels (range 0.1 – 50 ng ml<sup>-1</sup>). The PBDE standard solutions contained the following 11 compounds

(IUPAC designations) in *iso*-octane: BDE17; BDE28; BDE47; BDE66; BDE100; BDE99; BDE85; BDE154; BDE153; BDE138; BDE183; together with the internal standard CB200.

Quantitation of BDE209 was performed using an internal standard and 7 calibration levels (range 0.5 – 500 ng ml<sup>-1</sup>). The BDE209 standard solutions contained IUPAC BDE209 in *iso*-octane, together with the internal standard <sup>13</sup>C<sub>12</sub>-labelled IUPAC BDE209.

#### 1.3.7 Quality assurance / quality control procedures

AQC procedures included reagents purification, method blanks, and use of control charts created from repeated analysis of the SETOC 770 Certified Reference Material (CRM).

PCB and OCP concentrations were determined in the sediments and reported on a dry weight (dw) basis. The  $\Sigma$ ICES 7 CBs (CB28, CB52, CB118, CB153, CB138, CB 170, CB183), and the sum of all 25 measured CBs ( $\Sigma$ CBs) were calculated. Where individual congener concentrations were below the limit of detection (LOD) of 0.2  $\mu\text{g kg}^{-1}$ , a value of half the LOD was inserted for calculation of summed concentrations. The CB congener distribution was calculated from the proportion of the sum of  $\Sigma$ CBs that contained 3 chlorines (CB18, CB28, CB31), 4 chlorines (CB44, CB47, CB49, CB52, CB66), 5 chlorines (CB105, CB110, CB101, CB118), 6 chlorines (CB128, CB158, CB141, CB149, CB153, CB138, CB151, CB156), 7 chlorines (CB170, CB180, CB183, CB187), and 8 chlorines (CB194), respectively. Congener profiles at different stations were compared to identify stations with different sources.

The Total Organic Carbon (TOC) content in the < 2 mm fraction determined at a number of representative sampling stations was used to additionally calculate the contaminant concentration normalised to 2.5 % TOC content. The TOC data from the representative stations was used to estimate the TOC content at adjacent stations for which this value was lacking.

Concentrations of PCBs in the sediment were compared with various action limits, to investigate whether any adverse effects in benthic biota were likely to be expected as a consequence of their presence. The current Cefas ALs for dredge disposal are: AL1 if  $\Sigma$ ICES7 CBs > 10  $\mu\text{g kg}^{-1}$ ,  $\Sigma$ CBs > 20  $\mu\text{g kg}^{-1}$ , and AL2 if  $\Sigma$ CBs > 200  $\mu\text{g kg}^{-1}$ . Concentrations are expressed on a dw basis. According to the work of MacDonald *et al.* (2000), consensus-based TECs (Threshold effect concentrations), i.e. below which harmful effects are unlikely to be observed, are:  $\Sigma$ CBs < 59.8  $\mu\text{g kg}^{-1}$ ; and consensus-based PECs (Predicted effect concentrations), i.e. above which harmful effects are likely to be observed ( $\Sigma$ CBs > 277  $\mu\text{g kg}^{-1}$ ). Concentrations are expressed on a dw basis. OSPAR have set criteria for Background Assessment Concentrations (BAC) and Environmental Assessment Concentrations (EAC) for the ICES7 CBs in sediments (see Table A1.3.1). Concentrations are expressed in  $\mu\text{g kg}^{-1}$  dw normalised to 2.5% organic carbon. Concentrations below BACs would be considered to have

high environmental status. Concentrations significantly below EACs could be considered to have good environmental status and those above, bad environmental status. The station is deemed to have 'bad' environmental status if 'bad' status occurs for more than one ICES7 CB congener.

*Table A1.3.1. OSPAR assessment criteria for CBs in sediment from CP2.*

<b>Sediment (<math>\mu\text{g kg}^{-1}</math> dw, normalised to 2.5% TOC)</b>		
<b>Compound</b>	<b>BAC</b>	<b>EAC</b>
CB28	0.22	1.7
CB52	0.12	2.7
CB101	0.14	3.0
CB118	0.17	0.6
CB138	0.15	7.9
CB153	0.19	40
CB180	0.10	12

## **1.4 Trace Metals**

### **1.4.1 Methodology**

The sediment samples were collected in plastic bags and were frozen immediately after collection. The samples were collected for PSA and metal analyses on the < 63  $\mu\text{m}$  fraction. Details on obtaining the < 63  $\mu\text{m}$  sediment fraction can be found in the Particle Size Analysis technical report.

The sample is digested in a mixture of hydrofluoric, hydrochloric and nitric acids using enclosed vessel microwave, the digest is made up in 1% nitric acid and further diluted prior to analysis by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) and Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES). Quantification of Al, As, Cd, Cr, Cu, Fe, Li, Mn, Ni, Pb, Rb and Zn is conducted using external calibration with Indium as internal standard. A certified reference material is run within each sample batch for quality control. Results are reported in  $\text{mg kg}^{-1}$  (ppm dw).

Some samples contained insufficient silt/clay (< 63  $\mu\text{m}$ ) for trace metals determination. Values lower than the detection limits were omitted from the dataset. This is because several detection limits were higher than real values, causing spurious elevations.

### **1.4.2 Numerical assessments**

#### **1.4.2.1 Raw data**

Two approaches were carried out on the raw data:

1. Data comparison between the stations located inside the disposal sites and those that are situated outside the disposal site. The average concentration is obtained over a number of years and sites to allow data comparison. These data are averaged and so might not reflect the true observed trend for individual stations.
2. Temporal trend is also assessed for stations within the disposal sites and outside the disposal site. The average concentration is calculated for each year in order to carry out temporal trend analysis.

#### 1.4.2.2 Enrichment factors

In order to assess relative level of trace metal contamination for a sampled station, enrichment to a baseline is required. This report presents two assessment methods; (i) comparisons with OSPAR Background Assessment Concentrations (BACs) as in previous reports, and (ii) comparisons with regional baseline concentrations.

Metal raw value

Enrichment ratio is defined as: 
$$\frac{\text{Metal raw value}}{\text{OSPAR BAC or proposed baseline value}}$$

Enrichment is arbitrary defined at 4 levels:

0-1: no enrichment

1-2: slight enrichment

2-5: moderate enrichment

>5: high enrichment

The two assessment methods are detailed below (but refer to Cefas (2011) for a fuller explanation).

##### 1.4.2.2.1 OSPAR BACs

OSPAR (BACs) are defined for Clean Seas Environment Monitoring Programme (CSEMP) assessment to determine temporal trends in concentrations (OSPAR, 2008). They are derived from Background Concentrations (BCs) which are based on concentrations recorded in 'pristine' areas.

Normalisation of metal concentrations is required to account for differences caused by different sediment types present in the area surveyed. Normalisation of the metal concentrations to 5% aluminium using a pivot point is completed to derive the OSPAR BACs, using pivot point data defined in the assessment manual for contaminants in sediment and biota (OSPAR, 2008). Aluminium and lithium are both commonly used to normalise metal concentrations. Correlations between all trace metals, at each site, were completed to determine the best normaliser to use.

For most sites, there were no clear correlations between the trace metals and correlations values of aluminium and lithium indicate that the relationship between the normaliser and trace metals was not strong enough to endorse the use of Al or Li for normalisation.

As trace metal concentrations used for in this study were measured on the fine fraction of sediment (< 63 µm), normalisation to some extent has already been completed, therefore all enrichment calculations were based on the raw data.

#### 1.4.2.2.2 Regional baselines

The above-mentioned BCs are based on concentrations recorded in 'pristine' areas. There is only one set of values assigned by OSPAR for the whole North Atlantic (<http://www.ospar.org>). However, trace metal concentrations are known to show regional variation in the UK, largely related to the variable geology around the coast and historical industrial activity in the early 19<sup>th</sup> Century which has caused localised elevated levels (Ridgway *et al*, 2003; Rowlatt and Lovell, 1994; Cefas, 2005). Therefore, for assessing enrichments at disposal sites, Cefas have developed regional baselines utilising various spatial datasets around England and Wales. Recently, an extensive study was carried out on 8 regions defined in the Clean Seas and Environment Programme (CSEMP) (Figure A1.4.1) and the proposed metals baselines concentration derived from this study have additionally been used in this report as a validation tool to i) compare with OSPAR BACs values and ii)

to assess the credibility of using those proposed baselines values instead of the OSPAR BACs values when studying for metals enrichment. The proposed baselines for the areas are given in Table A1.4.1, along with the corresponding OSPAR BACs values for each metal (OSPAR, 2006).

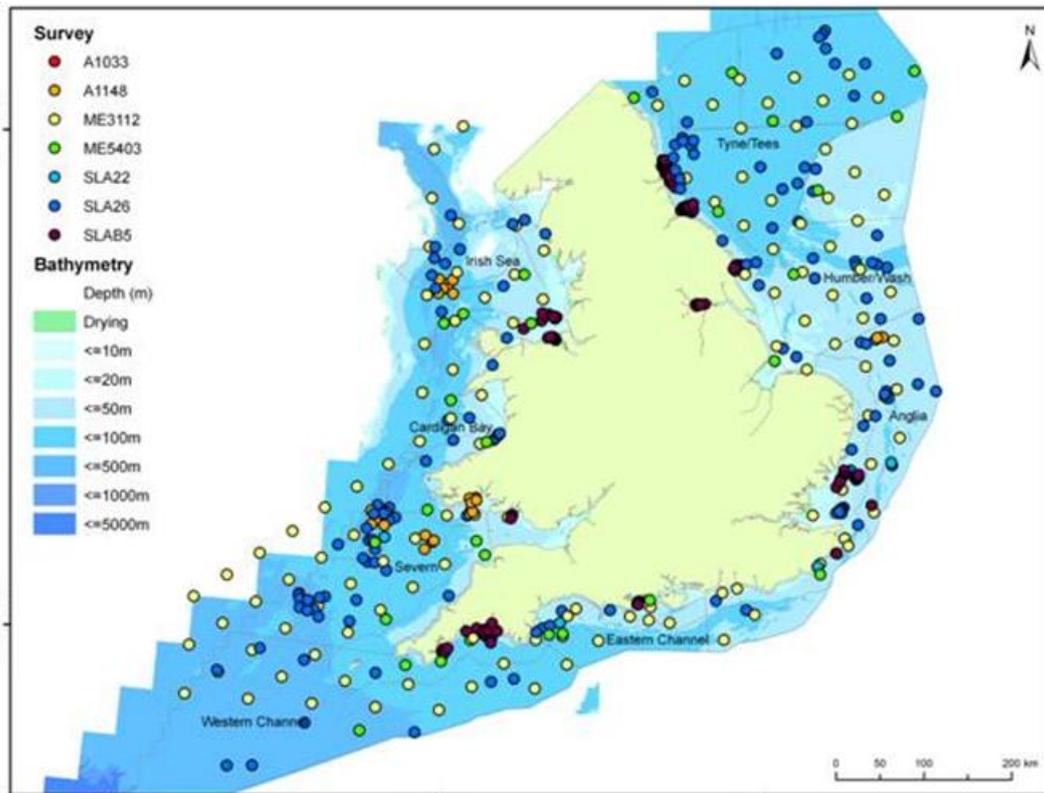


Figure A1.4.1. Location of stations sampled to provide metals data as part of the regional baseline approach.

Table A1.4.1. OSPAR BACs (in red) with proposed baselines for regions covered in disposal site assessment in 2010

	As (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Hg (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Anglia	33	0.2	115	40	0.16	56	46	130
Cardigan Bay	26	0.29	103	26	0.12	44	73	145
Eastern Channel	23	0.18	90	26	0.12	31	45	107
Humber Wash	30	0.17	109	31	0.21	44	67	129
Irish Sea	21	0.29	115	38	0.43	47	77	240
Severn	21	0.2	81	27	0.1	36	47	135
Tyne/Tees	27	0.31	135	29	0.35	55	131	171
West Channel	34	0.19	105	72	0.77	50	108	153
<b>OSPAC BAC</b>	<b>25</b>	<b>0.31</b>	<b>81</b>	<b>27</b>	<b>0.07</b>	<b>36</b>	<b>38</b>	<b>122</b>

## Appendix 2. Results

### 2.1 North Tyne (TY070)

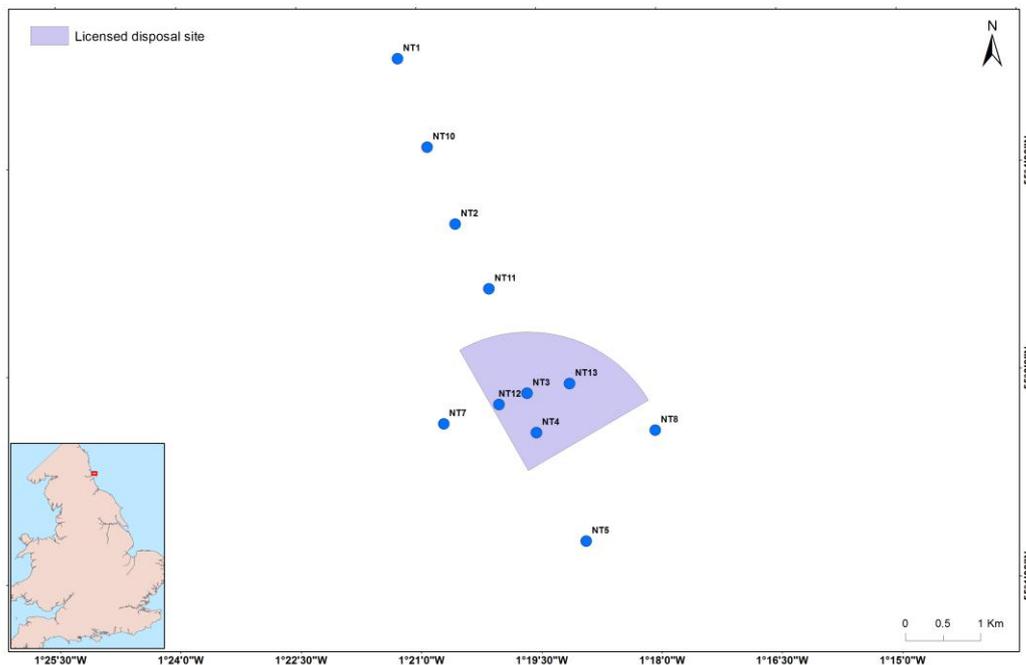


Figure A2.1.1. Locations of monitoring stations at North Tyne disposal site during 2012

#### 2.1.1 Background and issues

Material disposed of to North Tyne is predominantly silt and sand. In the past the site was used for capital and maintenance dredging, rock mine tailings and fly ash from power stations. A substantial amount of capital material from the Tyne navigational channel and arising from the deepening of berths was disposed of to the site in 2012.

The contaminated nature of the dredged material (e.g. trace metals and hydrocarbons) is a result of both the industrial background of the area and of the local geology. Material around action level (AL) 2 for zinc has been disposed of from Walker Technology Park to this disposal site. The historical ship-building industry on the Tyne and the large volume of shipping traffic has contributed to a legacy of TBT contamination. Previous sediment monitoring within and around the North Tyne disposal site has regularly highlighted high concentrations of such contaminants: macrofaunal changes are, however, somewhat localised and temporally predictable.

Monitoring conducted in 2012 paid particular reference to certain contaminant groups, particularly PAHs and organohalogenes, to ensure that their concentration is not increasing beyond the boundaries of the disposal site.

#### **RAT prioritisation assessment: Tier 1**

- Where a significant increase in the quantity of material disposed of has occurred.
- Where there is the potential for the occurrence of elevated contaminant concentrations (between Cefas AL 1 and AL 2 in proposed dredged sediments) arising from historical or current activities at source (especially heavily urbanised/industrialised estuaries).

#### **2.1.2 Parameters monitored**

Sediment particle size distribution

Sediment organic carbon and nitrogen

Sediment contaminants (PAHs, OHs).

#### **2.1.3 Results**

##### 2.1.3.1 Sediment particle size

North Tyne sediments are predominantly muddy sands, with some unimodal sands and some gravels and muds (Table A2.1.1). Sediment groups derived in 2012 are similar to those in 2011 and any differences reflect changes caused by additional stations being sampled in 2012 (note group NoT1 is now muddy sand as opposed to sandy mud and has more members than in 2011, and there are samples with > 21% silt/clay in sediment groups NoT1 (all), NoT2b (4/6), NoT3 (1/12), NoT4 (1/8)).

The temporal changes in sediment groups for stations sampled since 2006 are minimal except within the disposal site at NT4 and to a lesser extent at NT3, as well as south of the site at NT5 (Table A2.1.2). The greater temporal variation in sediment granulometry at stations within the disposal site may reflect changes in the nature of sediments being disposed, or variations caused by the differences in the proximity of samples to recent disposal events as indicated during 2011 (Bolam et al., 2012).

Table A2.1.1 Average sediment descriptions (top) and statistics for each sediment group (below) at North Tyne.

Sediment group	Number of samples	Sample Type	Sediment description
NoT1	8	Bimodal, Very Poorly Sorted	Slightly Gravelly Muddy Sand
NoT2a	10	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand
NoT2b	9	Bimodal, Poorly Sorted	Slightly Gravelly Muddy Sand
NoT3	12	Polymodal, Very Poorly Sorted	Muddy Sandy Gravel
NoT4	8	Unimodal, Poorly Sorted	Gravelly Muddy Sand
NoT5	5	Unimodal, Moderately Sorted	Slightly Gravelly Sand

Sediment group	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)
NoT1	4.99	55.49	39.51	2.93	4.31	10.73	17.54	19.97
NoT2a	3.87	79.11	17.01	2.80	4.60	10.41	31.26	30.05
NoT2b	1.88	76.87	21.25	1.17	3.26	20.03	38.14	14.28
NoT3	35.57	52.34	12.09	11.38	8.34	10.78	12.69	9.15
NoT4	6.30	79.68	14.03	3.03	5.11	26.51	28.81	16.23
NoT5	1.40	93.02	5.58	1.06	4.27	47.90	33.94	5.85

Table A2.1.2 Sediment groups for each sample code between 2006 and 2012 inclusive at North Tyne.

Sample code	Year						
	2006	2007	2008	2009	2010	2011	2012
NT1	NoT2a						
NT2	NoT2a	n	n	NoT3	NoT1	NoT1	NoT1
NT3	NoT2b	NoT5	NoT5	NoT2b	NoT5	NoT2b	NoT4
NT4	NoT1	NoT5	NoT5	NoT2b	NoT1	NoT2b	NoT2b
NT5	NoT3	NoT1	NoT2a	NoT2a	NoT4	NoT4	NoT1
NT6	NoT3	NoT3	NoT3	n	NoT3	n	n
NT7	NoT3	NoT3	n	n	NoT3	n	NoT3
NT8	NoT4	NoT4	NoT4	NoT4	NoT2b	NoT2b	NoT4
NT10	n	n	n	n	n	n	NoT3
NT11	n	n	n	n	n	n	NoT3
NT12	n	n	n	n	n	n	NoT1
NT13	n	n	n	n	n	n	NoT2b

The spatial variation in the proportional representation of gravel, sand and silt/clay for each sampling station in 2012 is shown in Figure A2.1.2. Of the stations within the disposal site NT4, and the newly-sampled station NT12, have the highest silt/clay content (23%). Higher silt/clay contents are, however, reported outside the disposal site at NT5 (45%) immediately

south of the site, and NT11 (42%) immediately north of the site. Both of these sites are on the tidal axis which is expected to be the main sediment transport pathway from the disposal site, so these elevated contents may indicate recent dispersal of silt/clay from the disposal site. Samples from NT6 (extreme south – station abandoned) have previously displayed notable proportions of gravel (Bolam et al., 2009; 2011; 2012), thus it is likely that gravel is responsible for the lack of successful grab operation in 2012.

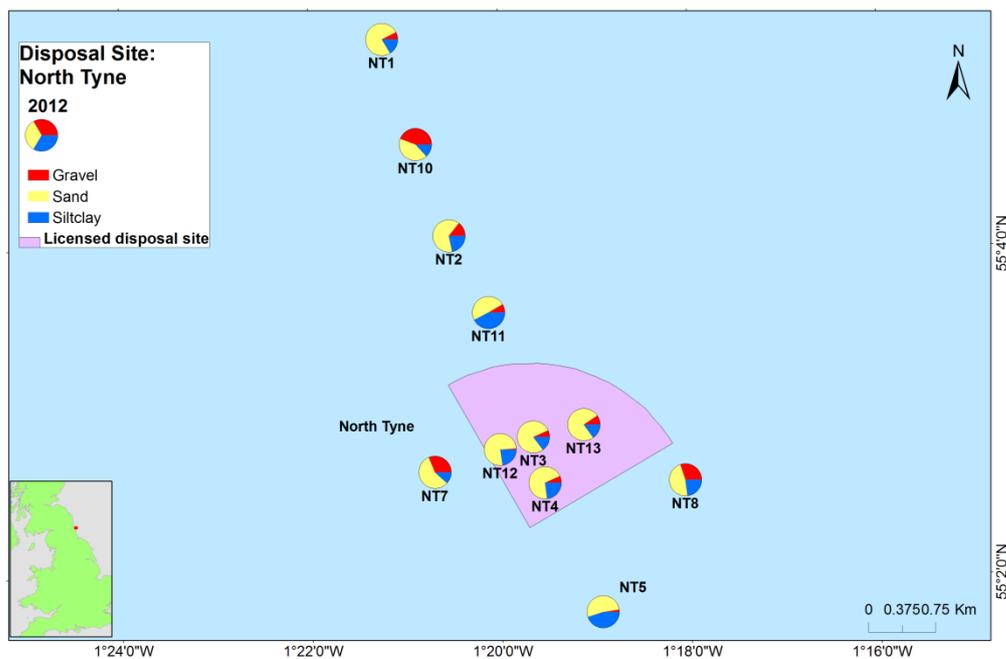


Figure A2.1.2 Pie charts of gravel, sand and silt/clay at North Tyne in 2012.

Silt/clay content of a subset of sediments sampled at North Tyne as part of the disposal licence application was 61% ( $\pm 10\%$ ). The present monitoring data indicate that the sediments at the receiving environment contain much lower silt/clay fractions than source sediments which supports the notion that silt/clay is dispersing away from the site.

#### 2.1.3.2 Sediment organic carbon & nitrogen

Organic carbon values (in the < 2 mm sediment fraction) ranged from 2.7 to 5.5 % and 0.1 to 0.2 % for nitrogen. These are similar to those observed between 2006 and 2011 (Bolam et al., 2009, 2011). Figure A2.1.3 indicates that the higher organic carbon contents were found at stations west and south of the disposal site (i.e. at NT5 and NT7).

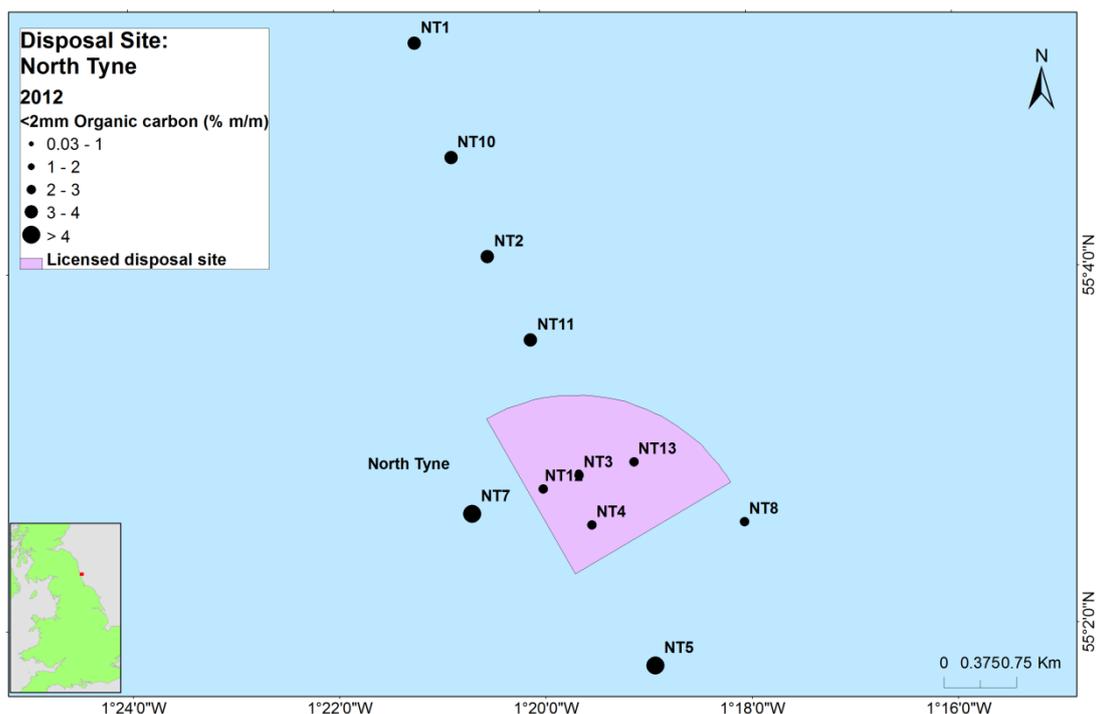


Figure A2.1.3. Organic carbon (%) in the < 2 mm fraction at North Tyne in 2012.

### 2.1.3.3 Sediment contaminants

#### 2.1.3.3.1 PAHs

The highest summed PAH concentration ( $\Sigma$ PAH) observed at North Tyne during 2012 was 64,100  $\mu\text{g kg}^{-1}$  dw found at NT7 just off the western edge of the disposal site (Figure A2.1.4). This station was not sampled in 2011 but displayed a concentration of 47,000  $\mu\text{g kg}^{-1}$  during 2010. This is similar to concentration found at NT4 in 2010 (45,200  $\mu\text{g kg}^{-1}$ ). The second highest concentration found during the 2012 survey was at NT5 (49,600  $\mu\text{g kg}^{-1}$ ): this station exhibited a concentration of 45,100  $\mu\text{g kg}^{-1}$  in 2011 and the highest concentration at North Tyne in the 2010 survey (92,500  $\mu\text{g kg}^{-1}$ ).

The lowest summed PAH concentration in 2012 was 11,000  $\mu\text{g kg}^{-1}$  dw at NT10, approximately 3km NNW of the disposal site (Figure A2.1.4). This sampling site has not been surveyed in previous years' monitoring, but the result is consistent with lower concentrations being found to the north of the disposal site in previous years.

Stations NT10-NT13 were added to the 2012 survey to provide data regarding the spatial variation of PAHs found in the disposal site. PAH concentration found at NT13 was very similar to that at NT3, NT12 to NT4 and NT11 to NT2.

All sediment samples at North Tyne collected in 2012 exceeded the ERL for low molecular weight (LMW) PAHs. Sediments from all stations except NT2, NT8, NT10 and NT11 exceeded the ERM for the LMW PAHs; these four stations are located outside the disposal site. All stations sampled, except NT8, NT10, NT11, NT12 and NT13, exceeded the ERL for the high molecular weight (HMW) PAHs, but no samples exceeded the ERM for HMW PAHs. Evaluation of the PAH data indicated that the source in all the sediment samples was predominantly petrogenic, generally with > 80% of the PAH content arising from oil rather than combustion sources.

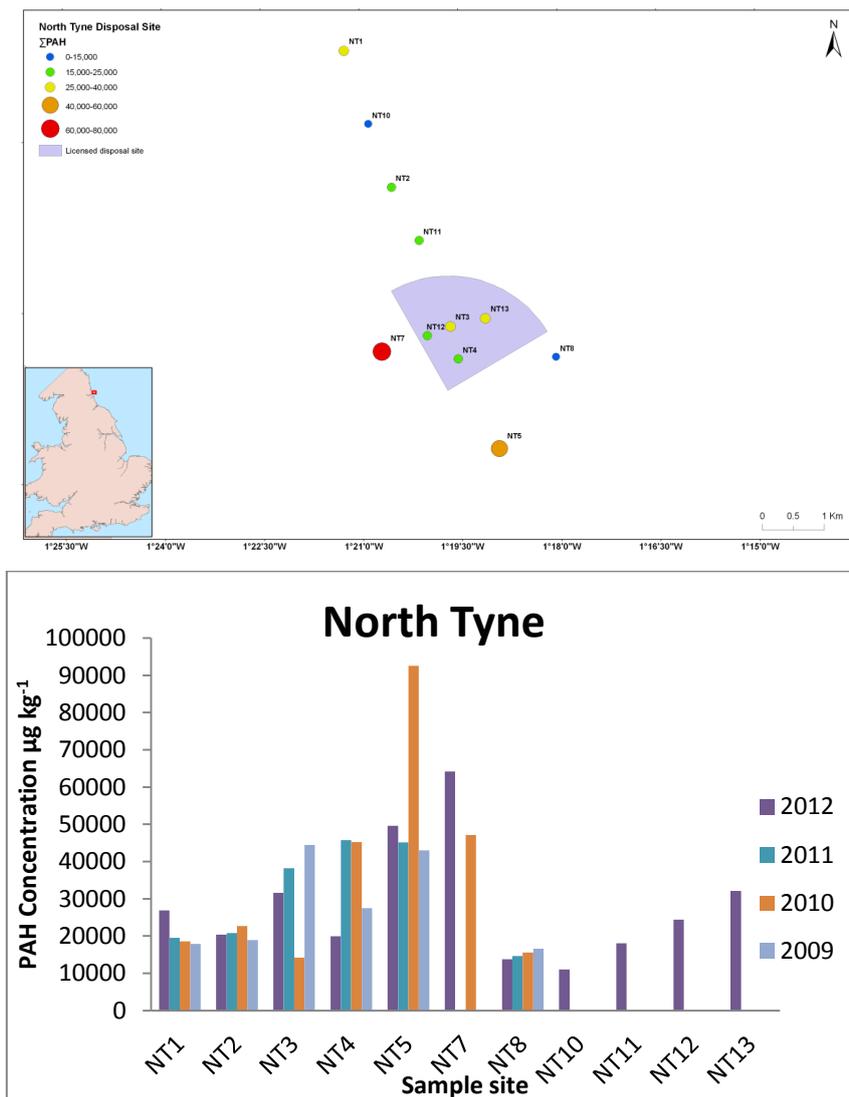


Figure A2.1.4. Summed PAH concentrations ( $\mu\text{g kg}^{-1} \text{dw}$ ) for stations sampled in 2012 at North Tyne (top) and concentrations observed during 2009 to 2012 (bottom).

### 2.1.3.3.2 Organohalogenes

At North Tyne, chlorobiphenyls (CBs) were detected at all stations ( $\Sigma$ ICES7 CBs range 1.1-17  $\mu\text{g kg}^{-1}$  dw). Concentrations of CBs were lowest to the north and east of the disposal site (Figure A2.1.5). The highest CB concentration was found at NT12 within the disposal site ( $\Sigma$ ICES7 CBs 17  $\mu\text{g kg}^{-1}$  dw) with the third highest concentrations also found within the site at NT3 ( $\Sigma$ ICES7 CBs 3.4  $\mu\text{g kg}^{-1}$  dw). The second highest concentration was found at NT5 ( $\Sigma$ ICES7 CBs 3.9  $\mu\text{g kg}^{-1}$  dw) to the south of the disposal site.

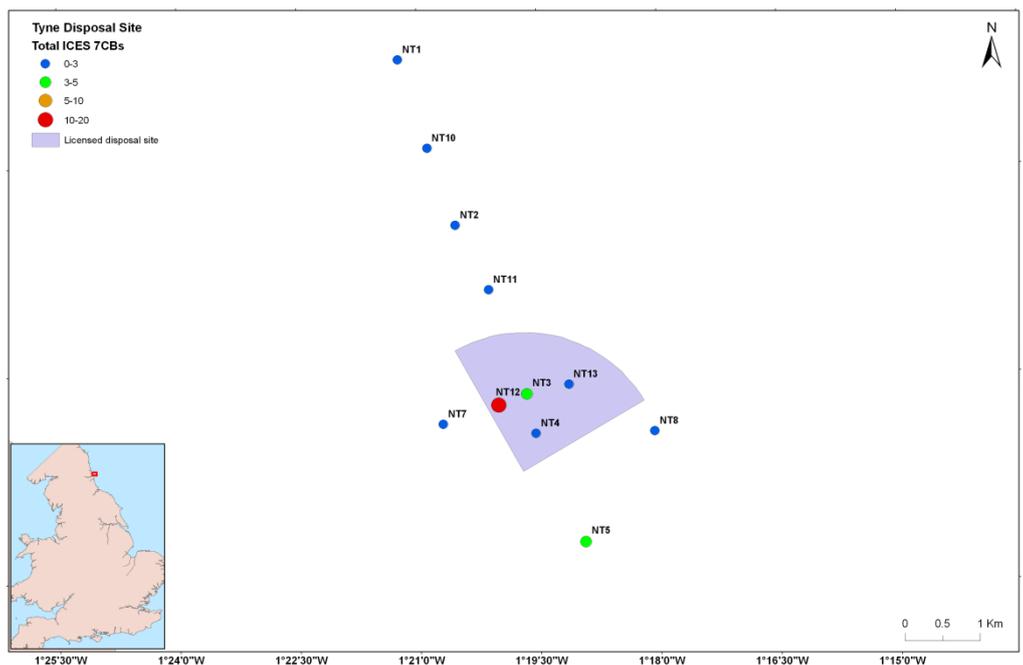


Figure A2.1.5.  $\Sigma$  ICES7 CB concentrations for the North Tyne Stations, 2012.

Brominated diphenyl ethers (BDEs) were detected at all stations ( $\Sigma$ 11 BDEs range 3.67-4.0  $\mu\text{g kg}^{-1}$  dw) (Figure A2.1.6). In contrast to polychlorinated biphenyls (PCBs), concentrations of BDEs were lowest inside the disposal site, with the highest value at NT8 to the east of the disposal site. BDE47 and BDE99 are the dominant congeners present, indicative of the pentaBDE technical mixture, but BDE183 was also detected in all samples, suggesting that the octaBDE or decaBDE technical mixture was also in use. Penta and octa PBDE technical mixtures are no longer in use, having been banned in the EU since 2004.

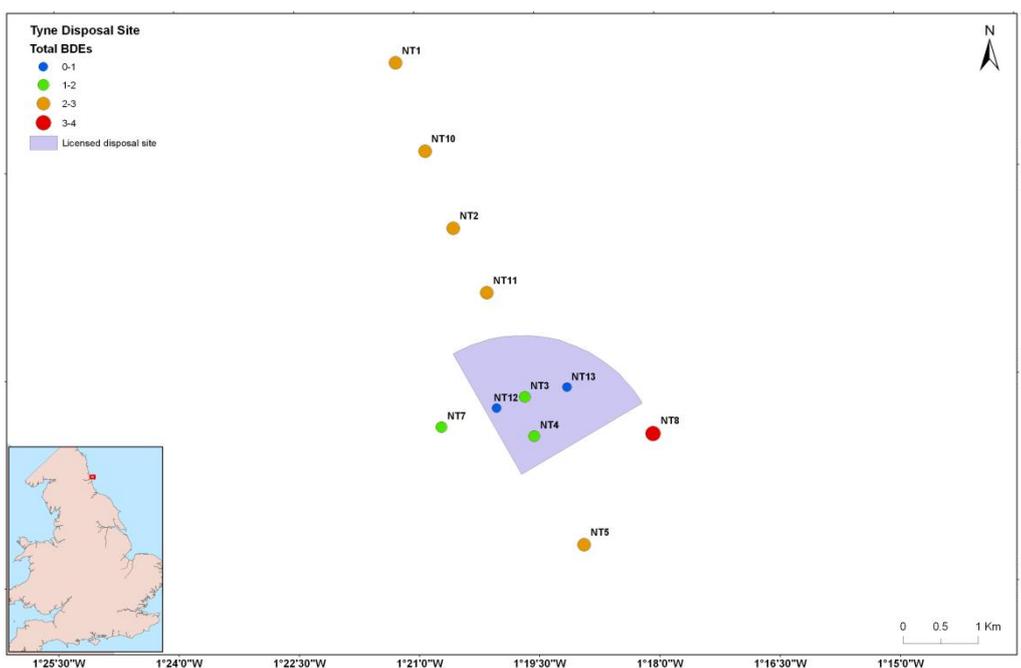


Figure A2.1.6.  $\Sigma$  11 BDEs concentrations for the North Tyne Stations, 2012.

BDE209 was detected at all stations and was at higher concentrations than the other measured organohalogens (range 4.9-273  $\mu\text{g kg}^{-1}$  dw). When included with the other BDEs, BDE209 made up > 80% of the BDEs present (range 55-99%), with the exceptions being at NT1 and NT8. BDE209 is indicative of the decaBDE technical mixture, which had been in use more recently than the other technical mixtures, although its use has been restricted in the EU since 2008. The highest concentration of 273  $\mu\text{g kg}^{-1}$  dw was detected at NT5 to the south of the disposal site, where the highest CB results were also found (Figure A2.1.7). The next three highest concentrations of 45, 38 and 35  $\mu\text{g kg}^{-1}$  dw were found at NT13, NT4 and NT3 respectively (all within the disposal site). Other stations showed low CB concentrations (< 17  $\mu\text{g kg}^{-1}$  dw).

Concentrations of CBs at all stations were mostly below Cefas action levels. The exception was NT12 which was above action level 1 for CBs. No Cefas action levels have been set for BDEs, including BDE209. According to the OSPAR guidelines, many stations had 'good' environmental status for all ICES 7 CBs and 'good' status overall. NT3, NT5, NT7 and NT10 had 'bad' environmental status for CB118 but 'good' status overall. NT12 had 'bad' environmental status for CB52, CB118 and CB101, and therefore 'bad' status overall. No OSPAR guidelines exist for BDEs currently.

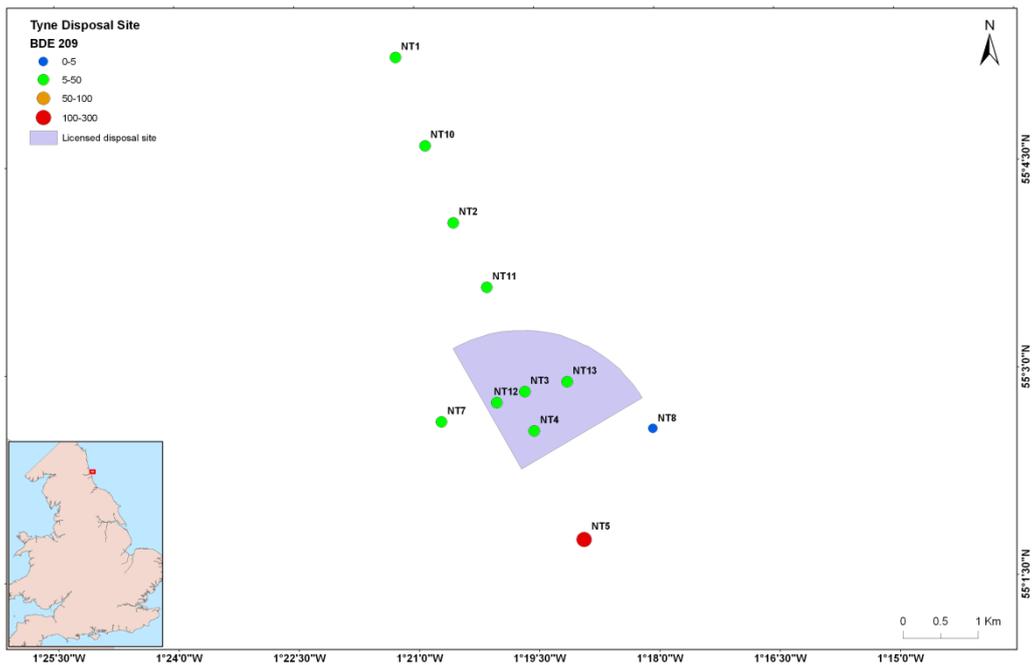


Figure A2.1.7. BDE209 concentrations for the North Tyne Stations, 2011.

There are data available to assess temporal trends of contaminants from 2006 to 2012 (see Table A2.1.3). For CBs, there are no clear trends overall, with some stations showing increases and other showing decreases. Levels of CBs at stations NT1, NT2 and NT8 are very similar to previous years, and levels at NT4 have halved since the last measurements were made, repeating the trend of the previous year. However, levels at NT2 and NT7 in 2012 are the highest they have been since sampling began in 2006.  $\Sigma$ 11 BDEs have increased slightly since 2011 for all stations except NT4, which showed a big decrease in 2012 (Table A2.1.4). BDE209 decreased at most stations, except for NT3 where it doubled and NT5 where it increased by more than a factor of 20 (Table A2.1.5).

Table A2.1.3 Temporal trends (2006-2012) of  $\Sigma$ ICES 7 CBs concentration (in  $\mu\text{g}/\text{kg dw}$ ) at North Tyne in the stations sampled during 2012.

Station code	$\Sigma$ ICES 7 CBs concentration (in $\mu\text{g}/\text{kg dw}$ )						
	2006	2007	2008	2009	2010	2011	2012
NT1	1.54	0.97	2.11	0.93	0.98	1.13	1.37
NT10							2.63
NT2				1.69	1.63	2.66	2.67
NT11							2.89
NT12							17.0
NT3	1.48	2.03	1.79	4.12	1.63	11.9	3.39
NT4	7.21		0.7	4.58	11.0	5.84	2.63
NT13							1.61
NT8	5.21	2.03	0.81	0.7	1.12	1.10	1.13
NT5	2.7	7.59	6.05	3.24	11.9	2.72	3.88
NT6	2.44	2.54	3.88		2.09		
NT7		1.55			1.76		2.24

Note, concentrations in italic represent estimates of concentrations for samples where all ICES 7 congener concentrations were below LODs.

Table A2.1.4. Temporal trends (2006-2012) of  $\Sigma$ 11 BDEs concentration (in  $\mu\text{g}/\text{kg dw}$ ) at North Tyne in the stations sampled during 2012.

Station code	$\Sigma$ 11 BDEs concentration (in $\mu\text{g}/\text{kg dw}$ )						
	2006	2007	2008	2009	2010	2011	2012
NT1	1.56	1.68	1.27	0.95	0.93	1.92	2.45
NT10							2.61
NT2	5.28			1.27	1.84	2.12	2.30
NT11							2.99
NT12							0.67
NT3	1.72	1.54	0.49	2.55	0.52	1.84	1.60
NT4	13.2		0.28	1.27	4.18	7.10	1.48
NT13							0.92
NT8	1.86	2.84	1.42	0.74	1.65	1.40	3.98
NT5	2.18	4.49	0.96	5.89	1.31	2.10	2.45
NT6	7.69	4.12	1.18		1.34		
NT7		1.77			0.84		1.98

Note, limits of detection for BDEs improved between 2007 and 2008 and therefore values assigned to congeners below LOD are lower from 2008 onwards, resulting in a step decrease in  $\Sigma$ 11 BDEs concentration for samples with congeners below LODs

Table A2.1.5. Temporal trends (2008-2012) of BDE209 concentration (in  $\mu\text{g}/\text{kg dw}$ ) at North Tyne in the stations sampled during 2012.

Station	BDE209 concentration (in $\mu\text{g}/\text{kg dw}$ )				
	2008	2009	2010	2011	2012
NT1	104.2	11.46	3.93	7.33	5.56
NT10					16.5
NT2		12.23	12.2	42.9	11.9
NT11					12.5
NT12					7.7
NT3	2.72	48.54	7.91	21.6	35.4
NT4	0.78	36.11	95.5	108	38.1
NT13					45.3
NT5	6.21	11.94	6.64	10.6	273
NT6	6.15		8.69		
NT7			17.5		8.46
NT8	8.03	8.95	20.1	7.21	4.91

## 2.2 Souter Point (TY081)

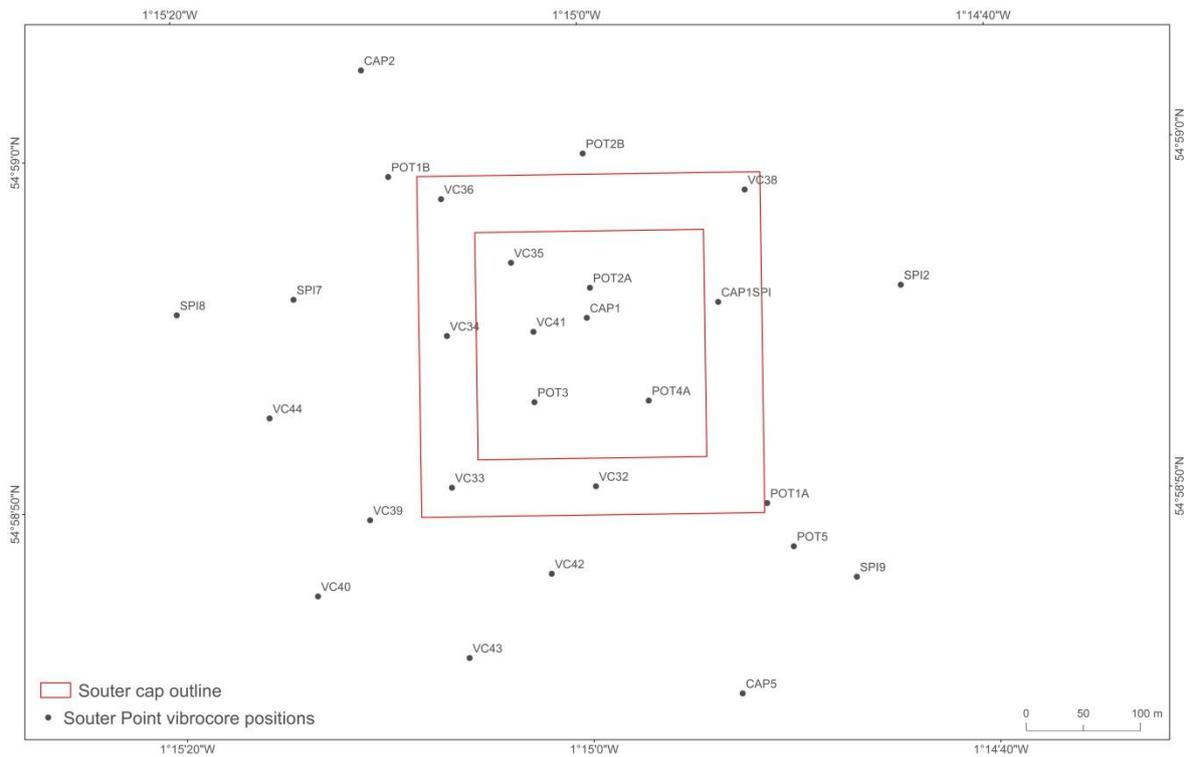


Figure A2.2.1. Location of the 27 vibrocore sampling stations at Souter Point, 2012, in relation to the 2004/5 placement area of CDM (inner box) and capping sediments (outer box).

### 2.2.1 Background

The sediments within the vicinity of Souter Point disposal site are muddy sands. However, these may vary to a large extent from this following dredged material disposal and in response to its earlier history of solid industrial wastes or other (unregulated) discharges inshore. The disposal site is located at a depth of approx. 40m, but this shallows by up to 5 m at the inshore end due to historical accumulations of minestone and fly-ash concretions. Tidal currents in the vicinity of the disposal site are moderate in strength and run generally parallel with the coastline, with a net residual drift southwards, at least in surface waters.

In December 2004 - April 2005 a trial level bottom-capping project was undertaken within the centre of the disposal site. The Port of Tyne disposed 60,000 m<sup>3</sup> of contaminated dredged material (CDM), which was to be covered with 100,000 m<sup>3</sup> of silt and around 60,000 m<sup>3</sup> of sand. On placement of the silt, around 80% was siphoned off to leave a 1.5m cap: 90,000 m<sup>3</sup> of sand was then later placed on top. Further material was deposited in 2006 and 2007 in an attempt to ensure isolation of the CDM. During this time the maintenance dredged material from the Tyne was disposed of to the North Tyne (TY070) disposal site.

Following the trial capping project undertaken at this site, there have been ongoing concerns regarding the integrity of the cap, specifically related to cap thickness. Previous monitoring of this site under the auspices of SLAB5 has included a number of techniques to determine the temporal changes in bathymetry (acoustics approaches) to assess areas of sediment/cap erosion, together with Nioz core sampling to allow acquisition of samples of the top 30 cm for sediment contaminant determinations. Sediment Profiling Imagery (SPI) techniques have also been used to allow *in situ* visual descriptions of the sediment profiles and the presence of faunal activity (burrows, tubes, cavities). However, although the Nioz core approach has allowed the determination of the physical and chemical profile of the sediments, the possibility that the core has not been penetrating the cap (and thus allowing samples of CDM to be analysed) has always been a possibility.

In 2012, therefore, monitoring at Souter under SLAB5 adopted the use of a vibrocorer to allow a deeper penetration of the sediments and the acquisition of intact sediment cores for subsequent slicing of the various sediment strata. This sampling device penetrates much deeper into the sediment matrix (up to 2 m) than the Nioz corer (approx 30 cm) and thus allows full acquisition of sediment both above, through and below the CDM. An acoustic survey, analogous to that previously undertaken, was also conducted to allow an improved time-series of bathymetric data from which to assess sediment erosion/deposition.

#### **RAT prioritisation assessment: Tier 1**

- where there is the potential for the occurrence of elevated contaminant concentrations (between Cefas action levels of 1 and 2 in proposed dredge sediments) (Appendix 1) arising from historical or current activities at source (especially heavily urbanised/industrialised estuaries).
- that have been observed or pose an increased risk to the surrounding area and receptors.
- identified as 'sites of local concern' by public, pressure groups, NGOs etc.

#### **2.2.2 Parameters monitored**

Sidescan sonar (SSS) and multibeam (MB)

\*Sediment particle size distribution

\*Sediment organic carbon and nitrogen

\*Sediment contaminants (TBT, PAHs, organohalogens, trace metals).

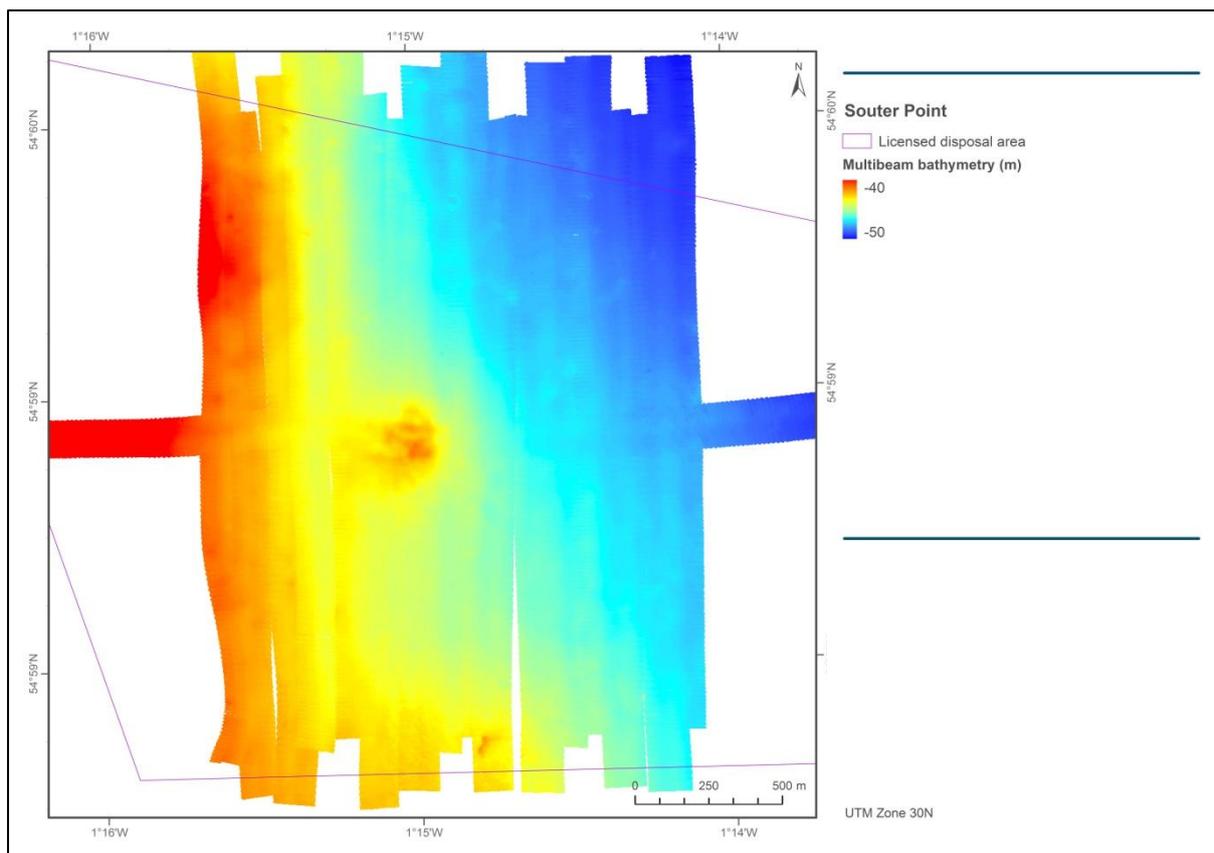
\*Samples to be processed represent sediment slices at various vertical depths as opposed to surficial sediments acquired by grabbing/coring techniques. These are aimed to determine cap thickness as opposed to spatial variability of surficial contaminants as undertaken in previous years (and at other disposal sites).

## 2.2.3 Results

### **2.2.3.1 Multibeam echosounding (to determine suitable areas for vibrocoreing)**

A geophysical acoustic survey was conducted in May 2012 at Souter Point dredged disposal site with the primary aim of acquiring multibeam and sidescan sonar data to enable the safe collection of vibrocore samples at the site in November 2012. Areas identified as coarse sediment were to be excluded for possible vibrocore sampling. The multibeam data were collected using a Kongsberg EM2040 multibeam echosounder onboard the *Cefas Endeavour* between 10-11<sup>th</sup> May 2012. The sidescan sonar data were acquired using an Edgetech 4200. Bathymetry data were processed employing CARIS HIPS and SIPS 7.1 SP2 and backscatter mosaics were produced using QPS Fledermaus Geocoder Toolkit (FMGT) software.

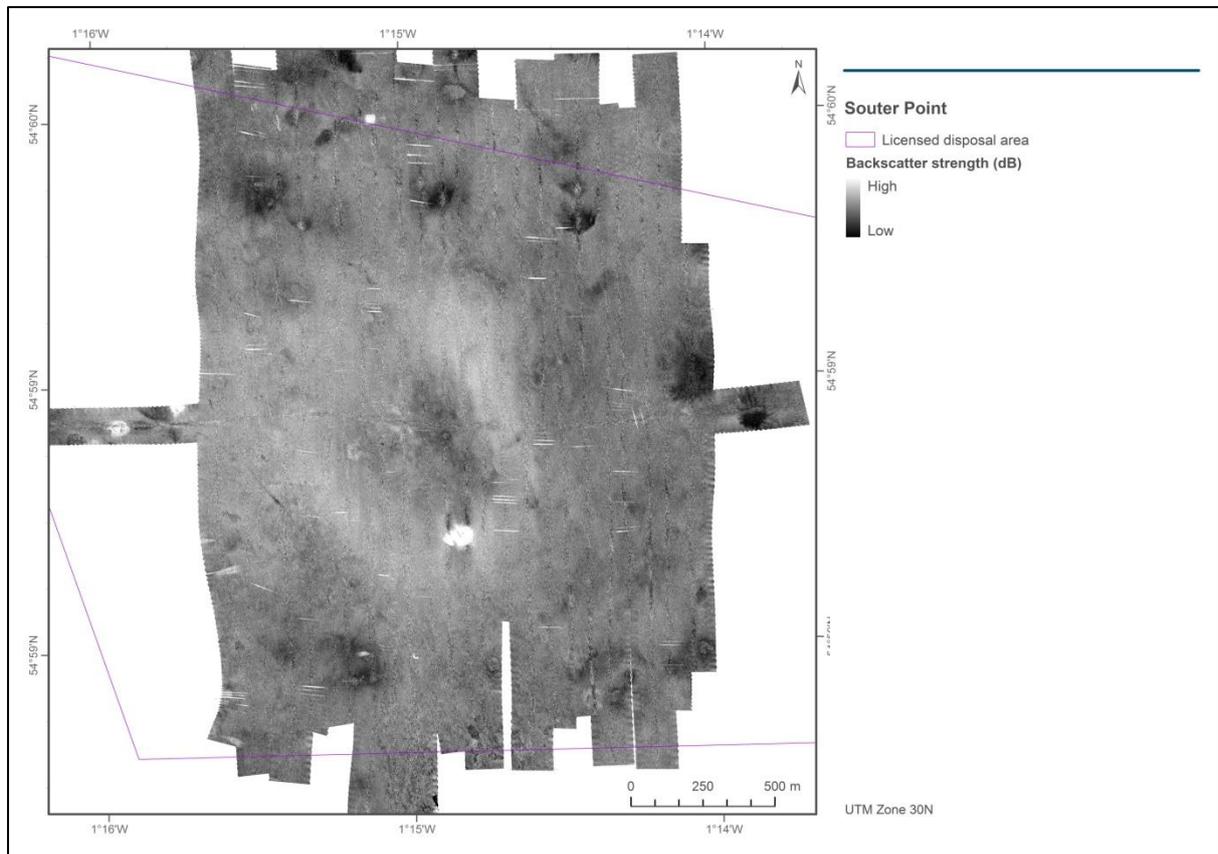
The data acquired indicated that the seabed at Souter Point disposal site has an average water depth of around 40 m (below Chart Datum). The multibeam bathymetry (Figure A2.2.2) revealed that the seabed to the west of the site is slightly shallower, with depths averaging 37 m in the north western edge. To the north east, the site deepens, reaching 51 m within the acoustic data collected.



*Figure A2.2.2. Souter Point seabed bathymetry from the May 2012 multibeam survey. The capping area (centre) can be distinguished as an area of raised seabed from non-capped sediments.*

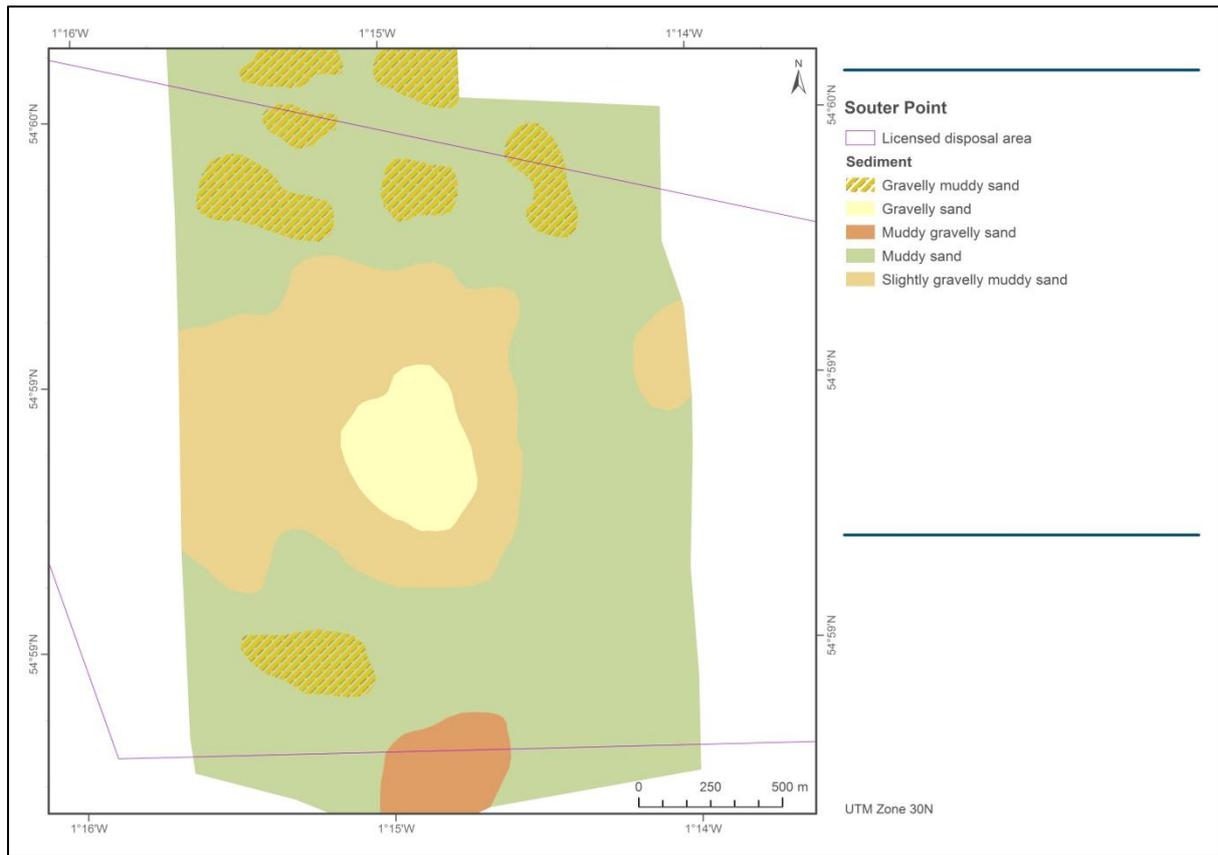
The majority of the disposal site has a medium backscatter return indicating a seabed with a homogeneous nature (Figure A2.2.3). The seabed has several patchy areas located near to the edge

of the acoustic coverage with a low backscatter signature, these sediment patches are likely to be associated with dredge material. The centre of the site also has a slightly lower return but, surrounding that, the backscatter intensity increases, suggesting a distinct sediment change.



*Figure A2.2.3. Multibeam backscatter collected in May 2012 at Souter Point. The purple line delineates the boundary of the dredged material disposal area.*

By utilising the acoustic and ground truthing data it was possible to attribute sediment type to the disposal site. Multibeam backscatter data were assessed and areas with distinct intensity return were delineated and characterised. Figure A2.2.4 illustrates the interpreted sediment map. The cap itself is centrally located within the disposal site and the surface consists of gravelly sand: the sediments surrounding it are also largely comprised of muddy sands. To the south of the acoustic coverage lies a patch of muddy gravelly sand where a sand ripple feature is clearly identified.



*Figure A2.2.4. Interpretation of the Souter Point 2012 survey*

As part of the May survey, areas were additionally targeted for ground-truthing by underwater video. Three camera tows took place and included the acquisition of video and photographic data. Figures A2.2.5, A2.2.6 and A2.2.7 present the sidescan sonar data with point location for the underwater stills. The areas chosen for underwater video were targeted due to their distinct signature on the sidescan sonar imagery. The still photographs correspond with the interpreted multibeam layers as patches of coarser sediment. The coarse pebbly sediment observed is probably linked to disposal activity in the area due to its dissimilarity to the surrounding sediments.

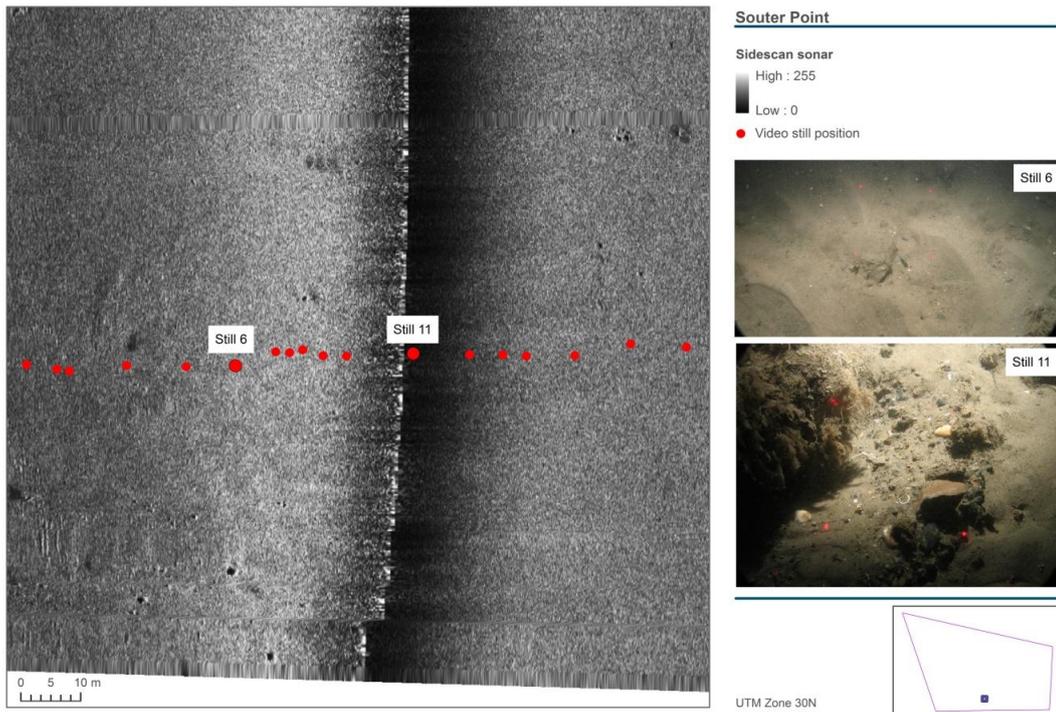


Figure A2.2.5. Sidescan sonar data overlaid with video still positions from the south of the site, with corresponding still imagery. The location of the data source relative to the disposal site boundary is displayed to the bottom right.

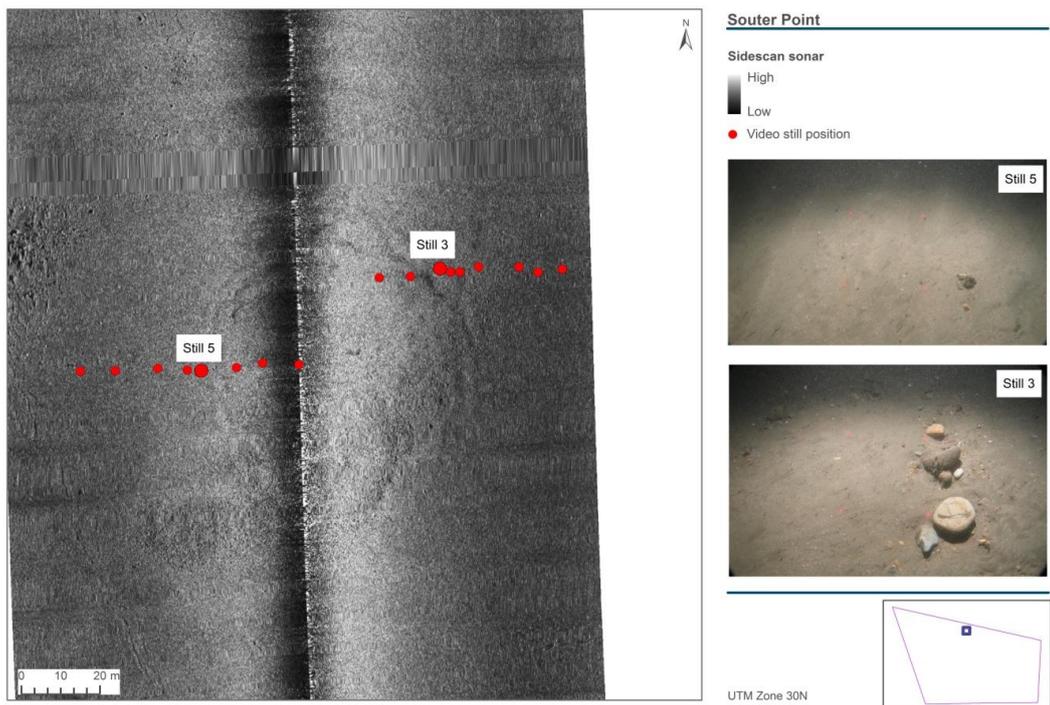


Figure A2.2.6. Sidescan sonar data overlaid with video still positions from the north of the site, with corresponding still imagery. The location of the data source relative to the disposal site boundary is displayed to the bottom right.

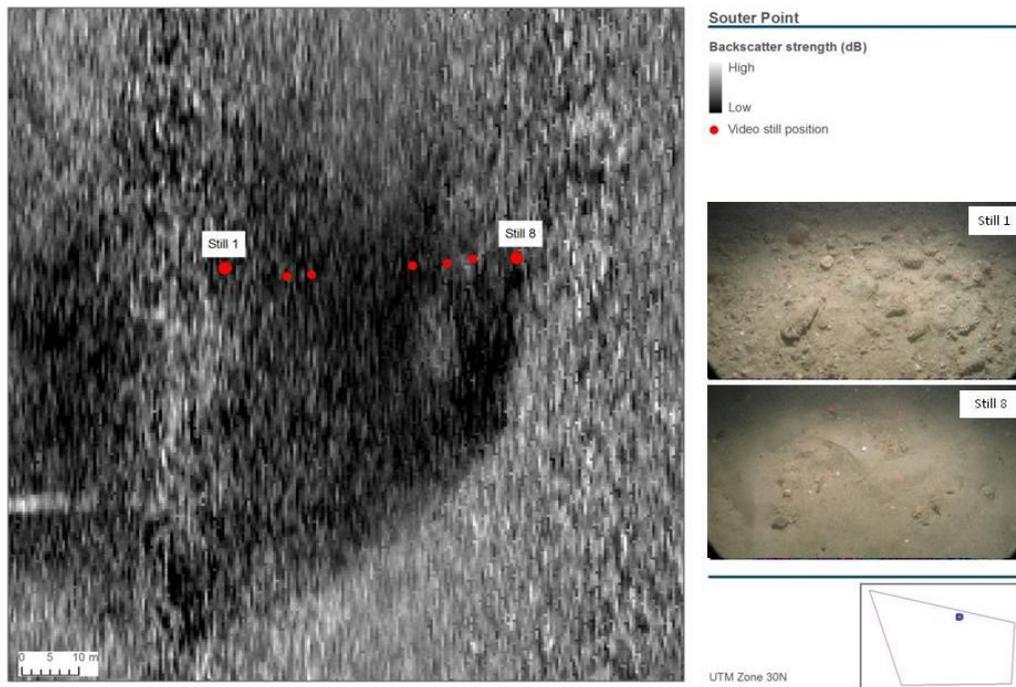


Figure A2.2.7. Multibeam backscatter overlaid with video still positions from the north of the site, with corresponding still imagery. The location of the data source relative to the disposal site boundary is displayed to the bottom right.

### **2.2.3.2 Temporal changes in bed profile**

Multibeam bathymetry data collected in 2005 and 2012 were analysed to enable the creation of a difference plot in metres over the seven years. The placement of the trial cap was completed in April 2005 and the 2005 acoustic data collected in June. The results suggest an increase in material on the cap area itself (Figure A2.2.8). There are no obvious changes to the cap thickness and extent identified, although the variable shading on the plot within the capping area implies some variability in relative bathymetric changes over time.

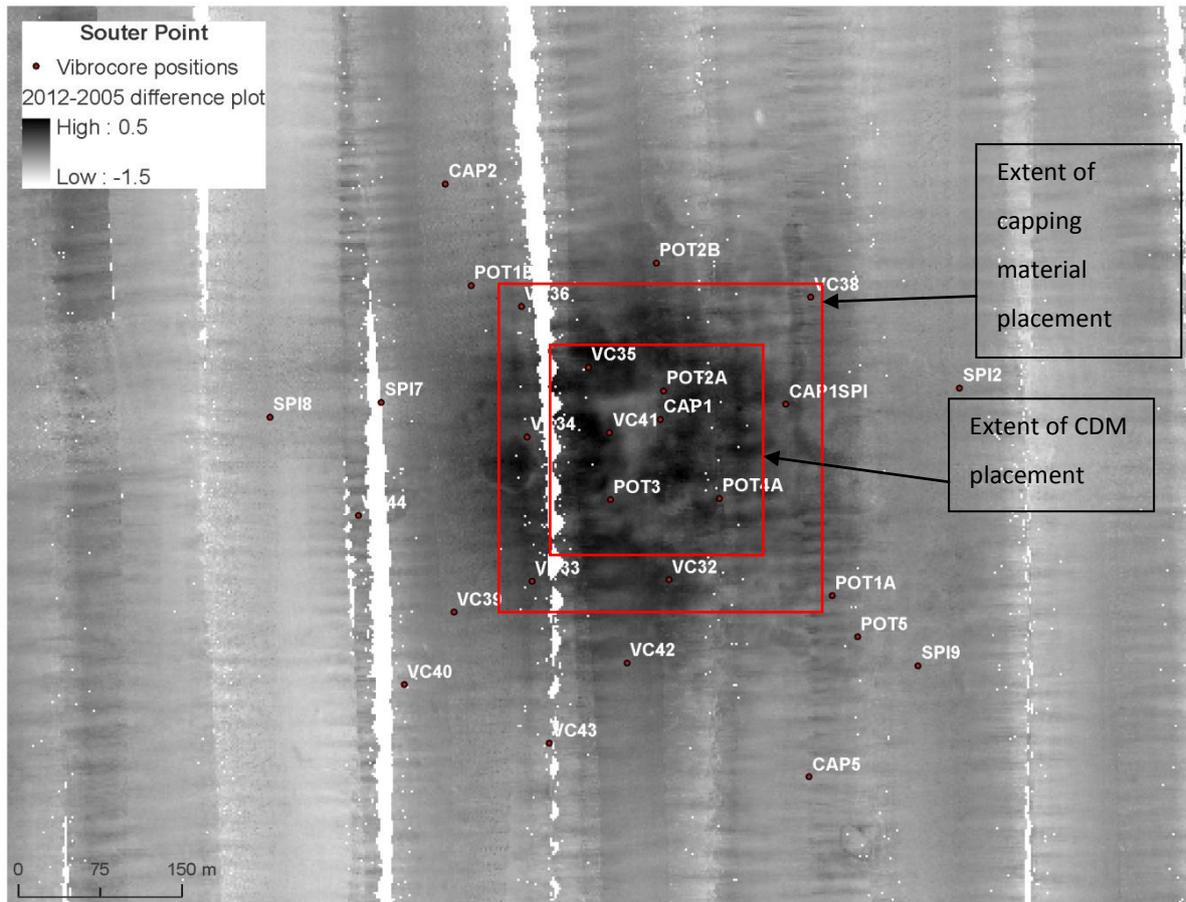


Figure A2.2.8. Difference plot showing the 2005 multibeam survey subtracted from the 2012 survey. The scale on the figure represents the removal of sediments from the 2012 to that of the 2005, therefore producing a minus output.

### **2.2.3.3 Vibrocore survey**

In November 2012, 27 vibrocores were collected at Souter Point (Figure A2.2.1) with the primary aim of ascertaining the depth of CDM below the current seabed surface. The stations were positioned to provide a good spatial cover of the area of CDM placement, cap placement and areas outwith the cap. All 27 stations were successfully sampled with the vibrocorer, although cores varied in the depth of sediment penetrated. Most cores collected vertical sediment profiles greater than 1m, with five penetrating deeper than 2m, whilst five cores collected less than 1m sediment depth (Figure A2.2.9). Following initial vertical slicing of the collected cores into 0.5m vertical sections, cores were visually assessed, photographed, and a summary log produced. Each core section was then sliced in half to expose the different sediment layers with depth of core. The sediment cores exhibited distinctive physical layers (colour, sediment type) enabling subsamples to be taken according to sedimentological and visual characteristics of the core rather based on set depths. These 'slices' (> 200 in total from the 27 cores) formed the basis for the samples for all the subsequent analyses. Following logging of their characteristics and depths, the slices were placed into glass jars and frozen for contaminant analysis. Core schematics were produced for each core showing the different layers (Figure A2.2.9).

The sediment types present in each of the cores were divided (based on visual characteristics) into (Figure A2.2.9):

- 'surface layers' (muddy sands, gravelly muddy sands);
- 'possible capping sediment' (clean sands and some brown muds);
- 'CDM' (black, amorphous mud with petrochemical smell);
- 'potential CDM' (black/dark brown muds/ sandy muds/muddy sands, generally thinner layers, closer to the surface);
- 'precapping layers' (brown, gravelly (shelly) muddy sands similar to sediment seen in earlier years at reference site TC4/TC3; and
- 'clay'

The primary aim of this study was to identify CDM and, thus, the chemical analysis was undertaken to provide data to allow us to assess which slices represented CDM and which ones depicted non-CDM material. As indicated in Table A2.2.1, source concentrations measured on dredged sediment prior to placement possessed high concentrations of TBT, Cd and Zn as well as PAHs; these contaminants were therefore considered most suitable for determining CDM from non-CDM sediments.

A total of 70 slices (pink and red layers in Figure A2.2.9) were analysed for metals using total HF < 63 µm (monitoring method used to compare with background/regional concentrations), TBT/DBT, PSA and TOC<63µm. The 70 slices also included all slices (regardless of sediment type depicted by visual appearance) from CAP 1 to help validate the relationship between the visual and chemical characteristics. Finally, slices immediately above CDM sediments were analysed to determine if any leeching from the CDM layer upwards had occurred. More detailed contaminant analysis was completed on 12 of the 70 slices (the red layers in Figure 2.2.9) and subsequently on an additional four slices after initial analyses of the 70 were completed which included metals by partial digestion of whole sediment (source metals analysis method linking to licensing action levels), PAHs, PCBs, and BDEs to increase confidence in CDM determination. Additionally, 45 samples were analysed for PSA (some surface samples, some possibly capping material) to increase confidence in field visual assessments as well as to assist ground truthing interpretation for the multibeam survey (see Section 2.2.3.1).

2.7m

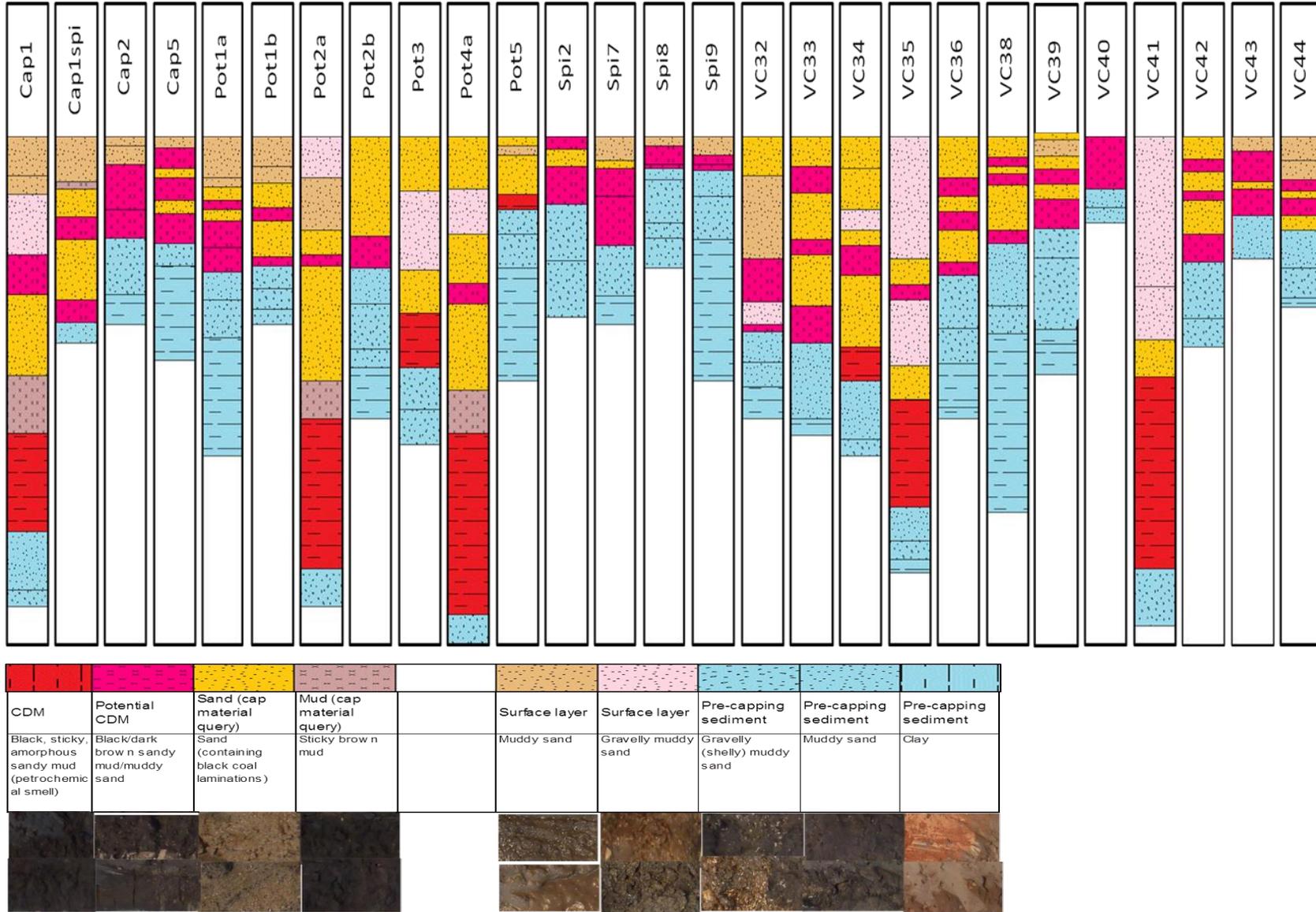


Figure A2.2.9. Core schematics showing the different sediment layers identified and subsampled.

Table A2.2.1. Characteristics of CDM based on source data prior to deposition under cap, with Action Level (AL) concentrations.

Parameter	CDM	AL 1 (mg kg <sup>-1</sup> )	AL 2 (mg kg <sup>-1</sup> )
Cd	>AL2	0.4	2
Cr	>AL1	40	400
Cu	>AL1	40	400
Hg	>AL1	0.3	3
Ni	>AL1	20	200
Pb	>AL1	50	500
Zn	>AL2	130	800
TBT	>AL2	0.1	1
PCBs	>AL1	0.02	0.2
		ERL	ERM
PAHs -LMW (*)	>ERM	0.552	3.16
PAHs -HMW (*)	>ERM	1.7	9.6
Sediment type	Silt/clay >83 +/- 5 %	-	-

For PAHs action level 2 has not been defined so ERL (Effects Range Low) and ERM (Effects Range Median) are used in assessments. TBT and concentrations are significantly higher than AL2 (3 X AL2) and are presented in bold font. LMW PAHS concentrations are 3 X ERM and are also presented in bold font.

### 2.3.3.4 CDM and potential CDM slices

#### Sediment characterisation

The full resolution particle size distribution (PSD) data (at 0.5  $\phi$  intervals) were grouped using Entropy, a non-hierarchical clustering method that groups sediments based on their full distribution. EntropyMax is a Windows-based software that groups large matrices of PSD data sets into a finite number of groups as described by Stewart et al. (2009). Four groups were assigned (group 4 being subdivided into a and b). Sediment slices identified as CDM or potentially CDM are mostly in group 1. Sediment statistics and descriptions using Gravistat (Blott and Pye, 2001) are produced for each group in Table A2.2.2.

Table A2.2.2. Sediment statistics and descriptions for each sediment group.

Group	Number of samples	Sample type	Textural group					
1a	31	Unimodal, Very Poorly Sorted	Slightly Gravelly Sandy Mud					
2a	23	Trimodal, Very Poorly Sorted	Slightly Gravelly Muddy Sand					
3a	11	Polymodal, Very Poorly Sorted	Gravelly Muddy Sand					
4a	31	Unimodal, Poorly Sorted	Slightly Gravelly Sand					
4b	19	Unimodal, Poorly Sorted	Gravelly Sand					

Group	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)
1a	0.58	32.91	66.51	0.56	2.88	8.01	10.18	11.28
2a	1.97	59.33	38.70	1.63	7.40	19.83	20.13	10.35
3a	21.08	56.08	22.84	4.79	11.21	19.10	14.58	6.40
4a	1.37	90.61	8.02	0.97	9.78	32.50	38.35	9.02
4b	6.03	90.23	3.74	3.65	21.94	37.13	24.23	3.28

Sediment groups and characteristics within each of the coring sediment types defined are summarised in Table A2.2.3. Note that representatives from all sediment groups are present in the potentially CDM sediment type, although they are mostly from sediment groups 1a and 2a. This is because some sand slices contained thin mud layers, too thin to separate into individual samples, which may be linked to CDM.

Table A2.2.3. Summary of sediment groups, and statistics for each coring sediment type

Sediment type	Number of samples measured	Sediment group	Gravel (%)	Sand (%)	Silt/clay (%)
CDM	8	1a	1.01	23.32	75.67
Potentially CDM	47	all	4.20	48.37	47.43
Potentially CDM	21	1a	0.42	36.28	63.29
Potentially CDM	16	2a	2.47	56.38	41.15
Potentially CDM	7	3a	19.76	52.57	27.67
Potentially CDM	2	4a	0.91	81.24	17.85
Potentially CDM	1	4b	8.81	79.02	12.17
Sand	7	4a(6), 4b (1)	5.34	91.56	3.09
Mud	3	1a (2), 2a (1)	0.63	45.54	53.83
Surface layers	3	3a (2), 4b (1)	17.38	68.87	13.75
Precapping layers	2	2a (1), 3a (1)	5.96	69.81	24.24

*Sediment organic carbon and nitrogen (< 63 µm fraction)*

Organic carbon values ranged from 1.45 to 7.65 % and for nitrogen from 0.13 to 0.37 % (Table A2.2.4). There was insufficient fine sediment present for 8 samples (sands). POT1A 59-72cm (potentially CDM) contained the highest organic carbon concentration of 7.65 %. In general, the OCN data suggest that the group of sediments termed 'CDM' display the highest OCN values, while those of 'potential CDM' and mud sediments also contain high OCN concentrations.

Table A2.2.4. Summary of organic carbon and nitrogen concentrations for each coring sediment type

Sediment type	Number of samples measured	Organic carbon (% m/m)	Nitrogen (% m/m)	Outliers (samples with +/- 2 X standard deviation)
CDM	8	6.85 +/- 0.70	0.34 +/- 0.02	None
Potentially CDM	47	5.43 +/- 0.8	0.29 +/- 0.03	Two (SPI8 15-17 - insufficient <63µm for measurement; CAP1SPI 87-99 organic carbon 1.45 %m/m)
Sand	7	nm	nm	One (POT 5 10-31 -11% silt/clay - black mud patches in sand has organic carbon of 4.55 % m/m)
Mud	3	5.53 +/- 0.47	0.28 +/- 0.04	None
Surface layers	3	4.64 +/- 0.86	0.23 +/- 0.04	One (CAP1 0-21 -insufficient <63µm for measurement)
Precapping layers	2	3.66 +/- 1.48	0.26 +/- 0.01	None

### Sediment contaminants

The sediment contaminant data, in combination, were used to help support the designation of the core slices such as CDM or non-CDM which were based on their visual appearance.

### TBT/DBT

TBT values ranged by over 5 orders of magnitude from below limit of detection (LOD) (<0.002 mg kg<sup>-1</sup> dw) to 21.67 mg kg<sup>-1</sup> dw and DBT values ranged from below LOD (<0.001 mg kg<sup>-1</sup> dw) to 0.492 mg kg<sup>-1</sup> dw. Several slices in potential-CDM sediment type possessed TBT concentrations above AL 2, including VC32 65-88cm which contained the maximum measurement of TBT (21.67 mg kg<sup>-1</sup> dw) observed from all the slices measured (Table A2.2.5).

These data suggest that although only potential-CDM based on visual appearance, some slices within this group may represent CDM. Similarly, CAP1 (127-158cm) described as 'mud' (i.e. not associated with CDM) exhibited TBT concentrations characteristic of CDM.

### Trace metals (Total HF digest on < 63 µm fraction)

Normalisation using Li proved to be the best normalisation procedure for some trace metals, and, in those cases, normalisation was adopted (normalisation was not required for some trace metals). Trace metals concentrations were measured on the mud fraction (< 63 µm) only and thus trace metal signatures of the CDM can be directly related. Trace metal concentration measurements on the mud fraction sediment are more likely to relate to the signatures of the CDM compared with trace metal concentrations from the total sediment.

Table A2.2.5. Summary of DBT/TBT concentrations for each coring sediment type

Sediment type	Number of samples measured	Mean DBT (range) mg/kg	Mean (TBT (range) mg/kg	Observations
CDM	8	0.213 (0.074-0.307)	6.668 (1.214-17.400)	All above AL2
Potentially CDM	47	0.040 (<0.001-0.409)	0.851 (<0.002-21.674)	POT1A (59-72cm); POT2B (53-70cm)SPI9 (15-19cm); VC32 (65-88cm); VC36 (40-50 and 67-74cm); VC42 (62-67cm); above AL2
Sand	6	0.005 (<0.001-0.298)	0.066 (0.017-0.233)	
Mud	3	0.133 (0.042-0.298)	2.235 (0.827-4.878)	CAP1 (127-158cm); above AL2
Surface layers	3	0.036 (<0.001-0.035)	0.169 (0.026-0.445)	
Precapping layers	2	<0.001	0.012 (0.09-0.015)	

A summary of trace metal concentrations of each sediment group (e.g., CDM, potential-CDM) is given in Table A2.2.6. All sediments of each group displayed trace metals concentrations above regional concentrations for Cd and Cu, although this is marginal with the pre-capping layers (only 2 samples measured). Cd is one of the most elevated concentrations present in the source CDM dredged material (Table A2.2.1) but because it is relatively elevated in all the layers being considered it makes it harder to use as an indicator of CDM. Zn is the other trace metal with the most elevated

concentrations present in the source CDM dredge material (Table A2.2.1). Again, elevated concentrations are prevalent in all layers except the pre-capping layers, and less so in the surface layers. As noted earlier, particularly where there are high concentrations of trace metals in the mud present in the sands measured, this may indicate movement of CDM sediment upwards towards the surface of the sediment. These data imply that trace metals are comparatively difficult to use for confirmation of CDM as opposed to non-CDM in isolation.

*CAP 1 (all slices analysed)*

All the core slices in CAP1 were analysed to allow an assessment as to whether contaminant concentrations varied in accordance with the different layers as depicted by the visual characteristics. The results (Figure A2.2.10) confirm that the highest contaminant concentrations are present in the CDM layer and the mud layer above (i.e., the brown layer presented in Figure A2.2.10), the latter was originally considered as potentially representing the silt capping material placed before the sand layer. It is expected that possible mixing of this capping material with the CDM sediment occurred during placement and this may explain these elevated concentrations. In general, the close relationship between particle size distribution, organic carbon content and sediment contaminant concentrations with the visual characteristics observed for CAP1 supports the allocation of sediment slices to the sediment groups.

Table A2.2.6. Summary of trace metal concentrations for each sediment group.

Sediment type	Number of samples measured	CdLi (mg kg <sup>-1</sup> dry weight)	CrLi (mg kg <sup>-1</sup> dry weight)	CuLi (mg kg <sup>-1</sup> dry weight)	HgLi (mg kg <sup>-1</sup> dry weight)	NiLi(mg kg <sup>-1</sup> dry weight)	PbLi (mg kg <sup>-1</sup> dry weight)	ZnLi (mg kg <sup>-1</sup> dry weight)
		OSAPR BAC:0.31	OSAPR BAC:81	OSAPR BAC:27	OSAPR BAC:0.07	OSAPR BAC:36	OSAPR BAC:38	OSAPR BAC:122
		Tyne Tees regional: 0.31 (0.5)	Tyne Tees regional: 135 (132)	Tyne Tees regional: 29 (58)	Tyne Tees regional: 0.35 (0.4)	Tyne Tees regional: 55 (62)	Tyne Tees regional: 132 (129)	Tyne Tees regional: 172 (193)
CDM	8	1.9 (0.8 - 2.9)	67 (64 - 71)	86 (54 - 114)	0.41 (0.18 - 0.54)	29 (28 - 34)	188 (118 - 250)	355 (210 - 448)
Potentially CDM	47	0.83 (0.27 - 2.96)	70 (61 - 105)	48 (19 - 86)	0.25 (0.11 - 0.67)	32 (28 - 43)	112 (45 - 233)	205 (82 - 492)
Sand	6*	0.72 (0.5 - 0.92)	81 (68 - 101)	83 (43 - 127)	0.37 (0.24 - 0.45)	38 (30 - 42)	139 (88 - 191)	242 (168 - 350)
Mud	3	1.13 (0.6 - 1.7)	65 (60 - 73)	64 (49 - 85)	0.3 (0.27 - 0.35)	29 (27 - 34)	123 (91 - 151)	274 (185 - 376)
Surface layers	3	0.66 (0.35 - 0.93)	65 (61 - 71)	41 (38 - 46)	0.45 (0.25 - 0.62)	30 (28 - 33)	95 (84 - 114)	183 (149 - 222)
Precapping layers	2	0.5 (0.41 - 0.59)	82 (70 - 94)	37 (34 - 41)	0.27 (0.25 - 0.29)	37 (34 - 40)	130 (85 - 176)	161 (126 - 196)

Li indicates normalisation to Li has been applied. The value represents the average concentration in that sediment type with the range of concentrations measured in brackets at the side of this. Colour coding: blue = >OSPAR BAC; pink = >Tyne/Tees regional baseline (the figure in brackets at the side of these is the baseline calculated using only outside disposal site data). \*1 slice from the 'sand' group had insufficient < 63 µm sediment for analyses.

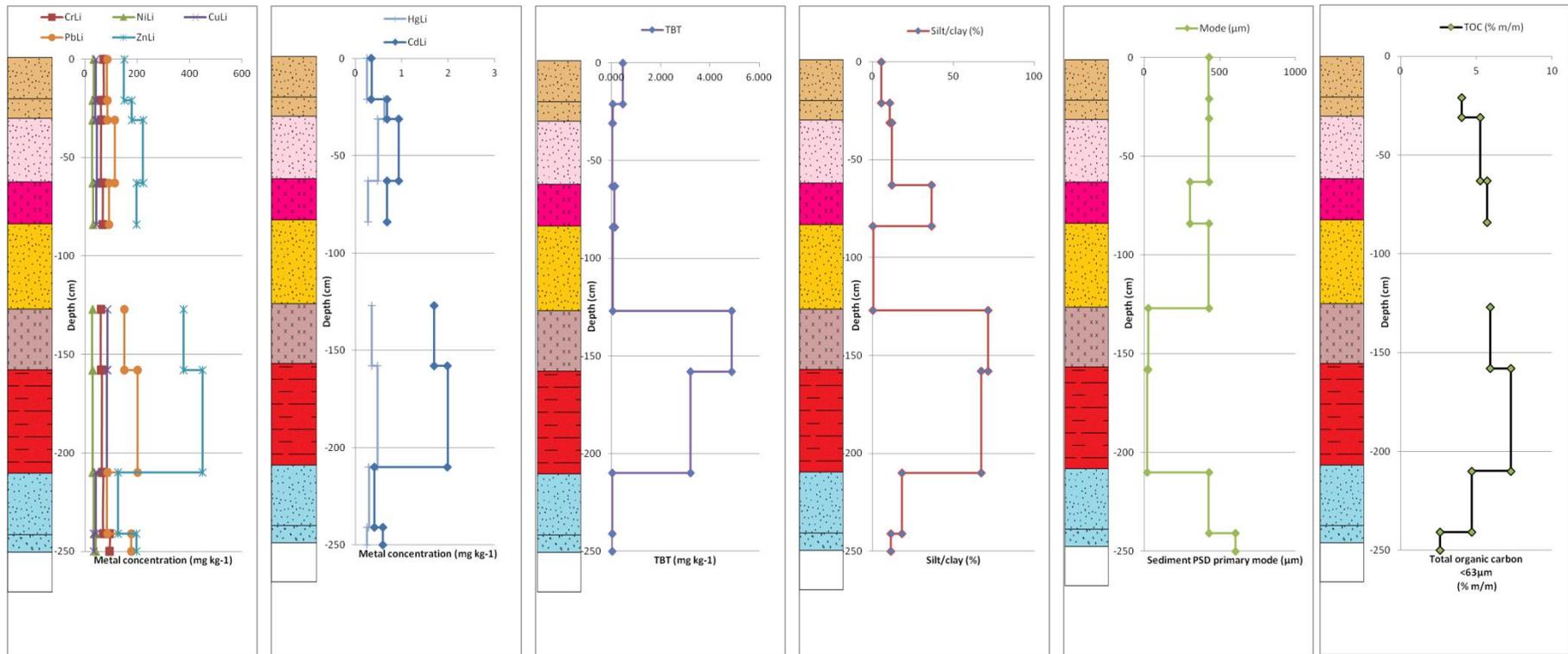


Figure A2.2.10. Core profiles of trace metal and TBT concentrations, percent silt/clay composition, modal size class and total organic carbon content of the nine sediment slices of CAP1.

### 2.2.3.5 Combined assessment

Cluster analysis of sediment contaminant and physical data was conducted to determine the presence of sediment groups based on a range of characteristics as opposed to separate characteristics in isolation. The approach was undertaken using the following metrics: TBT; DBT; As; Fe; Mn; Cd; Cr; Cu; Hg; Ni; Pb; Rb; V; Zn; sediment group; silt/clay (%); Mode 1; gravel(%); very coarse sand (%); coarse sand (%); medium sand (%); fine sand (%); very fine sand (%); very coarse silt (%); coarse silt (%); medium silt (%); fine silt (%); very fine silt (%); clay (%); and primary laser mode. Organic carbon and nitrogen results were excluded as some samples did not have sufficient < 63 µm fraction to enable measurement of these. One core slice was excluded (CAP1, 84-127cm) from this analysis due to insufficient data.

The data were normalised prior to hierarchical clustering by subtracting mean from value and then dividing this by standard deviation for each parameter. Multi-dimensional analysis (MDS) was also completed, the groups defined following the clustering procedure (Figure A2.2.11) were overlain on the resulting MDS (Figure A2.2.12).

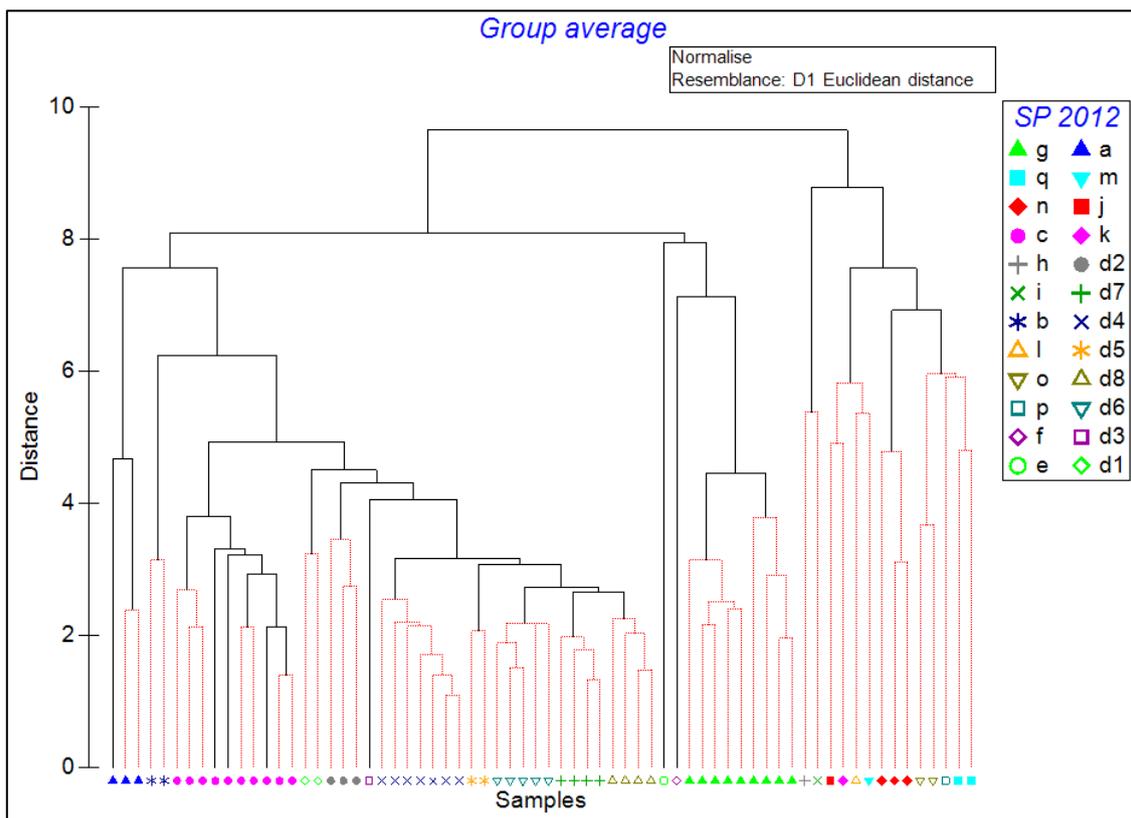


Figure A2.2.11. Cluster dendrogram of combined dataset. SIMPROF (red lines) shows significantly different groups at 5% level.

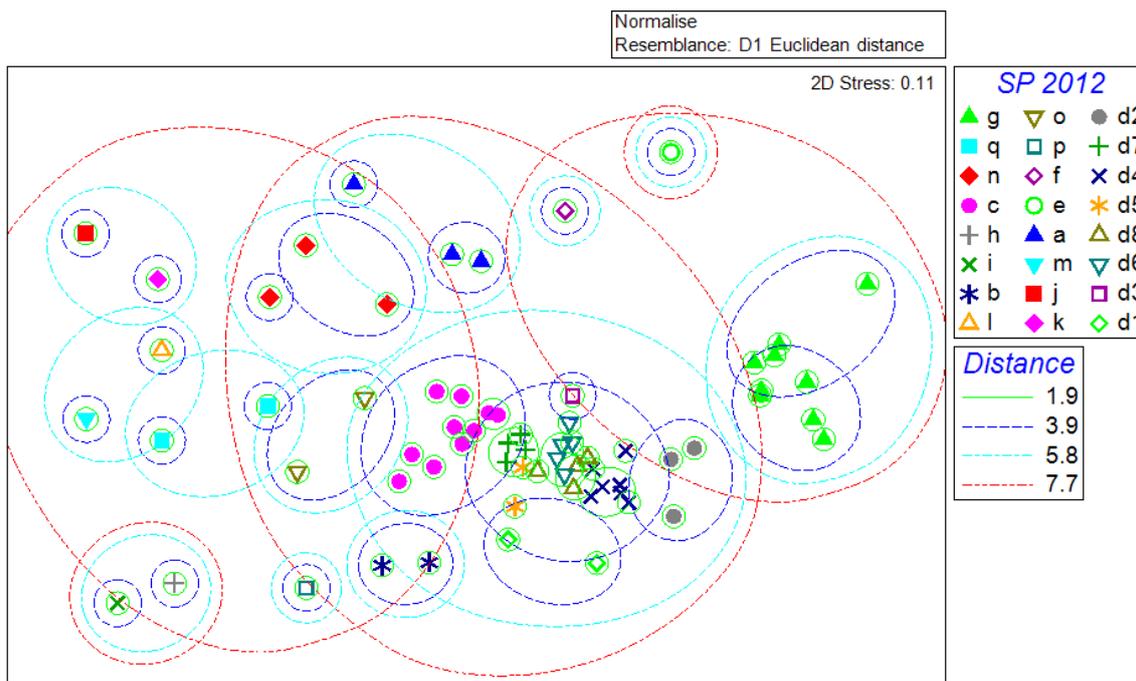


Figure A2.2.12. MDS of combined dataset overlain with results from cluster analysis.

Group g contains core slice samples that most represent CDM, while groups d2, e and f display characteristics which may be linked to CDM (d2, although significantly different to group g, is close to group g in the MDS). Thus, the core slices which were thought to represent CDM based on separate assessments of individual metrics all tend to be located on the right hand side of the MDS plot. Cluster group g members contain high concentrations of TBT, Cd, Cu, Zn and, to a lesser extent, Pb; e has highly elevated concentrations of TBT as well as Cd, while f has high concentrations of Cd, Cu and Zn. Cluster group d2 has high concentrations of Cd and Cu, as well as high concentrations of TBT for one slice in this group.

To allow an assessment of the concentrations of TBT, DBT and trace metals of each core slice to a standard assessment concentration, enrichment factors for each core slice were calculated (Table A2.2.7). These data support the allocation of the sediment core slices into the sediment groups and indicate two aspects:

- Enrichment is observed mainly in the samples representing the CDM material; and
- Contaminants which are able to be used for derivation of CDM signatures are TBT, Cd, Cu and Zn.

Cd and Cu are relatively elevated for many slices, indicating these may be reflecting regional concentrations rather than directly linked to the capping exercise. There are 2 slices (POT2B 53-70, and VC36 67-74) that have high concentrations of TBT and Cd but fall in cluster d outside of those samples identified as most likely to be CDM.

It is also notable there are some slices above suspected CDM have elevated concentrations (eg. POT4A, VC34, VC35, VC41), suggesting that vertical *in situ* leaching of contaminants from CDM may have occurred (as was concluded for CAP1; see earlier).

### 2.2.3.6 Confirmation of CDM

Twelve core slices (Table A2.2.8), either identified initially by visual appearance or subsequent analysis (see previous sections) as potential CDM, were selected for analysis of a wider range of contaminants (PAHs, Organohalogens (PCBs and BDEs and metals partial digest) to provide data to further support or refute them as CDM. Note, two of these surficial slices (VC40 and SPI2) were selected because they displayed similar visual appearance to potential CDM slices.

*Table A2.2.8. Details of samples analysed for full suite of contaminant analyses.*

Rationale	Sample code	Depth (cm)	Sediment description
CDM based on field evidence only.	CAP1	158-210	Thick, black, sticky, smelly mud, containing copper wire.
CDM based on field evidence only.	POT2A	150-230	Black, sticky, smelly amorphous mud containing gravel piece (chalk?) .
CDM based on field evidence only.	POT3	94_123	Thick, black, sticky, smelly, amorphous mud
CDM based on field evidence only.	POT4A	158-254	Thick, black, sticky, smelly (petrochemical), amorphous mud.
CDM based on field evidence only.	POT5	31-39	Thick, black, sticky, smelly (petrochemical), amorphous mud.
CDM based on field evidence only.	VC34	112-130	Black, amorphous, smelly mud containing organic fragments, thin sand layer, petrochemical smell.
CDM based on field evidence only.	VC35	140-197	Black amorphous mud containing organic fragments
CDM based on field evidence only.	VC41	128-230	Black amorphous mud
Post initial analysis - possibly CDM and at surface.	SPI2	0-7	Black mud
Post initial analysis - possibly CDM and at surface.	VC40	0-28	Black sticky amorphous sticky mud containing organic fragments. Thin sand band at top of this layer. Bioturbation present. Petrochemical smell.
Post initial analysis - possibly CDM	POT1A	59-72	Black, amorphous, smelly mud
Post initial analysis - possibly CDM	VC42	52-67	Black amorphous mud with very thin sand band at top of layer

These slices were selected as their identity regarding CDM or non-CDM could not unequivocally be determined by the other metrics.

Table A2.2.7. Enrichment factors in core slices to Action Level 2 for DBT/TBT or Tyne/Tees regional baselines for trace metal concentrations.

Samplecode_slice_cm_Isn	Sediment type and description	Cluster group	DBT	TBT	CdLi	CrLi	CuLi	HgLi	NiLi	PbLi	ZnLi		
			Enrichment to action level 2		Enrichment to Tyne Tees regional baseline								
			1	1	0.31	135	29	0.35	55	132	172		
SPI7_S2_13-17_2012/4310	S2_13-17_Sand	q	0	0	2	1	2	1	1	1	1		
SPI7_S3_17-32_2013/2824	S3_17-32_Mud	na	0	0	4	1	2	1	1	1	2		
SPI7_S4_32-58_2012/4311	S4_32-58_Grey/brown mud	b	0	0	1	1	1	1	1	1	1		
SPI8_S2_5-15_2012/4312	S2_5-15_Black mud	d1	0	0	2	1	1	1	1	1	1		
SPI8_S3_15-17_2012/4313	S3_15-17_Sand containing thin black mud layer	p	0	0	2	1	2	1	1	1	1		
SPI9_S2_10-15_2012/4314	S2_10-15_Black mud/muddy sand	d1	0	0	2	1	1	1	1	1	1		
SPI9_S3_15-18_2012/4315	S3_15-18_Sand containing thin black mud layer	f	0	1	8	1	3	2	1	1	3		
VC32_S4_65-88_2012/4316	S4_65-88_Black muddy sand/sandy mud with occasional gravel	e	0	22	5	0	3	1	1	1	2		
VC32_S6_100-104_2012/4317	S6_100-104_Black mud	c	0	0	2	0	1	0	1	1	1		
VC33_S2_16-30_2012/4318	S2_16-30_Black muddy sand (with coal?)	a	0	0	3	0	2	1	1	1	1		
VC33_S4_55-63_2012/4319	S4_55-63_Black muddy sand	d7	0	0	2	0	1	0	1	1	1		
VC33_S6_90-110_2012/4320	S6_90-110_Black muddy sand/ black amorphous mud	d8	0	0	2	0	2	0	1	1	1		
VC34_S5_58-74_2012/4321	S5_58-74_Black, muddy sand/black amorphous mud - petrochemical	c	0	1	2	0	2	0	1	1	1		
VC34_S6_74-112_2012/4322	S6_74-112_Sand (black laminations - coal?) at top of sand layer	m	0	0	2	1	4	1	1	1	1		
VC34_S7_112-130_2012/4278	S7_112-130_Black, amorphous, smelly mud containing organic	d2	0	1	5	1	2	1	1	1	2		
VC35_S3_79-87_2012/4323	S3_79-87_Black mud	a	0	0	2	0	2	0	1	1	1		
VC35_S5_122-140_2012/4324	S5_122-140_Clean sand	j	0	0	3	1	4	1	1	1	2		
VC35_S6_140-197_2012/4279	S6_140-197_Black amorphous mud containing organic fragments	g	0	17	6	0	4	1	1	1	2		
VC36_S2_22-32_2012/4325	S2_22-32_Black muddy sand/sandy mud	c	0	0	2	0	2	1	1	1	1		
VC36_S4_40-50_2012/4326	S4_40-50_Black, muddy sand/black amorphous mud - petrochemical	a	0	1	2	0	2	1	1	1	1		
VC36_S6_67-74_2012/4327	S6_67-74_Black amorphous mud	d4	0	1	3	0	2	1	1	1	1		
VC38_S2_11-16_2012/4328	S2_11-16_Black/dark brown mud	c	0	0	2	1	2	1	1	1	1		
VC38_S4_20-26_2012/4329	S4_20-26_Black/dark brown amorphous, sticky, unnatural smell	d7	0	0	2	1	1	0	1	1	1		
VC38_S6_50-57_2012/4330	S6_50-57_Black mud, smelly, containing organic fragments	d6	0	1	2	0	2	1	1	1	1		
VC39_S4_20-28_2012/4331	S4_20-28_Black sandy mud/muddy sand	d8	0	0	2	0	1	0	1	1	1		
VC39_S6_36-52_2012/4332	S6_36-52_Black mud	d4	0	0	2	1	2	1	1	1	1		
VC40_S1_0-28_2012/4333	S1_0-28_Black sticky amorphous sticky mud containing organic	d6	0	0	2	1	2	1	1	1	1		
VC41_S3_108-128_2012/4334	S3_108-128_Clean sand	k	0	0	3	1	4	1	1	1	1		
VC41_S4_128-230_2012/4280	S4_128-230_Black amorphous mud	g	0	9	6	0	3	1	1	1	2		
VC42_S2_12-19_2012/4335	S2_12-19_Brown, muddy sand/sandy mud	o	0	0	2	1	2	1	1	1	1		
VC42_S4_29-34_2012/4336	S4_29-34_Black amorphous mud/sandy mud	d8	0	0	2	0	1	1	1	1	1		
VC42_S7_62-67_2012/4337	S7_62-67_Black amorphous mud with very thin sand band at top of	g	0	4	7	1	3	1	1	2	2		
VC43_S2_8-24_2012/4338	S2_8-24_Black/dark brown, soft, slightly sandy mud over black	c	0	0	3	1	2	1	1	1	1		
VC43_S4_28-42_2012/4339	S4_28-42_Black, thick, amorphous mud	d4	0	0	3	1	2	0	1	1	1		
VC44_S3_23-29_2012/4340	S3_23-29_Soft, black mud containing a sand patch	d4	0	0	2	1	1	0	1	1	1		
VC44_S5_33-42_2012/4341	S5_33-42_Black, thick, amorphous mud	d2	0	0	2	1	2	1	1	1	1		

Colour coding: >2<3 light pink, >3<4 medium pink, >4 dark pink. nm means not measured (insufficient < 63 µm); na not included in cluster analysis.

#### *Sediment organic carbon and nitrogen (<2mm)*

Organic carbon values averaged (in the < 2 mm fraction) 7.15% m/m (+/- 0.74) and average nitrogen concentrations were 0.28% (+/- 0.3). SPI 2 0-7cm (potential CDM) contained notably lower organic carbon levels (5.6%) than expected for the CDM sediment slices measured.

#### *PAHs*

All the 12 core slices analysed for PAH concentrations were found to exceed both the ERL and ERM for LMW PAHs (Figure A2.2.13). All slices exceeded the ERL for HMW PAHs and all except POT5, as well as VC40 and SPI2 (surface slices) also exceeded the ERM for the HMW PAHs.

Evaluation of the original PAH data for the CDM disposed of in 2004 indicates that, generally, the source was mixed with approximately 60% being of petrogenic and 40% of pyrogenic origin. One exception was found in an area of navigation channel dredging which was predominantly petrogenic, generally with > 80% of the PAH content arising from oil sources. The similarity of the PAH fingerprint found in the 10 sediment slices (not including the 2 surface slices) analysed in 2012 with that of the source sediment may indicate that these samples reflect the source of the original disposed material, rather than the capping material placed on top. The latter tends to show much lower summed PAH concentrations with a more predominantly petrogenic profile.

#### *Organohalogenes*

Sediment PCB concentrations are elevated compared to those at the surface (capping material), and can be used as a 'fingerprint' for CDM material. Levels ranged from 36.2-324  $\mu\text{g kg}^{-1}$  dw for  $\Sigma$ ICES 7 CBs (Table A2.2.9). The levels found in the 12 CDM and potential CDM slices are consistent with those measured at the 3 dredging locations in 2004 that were the source of the CDM except the two surface samples, SPI2 and VC40 (Table A2.2.1).



Table A2.2.9. Concentration (in  $\mu\text{g kg}^{-1}$  dw) of PCBs in the Souter Point Capping Survey Vibrocore samples collected in 2012.

Station	Core layer (in cm)	Concentration (in $\mu\text{g kg}^{-1}$ dw)	
		$\Sigma$ ICES 7 CBs	$\Sigma$ 25 CBs
POT4A	158-234	324	576
POT3	94-123	249	518
POT1A	59-72	133	326
VC34	112-130	141	270
POT2A	150-230	128	249
CAP1	158-210	99.4	210
VC41	128-230	80.2	161
VC35	140-197	60.9	125
VC42	62-67	52.2	112
POT5	31-39	36.2	72.6
SPI2	0-7	5.43	11.0
VC40	0-28	7.6	15.3
Site 1*	-	6-324	11-630
Site 2*	-	141	277
Site 3*	-	70-73	150-151
Capping material*	-	0-12	0-26

\*From 2004 survey of dredge material that was to be disposed of in the capping project. Colours are based on  $\Sigma$ 25 CBs concentrations: red =  $>300 \mu\text{g kg}^{-1}$  dw; orange =  $200-300 \mu\text{g kg}^{-1}$  dw; green =  $50-200 \mu\text{g kg}^{-1}$  dw; and blue =  $< 50 \mu\text{g kg}^{-1}$  dw.

Sediment BDE concentrations (not including BDE209) of the CDM and potential CDM sediment slices were elevated compared to those values found at or near the surface (Figure A2.2.14). Levels ranged from  $9.8-34.7 \mu\text{g kg}^{-1}$  dw for  $\Sigma$ 11 BDEs. However, similar levels have occasionally been found in samples near the surface in previous surveys under the auspices of SLAB5 (Bolam et al., 2009; 2011). No BDE data are available for the material that was the source of the CDM and, for this reason,  $\Sigma$ 11 BDE concentrations cannot unequivocally be used as a 'fingerprint' of the CDM, although very high levels may be indicative.

Levels of BDE209 are high, ranging from  $74.3-303 \mu\text{g kg}^{-1}$  dw (Figure A2.2.14). However, as for PBDEs, levels at the bottom end of this range have occasionally been found in samples near the surface in previous surveys. No BDE209 results are available for the material that was the source of the CDM. For this reason, BDE209 concentrations cannot unequivocally be used as a 'fingerprint' of the CDM, although very high levels may be indicative.

Levels of HCB (0.89-3.15  $\mu\text{g kg}^{-1}$  dw) and *p,p'*-DDE (1.95-6.38  $\mu\text{g kg}^{-1}$  dw) of the 10 core slices are quite high and elevated above the levels in the two surface (VC40 and SPI2) samples analysed in 2012. However, data are not readily available for these chemicals from surface samples from other surveys, so we cannot say whether these can be used as a 'fingerprint' of the CDM.

*Trace metals (partial digest, whole sediment)*

In order to evaluate the trace metals results against the source data (i.e. the CDM material) and enable comparison with action levels, the 12 core slices that were initially identified as CDM or potential CDM by visual assessment, underwent the same methodology as used for the CDM source material, i.e. on the whole sediment and on the partial digestion (Figure A2.2.15). Note, DBT/TBT concentrations were included here with the metals data to allow an improved comparison with source CDM concentrations.

All elements showed levels above Cefas AL1 and in some cases above AL2, namely for Cd, Zn and to some extent Pb (Table A2.2.10). This observation supports the notion that these core slices represented CDM as the CDM was also highly elevated in these metals. Furthermore, in addition to the potential 8 CDM layers (identified by visual assessment and verified by analysis), the cluster analysis identified 2 further samples which belong to the same group of CDM layers. These were samples from stations POT1A (59-72cm) and VC42 (62-67cm). Metals analysis showed elevated Zn and Cd levels (>AL2) as for the source CDM, therefore confirming the likelihood of these samples also being CDM. The concentrations in the 2 surface sediments (VC40 and SPI2) had relatively low concentrations (all below AL2, most below AL1) so are unlikely to be linked to CDM.

*Table A2.2.10. Trace metal (partial digest/whole sediment) and DBT/TBT concentrations for CDM and potential CDM slices.*

Station, depth (cm)	DBT	TBT	Cd	Hg	Cr	Ni	Cu	Zn	As	Pb
CAP1, 158-210	0.126	3.207	5	1.0	91	51	255	1334	26	399
POT1A, 59-72	0.110	1.139	5	1.6	67	40	612	953	29	424
POT2A, 150-230	0.272	10.729	4	1.1	81	48	270	1095	28	425
POT3, 94-123	0.112	2.258	6	1.2	101	50	321	1438	25	486
POT4A, 158-234	0.182	4.562	5	0.9	200	50	248	1675	34	3178
VC35, 140-197	0.492	17.400	3	0.9	94	43	479	1644	26	406
VC41, 128-230	0.307	9.339	4	0.8	112	44	608	1651	26	527
VC42, 62-67	0.175	4.448	4	0.8	74	40	268	937	26	370
POT5, 31-39	0.140	4.638	9	0.4	52	34	146	440	26	654
VC34, 112-130	0.074	1.214	3	0.9	88	48	143	598	28	278
SPI2, 0-7	0.009	0.051	0.4	0.3	26	19	28	148	14	76
VC40, 0-28	0.019	0.092	1	0.3	29	21	34	177	17	96

Colour key: yellow indicates above AL1 <AL2, red indicates >AL2. Concentration units: mg kg<sup>-1</sup> dry weight.

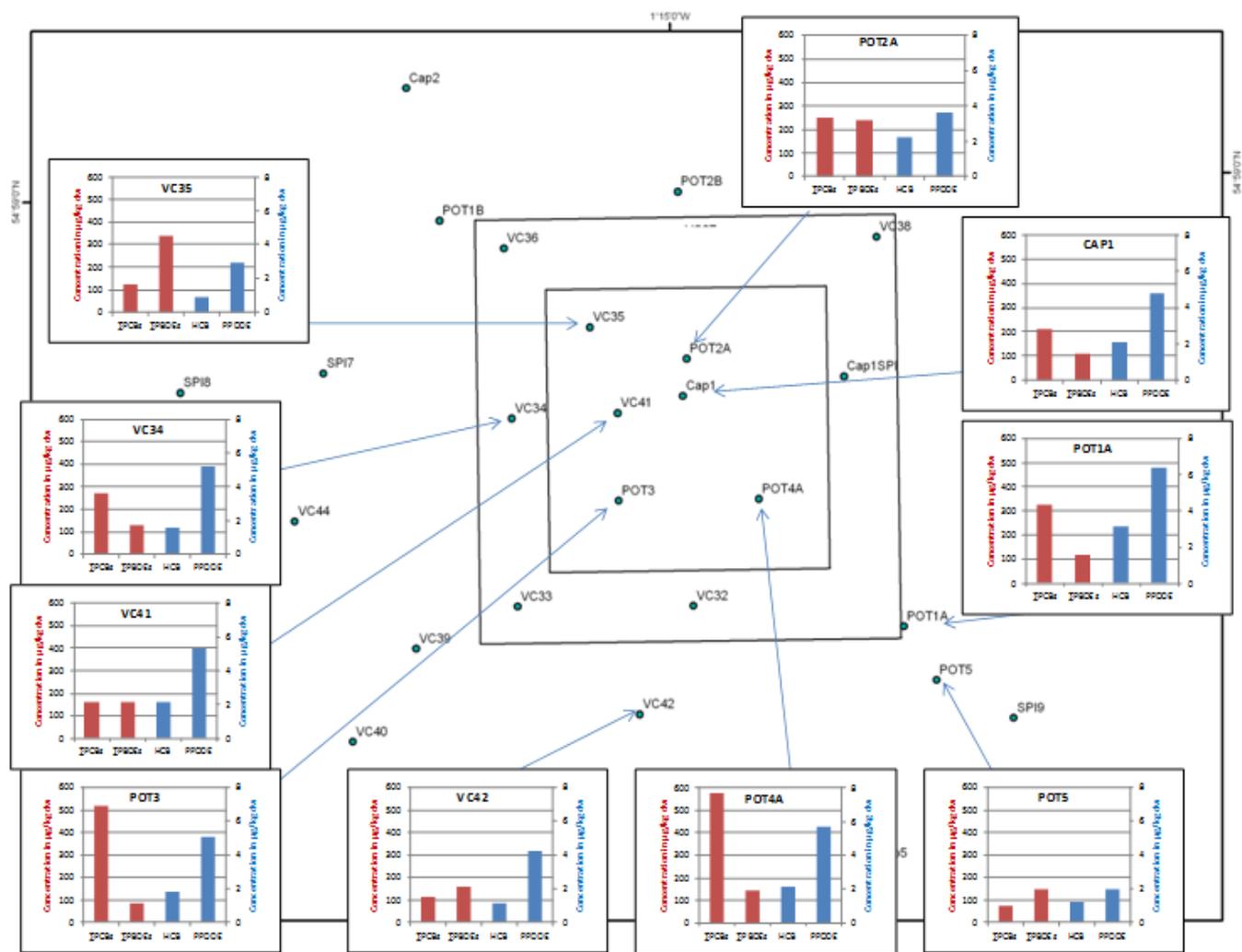


Figure A2.2.14. PCB/PBDE concentrations of core slices analysed in 2012. (VC40 and SPI2 surface slice results not indicated).

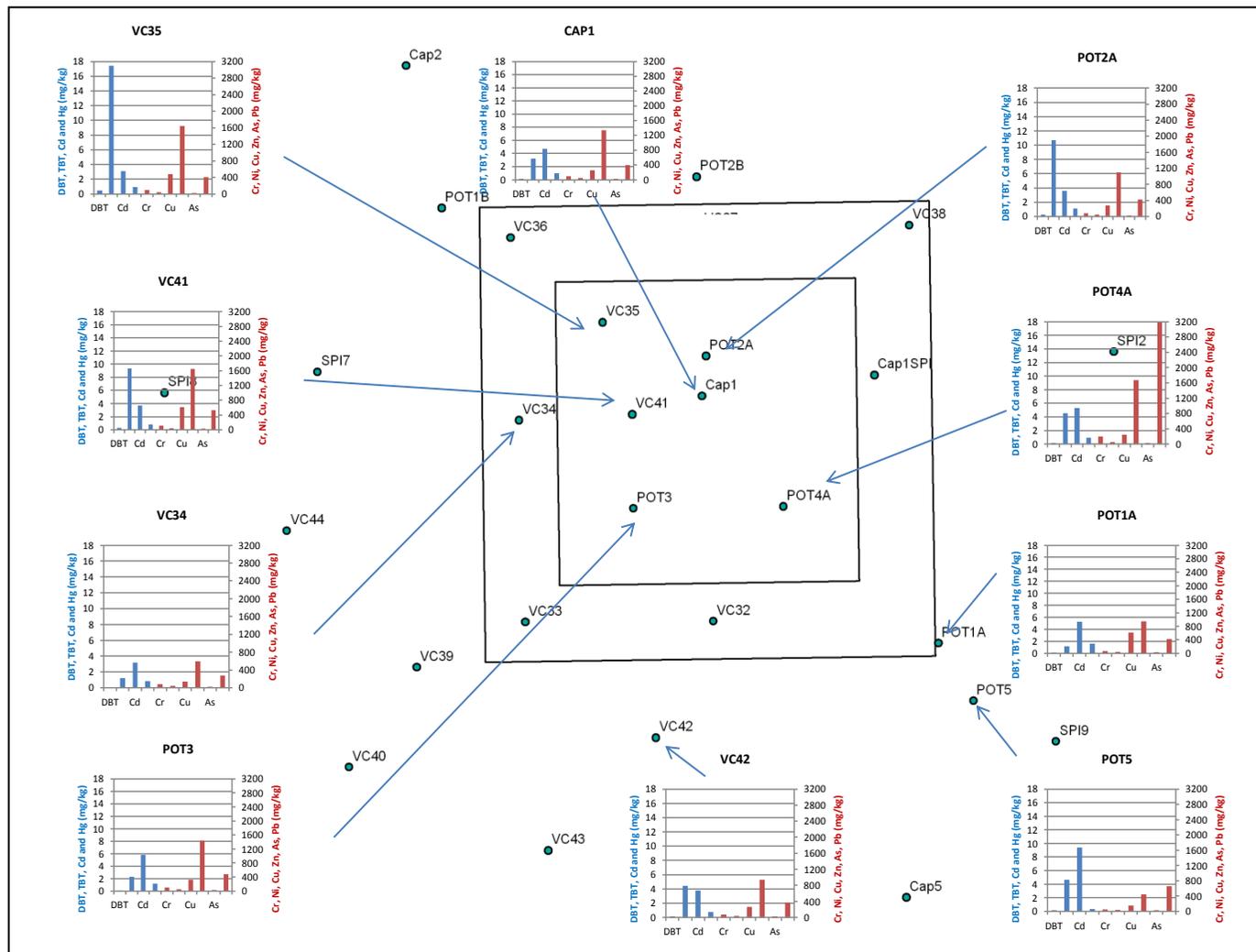


Figure A2.2.15. Trace metal (partial digest, whole sediment) and TBT/DBT concentrations for slices suspected to be CDM. (VC40 and SPI2 results not indicated).

Full contaminant suite analysis established, therefore, that 10 of the 12 core slices measured were confirmed as likely to be CDM. In addition, there are some slices (not confirmed with full suite analysis) that also may be potentially CDM. Therefore, to ensure slices without full suite analysis that may be potentially CDM are considered, the concentrations from each slice were ranked. Ranking of enrichment factors was completed for all slices measured with subset analysis independently for each contaminant considered appropriate for CDM fingerprinting (Table A2.2.1; i.e., TBT, CdLi, and ZnLi). Each parameter was placed in order of enrichment and then assigned a score 1 to 70 (70 = highest). All the scores for each parameter were totalled and divided by the number of parameters measured to give an average rank score. These average rank scores were then placed in order and assigned a number (1 to 70), with 70 representing the most contaminated slice measured (in relation to TBT, CdLi and ZnLi). The same was done for the 12 slices measured with full suite analysis (parameters – TBT, CdLi, ZnLi, Cd, Zn, LMW PAHs, HMW PAHs) to help gauge where to split the subset ranks.

Ranking results (Table A2.2.11) show that in three slices (SPI9, VC32 and CAP1 127-158cm) where only a subset was measured, the relative rankings were higher than for VC34 and POT5 measured with the full suite and these are now identified as being CDM. SPI9 and VC32 are classified as gravelly muddy sand /muddy sand respectively compared with the other CDM slices that are sandy muds. Note the decision where to split the CDM and potential CDM is subjective and so potential CDM slices are also indicated, which include VC34 and POT5. Potential CDM slices contain elements of the expected CDM profile, as indicated in Table A2.2.11. Overall, 11 slices are confirmed as CDM and a further nine slices as potentially CDM, within 16 of the 27 cores collected. For four cores, there are two slices identified. For all of these, the most contaminated slice is beneath the lesser contaminated and, for some of them, the sediment type is sand/muddy sand rather than mud. The elevated concentrations in these could be the result of transfer of CDM to capping sediment/sediment above during the capping process.

Table A2.2.11. Core slices identified as CDM or potentially CDM. Slices are in order of contamination (top = most contaminated). Red indicates CDM, purple indicates potentially CDM.

Core	Depth (cm)	Thickness of slice (cm)	Average rank	Rank order	TBT (mg kg-1 dry weight)	CdLi (mg kg-1 dry weight)	ZnLi (mg kg-1 dry weight)	Cd partial whole (mg kg-1 dry weight)	Zn partial whole (mg kg-1 dry weight)	LMW (µg/kg dry weight)	HMW (µg/kg dry weight)	Cluster group	Sediment Group	Sediment textural group	Silt/clay(%)
CAP1	158-210	52	63	70	3.2	1.99	448	4.70	1334	21551	21636	g	1	Sandy Mud	67.14
POT1A	59-72	13	62	69	1.1	2.96	492	5.26	953	21143	19448	g	1	Sandy Mud	69.90
VC35	140-197	57	61	68	17.4	1.80	382	3.10	1644	13622	13498	g	1	Sandy Mud	65.66
POT4A	158-234	76	61	67	4.6	2.49	395	5.30	1675	20500	19225	g	1	Sandy Mud	65.22
POT2A	150-230	80	61	66	10.7	1.75	357	3.60	1095	13704	13825	g	1	Sandy Mud	72.87
VC42	62-67	5	61	65	4.4	2.08	388	3.80	937	16276	17744	g	1	Sandy Mud	62.54
VC41	128-230	102	61	64	9.3	1.86	362	3.70	1651	18387	18725	g	1	Sandy Mud	69.03
VC32	65-88	23	61	63	21.7	1.44	299	nm	nm	nm	nm	e	2	Muddy Sand	41.38
SPI9	15-18	3	61	62	1.4	2.55	467	nm	nm	nm	nm	f	2	Gravelly Muddy Sand	33.72
POT3	94-123	29	61	61	2.3	2.91	414	5.80	1438	19917	18257	g	1	Sandy Mud	70.54
CAP1	127-158	31	59	60	4.9	1.70	376	nm	nm	nm	nm	g	1	Sandy Mud	71.52
VC34	112-130	18	54	59	1.2	1.58	276	3.20	598	17117	11708	d2	1	Sandy Mud	69.08
POT4A	135-158	23	48	58	1.0	1.08	263	nm	nm	nm	nm	c	2	Muddy Sand	23.35
POT2B	53-70	17	39	57	1.6	1.09	257	nm	nm	nm	nm	d6	1	Sandy Mud	54.31
SPI7	17-32	15	37	56	0.2	1.12	270	nm	nm	nm	nm	na	1	Sandy Mud	76.95
POT5	31-39	8	36	55	4.6	0.81	210	9.40	440	11542	8248	d2	1	Sandy Mud	61.32
VC35	122-140	18	32	54	0.2	0.92	350	nm	nm	nm	nm	j	4	Sand	0.65
VC36	67-74	7	31	53	1.3	1.07	231	nm	nm	nm	nm	d4	1	Sandy Mud	56.95
POT1B	64-69	5	31	52	0.6	0.78	209	nm	nm	nm	nm	d6	1	Sandy Mud	50.61
POT1A	45-59	14	31	51	0.6	0.83	215	nm	nm	nm	nm	d8	1	Sandy Mud	47.45

Colour key: red = CDM, purple = potential CDM. Colour key for source contaminant concentrations: yellow indicates above AL1 <AL2, red indicates >AL2 (see Table A2.2.1.) pink indicates >Tyne/Tees regional baseline. Li indicates normalisation to Li has been applied.

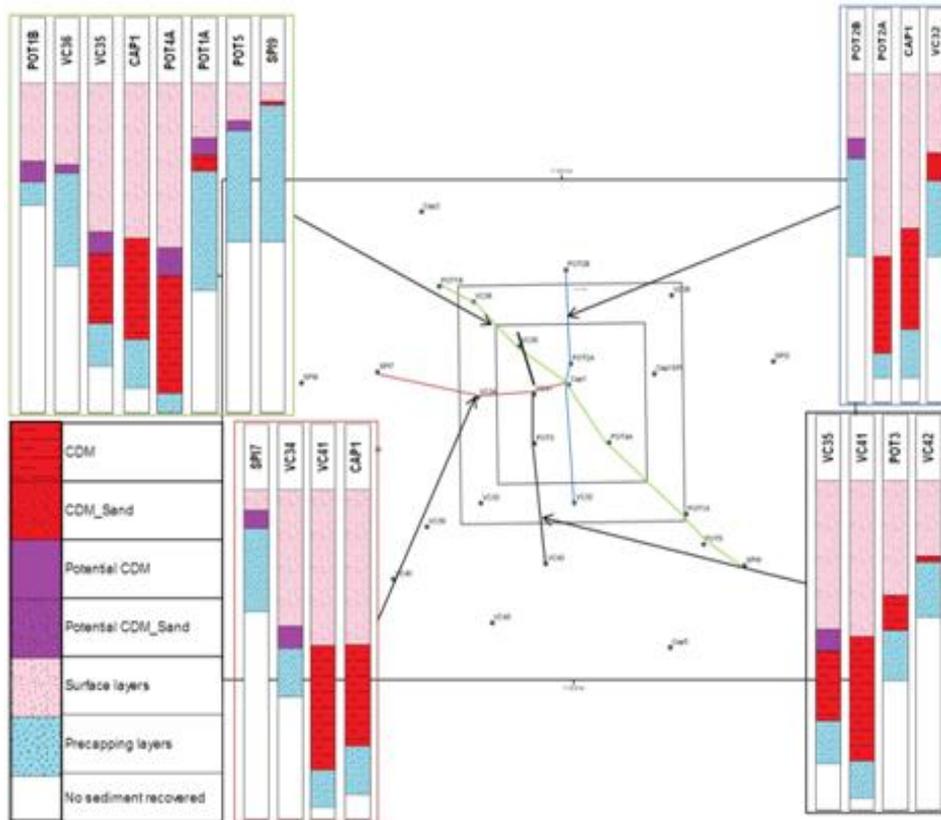


Figure A2.2.16. Map showing core schematics for cores with CDM and potential CDM slices. Note, bathymetry differences not accounted for when comparing core schematics. The surface is higher in the cap area as discussed in Section 2.2.4.1 previously and as indicated below in Figure A2.2.17.

### 2.2.3.7 Conclusions

The approach adopted during 2012 under the auspices of SLAB5 at Souter has successfully provided evidence of presence of CDM after capping placement in 2004 (and subsequent years with infilling of cap). By obtaining deep sediment cores which could be subsequently visually inspected and sub-samples of various strata taken, we have been able to confirm the nature of each sediment strata using a combination of physical and chemical analyses. By using information of the depths of the observed CDM core slices and their geographical location (particularly with respect to their location relative to the CDM placement and capping boundaries), we have been able to postulate the fate of the CDM and make recommendations regarding future monitoring for the site.

In 2012, the cap was thickest in the centre of the defined cap placement area (1.5m POT2A, 1.27m CAP1), thinning to the edges within cap area (west VC34 1.12m, south VC32 0.65m, northwest VC36 0.67m). There is some evidence of CDM/CDM linked sediment in cores along NW/SE transect. These are thin and quite close to the surface. It is possible when CDM was deposited it spread further than the defined capping area, and then was not capped with full depth cap sediment. Also this is the main tidal axis along

which any erosion is most likely to happen. This is most evident in the SE corner.

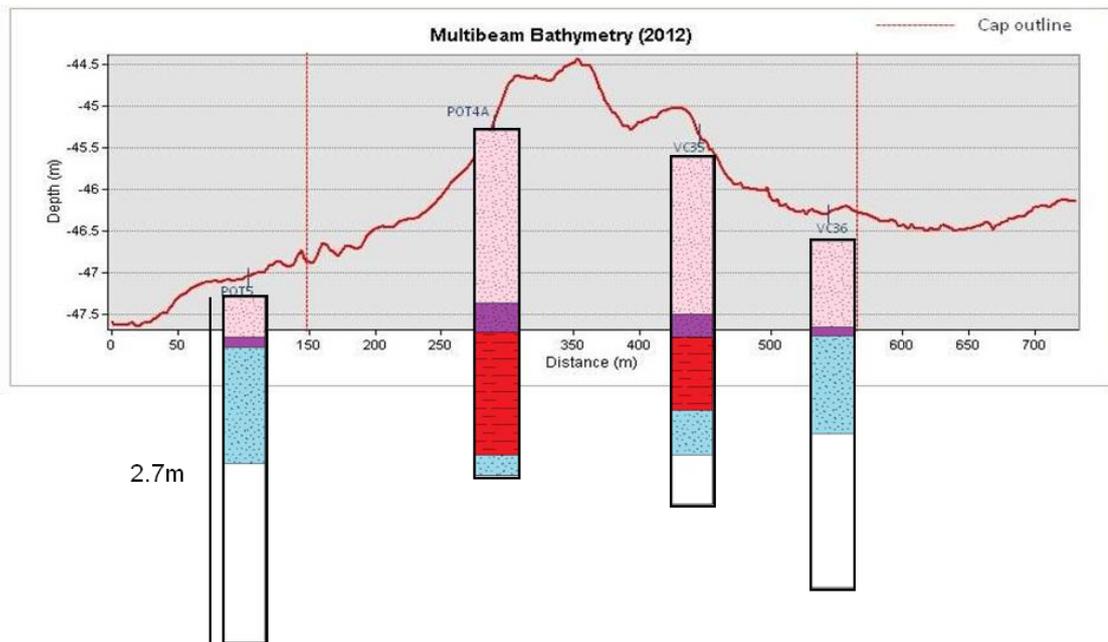


Figure A2.2.17. Graph illustrating the profile across the actual multibeam bathymetry collected in May 2012, overlain with four core schematics to help demonstrate the difference in thickness of sediment in core reflecting additional sediment added as a result of the capping exercise. Note scale of core schematic (each one is 2.7m) is not the same scale as bathymetry profile so should be used as a relative comparison only.

The data acquired under the 2012 survey have allowed us to determine the current contaminant concentrations of the CDM *in situ* and thus, an understanding of not only which contaminants can be regarded as reliable indicators of CDM (as opposed to non-CDM material) but the concentrations which it exhibits. This data has also allowed us to put into context the findings of previous monitoring undertaken using the Nioz core at a small number of stations. That is, we have some confidence that the elevated contaminant concentrations previously found were not CDM, rather relatively contaminated maintenance material (below ALs from the pre-dredged assessment samples). The 2012 data have revealed that (based on the 27 stations; we cannot unequivocally interpolate this to all sediments) the cap is still intact although there are some regions where the CDM is relatively near the sediment surface. Future monitoring should focus on monitoring the thickness of the cap in the south east area where the cap is currently thinner. This can be achieved using a Nioz corer and determining whether CDM is detected (and at what vertical depth) within the 20-30 cm that this sampling device readily penetrates. Assessment should be based on visual appearance of the various sediment sections, together with data regarding TBT, trace metals and PAHs.

## 2.3 Inner Tees (TY160)

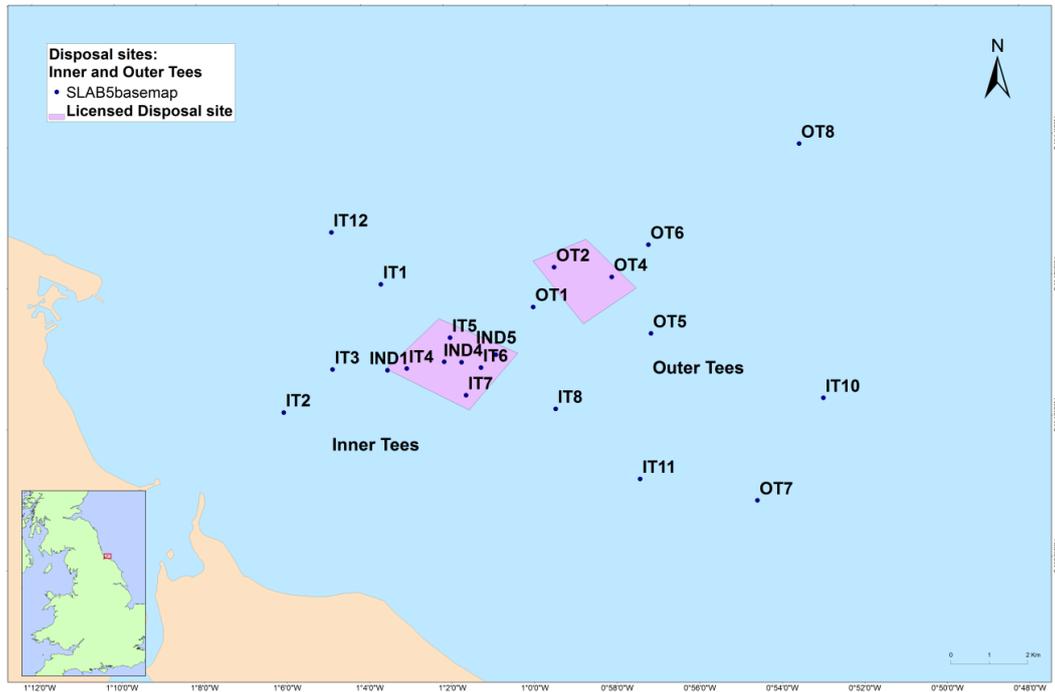


Figure A2.3.1. Location of sample stations at Inner Tees (IT and IND prefixes), 2012. The locations of stations previously sampled for the Outer Tees site (OT prefix) are also shown.

### 2.3.1 Background and issues

Previous surveys of Inner Tees disposal site showed the area to have a very homogeneous substrate of muddy sand. Some of the stations sampled within the disposal area showed evidence of previous spoil disposal with small lumps of black mud and black flecks present which were probably coal.

Inner Tees receives most of the 2.7 million tonnes of maintenance dredged material per year for the Tees Estuary, Seaton Channel and Hartlepool. In recent years the material to this site was seen to shoal at the western boundary. Therefore, since 2006, disposal has followed a more co-ordinated spatial sequencing to ensure that the whole site receives material.

There has been a number of high profile construction and dredging applications made under the FEPA/Marine Coastal and Access Act 2009 with regard to the Tees. It is anticipated that in addition to the 2.7 million tonnes of maintenance dredge there are currently three major disposal operations proposed for disposal to these two sites. The issue of a 3-year licence for the disposal of sand from a turning circle and silt/sand from a berth of Conoco Phillips LNG terminal was issued in December 2008 for disposal at the inner disposal site.

Permission has been given to permit Able UK to dismantle ships within a cofferdam. Additionally, to allow larger draft vessels, the Seaton Channel will be dredged and 2 million tonnes of material will be disposed of into the two Tees disposal sites. Permission has also been granted for the Northern Gateway container terminal which will include dredging of turning circles and berth pockets in the Tees, resulting in a 2 million tonne dredge. Due to the physical nature of some of the material it is anticipated that this material would be divided between the two disposal sites.

The Tees has a large quantity of chemical industries which have resulted in elevated levels of contaminants within dredged sediments. ICI, Titanium Dioxide factories and brominated flame retardant producers have all discharged into the Tees. Also, the analysis of dredge material from the Tees has resulted in some of the highest levels of polycyclic aromatic hydrocarbons found in the UK.

### **RAT prioritisation assessment: Tier 1**

- where a significant increase in the quantity of material disposed of has occurred.
- where there is the potential for the occurrence of elevated contaminant concentrations (between Cefas AL1 and AL2 in proposed dredge sediments) (Appendix 1) arising from historical or current activities at source (especially heavily urbanised/industrialised estuaries).
- where the material to be disposed of is very different (sediment type) to the receiving environment.

#### **2.3.2 Parameters to be assessed:**

Multibeam bathymetry and backscatter acoustic  
Sediment particle size  
Sediment contaminants (PAHs)

#### **2.3.3 Results**

##### 2.3.3.1 Multibeam bathymetry and backscatter

An acoustic survey was undertaken at Inner Tees dredged disposal site during November 2012 onboard the RV *Cefas Endeavour*. The acquisition of acoustic data (using a Kongsberg EM2040 dual head multibeam echosounder) enabled the characterisation of the disposal site and provided multibeam bathymetry and backscatter data of approximately 5 km<sup>2</sup> of seabed. Historic deposition at the site has led to the accumulation of disposal material in the south western edge of the boundary (Figure A2.3.2). This material is notably higher (5-10m) than the surrounding seabed, creating a raised dome 20 m below Chart Datum (CD). The average water depth at the site is approximately 30 m, with a gently sloping seabed to the north east, reaching approximately 40 m.

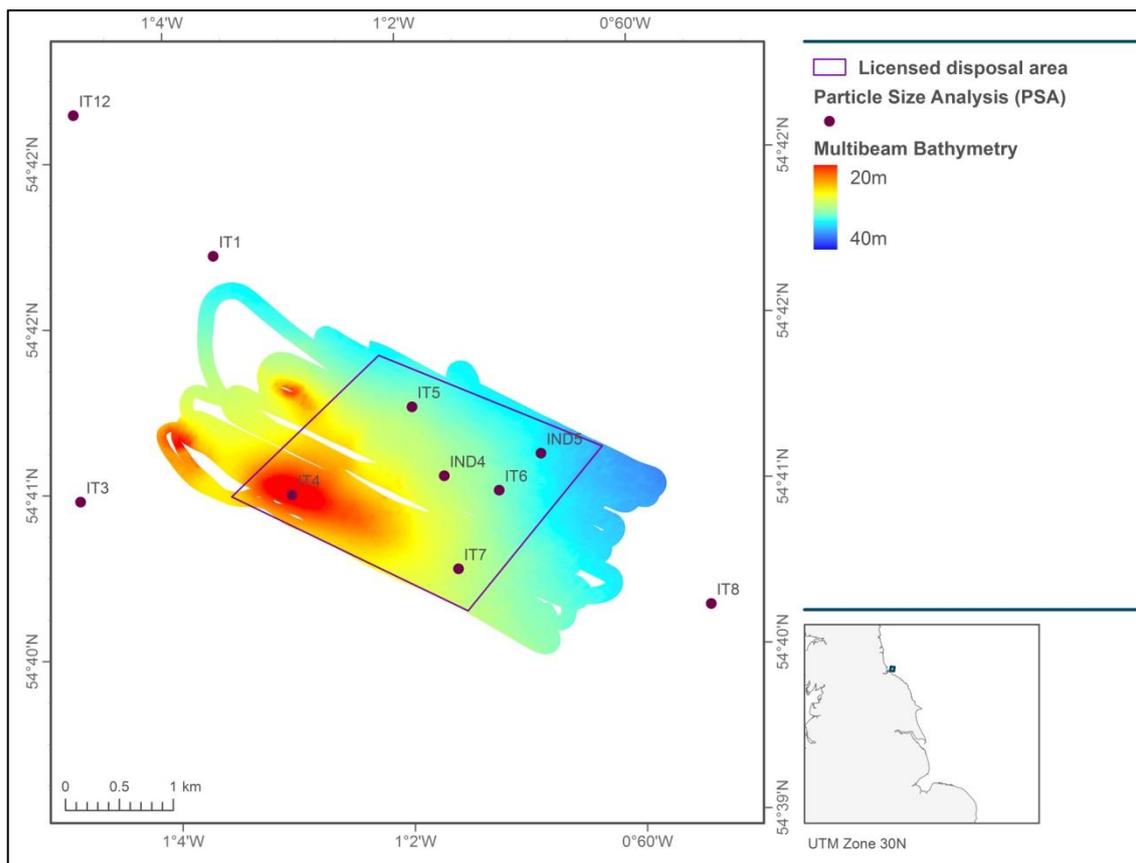
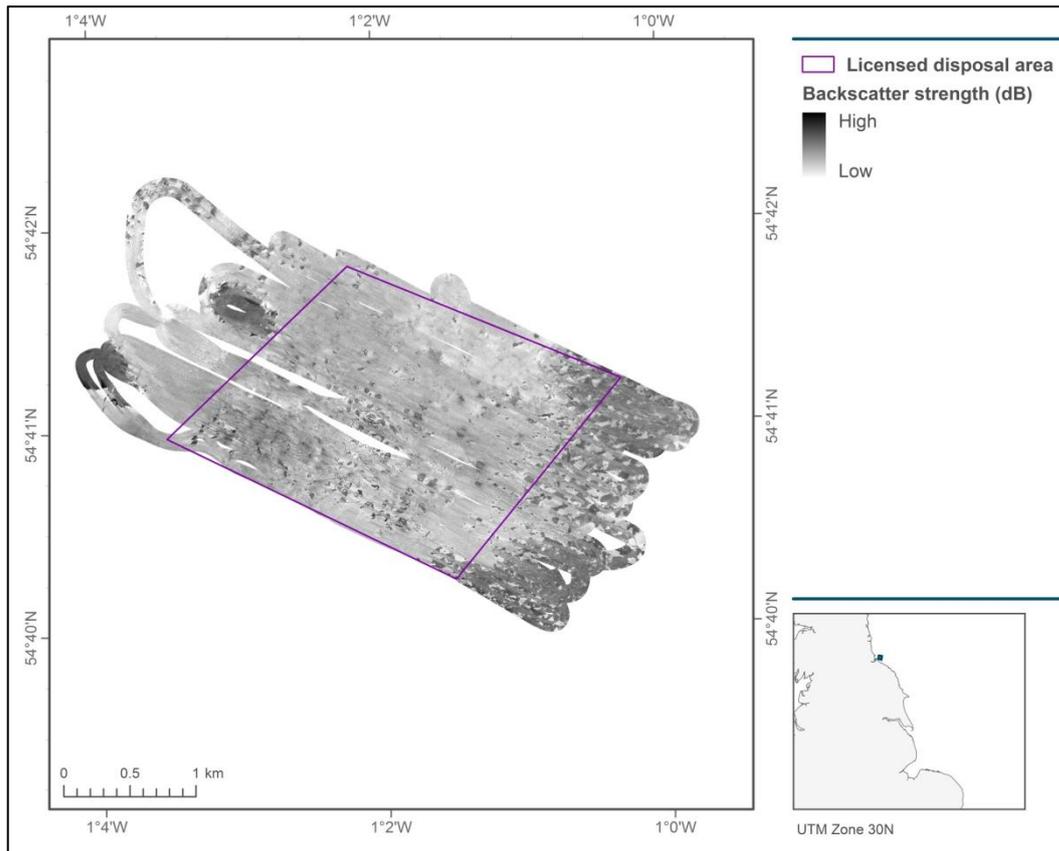


Figure A2.3.2. Multibeam bathymetry of Inner Tees dredged disposal site from the 2012 survey. Locations of the ten stations sampled for ground-truthing are indicated.

Ten Particle Size Analysis (PSA) samples were collected from the site using a Day Grab (Figure A2.3.2); six from within the disposal area and four outside the licensed boundary. The PSA data were used to aid (or ground truth) the acoustic interpretation.

The multibeam backscatter data (Figure A2.3.3.3) derived from the multibeam echosounder shows a higher backscatter return from sediments outside of the disposal site. The area to the east has a mottled signature indicating an area of mixed and coarse substrates, heterogeneous in nature. The majority of the site has a low backscatter return, suggesting a uniform seabed. The area associated with the disposal activity, indicated by a raised seafloor in the multibeam bathymetry, has a mixed substrate and therefore emits numerous high and low backscatter returns. Comparison of the multibeam backscatter between 2010 and 2012 shows that, although some changes in the nature of the seabed have taken place, the extent of certain sediments have remained the same, including the sandy mud located to the east of the boundary.



*Figure A2.3.3. Multibeam backscatter of Inner Tees dredged disposal site from the 2012 survey.*

Figure A2.3.4. presents the yearly multibeam backscatter comparison from 2008-2012 (excluding 2011 when no data were collected). The overall nature of the seabed at Inner Tees dredge disposal site has remained the same during this period: the main impacted area has retained a higher backscatter reflectivity than the surrounding seabed and can clearly be identified from each of the four years. It is important to factor certain disparities between the backscatter results, for example the multibeam echosounder employed to acquire the data changed for the 2012 survey. The setting used to process the backscatter data can also vary from year to year, although this would not affect the overall results it can impact on the colour ranges and therefore cause the high and low returns to appear different.

Figure A2.3.5. provides a detailed comparison of two backscatter data sets from 2009 and 2012. The 2009 survey was chosen for comparison based on the area of interest i.e. disposal material placement, as it clearly demonstrates the extension of the material to the south east of the disposal boundary. The 2009 survey is clearly void of material to the south east whereby in the backscatter data collected in 2012 there is a large accumulation of coarse material present.

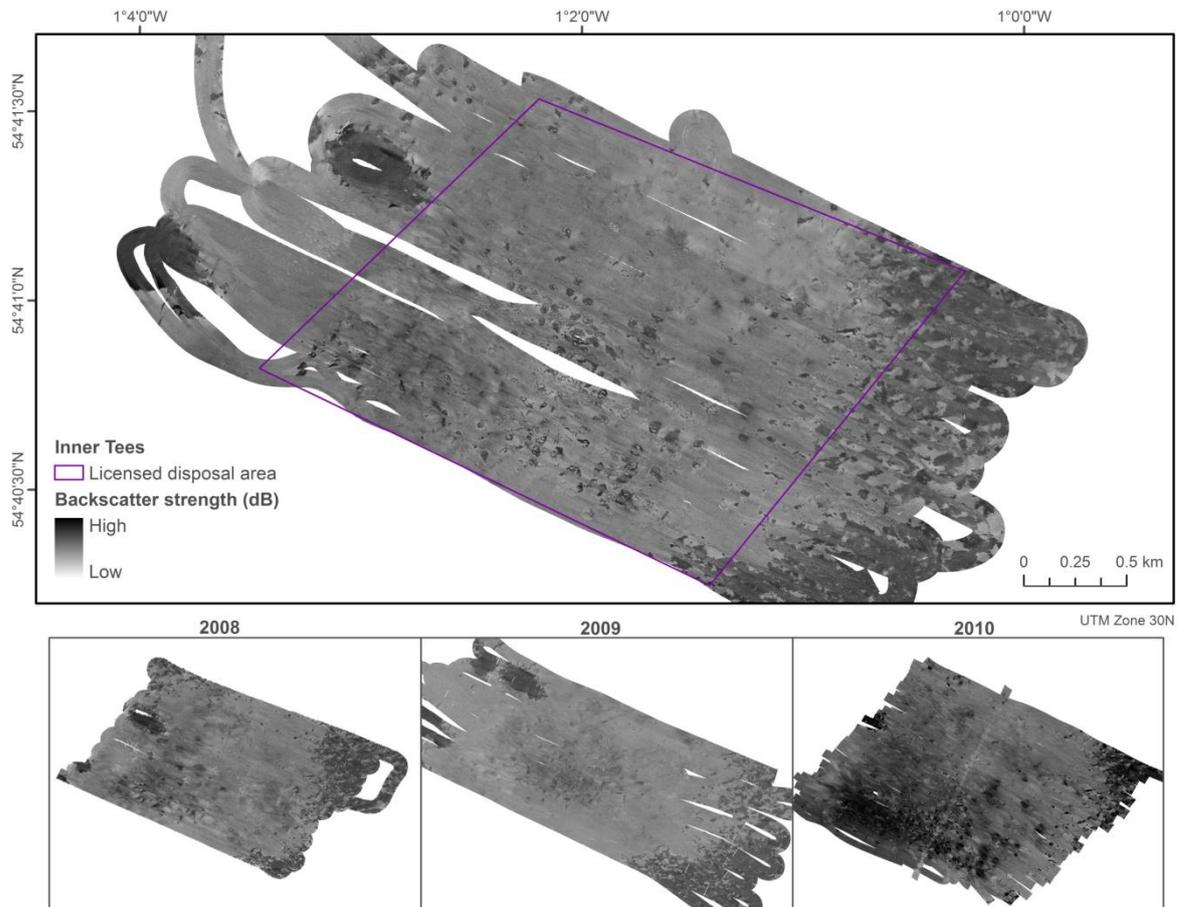


Figure A2.3.4. Comparison of the multibeam backscatter results for the acoustic surveys undertaken in 2008, 2009, 2010 and main image 2012.

The area is mainly comprised of slightly muddy sand with the main disposal area containing a higher gravel percentage than the surrounding sediments (Figure A2.3.6). The temporal comparison of the slightly gravelly muddy sand associated with the dredged disposal material shows very little change when compared to the 2010 interpretation outline. Figure A2.3.6 also illustrates the disposal outline overlaid on the interpreted layer from 2012, the red line identifying the extent of the main impacted area from the 2010 survey. The majority of the material has remained in the same location suggesting a more compacted nature with a minor change to its overall shape.

In summary, the seabed at the Inner Tees dredged material disposal site has a varied sediment composition and there has generally been very little change in the constituents that make up the site. When comparing the 2012 data with that of 2008, 2009 and 2010 there are no obvious distinct changes other than the expected increase in material within the site.

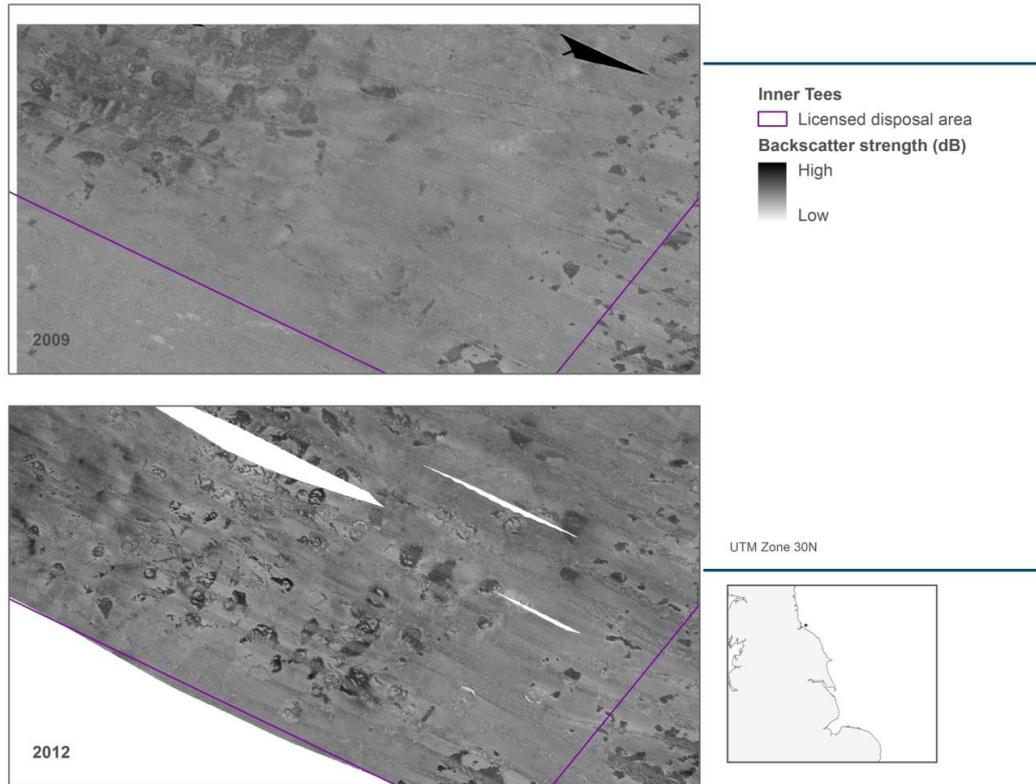


Figure A2.3.5. Detailed comparison of the 2009 (top) and 2012 (bottom) multibeam backscatter of the southeast sector of the licensed disposal area.

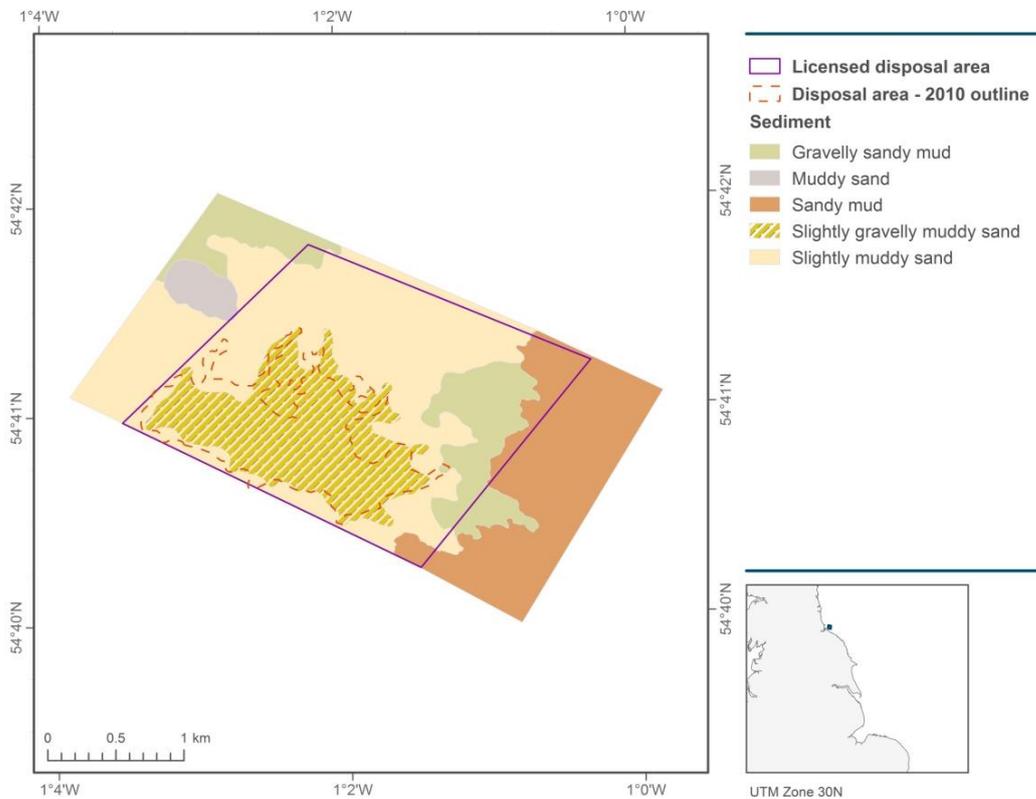


Figure A2.3.6 Interpretation of the Inner Tees 2012 survey with the outline of the 2010 disposal area overlaid in red hash.

### 2.3.3.2 Sediment particulate size

Inner Tees sediments are predominantly muddy sands and unimodal sands, with small but varying amounts of gravel (Table A2.3.1). IND1, IND2, IT2 and IT10 were not sampled in 2012 (a vessel was anchored at the site (IND1 and IND2) and hard ground (IT2 and IT10) were the reasons). Temporal changes in sediment groups are shown in Table A2.3.2 for each sample code from 2006 to 2012 inclusive. Most stations have shown very little change in sediment group in 2012, displaying the same or adjacent sediment group to previously. The only exceptions were IND4 (inside the disposal site; InT3a to InT4a) due to elevated sand component, IT1 northwest of the site (InT2 in 2011 to InT1b in 2012) and IT3 to the west of the site (InT4b in 2011 to InT3c in 2012) which have both become more muddy in composition.

*Table A2.3.1 Average sediment descriptions (top) and statistics for each sediment group (bottom) at Inner Tees, 2012.*

Sediment group	Number of samples	Sample Type	Sediment description					
InT1a	1	Unimodal, Poorly Sorted	Slightly Gravelly Mud					
InT1b	5	Bimodal, Poorly Sorted	Slightly Gravelly Muddy Sand					
InT2	3	Polymodal, Very Poorly Sorted	Gravelly Muddy Sand					
InT3a	26	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand					
InT3b	9	Unimodal, Moderately Sorted	Slightly Gravelly Muddy Sand					
InT3c	9	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand					
InT4a	17	Unimodal, Moderately Sorted	Slightly Gravelly Sand					
InT4b	11	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand					

Sediment group	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)
InT1a	0.04	0.34	99.61	0.03	0.02	0.03	0.13	0.13
InT1b	0.21	51.84	47.95	0.32	1.09	2.72	8.57	39.13
InT2	21.15	61.81	17.03	14.33	16.98	10.26	6.51	13.73
InT3a	0.41	85.67	13.92	0.64	1.86	5.62	35.10	42.47
InT3b	0.59	82.87	16.54	0.50	1.00	2.33	11.94	67.10
InT3c	2.57	79.75	17.67	3.47	8.29	15.49	34.62	17.89
InT4a	1.34	93.30	5.36	1.66	3.86	10.03	50.18	27.58
InT4b	0.14	97.92	1.94	0.43	1.84	13.85	67.64	14.16

Figure A2.3.7 reveals the predominantly sandy nature of the sediment across the survey area in 2012 with some stations (particularly those outside the disposal area) displaying a higher silt/clay component. Silt/clay content in a subset of dredged sediments for licensing applications to dispose of at the Inner Tees site was 66% ( $\pm 8\%$ , 95% CI). Most monitoring

samples contained less silt/clay than this, except sediments in sediment group InT1, suggesting that the finer fractions of the material are being dispersed following disposal.

Table A2.3.2 Sediment groups for each sample code (2006-12) at Inner Tees.

Sample code	Year						
	2006	2007	2008	2009	2010	2011	2012
IND1	InT3a	InT3a	InT4a	InT3a	InT3a	InT3a	n
IND2	InT4b	InT4a	InT4b	InT1a	InT3c	InT4b	n
IND4	n	InT4a	InT3a	InT3a	InT4a	InT3a	InT4a
IND5	n	InT4a	InT4b	InT4b	InT4b	InT4b	InT4b
IT1	InT3a	InT3a	n	InT3b	InT3b	InT2	InT1b
IT2	n	n	n	InT4b	InT4b	n	n
IT3	InT4a	InT1b	InT3c	n	InT1b	InT4b	InT3c
IT4	InT3a						
IT5	InT4a	InT3a	InT4a	InT4a	InT3a	InT4a	InT4a
IT6	InT4a	InT3c	InT3c	InT3a	InT4a	InT4a	InT4a
IT7	InT3a	InT4a	InT3a	InT3a	InT3a	InT3a	InT3a
IT8	InT3b						
IT10	InT3c	InT3c	InT3	InT3c	InT4	InT3c	n
IT11	n	n	n	n	n	n	InT1b
IT12	n	n	n	n	n	n	InT1b

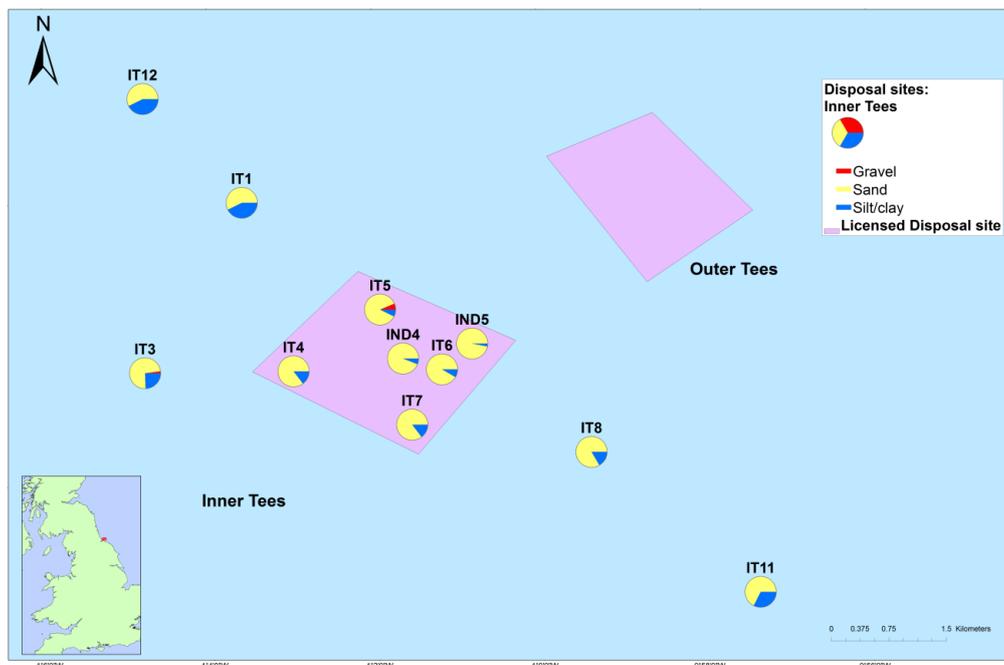


Figure A2.3.7. Pie charts of gravel, sand and silt/clay at Inner Tees, 2012.

### 2.3.3.3 Sediment contaminants

#### 2.3.3.3.1 PAHs

Figure A2.3.8 presents the summed PAH concentrations ( $\mu\text{g kg}^{-1}\text{dw}$ ) for stations sampled in 2012 around the Inner Tees disposal site (top) and concentrations observed during 2009-2012 (bottom). The highest summed PAH concentration of  $92,200 \mu\text{g kg}^{-1}\text{dw}$  was found at IT6 on the central eastern transect of the disposal site in 2012. In 2011, the highest concentration was found at IT7 at the southern part of the disposal site ( $132,000 \mu\text{g kg}^{-1}\text{dw}$ ), but in 2012 was found to be much lower ( $67,900 \mu\text{g kg}^{-1}\text{dw}$ ). A high summed PAH concentration was also found at IT11, approximately 4.5 km to the southeast of the disposal site,  $77,500 \mu\text{g kg}^{-1}\text{dw}$ . IT11 is close to the Outer Tees disposal site survey station OT7 which, in previous years, has seen summed PAH concentrations as high as  $270,00 \mu\text{g kg}^{-1}\text{dw}$  (2008) and as low as  $38,700 \mu\text{g kg}^{-1}\text{dw}$  (2010). The lowest summed PAH concentration found in 2012 was located towards the eastern tip of the disposal site, at IND6, with a summed PAH concentration of  $22,300 \mu\text{g kg}^{-1}\text{dw}$ .

Sediments from all sampling stations were found to exceed the ERL and ERM for LMW PAHs. The ERL for the HMW PAH was breached at all stations except IND4, IND5 and IT5, which are located in the northern half of the disposal site. No station exceeded the ERM for the HMW PAHs. There was no disposal activity to Inner Tees during 2011-12, which could account for the lower concentrations seen at most of the disposal ground sampling points.

Evaluation of the PAH data indicated that the predominant source in all the sediment samples was petrogenic, with  $> 87\%$  of the PAH content arising from oil sources. The phenanthrene/anthracene (P/A) ratio was greater than 10 at stations IND4, IND5, IT3, IT5, IT6 and IT7, which is indicative of a predominantly petrogenic source.

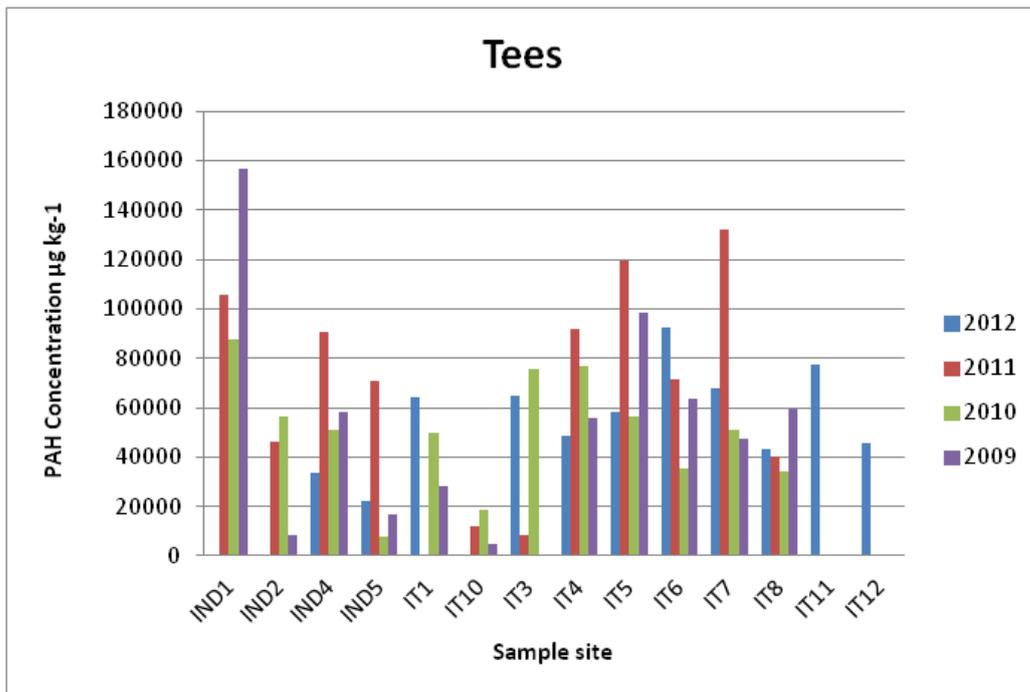
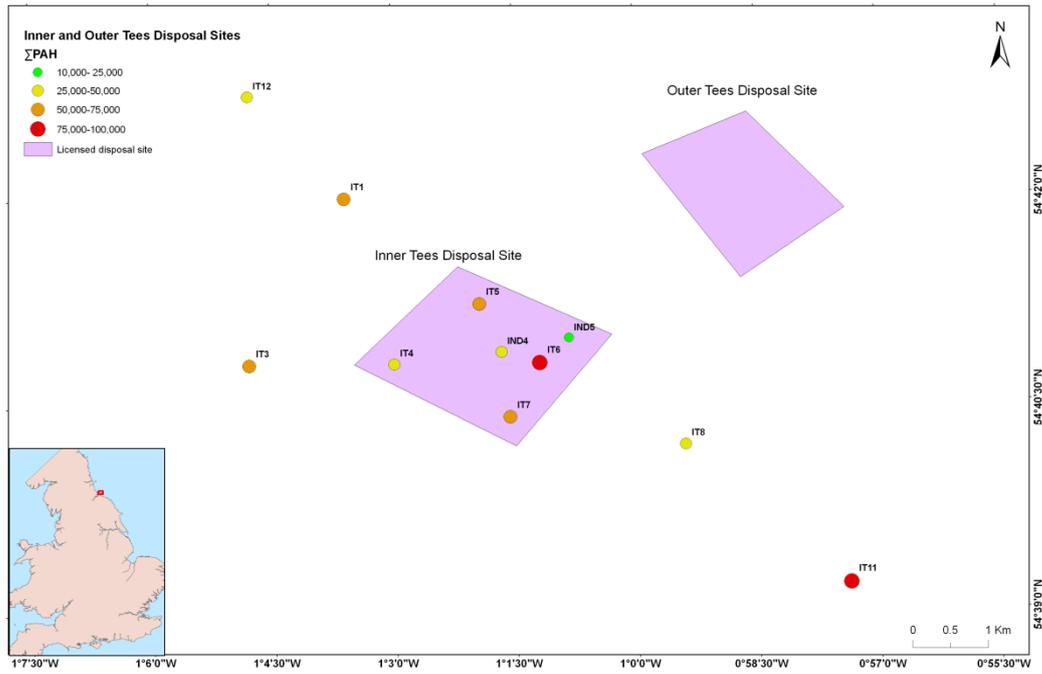


Figure A2.3.8. Summed PAH concentrations ( $\mu\text{g kg}^{-1}\text{dw}$ ) for stations sampled in 2012 at Inner Tees (top) and concentrations observed between 2009 and 2012 (bottom).

## 2.4 Goole (HU041)

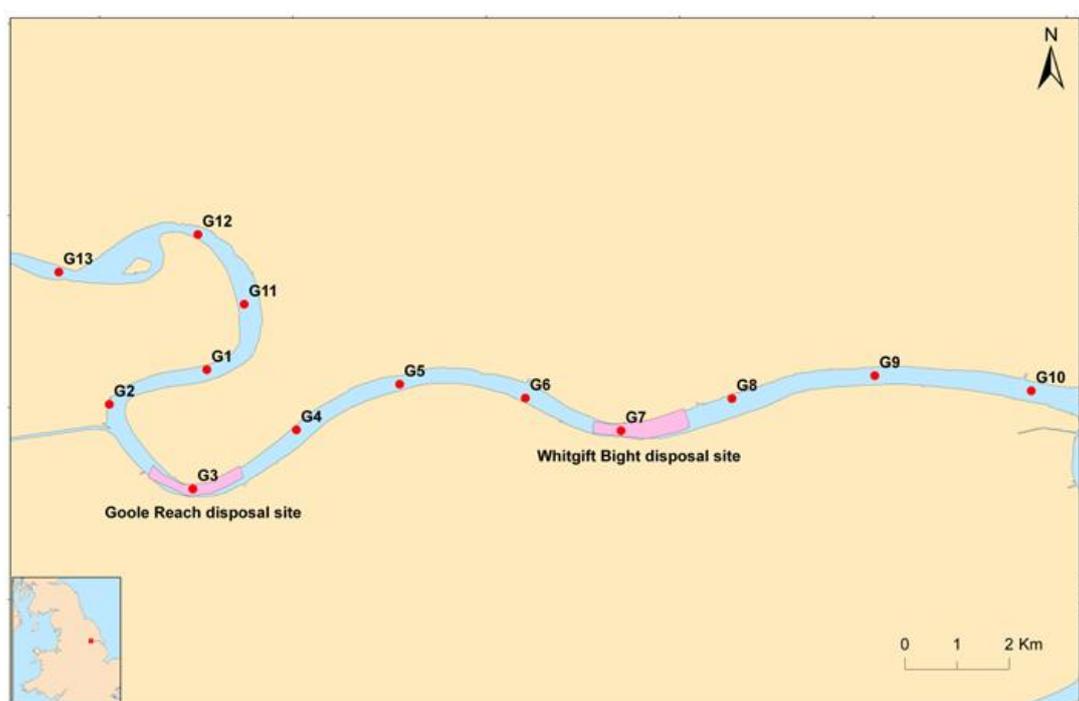


Figure A2.4.1. Location of the 13 sampling stations at Goole (River Ouse, Humber Estuary), 2012.

### 2.4.1 Background

Goole Reach (HU041) and Whitgift Bight (HU040) are both located on the River Ouse, in the Humber Estuary. This is a dynamic area and material is rapidly dispersed and diluted within the estuary. HU040 was opened in 1982, although disposal did not commence until 1984, while disposal first took place at HU041 in 1990. Maintenance dredged material (sand and silt/clay) from Goole docks is disposed of to these sites. The docks have a current disposal licence for the disposal of 49,000 tonnes (37,690 m<sup>3</sup>) of maintenance dredged material. Dredging operations take place around high water, with the disposal of approximately 1100 tonnes per tide.

These disposal sites were targeted for sampling under SLAB5 as the dredged material (prior to dredging) from Goole docks shows elevated levels of PAH. Sampling at, and adjacent to, the disposal sites under SLAB5 during 2010 and 2011 revealed high levels of PAHs and DDT. The survey undertaken in 2011 included an increased number of stations with increased spatial cover for this part of the Humber to provide a further assessment of the concentrations of these contaminants: the 2012 survey maintains this increased spatial survey for these contaminants.

## RAT prioritisation assessment: Tier 1

- Where there is the potential for the occurrence of elevated contaminant concentrations (between Cefas action levels of 1 and 2 in proposed dredge sediments) arising from historical or current activities at source.

### 2.4.2 Parameters monitored (via non-Cefas charter vessel):

Sediment particle size  
Sediment organic carbon and nitrogen  
Sediment contaminants (TBT, PAHs)

### 2.4.3 Results

#### 2.4.3.1 Sediment particle size

Goole sediments are predominantly muddy sands (Table A2.4.1). Changes in sediment groups from 2008 to 2012 are shown in Table A2.4.2; such changes in 2012 compared with 2011 include an increase of fines at G1 (towards the top of the river), G7 (within Whitgift Bight disposal site) and G9 (close to the entrance to the Humber), and a decrease of fines at G2 (towards the top of the river), G3 (within Goole Reach disposal site) and G6 (further up river to the Whitgift Bight disposal site).

Pie charts of gravel, sand and silt/clay for 2012 (Figure A2.4.2) reinforce the above findings of the predominantly sandy nature of the sediments, with increased proportions of silt/clay at several stations (i.e. those in sediment group Go1).

*Table A2.4.1 Average sediment descriptions (top) and statistics for each sediment group (bottom) at Goole, 2012.*

Sediment group	Number of samples	Sample Type			Sediment description			
Go1	11	Bimodal, Poorly Sorted			Slightly Gravelly Sandy Mud			
Go2	24	Unimodal, Moderately Sorted			Slightly Gravelly Muddy Sand			
Go3a	10	Unimodal, Moderately Well Sorted			Slightly Gravelly Sand			
Go3b	4	Unimodal, Moderately Sorted			Slightly Gravelly Sand			
Sediment group	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)
Go1	0.00	42.73	57.26	0.04	0.23	0.36	3.17	38.93
Go2	0.01	85.63	14.36	0.02	0.09	1.22	11.47	72.82
Go3a	0.01	96.81	3.19	0.02	0.11	3.87	58.09	34.74
Go3b	2.06	96.08	1.86	1.26	8.26	53.89	27.66	5.01

Table A2.4.2 Sediment groups for each sample code in 2008, 2010, 2011 and 2012 at Goole.

Sample code	Year			
	2008	2010	2011	2012
G1	Go3a	Go1	Go3a	Go2
G2	Go2	Go2	Go1	Go2
G3	Go2	Go2	Go1	Go2
G4	Go3a	Go3b	Go3a	Go3a
G5	Go2	Go1	Go1	Go1
G6	Go3b	Go3a	Go1	Go2
G7	Go2	Go2	Go3a	Go2
G8	Go3a	Go2	Go1	Go1
G9	Go3b	Go3a	Go3a	Go2
G10	Go1	Go2	Go1	Go1
G11		Go1	Go2	Go3b
G12		Go2	Go2	Go2
G13		Go2	Go2	Go2

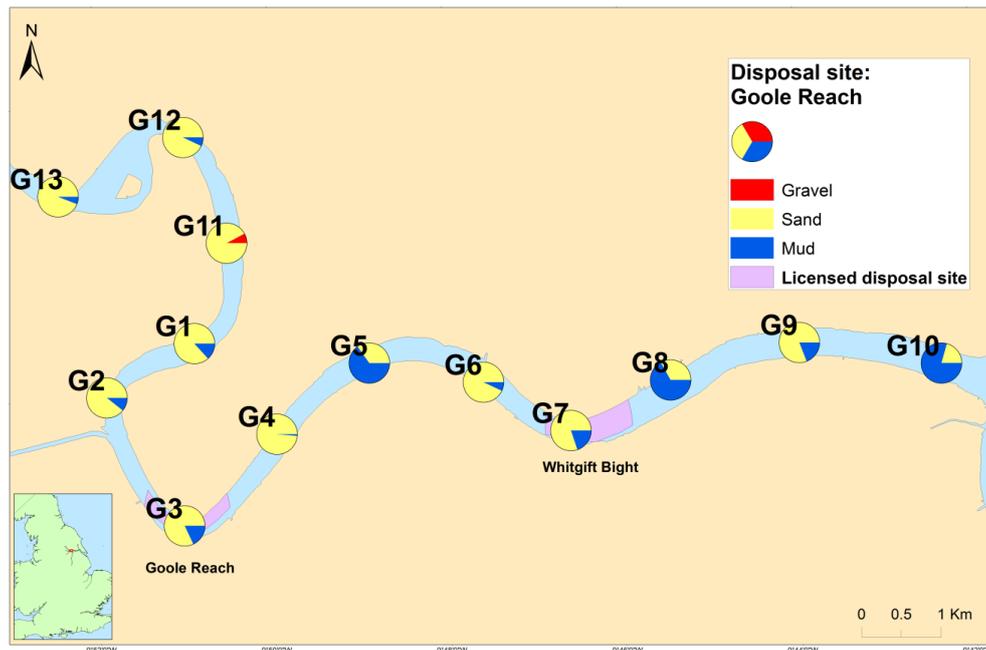


Figure A2.4.2 Pie charts of gravel, sand and silt/clay at Goole in 2012.

#### 2.4.3.2 Sediment organic carbon and nitrogen

Organic carbon values in 2012 (in the < 2 mm fraction) ranged from 0.33 to 4.13% (Figure A2.4.3) and from below detection (<0.03%) to 0.18% for nitrogen. These data indicate that organic carbon contents are higher notably at G11 when compared to concentrations measured previously in this area (Bolam et al., 2009, 2011).

Black carbon, a component of organic carbon, was also measured in 2012. It is believed the black carbon within organic carbon absorbs organic contaminants such as PAHs, and effectively reduces their availability in the environment. In general, black carbon content in sediment samples from Goole (Figure A2.4.4) are low (< 0.2%). There are only two samples with black carbon content below limits of detection, G5 and G11. The ratio of black carbon to organic carbon for both of these is 0.08% for G5 and 0.11% for G11. More work on use of this parameter for monitoring assessments is expected in future years.

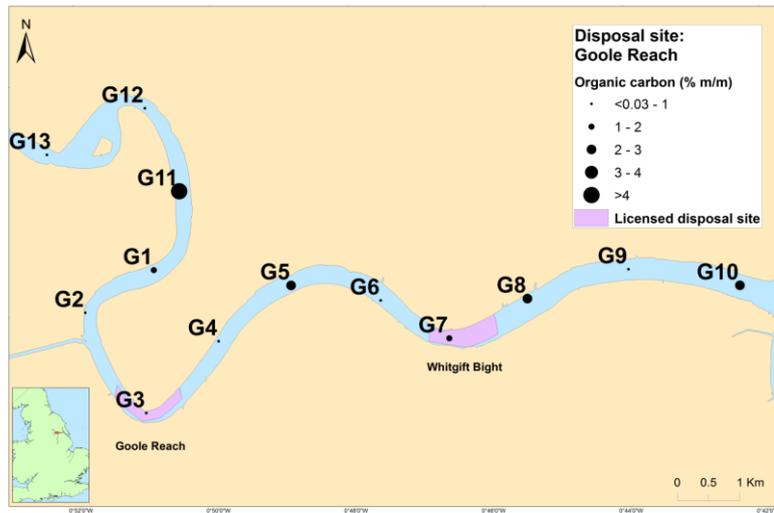


Figure A2.4.3. Organic carbon (%) in the < 2 mm fraction at Goole, 2012.

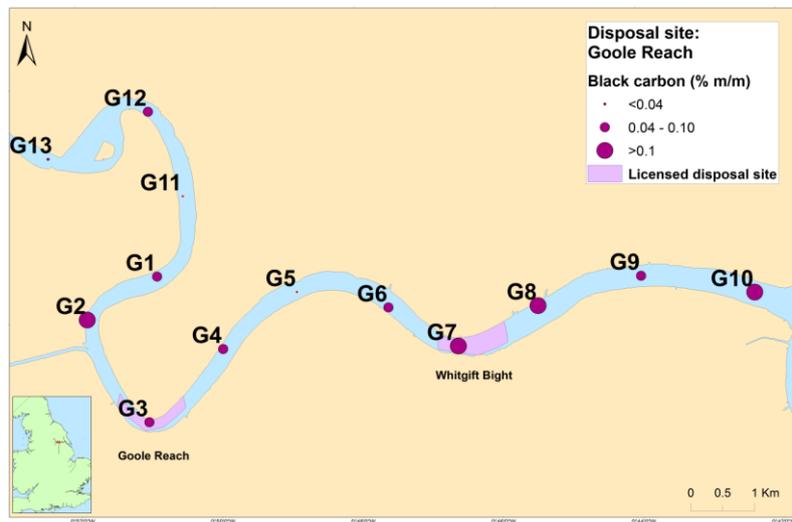


Figure A2.4.4. Black carbon (%) in the < 2 mm fraction at Goole, 2012.

### 2.4.3.3 Sediment contaminants

#### 2.4.3.3.1 TBT

Sediments from all the stations sampled at Goole 2012 exhibited TBT concentrations below limit of detection. TBT concentrations at the Goole stations have consistently been low, with

all but two stations (G5 and G8) sampled during 2011 displaying concentrations below the limit of detection. Concentrations at G5 and G8 in 2011 were 0.012 and 0.016 mg/kg respectively, which are both below Action Level 1 for TBT. Thus, the 2012 data indicate a further reduction in TBT concentrations along the Goole survey area, continuing the trend previously observed here under SLAB5 and consistent with the national pattern of declining TBT levels (Bolam et al., 2014).

#### 2.4.3.3.2 PAHs

The highest summed PAH concentration was found at G11 (107,300  $\mu\text{g kg}^{-1}$  dw) situated upstream from Goole Reach disposal site (Figure A2.4.5). The second highest concentration was observed at G5 (45,900  $\mu\text{g kg}^{-1}$  dw) situated midway between the two disposal sites. Disposal of maintenance dredged material at HU040 during 2011 increased at Whitgift Bight to 12,250 tonnes (from 2,230 tonnes in 2010) which could account for increases in concentration found downstream from the disposal site. Because this area is affected by strong tidal currents, concentrations may reflect redistribution of both river bed sediments and material arising from dredgings disposal. There was no maintenance dredging disposal at Goole Reach during 2011 which could account for a decrease in summed PAH concentrations at G3 and G2 during the 2012 survey.

The ERL for LMW PAHs was exceeded at all stations except G4, G6, G12 and G13, where the summed PAH concentrations were less than 3,600  $\mu\text{g kg}^{-1}$  dw. The ERM for LMW PAHs was exceeded only at G5, G8 and G11. The ERL for HMW PAHs was also exceeded at G5, G8, and G11. G11 was the only station to breach the ERM for HMW PAHs. The source of PAH was found to be > 70% oil-derived at G1, G2, G3, G5, G7 and G9, with a more mixed oil/combustion source evident for the other stations sampled.

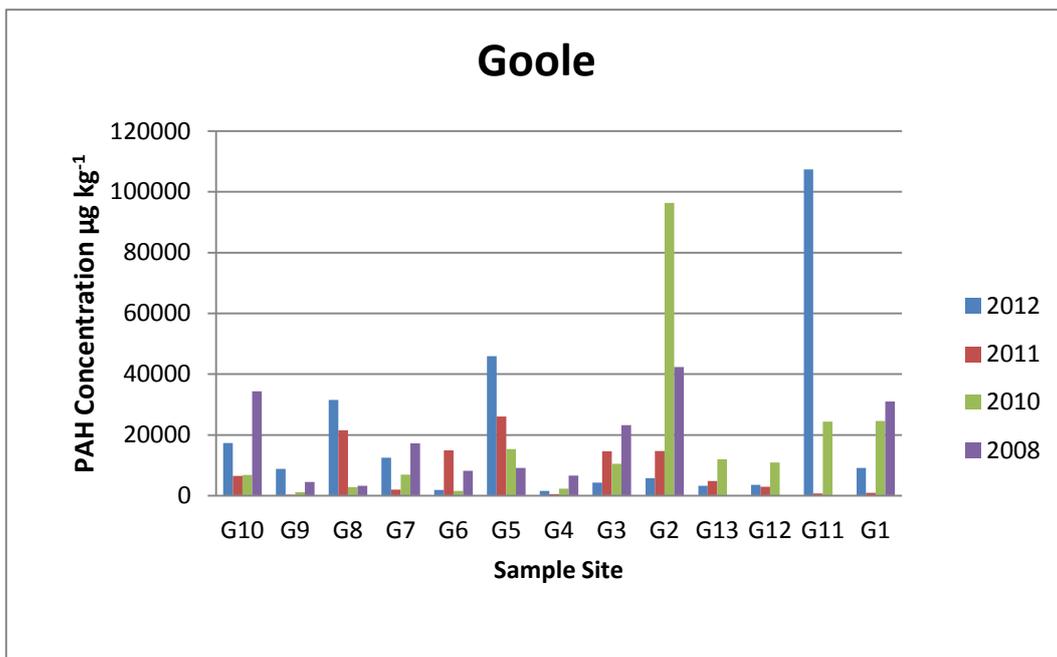
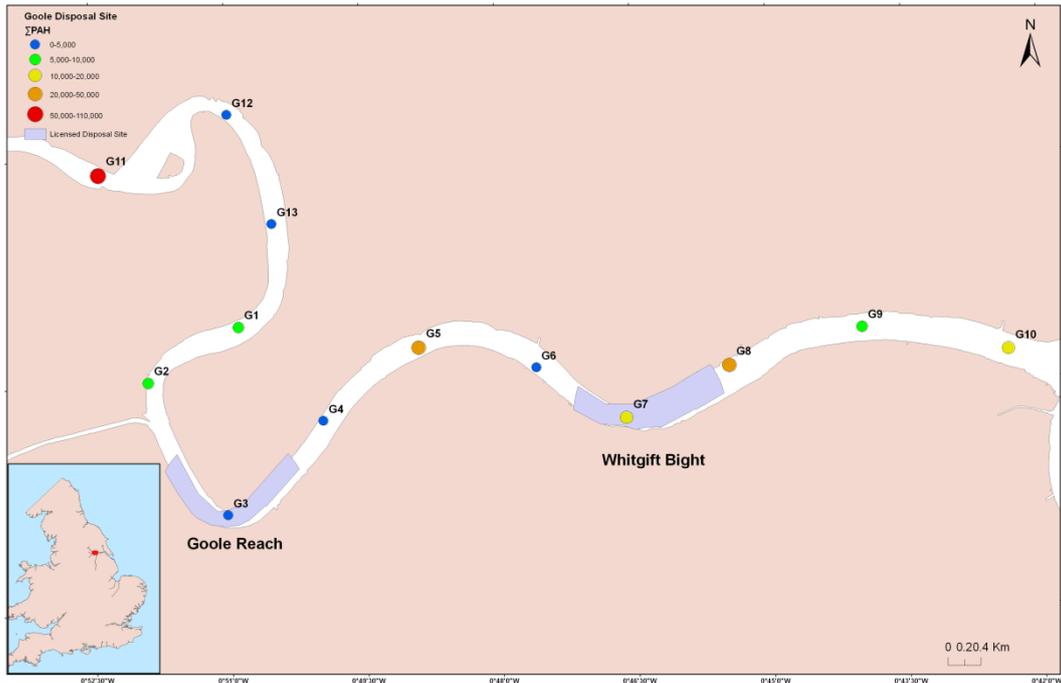


Figure A2.4.5. Summed PAH concentrations ( $\mu\text{g kg}^{-1}$  dw) for Goole stations sampled in 2012 (top), and concentrations observed in 2008, 2010, 2011 and 2012 (bottom).

## 2.5 Inner Gabbard East (TH056)

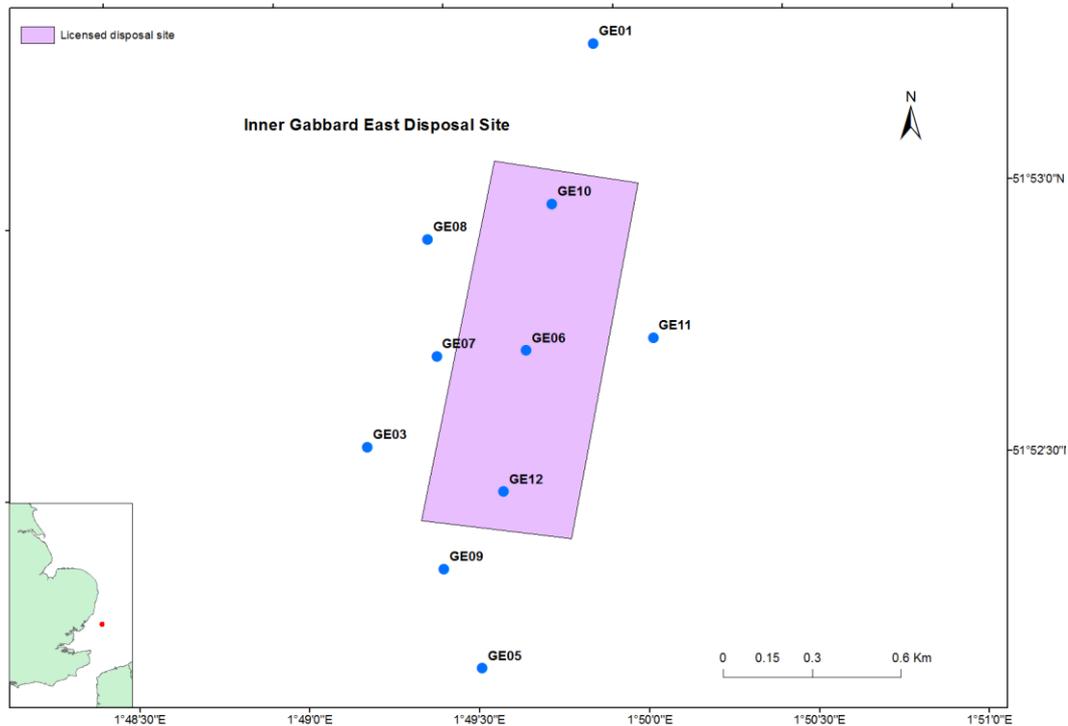


Figure A2.5.1. Map showing the position of the stations sampled for ground-truthing at Inner Gabbard East, 2012.

### 2.5.1 Background

Inner Gabbard East (TH056) is a relatively new site characterised by Harwich Haven Authority (HHA) to take consolidated capital dredged material from the proposed container port development at Bathside Bay and the Felixstowe South Redevelopment (FSR). The site is broadly similar in terms of wave and tidal flow climates and bed conditions to the existing Inner Gabbard (TH052) disposal site, being characterised as fairly featureless, with flat sand and gravel beds. The main difference is depth; TH056 encompasses an elongated depression in the seabed approximately 55 m deep.

Dispersion of material from the IGE site resulting from the FSR operation was not seen as a major issue, however, it was proposed that dispersion would be minimised by making a series of placements at one location, creating localised mounds and effectively trapping material in the lower layers. As the location of the disposal site is in an elongated depression trending north to south, it was also proposed to form bunds to the northern and southern ends of the site at the start of the disposal operations; these would consist of more consolidated material and would form less 'erodable' ends to the deposit, providing some shelter from the prevailing

currents and a measure of constraint to what would be more mixed material (sand/ clay/ stone) which would be placed between. The bunds would also prevent possible downslope movement of clay subsequently placed. Conditions were placed on the licence to ensure that the disposal was carried out as described.

However, more of the dredged material from the FSR was suitable for use in the reclamation than previously planned and so the amount of material going to TH056 was less than anticipated. In addition, as a result of changes to the dredging methodology, more of the material destined for the IGE site, and particularly most of that dredged at first, was likely to be finer material, containing a mixture of sands, clays and smaller stone pieces. Therefore it was not possible to form initial bunds at the ends of the site. License conditions were amended so that material would initially be placed evenly over the site with more consolidated material deposited at the ends later in the operation. As a result of these changes, monitoring was required to ensure that the disposal operation was carried out as per the licence conditions, and to determine whether the deposited material is remaining where deposited or being eroded.

An acoustic multibeam (bathymetry and backscatter) survey was undertaken at IGE under SLAB5 during 2009 and repeated during 2010 and 2011. Additional data acquired during 2012 improves the ongoing assessment regarding the fate of the disposed material and whether licence conditions are met. Additionally, the value of such data has been enhanced since deposits of material from the London Gateway Project were accepted for this site in 2011 (1.25MT) of capital dredge material from the approach channel of the London Gateway.

#### **RAT prioritisation assessment: Tier 1.**

- where a significant increase in the quantity of material disposed of has occurred (*new site*)
- where specific concerns have been raised
- that have been observed or pose an increased risk to the surrounding area and receptors

**2.5.2 Parameters monitored:** Sidescan and multibeam  
Sediment particle size

#### **2.5.3 Results**

##### 2.5.3.1 Sidescan and multibeam

The IGE site was surveyed using the RV *Cefas Endeavour* in June 2012 using a Kongsberg EM2040 multibeam echosounder. The acoustic coverage extended outside of the licensed disposal site to provide a larger extent of the survey area, allowing detection of any potential

disposal activity outside of the site boundary. Bathymetry data were processed employing CARIS HIPS and SIPS 7.1 SP2 and backscatter mosaics were produced using QPS Fledermaus Geocoder Toolkit (FMGT) software.

The seabed within the disposal site boundary itself is relatively flat and homogeneous. The average water depth within the boundary is 35 m below chart datum (CD). The bathymetry presented in Figure A2.5.2 contains a vertical exaggeration of 5x to accentuate any vertical features on the seabed (without the exaggeration, bathymetric features would be too small to visually identify relative to the horizontal scale). The site is characterised by a central channel running in a more-or-less north to south orientation with a depth of 55 m, rising to 35 m to the southwest of the site.

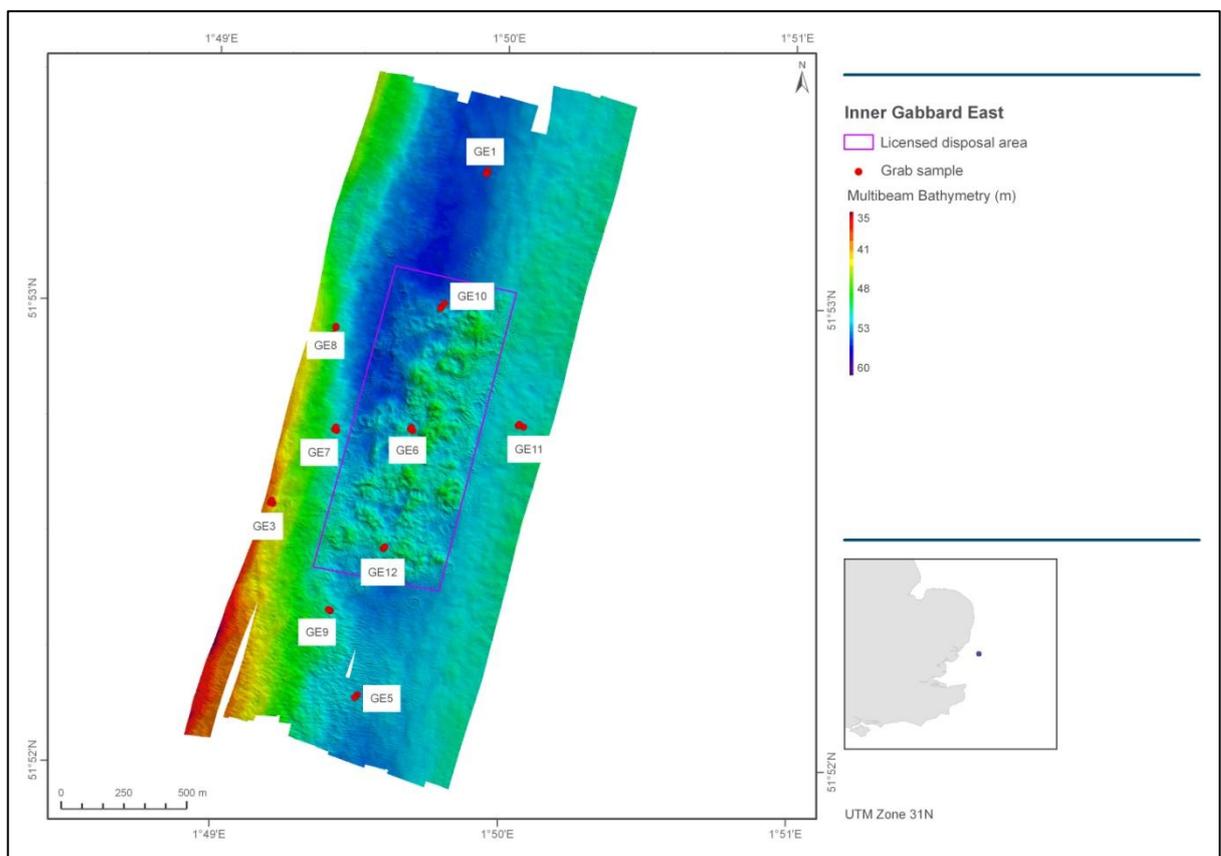


Figure A2.5.2. Inner Gabbard East seabed bathymetry, June 2012. Locations of sampling stations for ground truthing are also displayed (red dots).

In addition to the acoustic multibeam bathymetry and backscatter data, seabed samples from 10 locations (Figure A2.5.2) for particle size analysis were gathered via a 0.1m<sup>2</sup> Day Grab (three replicates) to improve the interpretation of the acoustic data. The position of two ground truthing stations (GE3 and GE9) were relocated from previous years for the 2012 survey to enable better coverage across the site, this included the capture of varying

sediment types on the seabed. In addition to the substrate analysis provided by the particle size results, *in situ* sediment descriptions were used to aid interpretation.

The backscatter data collected allows analysis of the seabed sediment type to be carried out. The return signal can be analysed to determine the intensity and therefore type and uniformity of the seabed from which it was emitted. The majority of the seabed surrounding IGE has a homogeneous backscatter intensity indicating a medium return (Figure A2.5.3). The differences in depth highlighted on the multibeam bathymetry is absent from the backscatter results, indicating a sediment type of a similar nature across the acoustic coverage. The seabed within and directly associated with the disposal site has a varied backscatter signature with a mixture of high and low intensity returns. Features likely to be associated with dredged material disposal activity can be seen to the west and north of the license boundary, producing a low backscatter return. Directly to the southwest of the licensed area is an area of low backscatter return and sand ripple features can be clearly seen.

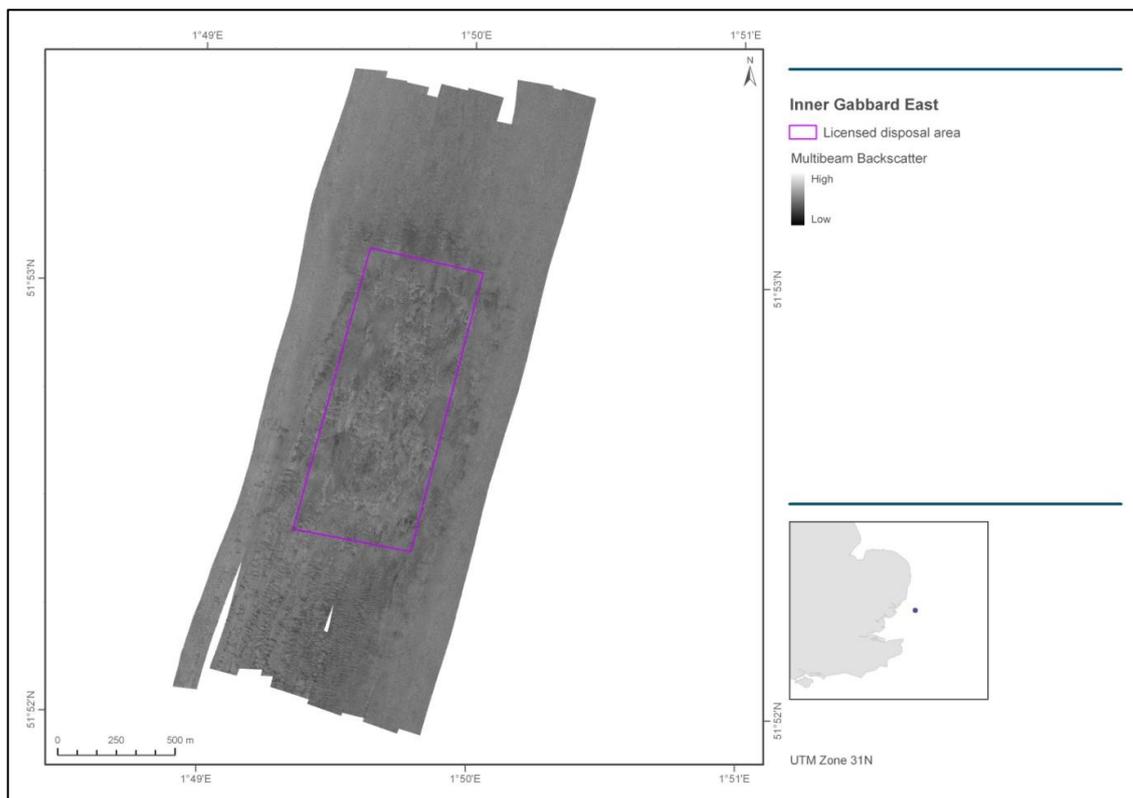


Figure A2.5.3. Multibeam backscatter acquired at Inner Gabbard East, June 2012.

The interpreted data layer for the acoustic region is shown in Figure A2.5.4. The sediments associated with IGE are of a similar nature, mainly comprised off gravelly muddy sands and lightly muddy sandy gravel. The seabed to the north and east of the licensed boundary is mainly comprised of muddy sandy gravel; this is also the case for the west of the site but with the addition of higher percentages of mud. The area to the south consists of slightly gravelly

muddy sand, supported by the particle size data (see Section 2.5.3.2) and the appearance of sand ripples on the multibeam backscatter.

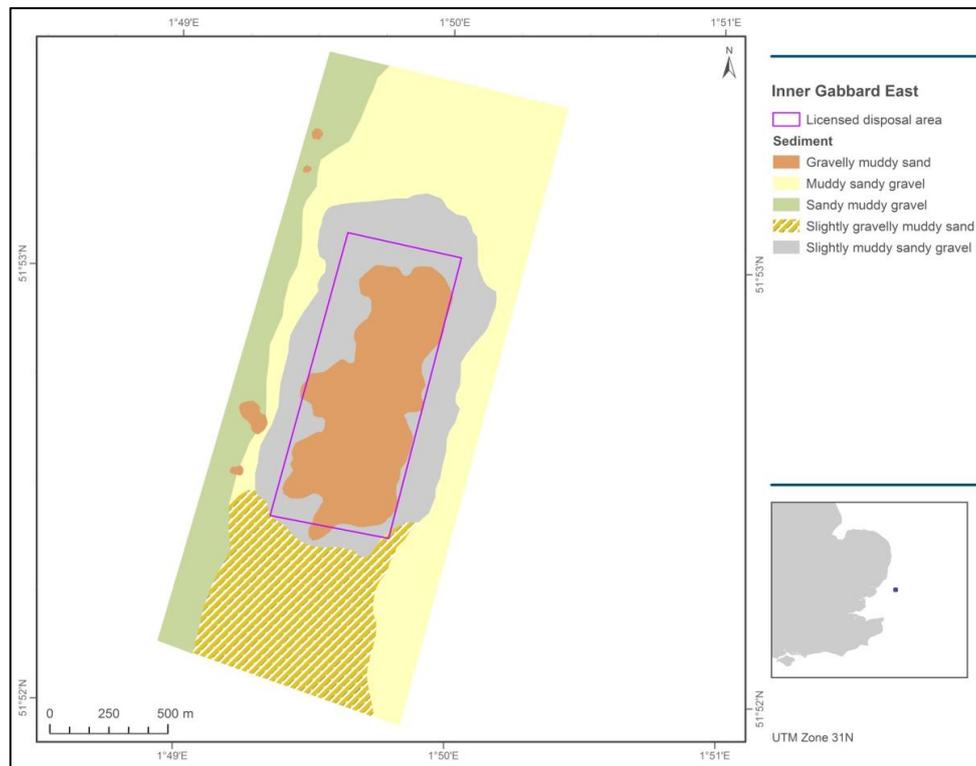


Figure A2.5.4. Interpretation of the Inner Gabbard East 2012 acoustic survey region

There has been very little change to the seabed and the sediment within and surrounding IGE over the last 12 months. Figure A2.5.5 illustrates the 2012 sediment classifications together with the outline of the gravelly muddy sand (considered to depict disposed material) region from 2011. Disposed material has previously been identified outside of the license boundary (Bolam et al., 2012) and this remains the case from the 2012 acoustic survey. Patches of gravelly muddy sand associated with the central dredged disposal material can be seen to the west of the site. The majority of the seabed within the licensed boundary shows minimal change between the 2011 and 2012 surveys. In fact, the backscatter signature for the 2012 survey indicates a reduction of the gravelly muddy sand located within the licensed boundary, particularly in the regions to the north and south of the current classification.

As a result of the way acoustic data are acquired and processed it is sometimes difficult to ascertain whether the temporal differences indicated by Figure A5.2.5 result from natural changes or a result of a change in activity within the disposal area. Overall, the nature of the seabed within IGE remains unchanged and the majority of the disposal material has remained within the license boundary.



Figure A2.5.5. Interpretation of the Inner Gabbard East 2012 survey with the outline of the 2011 gravelly muddy sand overlaid as a black outline.

### 2.5.3.2 Sediment particle size

I GE sediments are predominantly mixed, composed of gravelly muds, gravelly muddy sands and muddy sandy gravels (Table A2.5.1; Figure A2.5.6). Changes in sediment group between 2009 and 2012 are shown in Table A2.5.2; these data indicate that temporal changes between 2011 and 2012 show significantly less fines at most sampling stations except at GE7 (immediately west of the disposal site) which has slightly increased silt/clay content.

Table A2.5.1 Average sediment descriptions (top) and statistics for each sediment group (bottom) at Inner Gabbard East, 2012.

Sediment group	Number of samples	Sample Type					Sediment description		
GaE1	17	Polymodal, Extremely Poorly Sorted					Gravelly Mud		
GaE2	11	Unimodal, Very Poorly Sorted					Gravelly Muddy Sand		
GaE3	17	Polymodal, Extremely Poorly Sorted					Muddy Sandy Gravel		
Sediment group	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)	
GaE1	18.27	24.18	57.54	3.92	5.71	5.44	7.15	1.96	
GaE2	10.31	70.32	19.36	5.79	12.71	33.61	17.00	1.21	
GaE3	41.61	41.21	17.18	5.40	10.43	11.92	11.59	1.86	

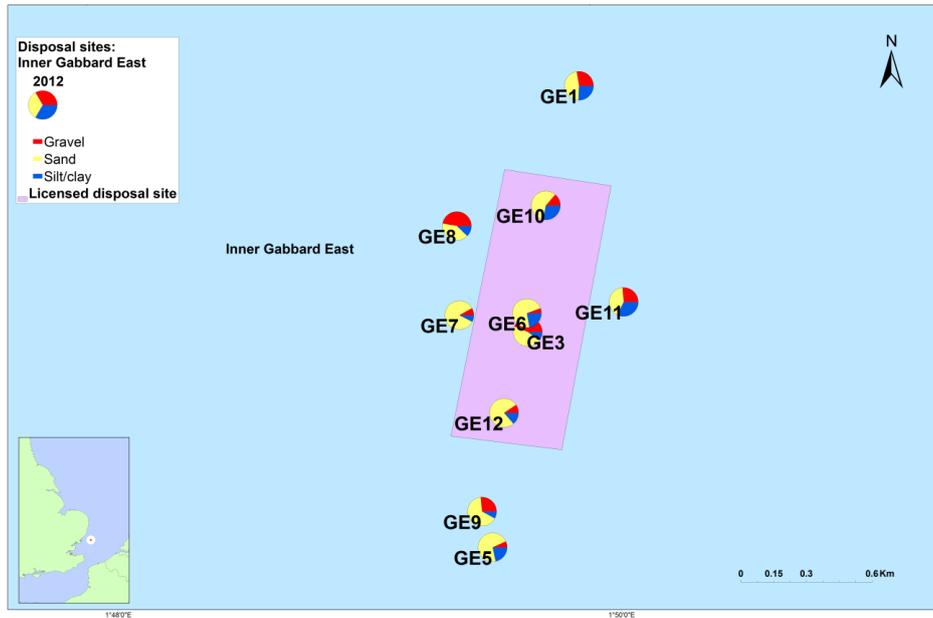


Figure A2.5.6. Pie charts of gravel, sand and silt/clay at Inner Gabbard East in 2012.

Table A2.5.2 Sediment groups for each sample code for 2009 and 2012 at Inner Gabbard East.

Sample code	Year					
	2009 (all HG)	2010 (HG)	2010 (SH)	2011 (HG)	2011 (SH)	2012 (all SH)
GE1	GaE1	GaE1	GaE1	GaE1	GaE3	GaE3
GE2	GaE1	GaE1	GaE3	n	n	n
GE3	GaE3	GaE1	GaE1	GaE1	GaE2	GaE3
GE4	GaE3	GaE1	GaE3	n	n	n
GE5	GaE1	GaE1	GaE2	GaE2	GaE2	GaE2
GE6	n	n	n	GaE3	GaE3	GaE2
GE7	n	n	n	GaE3	GaE3	GaE2
GE8	n	n	n	GaE3	GaE3	GaE3
GE9	n	n	n	GaE3	GaE2	GaE2
GE10	n	n	n	GaE1	GaE1	GaE2
GE11	n	n	n	GaE1	GaE3	GaE3
GE12	n	n	n	GaE1	GaE1	GaE2

Hamon grab (HG) samples (mixed sediment to ~8cm only) and Shipek (SH) grab samples (surface integral) are collected at this site. HG only in 2009, SH only in 2012, and in 2010 and 2011 HG and SH collected. Replicates averaged before sediment groups derived. n – no sample.

## 2.6 Mersey

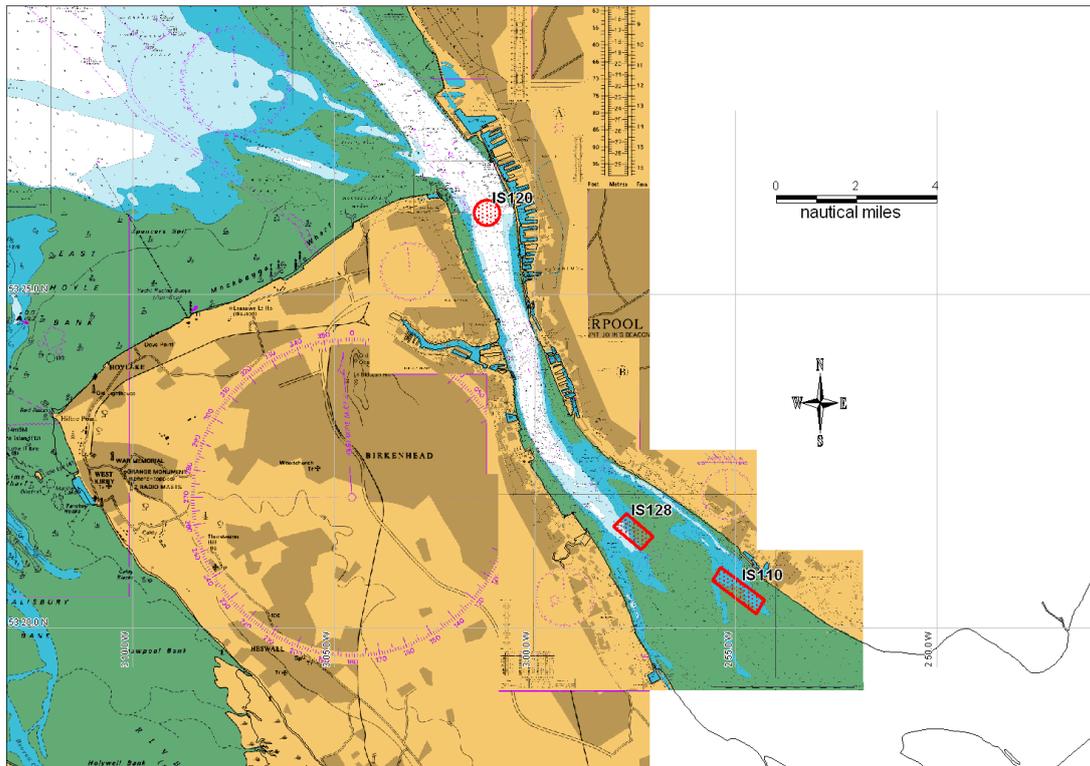


Figure A2.6.1. Locations of the three disposal sites (IS120, IS128 and IS110) in the Mersey Estuary that are the focus of the current study.

*[The modelling work conducted here to address the specific issues that pertained to the three disposal sites within the Mersey was sub-contracted to National Oceanographic Centre (NOC), Liverpool. The following text and results within the following sub-sections in this report were largely taken (or distilled) from the final report produced under this sub-contract. For a full account of the methods and results, please refer to Brown et al. (2013), available on request from S. Bolam].*

### 2.6.1 Background and issues

New development of the Liverpool docks is anticipated to result in an increase in dredging activity and the consequent disposal regime. An increase in disposal at three existing sites (Figure A2.6.1) in the Mersey may alter the sediment dynamics within this system. A circulation model has therefore been employed to gauge the carrying capacity at these sites and the suspended sediment transport pathways over an annual cycle. There is a need to ascertain if the sediment will contribute to the build-up of the existing sand and mudflats within the estuary, or increase the need to dredge in order to maintain a clear passage to the port.

In the present modelling study conducted under the auspices of SLAB5, a typical three month period (January – March 2008) was simulated to explore the transport pathways over the medium-term when

the river influence varies between high and low flow rates. Three sediment classes (silt, fine sand and medium sand) were investigated to represent different sediment mixes and volumes of deposited material at the three disposal sites. The study aims to identify both the particle tracks and the long-term sediment sinks for the disposed material. Modelling the fate of disposed material improves predictions regarding how any increases in disposal at the three locations could influence: (i) the dredging requirements of the port; and (ii) the sand/mud flat accretion at the deposition sites.

### **2.6.2 The scenarios investigated**

Five scenarios were modelled to investigate the behaviour of two sediment mixes and three different disposal tonnages under realistic conditions. The same three disposal sites (i.e. IS120, IS128 and IS110; Figure A2.6.1), which currently receive maintenance dredged material within the Mersey, were used in each simulation. The sediment classes and fractions applied are those thought to be representative of the estuary, in the absence of actual particle size distribution data. In each scenario the particles are released from the start of the simulation (00:00 1st January 2008), which is the start of the ebb tide. At this time the modelled depth-average current through the narrows was 0.25 m/s, which is 14% of the peak (1.79 m/s) modelled depth-average tidal flow during this study period. The tide continued to ebb for 5 hours following the release of the particles. The initial tidal range was 4.45 m, slightly larger than a mean neap tide (4.29 m, NTSLF). The simulation then ran for a three month hindcast period to track the pathways over a moderate time period.

### **2.6.3 Sediment classes**

Three different sediment classes were considered: silt, fine sand and medium sand. The principal difference between these classes is the value of the constant settling velocity employed. A settling rate of 1 mm/s for silt, 9 mm/s for fine sand, and 3.5 cm/s for medium sand was used in the present study. Based on the van Rijn (1993) formulation for settling velocity, the selected settling rate values correspond to silt of approximately 30 to 50 micron diameter depending on the density, and to sands of approximately 100 and 250 micron diameter. Unfortunately, data regarding the particle size distributions of the material disposed of to the three sites were not available. Two sediment configurations were therefore arbitrarily chosen: one combining 70% silt with 30% medium sand, and the second an equal split between fine and medium sands.

### **2.6.4 Deposition methods**

All particles were introduced at the bed over an area representative of the three existing disposal sites (Figure A2.6.2). The percentage of the total volume deposited at each site (IS120, IS128 and IS110) was 33.13%, 23.47% and 43.40%. This volume is represented by a number of particles representing the sediment class ratios above. In each scenario the particles at each site were applied evenly across the site areas to represent the sediment mix. In cases with a few remaining particles, these were added at the centre of the site. The initial simulation considered 10000 particles each with a representative mass of 1kg, giving a total disposal volume of 10 tonnes. This enabled a computationally efficient model simulation to understand the particle tracks. The representative mass

was then increased to 50kg to simulate 500 tonnes of sediment. The larger representative mass takes longer to erode and become mobile, thus representing a slower release from the bed, which could be achieved by drip feeding. Next the number of particles was increased to 30000, the representative mass remaining at 50kg, giving 1500 tonnes of sediment. This method of increased tonnage represents an increase in the thickness of the sediment deposits at the bed. The surface layers providing a sheltering to the layers below, increasing the time period to erode the sediments. In reality this could be achieved through increased deposition at one time or by reducing the area of deposition. The applied tonnage is small a fraction ( $< 0.21\%$ ) of the annual maintenance dredging that was actually disposed of to these sites in 2008. In the absence of sediment disposal volumes representative of the new dock development, these scenarios may be used to indicate the potential pathways for different deposition methods.

### **2.6.5 Results**

For each of the six scenarios, the final position of the particles is presented for the individual disposal sites. For each site the particles are separated by sediment fraction to clearly identify the final position of each particle class from the three sources. The sediment volume as a percentage of the total initial deposit of each sediment class at each site is tabulated to show:

- (i) The volume that has left the Liverpool Bay (cell 11 a and b) model domain through northerly drift.
- (ii) The volume that has drifted north of Formby Point (Latitude  $> 53.55^\circ$ ) but remains within Liverpool Bay.
- (iii) The volume that remain within the Mersey Estuary (Latitude  $< 53.45^\circ$  and Longitude  $> -3.04^\circ$ ).
- (iv) The volume that have migrated further up estuary (Latitude  $< 53.39^\circ$  & Longitude  $> -2.85^\circ$ ).
- (v) The volume of particles close to the Wirral and Liverpool shorelines within the Mersey Estuary.
- (vi) The volume of particles that are still suspended within the water column at the final model time step (31st March 23:30).

The domains used to identify the final position of the particles for analysis are given in Figure A2.6.2 (bottom). Although the majority of the particles are on the bed by the final time step this does not mean they could not be re-suspended by a storm event or spring tides to continue along their sediment path. Each scenario has an accompanying 3 month animation of the partial tracks (available on request). The representative particles in each final scenario are colour coded to identify which disposal site they have originated from (IS120:red, IS128:green, IS110:blue). The animations are for the full Liverpool domain and also a close up of the Mersey Estuary to clearly visualise the movement.

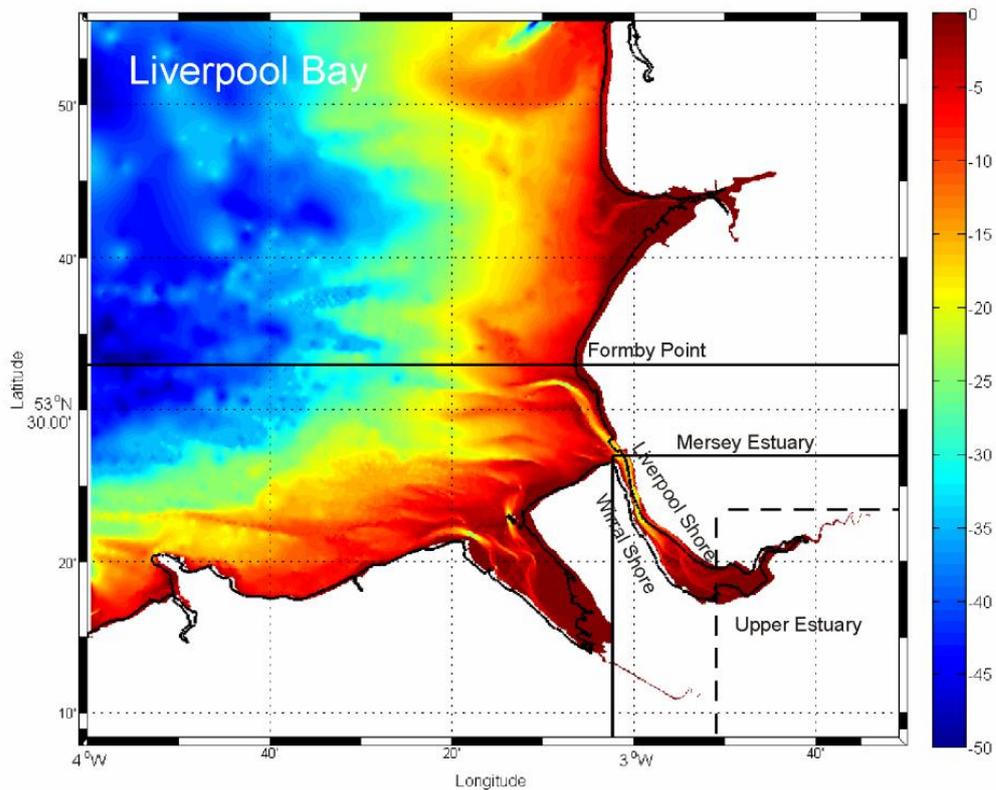
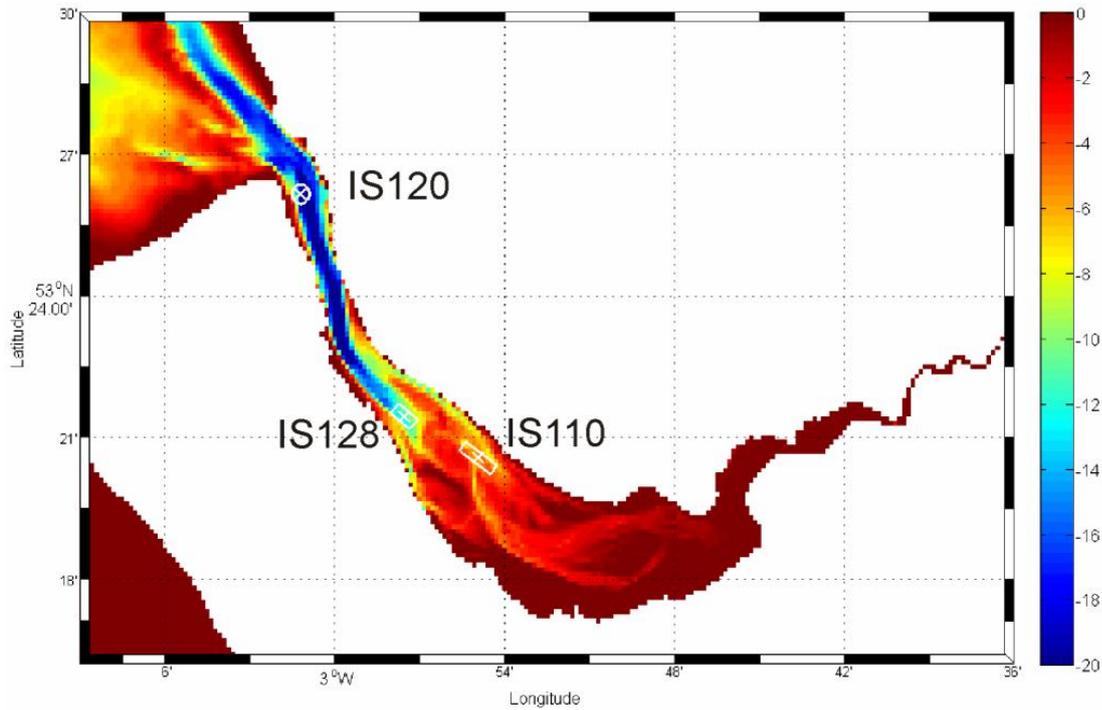
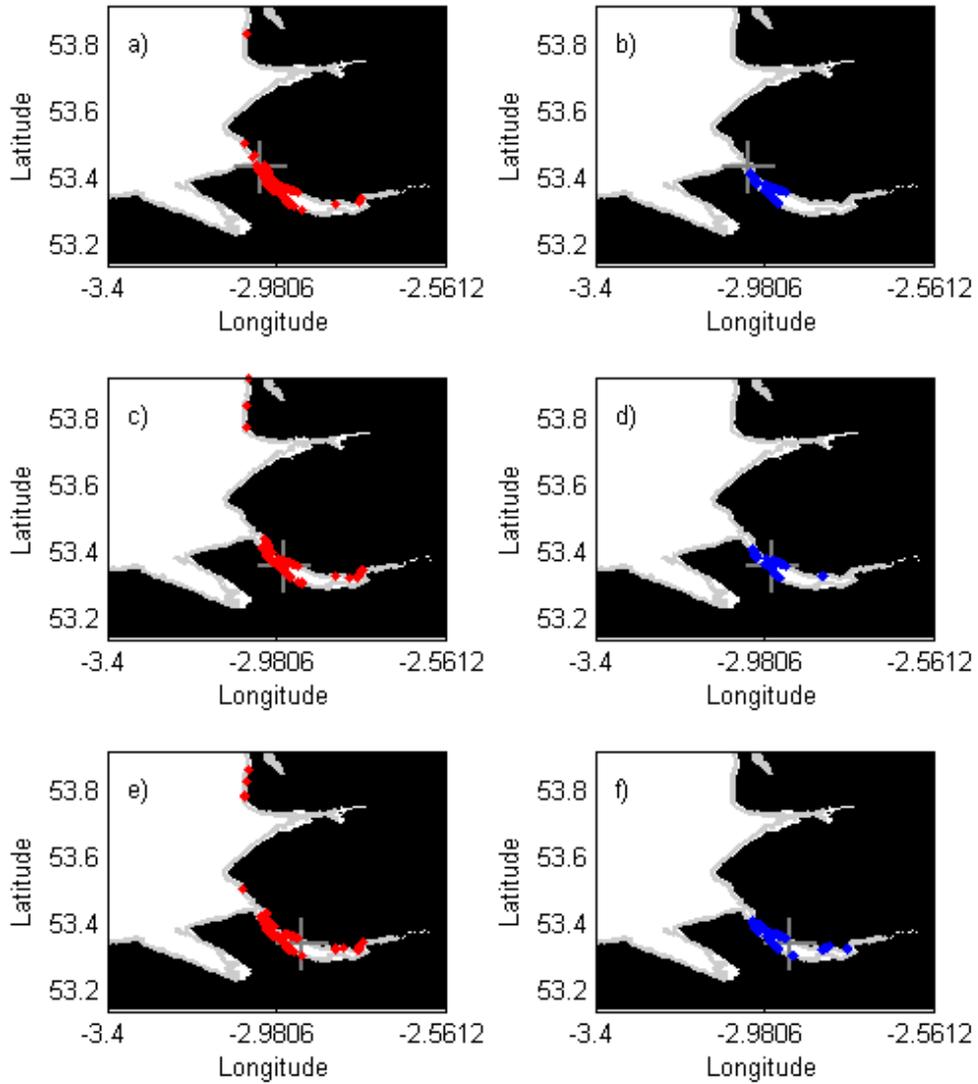


Figure A2.6.2. The modelled areas representing the disposal sites within the Mersey Estuary (top panel) and the Liverpool Bay model domain (bottom panel) with the sub regions marked (solid dark lines) to identify the particle positions at the end of the model simulation. The depths shown in colour are meters below the mean tidal level.

It is seen in the animations that towards the end of the simulation the offshore particles have most mobility during the spring tides and minimal movement on the neap tides. Within the estuary the majority of the particles have come to rest in the calm regions close to the estuary shorelines. Very few particles have moved up estuary as the net transport is generally towards the estuary mouth. The strong flows in the Narrows (located in Figure 3 of Brown et al., (2013)) limit particle deposition, the particles therefore tend to deposit in the wide region of the Inner Estuary (identified in Figure 3 in Brown et al., 2013). Particles that leave the estuary tend to remain in the outer part of the main offshore channel. However, if they leave the channel they more frequently become incorporated into the net northerly flow within Liverpool Bay and slowly travel north out of the domain. In a few cases the particles continue to move westerly offshore, slowly migrating south (similar to the findings Souza and Lane, 2013). The accumulation of sediment close to the shorelines suggests there is a risk that the sediment could increase the present maintenance dredging of the docks.

#### 2.6.5.1 "10 tonne 70:30" mix

The Mersey animation (10T\_7030mix\_Mersey) clearly shows that the deposited particles are rapidly eroded (< 5 days) becoming deposited towards the shorelines of the estuary. The full domain animation (10T\_7030mix\_LiverBay) shows some of the particles leave the Mersey Channel (after ~12 days) and travel north in the residual circulation of the bay. Figure A2.6.3 shows that the majority of the particles 20 deposited in this scenario remain within the inner estuary, situated towards the shoreline. Very few particles become deposited along the English coast and those that do are from the fine fraction. The particles more typically become deposited on the Wirral shoreline (Table A2.6.1). Site IS110 releases most fine sediment to the offshore bay, but this result only occurs in this scenario. By the end of the three month simulation all the particles have become deposited on the bed under the current dynamics.



*Figure A2.6.3. The position of the fine (1 mm/s Ws, red left column) and coarse (9 mm/s Ws, blue right column) sediment classes at the last model time step (31st March 23:30). The first row depicts particles from station IS120, the second from IS128 and the third from IS110. The disposal site location is marked with a '+'.*

Table A2.6.1. The percentage of the total volume of each sediment class deposited at the individual disposal locations at the last model time step (31st March 23:30) in the specified locations.

Location	Settling Velocity, mm/s	No longer in domain	North of Formby Point	Within the Mersey Estuary main body	Within the upper parts of the inner Mersey Estuary	Towards the Wirral estuary shoreline	Towards the Liverpool estuary shoreline	Still suspended in the water column
ISO120	1	0.00	0.03	99.80	0.16	77.29	22.51	0.00
	9	0.00	0.00	100.00	0.00	92.01	7.99	0.00
ISO128	1	0.00	0.18	99.82	1.64	61.72	38.10	0.00
	9	0.00	0.00	100.00	0.57	56.25	43.75	0.00
ISO110	1	0.17	0.22	99.57	3.36	62.74	36.83	0.00
	9	0.00	0.00	100.00	5.33	25.96	74.04	0.00

#### 2.6.5.2 "10 Tonne 50:50" mix

This coarser sediment mix remains within the estuary domain (Figure A2.6.4). The particles are able to reach the upper most part of the estuary and the offshore extent of the Mersey Channel (see 10T\_5050mix\_Mersey). However, they never leave the estuary domain and have become motionless by the end of the first month (10T\_5050mix\_LiverBay). Again the deposits tend towards the shoreline of the estuary (Figure A2.6.4), generally towards the Wirral coast (Table A2.6.2) unless from IS110. By the end of the simulation all the particles are deposited under the current regime at that time.

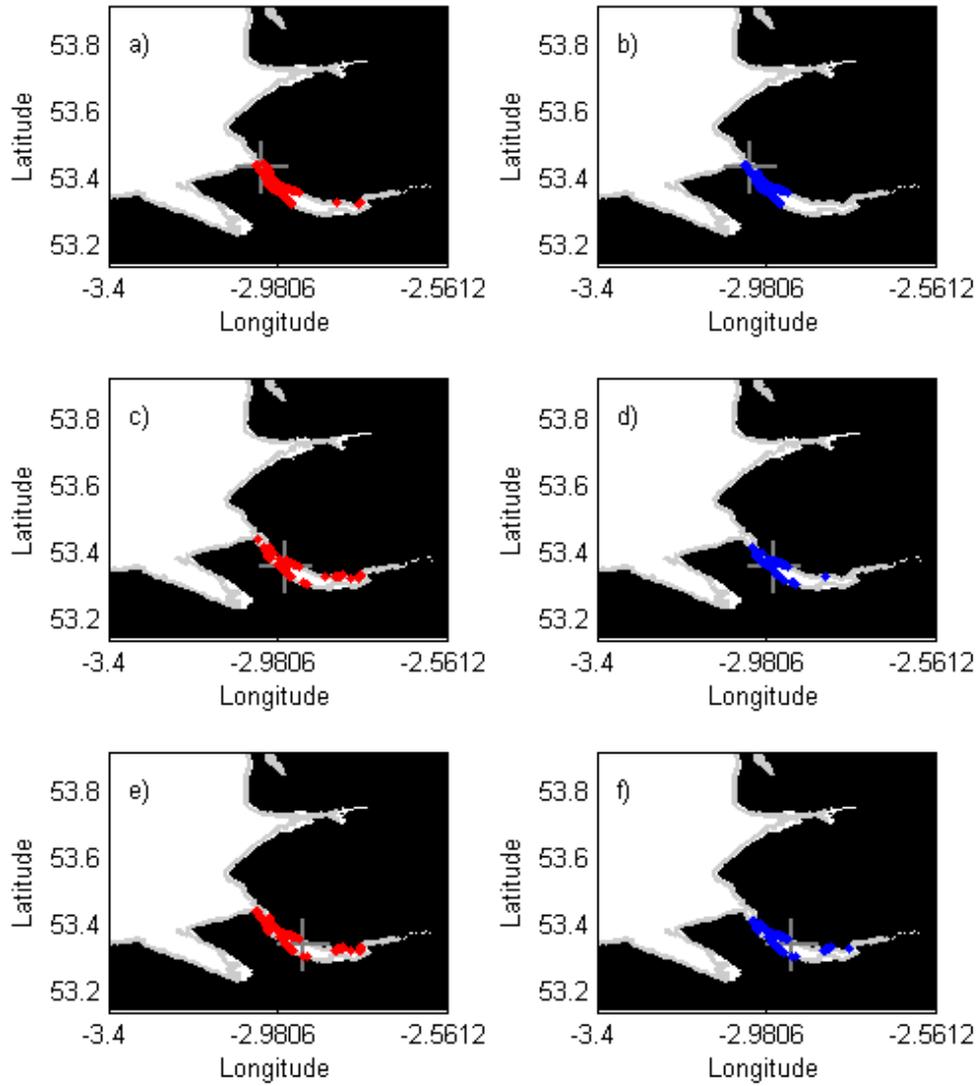


Figure A2.6.4. The position of the fine (9 mm/s Ws, red left column) and coarse (35 mm/s Ws, blue right column) sediment classes at the last model time step (31st March 23:30). The first row depicts particles from station IS120, the second from IS128 and the third from IS110. The disposal site location is marked with a '+'.  
 location is marked with a '+'.

Table A2.6.2. The percentage of the total volume of each sediment class deposited at the individual disposal locations at the last model time step (31st March 23:30) in the specified locations.

Location	Settling Velocity, mm/s	No longer in domain	North of Formby Point	Within the Mersey Estuary main body	Within the upper parts of the inner Mersey Estuary	Towards the Wirral estuary shoreline	Towards the Liverpool estuary shoreline	Still suspended in the water column
ISO120	9	0.00	0.00	100.00	0.18	89.77	10.23	0.00
	35	0.00	0.00	100.00	0.00	87.88	12.12	0.00
ISO128	9	0.00	0.00	100.00	4.18	63.43	36.57	0.00
	35	0.00	0.00	100.00	0.17	54.00	46.00	0.00
ISO110	9	0.00	0.00	100.00	18.96	27.60	72.40	0.00
	35	0.00	0.00	100.00	2.47	39.77	60.23	0.00

### 2.6.5.3 “500 Tonne 70:30” mix

Although the greater representative particle mass reduces the release rate from the sites after ~7 days the particles have begun to travel north along the English coast (500T\_7030mix\_Mersey). A considerable number of particles enter the Ribble Estuary and interact with the dynamics slowing their net migration north. A couple of particles also become transported further offshore slowly migrating west (500T\_7030mix\_LiverBay). Under this scenario more particles begin to leave the domain and a larger percentage becomes deposited along the English coast (Table A2.6.3). Some fine particles are still suspended within the water column at the end of the simulation, suggesting greater mobility than in the “10 tonne 70:30 mix” scenario. The majority of the particles remain within the inner estuary close to the shorelines (Figure A2.6.5), with the fine fraction moving along the English coast. Fines seem to favour the Wirral shore and coarse grains the Liverpool shore. Particles from each site are present in the upper estuary (Table A2.6.3).

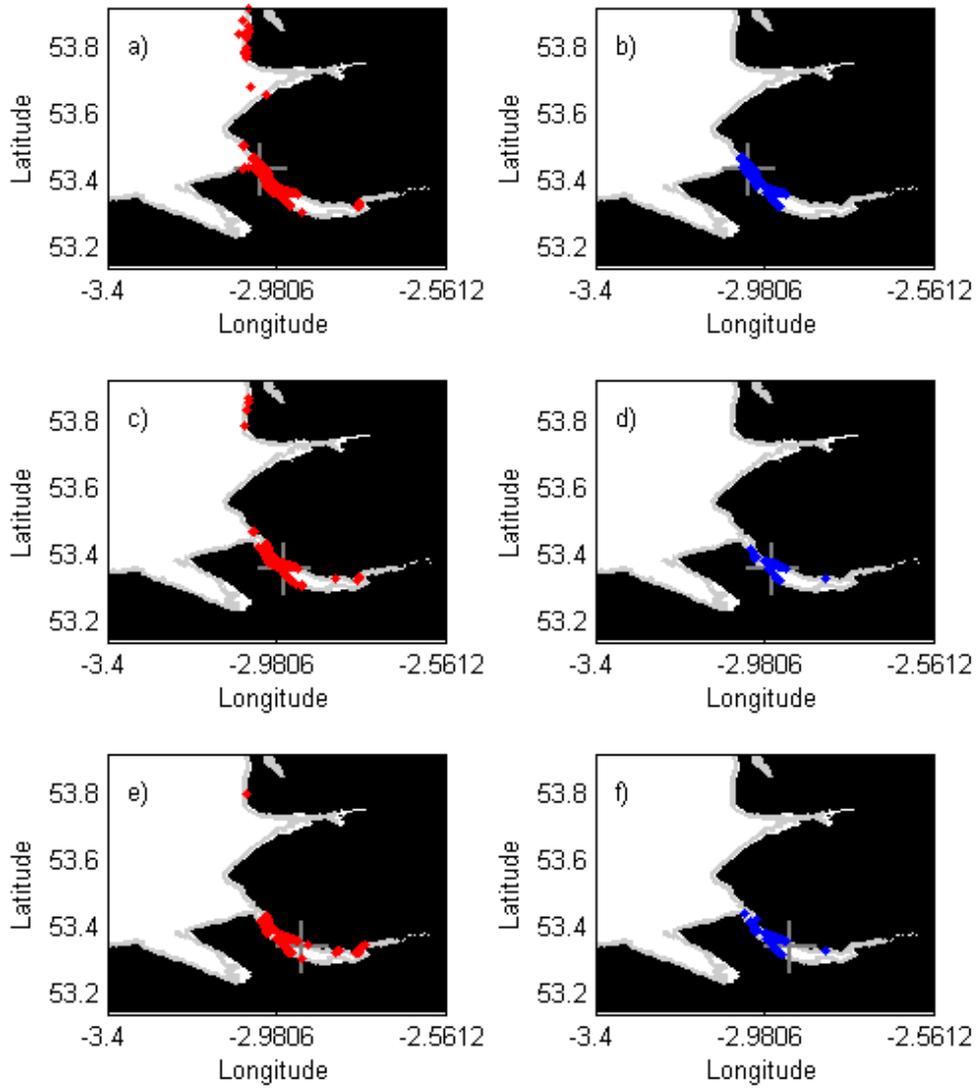


Figure A2.6.5. The position of the fine (1 mm/s Ws, red left column) and coarse (9 mm/s Ws, blue right column) sediment classes at the last model time step (31st March 23:30). The first row depicts particles from station IS120, the second from IS128 and the third from IS110. The disposal site location is marked with a '+'.  
 +

Table A2.6.2. The percentage of the total volume of each sediment class deposited at the individual disposal locations at the last model time step (31st March 23:30) in the specified locations.

Location	Settling Velocity, mm/s	No longer in domain	North of Formby Point	Within the Mersey Estuary main body	Within the upper parts of the inner Mersey Estuary	Towards the Wirral estuary shoreline	Towards the Liverpool estuary shoreline	Still suspended in the water column
ISO120	1	0.63	2.93	95.16	0.20	64.09	31.07	0.13
	9	0.00	0.00	97.85	0.00	38.63	59.22	0.00
ISO128	1	0.12	0.30	99.45	0.61	70.30	29.15	0.00
	9	0.00	0.00	100.00	0.43	23.30	76.70	0.00
ISO110	1	0.09	0.17	99.74	1.81	50.58	49.16	0.00
	9	0.00	0.00	100.00	0.10	16.20	83.80	0.00

#### 2.6.5.4 "500 Tonne 50:50" mix

The coarser sediment mix takes a little longer to begin to leave the estuary and travel north (~10 days, 500T\_7030mix\_Mersey). Within the second month the particles are clearly more mobile on the spring tides (500T\_7030mix\_LiverBay) and over the full simulation do not extend so far offshore as the fine mix. It is clearly the finer sediment fraction (Figure A2.6.6) that extends furthest along the English coast, especially from the site nearest the estuary mouth. Liverpool is the favoured estuary shoreline, for both fractions (Table A2.6.3).

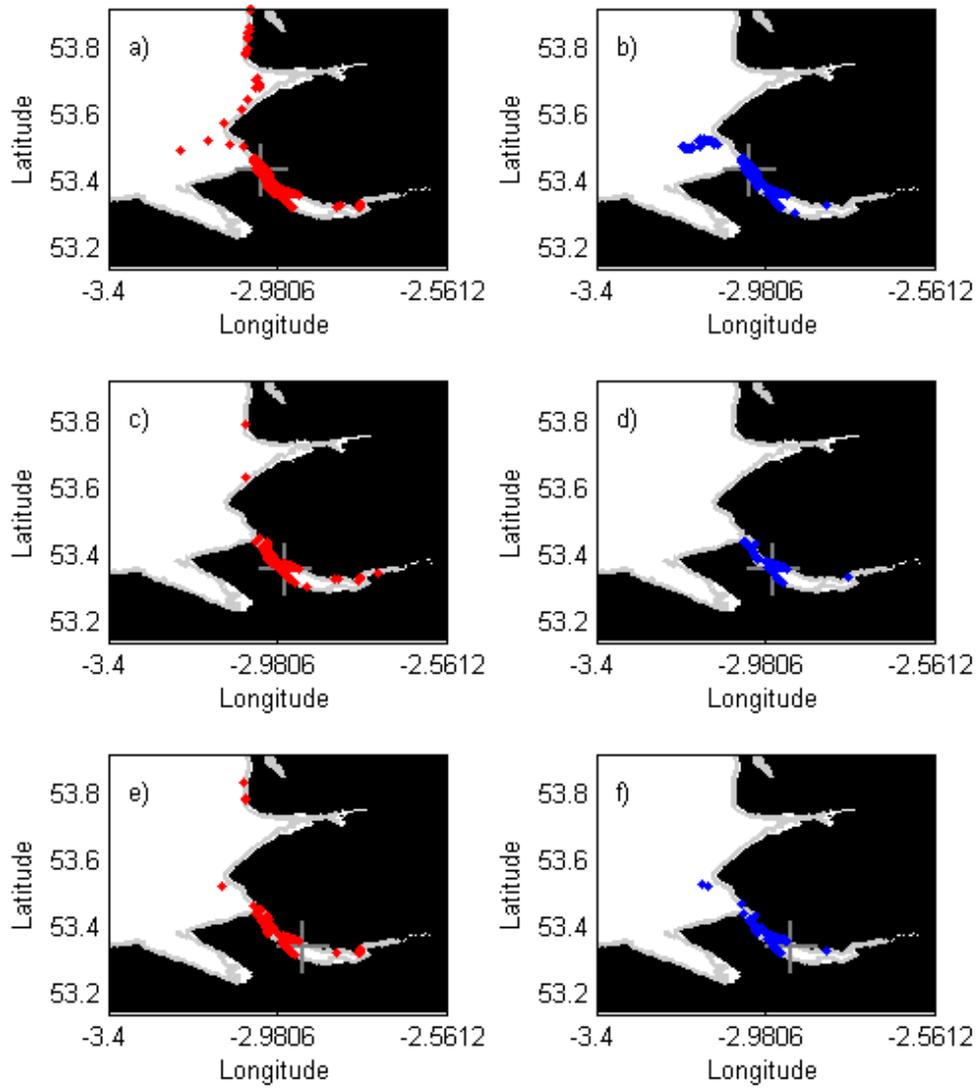


Figure A2.6.6. The position of the fine (9 mm/s Ws, red left column) and coarse (35 mm/s Ws, blue right column) sediment classes at the last model time step (31st March 23:30). The first row depicts particles from station IS120, the second from IS128 and the third from IS110. The disposal site location is marked with a '+'.  
 +

Table A2.6.3. The percentage of the total volume of each sediment class deposited at the individual disposal locations at the last model time step (31st March 23:30) in the specified locations.

Location	Settling Velocity, mm/s	No longer in domain	North of Formby Point	Within the Mersey Estuary main body	Within the upper parts of the inner Mersey Estuary	Towards the Wirral estuary shoreline	Towards the Liverpool estuary shoreline	Still suspended in the water column
ISO120	9	0.23	1.94	96.82	1.01	45.99	50.83	0.23
	35	0.00	0.00	93.64	0.05	32.90	60.74	0.00
ISO128	9	0.00	0.26	99.66	2.56	43.90	55.75	0.00
	35	0.00	0.00	100.00	0.09	23.76	76.24	0.00
ISO110	9	0.00	0.30	99.40	4.29	23.91	75.48	0.00
	35	0.00	0.00	99.82	0.24	13.70	86.12	0.00

#### 2.6.5.5 “1500 Tonne 70:30” mix

Increasing the number of particles has little effect on how long it takes the particles to leave the Mersey and begin to travel north (1500T\_7030mix\_Mersey). More particles travel further offshore and also towards the Welsh coast and the Dee Estuary by the end of the simulation (1500T\_7030mix\_LiverBay), especially from the fine fraction deposited close to the estuary mouth (Figure A2.6.7). An increase in the number of particles lost through the north boundary of the model domain is seen (Table A2.6.4). However the majority remain within the estuary, with the fines close to the Wirral shore and the coarse grains towards the Liverpool shore. The larger number of particles increases the number still mobile at the end of the simulation.

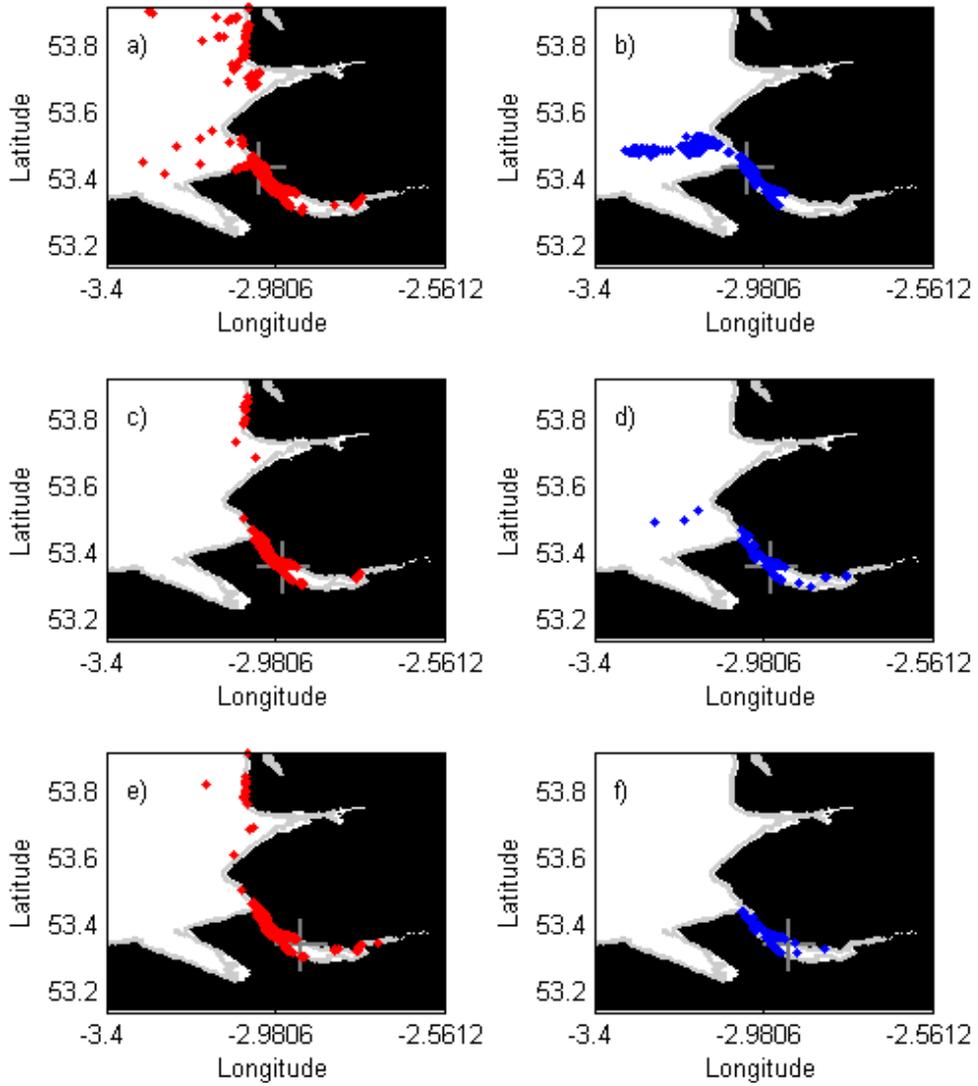


Figure A2.6.7. The position of the fine (1 mm/s Ws, red left column) and coarse (9 mm/s Ws, blue right column) sediment classes at the last model time step (31st March 23:30). The first row depicts particles from station IS120, the second from IS128 and the third from IS110. The disposal site location is marked with a '+'.  
 +

Table A2.6.4. The percentage of the total volume of each sediment class deposited at the individual disposal locations at the last model time step (31st March 23:30) in the specified locations.

Location	Settling Velocity, mm/s	No longer in domain	North of Formby Point	Within the Mersey Estuary main body	Within the upper parts of the inner Mersey Estuary	Towards the Wirral estuary shoreline	Towards the Liverpool estuary shoreline	Still suspended in the water column
ISO120	1	1.99	6.73	89.01	0.24	54.78	34.22	0.60
	9	0.00	0.00	83.05	0.00	29.65	53.41	0.00
ISO128	1	0.22	0.47	99.21	0.49	68.72	30.49	0.04
	9	0.00	0.00	99.76	0.19	29.36	70.41	0.00
ISO110	1	0.10	0.53	99.22	1.54	52.44	46.79	0.04
	9	0.00	0.00	100.00	0.07	17.47	82.53	0.00

#### 2.6.5.6 “1500 Tonne 50:50” mix

Increasing the number of particles in the coarse mix scenario has little influence on the time it takes the particles to leave the estuary. It just increases the number leaving at the onset of the northerly drift (1500T\_7030mix\_Mersey). The increased numbers of particles leaving the estuary still remain close to the coast and do not spread offshore (1500T\_7030mix\_LiverBay). The fine particles dominate the volume in the offshore domain (Figure A2.6.8), but both fractions have the majority of particles in the inner estuary (Table A2.6.5), with slightly more towards the Liverpool shoreline.

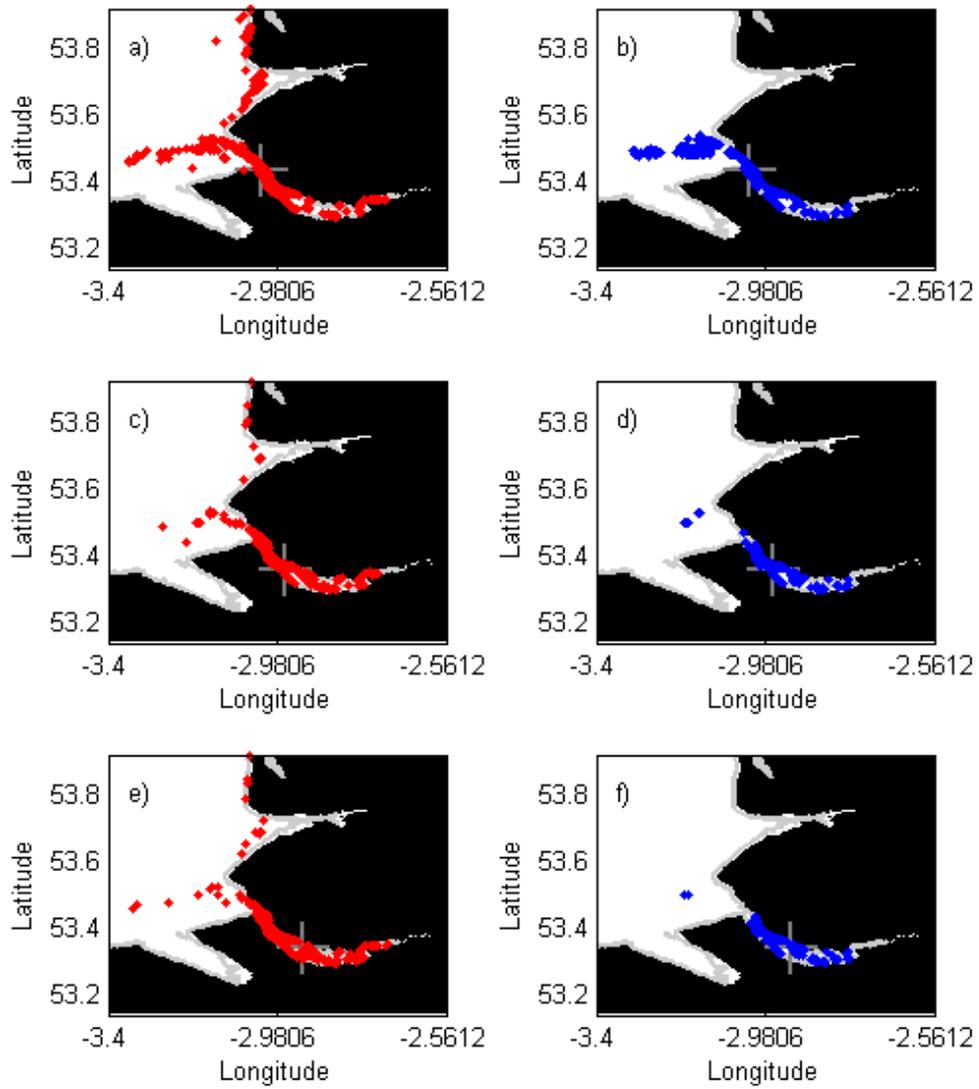


Figure A2.6.8. The position of the fine (9 mm/s Ws, red left column) and coarse (35 mm/s Ws, blue right column) sediment classes at the last model time step (31st March 23:30). The first row depicts particles from station IS120, the second from IS128 and the third from IS110. The disposal site location is marked with a '+'.  
 location is marked with a '+'.

Table A2.6.5. The percentage of the total volume of each sediment class deposited at the individual disposal locations at the last model time step (31st March 23:30) in the specified locations.

Location	Settling Velocity, mm/s	No longer in domain	North of Formby Point	Within the Mersey Estuary main body	Within the upper parts of the inner Mersey Estuary	Towards the Wirral estuary shoreline	Towards the Liverpool estuary shoreline	Still suspended in the water column
ISO120	9	0.31	3.13	88.56	3.63	37.88	50.68	0.71
	35	0.00	0.00	84.53	1.14	33.35	51.18	0.00
ISO128	9	0.00	0.28	98.41	8.86	45.20	53.21	0.40
	35	0.00	0.00	99.55	4.80	30.13	69.41	0.00
ISO110	9	0.00	0.22	99.09	9.92	26.02	73.07	0.44
	35	0.00	0.00	99.94	2.09	12.09	87.85	0.00

## 2.6.6 Discussion

The different scenarios present similar overall transport pathways. The majority (> 83%) of each sediment class deposited at each location remains within the Mersey Estuary. In the animations it is clear that the net offshore movement of particles is constrained within the main channel. Once at the offshore end of the channel, the particles are able to diffuse and become influenced by the residual circulation of the bay. The channel prevents the particles experiencing the coastal drift back towards the estuary mouth (Sly, 1966; Pye and Blott, 2010). From offshore the fine particles are transported back onshore in the diverging circulation at Formby Point, where they are typically incorporated into the northerly flow. The particles are transported north by the residual current into the Ribble estuary before continuing to travel north, with a few leaving the model domain. Souza and Lane (2013) demonstrate how sediment deposits offshore away from the end of the Mersey Channel return to the estuary due to the underlying circulation patterns. It is therefore suggested that sediment released within the main channel flows will tend to combine with the northerly sediment drift if it leaves the estuary, while deposits within the outer estuary away from the main channel will return to the estuary.

By the end of the simulated 3 month period the particles remaining within the domain have generally settled to the bed and are within the inner part of the Mersey Estuary. However, the scenarios with increased tonnage in the initial deposit still have a significant number of particles mobile towards the end of the simulation during the faster current flows, and especially at spring tide, suggesting that the particles will continue to move until they settle in areas where the maximum currents are unable to be re-suspended them from the bed. The particles tend to settle towards the shorelines of the estuary. The scenarios with the larger tonnages show that a larger percentage of silt moves towards the Wirral shore, while sand moves towards the Liverpool shore. The dominant drift towards the shorelines suggests maintenance dredging within the docks may increase due to the additional sediment disposal, while the navigation channels are likely to remain unaffected. The fine particles are able to spread over the greatest area, while particles disposed at IS120 are more likely to leave the estuary.

The scenarios with a coarser sediment mix lose fewer particles offshore and to the surrounding coast. This is likely to be related to the gravitational circulation, transporting particles in the lower water column towards the upper estuary and particles in the upper water column offshore. However, the 100 micron sand is present in all scenarios, either as the coarse or fine fraction. The different transport pathways suggest it is the quantity of the sediment that influences whether a significant amount can escape the estuary. The increase in deposited particle volume, through increased representative mass or number of particles, enabled more particles to spread offshore, the fine particles tending to move to the north and the coarse particles to the west. This westerly movement suggests an additional pathway exists due to the interaction of the flow from the Mersey, constrained in the offshore channel and the circulation within the bay. The larger representative mass meant longer periods of currents capable of eroding the sediment were required to mobilise a particle. This means if on the bed it remains there for longer, reducing its tidal excursion and allowing asymmetries in the current field to have more influence, thus enabling the residual current to have more influence in a shorter period. Increasing the number of particles enhanced the volume of particles following the different transport pathways. The delay in eroding the deposit, due to increased representative particle mass and/or number of particles, was minimal, and had little influence on the initial movement from the disposal sites. This suggests that drip feeding the deposit over a period of time, depositing sediment at different states of the tide or increasing the deposit thickness on the bed (reduced area of deposit or increased volume deposited at an instance) will have little influence on the long-term transport. Although the particles' net movement during the initial tide may vary, the long-term transport is dependent on the residual circulation, due to tidal and density driven residuals. Although the particles experience a large excursion during a single tide, especially at a spring tide, the net transport caused by tidal flow asymmetry and baroclinicity (Bolanos et al., 2013) is more important in influencing the net transport of the particles. In each scenario, the particles have been released on the ebb tide. After a few tidal cycles the net transport is out of the estuary for the particles that have not become deposited along the shoreline of the inner estuary. Releasing the particles at different times within the tidal flow (slack water before ebb or maximum ebb flow) may slow the net transport, but only by the net movement during that (full or partial) tidal cycle. Since the particles begin to leave the estuary domain within a few days, delay to the net long-term transport will be of the order a few tidal cycles, which is insignificant.

The conclusions are:

- (i) In the scenarios at least 83% of the sediment remains within the Mersey estuary, typically becoming deposited close to the inner estuary shorelines;
- (ii) It is possible for sediment from all three disposal sites to become released into the bay. However, sediment deposited close to the Mersey Narrows is more likely to migrate offshore;
- (iii) The fine particles deposited are able to move north along the English coast. However, very few leave the coastal cell (11 a and b) within the three month modelled period;
- (iv) The coarse particles, when present in large volumes, are able to leave the estuary and move west towards the Welsh coast;

- (v) Increasing the sediment tonnage only slightly slowed the release of particles from the disposal sites;
- (vi) The particle transport pathway is influenced by the residual circulation within the main channel which feeds into the diverging coastal circulation at Formby Point;
- (vii) Depositing sediment in the offshore estuary away from the main channel may produce very different transport pathways; and
- (viii) There is a risk that maintenance dredging of the docks will need to increase in response to the migration of disposed sediment towards the inner estuary shorelines.



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