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In Situ Contaminated Sediments Project Work Package 1A Report

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In Situ Contaminated Sediments Project Work Package 1A Report

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Work Package 1A Report

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Summary

Project aims

Defra is seeking to understand the magnitude of risks (e.g. to aquatic ecology and human health) or impacts (e.g. on the way that water bodies are managed) posed by contaminated sediment in England, as part of its work towards meeting its environmental objectives.

In the context of this project, in-situ contaminated sediment is defined as:

> *Chemically contaminated sediment within the water column, bed, banks and floodplain of a surface water body that has been transported alongside the normal sediment load and deposited by fluvial or coastal processes.*

This project considers the risk posed by non-agricultural diffuse pollution sources in England that result in the contamination of in-situ sediments (for example, contamination from toxic metals, hydrocarbons and surfactants). The scope encompasses both freshwater and marine sediments in England and extends to one nautical mile off-shore (the seaward limit of coastal waters under the Water Framework Directive (WFD) in England).

Previous national strategies, including the 2007 Defra UK Strategy for Managing Contaminated Marine Sediments (CDMS), focussed on characterising the risks associated with contaminated sediments in the marine environment. However, while extensive research has been carried out in many locations (including as part of WFD implementation studies) and for particular sources of contamination (e.g. historical metal mining; Environment Agency, 2008) there has not been a comprehensive overview of sediment contamination on a national scale. This project seeks to build on the existing evidence base, drawing together information on the freshwater environment to complement that already gathered for marine waters. This project's overall aim is to provide a sound evidence base on the contamination of in-situ sediments, which can underpin the development of tools and methods that will help Defra, the Environment Agency and other bodies engaged in regulation and protection of water quality.

Legislative and environmental objectives

A review has been undertaken of the wide variety of statutory and non-statutory controls pertaining to the management and control of in situ contaminated sediment. This includes legislation covering sediments as part of ecological status, as part of nature conservation, as wastes and as land affected by contamination, as well as legislation governing point source discharges, protection of shellfish, industrial emissions and urban wastewater treatment. Planning policy and environmental impact assessment can also influence how contaminated sediments are assessed and managed.

There are currently no statutory sediment quality objectives for England. The requirement to mitigate or remediate in situ contaminated sediment will, therefore, depend upon the characteristics of each individual situation, the legal significance and any protection afforded to the impacted feature (local, national, European, etc.), and the weight of evidence supporting the contaminated sediment as being the cause of the observed impact. Unlike the legal provisions made for controlling risks from terrestrial contaminated land which is not being redeveloped under the planning regime (Environmental

Protection Act, 1990, Part 2A, as amended), there is no regime in force which requires public bodies, landowners or other parties to identify register and remediate contaminated sediment.

Conceptual model for in-situ contaminated sediments

A large number of contaminant linkages (source-pathway-receptor linkages) may result in receptors being exposed to contamination in sediment associated with a water body. A conceptual model is presented in **Section 3** of this report which provides a simplified representation of the main catchment[1] processes considered likely to be associated with the release, movement, transportation and deposition of contaminated sediment and the impacts associated with this sediment. The importance of each linkage will vary depending on local factors such as the nature and individual characteristics of the catchment, the reach of the catchment under consideration, and the location of the sediments in the freshwater, estuarine and marine environments. The linkages may also be affected by process such as flood events and climate change.

Many activities that are carried out within river catchments, estuaries and coastal waters may also affect the linkages identified in the conceptual model. Sediments could be disturbed by a range of natural processes, including flood events, tidal movements and bioturbation, and anthropogenic activities such as capital and maintenance dredging programmes, propeller action from ships, boats and other vessels, construction activities, commercial and recreational fishing,

A number of methods have been developed with the aim of controlling contamination before it reaches a water body, such as sediment traps; waste management controls and treatment of effluent discharges. A range of management techniques are also in use which are specific to contamination in sediments. These include removal by dredging, in situ stabilisation, sediment capping and ex situ remediation.

A further suite of techniques is used routinely within catchments to control or influence the processes of sediment deposition and erosion within the system as well as extraction for commercial purposes (dredging of aggregates). The primary aim of these activities is to control the sediment itself rather than any contaminants associated with it, although they have significant overlap with the measures outlined above for remediation of contamination in sediments. These include activities in the water, such as dredging, desilting, scour prevention and engineering structures to prevent or encourage siltation, and activities on land such as engineering works to reduce erosion, setting back of flood defences to increase suspended sediment deposition on the floodplain, and beach replenishment.

Potential substances of concern

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[1] Within this study *a catchment is defined as an area of land from which surface water flows converge to exit at a single point, and as such represents the area that is drained by a particular body of water. This area includes the network of watercourses that drain into the water body as well as the land surface surrounding them. In addition to flows, the catchment also supplies sediment to the water bodies that are situated within it. The edge of a catchment is defined be an area of higher elevation, often referred to as a catchment boundary or watershed, that separates it from adjacent catchments. Catchments are hierarchical and nested in nature, with small catchments draining into larger catchments until they eventually drain into the sea.*

A wide range of contaminants have the potential to have been released into the aquatic and/or sedimentary environment. These include contaminants which have, historically, frequently been tested for in environmental water and sediment samples (e.g. as part of routine water or sediment quality analyses) and also emerging contaminants that are suspected to be present but have not historically featured in analytical testing suites.

A number of contaminants have been identified which may be of concern for the aquatic environment and/or specifically for the sedimentary environment for more detailed consideration during this project. These have been identified using existing legislation (primarily the WFD), existing UK sediment threshold lists, and water quality and sediment contamination studies from the UK and other European countries.

Processes that affect contaminant mobility in sediments

Potential pathways for exposure of sensitive receptors to sediment contamination are discussed in the conceptual model presented in **Section 3** of this report. Each pathway has a series of component processes. For example, sediment-associated contaminants may dissolve into the water column and subsequently become taken up by fish; or be directly ingested by aquatic organisms.

A number of the characteristics of individual contaminants may affect how they interact with sediments, the overlying water column and the air, should the sediments be exposed to this. These include oral, dermal and inhalation toxicity, potential to bioaccumulate, ability to partition between water and sediment and persistence in the environment.

The characteristics of the sediment are also likely to have a pronounced effect on whether contaminants bind to the sediment or release into the water. These characteristics include particle size distribution, specific surface area, cation exchange capacity, partition coefficients, pH, organic matter content and mineral constituents.

The remobilisation of metal-rich sediments from floodplain stores has been identified by previous studies as a potentially serious environmental problem. The release of large volumes of sediment-bound contaminants can severely damage the aquatic ecosystem and, if deposited overbank further downstream, cause problems for floodplain-surface activities such as agriculture.

Current understanding of the nature and scale of in situ sediment contamination in England

A targeted literature review encompassing key databases from regulatory and research bodies, scientific publications and ‘grey’ literature has been undertaken using the project team’s in house libraries, academic databases and references provided by the project’s steering panel. Information on sediment quality and sampling techniques has been collected in a spread sheet format with geographical references to enable development of a mapping tool in later work packages.

Individual studies were selected for inclusion based on the following criteria:

- **Spatial coverage**: To give a comprehensive overview, studies were selected from major river systems in each region of England (e.g. NE England, NW England). Where possible, the broadest study (in terms of spatial coverage) per catchment was used;

- **Range of contaminants**: Studies were selected that investigated a wide range of potentially hazardous metals and organic substances. Some studies were included that reported a limited number of potential contaminants if there was little other material available for a given area ; and
- **Depositional environment:** Studies that investigated a range of sedimentary environments, such as channel bed sediments, flood sediments and floodplain sediments were selected.

Preliminary risk screening

As an initial risk screening exercise, the collated sediment quality data have been compared against UK threshold values. The sediment quality data comprise a combination of highly targeted, semi-targeted and untargeted data. For the purposes of this initial screening exercise, freshwater sediments have been defined as those above Mean High Water Springs (MHWS) level, with coastal and marine sediments being all those below this level.

The data sets have been compiled by different organisations over potentially prolonged periods of time and hence a number of differences and limitations in the data are apparent when these are compiled and interrogated as one data set, including errors in coordinates, differences in analytical techniques and ambiguity over units. Based on the limitations outlined above, only very broad conclusions can be drawn from this exercise, which has been carried out prior to the development of a national risk assessment methodology.

A number of clear gaps were identified in the currently available sediment quality data. These include the following:

- **Spatial extent of current sediment quality data**: The data sets provide a reasonable scatter of data points along the whole of the English coastline, with higher concentrations in some areas than in others. For freshwater sediments, a very dense coverage is available for large parts of the country but is entirely absent from others.
- **Extents of studies examined**: Many studies which have been examined as part of this Work Package, especially those located outside northern England, have focused almost exclusively on estuaries and shallow sediments; few studies report pollutant concentrations in flood sediments or floodplain cores.
- **Analytes**: Whilst many of the “established” contaminants are well represented in the data sets, for others there is scarcely any data available.
- **Consistency of analysis**: Although some contaminants, or groups of contaminants such as polychlorinated biphenyls (PCBs), are represented in the dataset that has been compiled for this report, the data are difficult to assess as a whole due to variation in the analyses undertaken.

Evidence of harm

Case studies have been sought which document an impact (e.g. deterioration of an ecosystem) where it is either proven or suspected that contamination in sediments may be playing a significant role. The complexities of environmental conditions can make it difficult to prove a causal link between an effect observed in the field and a source contaminant or a particular contaminant pathway. However, several studies and reviews have been highlighted which report indications of harm to aquatic receptors which are attributed (although in most cases tentatively) to contamination and, in some cases, specifically sediment contamination. In addition, contaminated out-wash sediments have also been recorded to have an adverse impact on livestock grazing on mining-affected floodplains.

Conclusions

It is clear that there will be current differences between catchments and differences over time which will affect which pollutant linkages are active for exposure of receptors to contamination in sediment. These include variations in land uses and the response of the catchment or coastal system to climate change.

Analysis of the results compiled in the sediment quality database have shown that in situ sediment contamination, as a result of historical metal mining, heavy industry and urban diffuse pollution, is a pervasive and locally chronic problem in England. Despite improvements in water quality over recent decades, high levels of floodplain contamination form a significant store of unregulated pollutants that constitute a limiting factor to further improvements in river system health within some catchments. Several studies demonstrate the potential for flood remobilisation of contaminants and these problems are likely to intensify due to climate change and/or human intervention (e.g. dredging).

Analysis of sediment quality data for England against freshwater and coastal/marine Action Levels and Sediment Quality Guidelines has indicated significant numbers of exceedances for some contaminants (e.g. arsenic, cadmium and some polycyclic aromatic hydrocarbons) as well as a lack of data for other contaminants (e.g. silver and pesticides). On the national scale, differences between surface soils inside and outside the floodplain were difficult to identify.

In some case studies, although controls on the identified point source discharges may have improved in recent years, there appear to be ongoing issues not only from the residual contaminant loadings from the discharges themselves but also from contaminants stored in the estuaries. It is considered highly likely therefore that sediment is playing a role in storing, transporting and re-releasing contaminants in some locations.

Based on the preliminary risk screening results presented in this report, it is considered that there is a potential risk to sensitive receptors from selected contaminants. In some cases, this risk may be localised and in other cases potentially more widespread. However, in order to produce a robust, transparent and defensible national risk assessment, further investigation and assessment is considered to be necessary.

Recommendations

Two key questions that require further detailed consideration in subsequent work packages are:

1. Whether ongoing human activities and future effects due to climate change are likely to mobilise in-situ contamination and increase the risk of status deterioration occurring in the future (to provide supporting information for whether the ‘no deterioration’ objectives are likely to be met); and

2. Whether in situ contaminated sediments pose a problem in terms of compliance of WFD objectives and other nature conservation objectives, notably conservation objectives for Sites of Special Scientific Interest (SSSI), Special Protected Areas (SPA), Special Areas of Conservation (SAC) and Marine Conservation Zones (MCZ), and that there is a need to take action in order to achieve compliance.

The following actions are recommended in order to provide an improved understanding of in situ sediment contamination in England, although outside the current scope of this project:

1. Adoption of a standardised framework for sample collection, analysis and reporting by organisations undertaking sampling
2. Development of a set of national guidelines for sediment sampling,
3. Research to address the previously identified evidence gap in demonstrating causal links between sediment contamination and harm in the environment

In addition, suggestions have been provided for further analysis of the sediment quality database which may be possible following completion of the national risk assessment methodology. These suggestions have been made here for consideration in the subsequent work packages of this project.

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Appendix 4 – Reasons for Failure Entries for Contaminated Sediments

Abbreviations

BGS	British Geological Survey
CDMS	Contaminated marine Sediments Databased (hosted by Cefas)
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CIP	Chemicals Investigation Programme commissioned by UK Water Industry Research
CRT	Canal and Rivers Trust (previously British Waterways)
EIA	Environmental Impact Assessment
ELD	EU Environmental Liability Directive
EPR	Environmental Permitting Regulations
GIS	Geographical Information System
K_d	Soil-Water Partition Coefficient
K_{oc}	Organic Carbon-Water Partition Coefficient
K_{ow}	Octanol-Water Partition Coefficient
LOIS	Land Ocean Interaction Study
LNR	Local Nature Reserve
MCZ	Marine Conservation Zone
MHWS	Mean High Water Springs tide level
NGR	National Grid Reference
NNR	National Nature Reserve
OSPAR	Convention for protection of marine environment (named after the original Oslo and Paris Conventions)
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
PEL	Probable Effect Level
RFF	Environment Agency WFD Reasons for Failure database
SAC	Special Area of Conservation
SPA	Special Protection Area
SQG	Sediment Quality Guideline

SSSI	Site of Special Scientific Interest
TBT	Tributyl Tin Compounds
TEL	Threshold Effect Level
UDP	Urban Diffuse Pollution
WIMS	Environment Agency Water Information Management System
WFD	EU Water Framework Directive

1 Introduction

1.1 Need for and objectives of the in situ contaminated sediments project

As part of working towards meeting its environmental objectives, Defra is seeking to understand the magnitude of risks to sensitive receptors (e.g. aquatic ecology and human health) or impacts (e.g. on the way that water bodies are managed) posed by contaminated sediment in England. Defra's requirements included a systematic review of the contamination status of sediments associated with water bodies through the application of a risk assessment approach. This review will then provide the basis for a comprehensive review of the potential mitigation options available for addressing those locations where the risks may be significant.

The Project's overall aim is to provide a sound evidence base on contamination in in-situ sediments, which can underpin the development of tools and methods that will help Defra, the Environment Agency and other bodies engaged in regulation and protection of water quality. This will enable these bodies to make evidence-based decisions for funding to deliver maximum value for money in addressing risks to water quality, in particular to meet Water Framework, Marine Strategy Framework and Habitats Directives requirements.

This project is seeking to analyse and assess the risk posed by contaminated sediments and to identify practical and cost effective mitigation measures that can be applied, when needed, as part of a national risk assessment and management approach.

1.2 Project scope

The scope of the in-situ contaminated sediments project encompasses both freshwater and marine sediments in England and extends to one nautical mile off-shore (the seaward coastal waters under the EU Water Framework Directive in England)[2]. In 2007, Defra developed a UK Strategy for Managing Contaminated Sediments. The outputs of this project were published as a series of reports which are currently hosted on the Cefas website[3] . This focussed on tidal waters and collated data on certain pollutants in material dredged from ports and harbours as well as reviewing mitigation measures for contaminated sediment. The strategy also identified datasets that could contribute to a more comprehensive picture of sediment contamination in tidal waters. With respect to the freshwater environment, while extensive research has been carried out in many locations (including as part of Water Framework Directive implementation studies) and for particular sources of contamination (e.g. historical metal mining; Environment Agency, 2008) there has not been a comprehensive overview of sediment contamination on a national scale. This project seeks to build on the existing evidence base, drawing together information on the freshwater environment to complement that already gathered for marine waters.

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[2] Chemical status extends to 12 nautical miles; however, 1 nautical mile is considered to encompass the large majority of the in situ contaminated sediments and their sources.

[3] http://www.cefas.defra.gov.uk/our-science/assessing-human-impacts/dredged-marine-sediments/managing-contaminated-sediments.aspx (accessed September 2014).

This project considers the risk posed by non-agricultural diffuse pollution sources that result in the contamination of in-situ sediments (for example, contamination from toxic metals, hydrocarbons and surfactants). Sources of these contaminants have changed over recent decades with changes in industrial and domestic practices and the increased use of motor vehicles. Surface water run-off, containing contaminants from fuel combustion, brake pads and tyres, is now thought to be one of the most significant contributors to sediment contamination in rivers, estuaries and coastal waters[4]. This trend is potentially being exacerbated by the increased number of extreme rainfall events and consequent increases in run-off and combined storm overflow discharges into rivers and seas. Surface water run-off is only one source of contaminants, and there are many other factors (both present day and historic) that affect the distribution of contamination in sediments and the risk it poses to the environment. For example, some substances, the use of which has been banned for many years, are known still to be present in the sediment column in some water bodies (UK Marine SACs Project, 2001; Broads Authority, 2014; Ospar Commission, 2009), as a result of their persistence in the environment and, potentially, their continued use in small quantities (e.g. by consumers).

1.3 Reasons for assessment of risks from sediment contamination

The Water Framework Directive (WFD; Directive 2000/60/EC) introduced specific objectives to restore and protect inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters, groundwater, and associated ecosystems. Key amongst these objectives is the benchmark of achieving “good status” for all water bodies by 2015, or where more time is realistically required to investigate and address pressures, by 2021 or 2027. Guideline values for water quality have been set within the WFD. However, despite the fact that a significant proportion of contaminants in river catchments are sediment-associated and transported as part of a rivers’ sediment load (Macklin et al., 2006), chemical sediment quality guidelines have not been established. This reflects the complexity of the link between sediment contamination and effects on biodiversity (including complexities involved in assessing risk associated with exposure when contaminants desorb into the water column) and a lack of ecotoxicological data for benthic species.

Persistent organic pollutants (POPs) and WFD priority substances (Directive 2008/105/EC; Förstner, 2009), which arise from a diverse range of industrial processes (producer sources) and residential emissions (user sources), can also be transported in particulate-associated form. Transport of these organic and inorganic pollutants means that contaminants are readily stored as in-situ channel bed sediments, floodplain alluvium, estuarine sediments and coastal sediments, which can be remobilised to form significant sources of unregulated diffuse pollution. As a result, the requirements to achieve good chemical and ecological status (physico-chemistry, including concentrations of Specific

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[4] A broad summary of pollution sources is provided on the webpage of the Foundation for Water Research - http://www.euwfd.com/html/source_of_pollution_-_overview.html. The Environment Agency has also collated detailed information on particulate emissions in relation to leaf litter.

Pollutants[5], is a supporting element that, along with biology and hydromorphology, defines ecological status) set by the WFD could potentially be infringed by sediment-associated contaminants, especially when these contaminants are disturbed by flooding or human activity (e.g. desilting and dredging). As well as ecosystem health, re-suspension of potentially hazardous contaminants and their deposition on floodplains may severely impact economic activities such as agricultural production (e.g. via contaminant uptake by livestock or some food crops).

In addition to regulatory drivers, a number of factors have made sediment contamination in English catchments/water bodies a topic of current concern. These include:

- An increasing frequency of hydrometeorological extremes (potentially due to climate change) will lead to appreciable contaminant flux (Foulds et al., 2014). There is also the potential for resuspension of pollutants in estuaries and near shore environments due to increasingly stormy winter weather and tidal surges (e.g. January 2014), which may deposit contaminated sediment inland.
- Following severe flooding in autumn 2013 and winter 2014, desilting or dredging may be more routinely used as a flood risk management tool in low gradient rivers and estuaries (e.g. Somerset Levels). These types of environment often accumulate organic and inorganic contaminants associated with fine grained sediment that may be remobilised by dredging and, potentially, spread on agricultural land.

In the wider context, Defra and the Environment Agency wish to deliver maximum value for money in addressing risks to water quality, not only in order to meet the Water Framework, Marine Strategy Framework and Habitats Directives requirements but also to deliver wider societal benefits.

1.4 What is in situ contaminated sediment?

In the context of this project, in-situ contaminated sediment is defined as:

> *Chemically contaminated sediment within the water column, bed, banks and floodplain of a surface water body that has been transported alongside the normal sediment load and deposited by fluvial or coastal processes.*

This broad definition encompasses sediment that is contaminated as a result of natural processes and anthropogenic activities and cycled through river, estuarine and coastal water bodies alongside the natural, uncontaminated sediment load.

Contaminants occur within sediment in two main forms (Förstner and Wittmann, 1979):

- Particulates, including fragments of metals, which are transported alongside the rest of the sediment load (in suspension or as part of the bed load) in a watercourse; and
- Materials that are sorbed onto the surface of sediment particles.

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[5] Specific Pollutants are substances that can have a harmful effect on biology, which may be identified by Member States as being discharged to water in “significant quantities”. An initial list of Specific Pollutants is provided in Annex VIII of the WFD.

In considering the potential sources of contamination, the project considers ‘new’ contaminant inflows (consented and non-consented discharges), current and historical sources. The sediments considered include:

- Sediments that are mobile within the water body (those transported in suspension or along the bed); and
- Accessible sediments (those stored in the bed, banks and floodplain which may be subject to remobilisation at a later date).

Key to the understanding of practical options for the management of sediment contamination in the coming years are the effects of climate change and channel mobility. These factors are incorporated throughout the project.

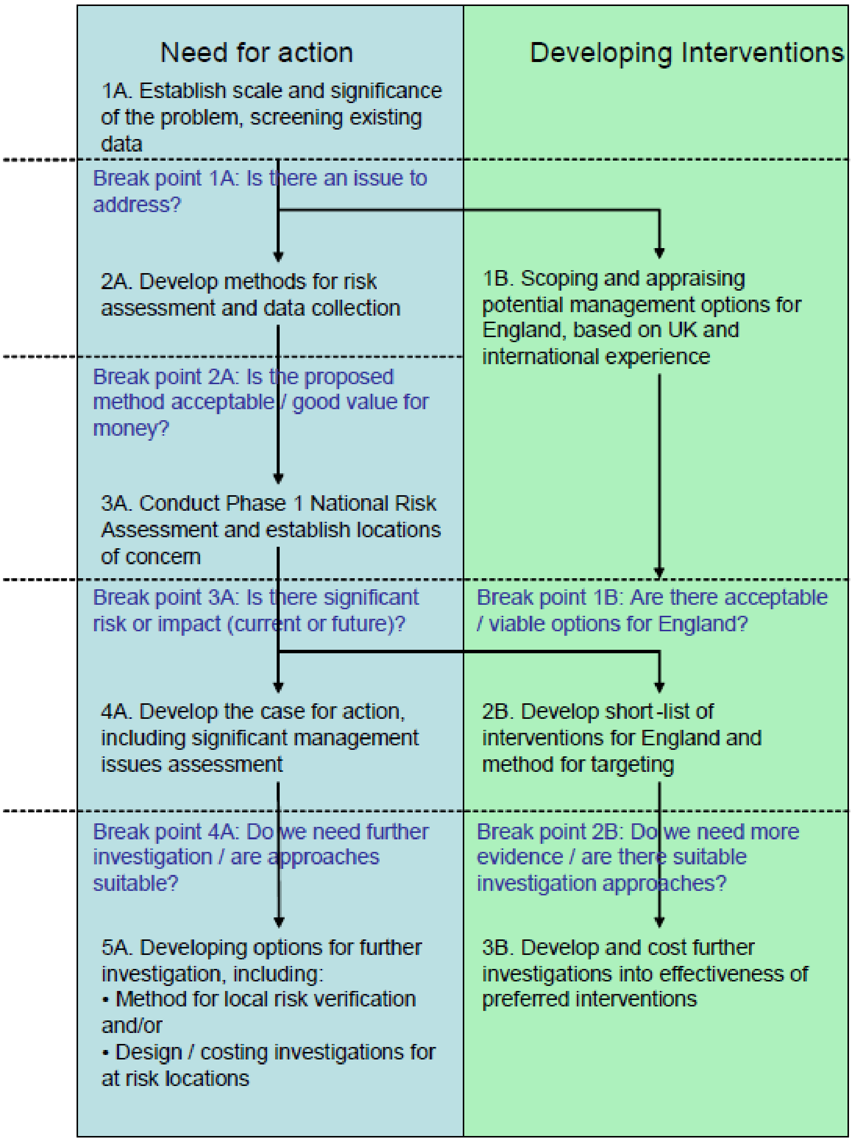
1.5 Project structure

The project is divided into two workstreams, and each of these is subdivided into a number of work packages:

- **Workstream A: Need for action.** This workstream will gather evidence of in situ sediment contamination in England and undertake an assessment of the risks that this could pose; and
- **Workstream B: Developing interventions.** This workstream will gather evidence on the range of interventions that can be used to address the issues posed by in situ contaminated sediments, and undertake an economic assessment.

Figure 1.1 shows the progression of tasks within each workstream as well as the interactions between the workstreams. This report presents the findings of **Work Package 1A**.

Figure 1.1: **Structure of Project Work Packages**



Need for action

1A. Establish scale and significance of the problem, screening existing data

Break point 1A: Is there an issue to address?

2A. Develop methods for risk assessment and data collection

Break point 2A: Is the proposed method acceptable / good value for money?

3A. Conduct Phase 1 National Risk Assessment and establish locations of concern

Break point 3A: Is there significant risk or impact (current or future)?

4A. Develop the case for action, including significant management issues assessment

Break point 4A: Do we need further investigation / are approaches suitable?

5A. Developing options for further investigation, including:
- Method for local risk verification and/or
- Design / costing investigations for at risk locations

Developing Interventions

1B. Scoping and appraising potential management options for England, based on UK and international experience

Break point 1B: Are there acceptable / viable options for England?

2B. Develop short-list of interventions for England and method for targeting

Break point 2B: Do we need more evidence / are there suitable investigation approaches?

3B. Develop and cost further investigations into effectiveness of preferred interventions

1.6 Objectives of Work Package 1A

Work Package 1A has been divided into a series of tasks as set out below. A detailed scope for each of the tasks is outlined at the start of the relevant section.

- Determining the nature and scale of the problem:
    - Initial data collation and review;
    - Identification of environmental objectives;
    - Identification of substances of concern; and
    - Review of processes which affect contaminant mobility.

- Development of a conceptual model:
    - Initial model development; and
    - Qualitative assessment of pathways and influence of climate change.

- Initial risk assessment screen (prior to further consideration for risk assessment methodologies in Work Package 2A.

- Provision of conclusions and recommendations.

1.7 Report structure

The remainder of this report is divided into the following sections:

- **Section 2**: Legislative and environmental objectives context;
- **Section 3**: Conceptual model for in situ sediment contamination;
- **Section 4**: Substances of concern for in situ sediment contamination;
- **Section 5**: Processes which affect contaminant mobility in sediments;
- **Section 6**: Nature and scale of in situ sediment contamination in England; and
- **Section 7**: Conclusions of Work Package 1A and recommendations.

2 Legislative and environmental objectives

Scope of task:

- To undertake a targeted review of the key environmental objectives and management tools which arise from this legislation has been completed in order to give the regulatory context for the management of contaminated sediments, building on a review undertaken by the Environment Agency (Environment Agency 2001).
- To consider, as well as core legislation such as the EU Water Framework Directive, wider legislation and conventions where sediment quality may affect the achievement of objective and management targets.
- To identify potentially polluting substances that are controlled within the current legislative framework and the identification of the critical human health and environmental receptors upon which the objectives have been based, where this information is available. [*Note that this will be discussed in detail in* ***Section 4.***]

2.1 Legislation

There are a wide variety of statutory and non-statutory controls pertaining to the management and control of in situ contaminated sediment. This section outlines the legislation that has the potential to drive the further investigation and potential remediation of in situ contaminated sediment, through the use of environmental objectives, and to control activities that could result in disturbance to in situ contaminated sediment or the release of contaminants into the environment and contaminating sediment.

2.1.1 Sediments as part of ecological status

Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy (otherwise known as the Water Framework Directive or WFD) requires European Union (EU) Member States to achieve good qualitative and quantitative status of water bodies by 2015. In December 2003, the WFD was transposed into English national law by means of the Water Environment (WFD) (England and Wales) Regulations 2003. These Regulations provide for the implementation of the WFD through the designation of all surface waters (rivers, lakes, transitional (estuarine) and coastal waters) and groundwaters as water bodies and setting targets to achieve Good Ecological Status or Potential.

The ecological status of the surface water body is determined by the quality of the plant, invertebrate and fish communities it supports, the flow and physical habitat conditions, and the quality of physico-chemical parameters such as pH, temperature and concentrations of various chemicals (specific pollutants). Physico-chemical parameters are assessed according to stringent standards that have been set at a national level.

The Chemical Status of a water body is assessed against a suite of Environmental Quality Standards for priority substances. When a body of water does not reach these standards, the Environment Agency is the competent authority with the responsibility to improve its status and achieve compliance with the WFD in England. Chemicals considered to pose the greatest risk of harm to or via the aquatic environment at a European level are classed as priority substances (or priority hazardous substances). Those considered as of concern at a national level have been termed “River Basin Specific Pollutants”. The list of priority substances in the 2008 Environmental Quality Standards Directive has been revised via the 2013 Priority Substances Directive and it is intended that the standards it sets will apply for the purposes of the second cycle of River Basin Management Plans.

Meeting WFD objectives is relevant to sediment-associated contaminants in several ways:

- Sediments form important habitats for aquatic biota and also act as a sink for many contaminants discharged into aquatic environments (where they may bind to solid matter and accumulate). Once contaminants have become associated with sediment, they could become directly available as a food source to the biota that lives on or within the deposits, and as such could cause potentially toxic reactions. Sediment-associated contaminants therefore have the potential to adversely impact upon the status of the biological quality elements within a surface water body, although uptake of dissolved contaminants across the skin and gills is also considered to be a significant route for exposure to most contaminants by aquatics biota;
- As well as directly affecting sediment quality, sediment-bound contaminants may also have secondary impacts on water quality. Many contaminants will remain attached to sediment if it is remobilised, but depending on chemical parameters such as pH, redox potential, oxygen saturation and the individual properties of the contaminants themselves, some may disassociate and become dissolved in the water column (known as partitioning into the water). This means that contaminants stored in sediment have the potential to impact on the status of the chemical quality elements, and on the status of the biological quality elements within a surface water body;
- Depending upon the level of connectivity between surface and groundwaters, there may also be potential for sediment-associated contaminants to enter groundwaters in the dissolved phase (or vice versa). Although this may not extend beyond the hyporheic zone, there may be some potential for adverse impacts on the chemical status of the underlying groundwater; and
- The WFD also requires that objectives are set, recorded and implemented for water-dependent sites that have been designated as Protected Areas under other EU Directives. This includes sites designated under the Habitats and Birds Directives (Natura 2000 sites), shellfish and freshwater fish protected areas, bathing waters, nitrate vulnerable zones and groundwater protected areas.

This demonstrates that sediment-associated contaminants have the potential to adversely impact upon the biological and chemical status of surface water bodies and upon the chemical status of groundwater. It is therefore important that sediment-associated contaminants are considered carefully to ensure that the requirements of the WFD can be delivered in water bodies that are affected by contaminant-related pressures.

The UK Technical Advisory Group on the WFD (WFD UKTAG) has developed a suite of environmental quality standards, in addition to the Priority Substances and Priority Hazardous Substances standards, against which the chemical status objectives of the WFD are assessed. These have been established for freshwater and marine water bodies and, where possible, have been derived based on large-scale scientific data. 19 chemical substances were originally identified, and a further 14 substances were added in 2013 (UKTAG, 2013). The standards are based on ecotoxicity in the dissolved phase (i.e. the concentrations of each substance in fresh and marine waters), and as such do not apply directly to concentrations within in situ contaminated sediments.

For selected contaminants, EQS for biota have been developed[6]. This is preferred where a contaminant is highly lipophilic (tending to repel, rather than dissolve in, water). Lack of data has, to date, precluded the introduction of sediment EQS.

The European Marine Strategy Framework Directive (2008/56/EC) was transposed into English law on 15 July 2010 by the Marine Strategy Regulations 2010. The Directive requires Member States to prepare national strategies to manage their seas to achieve Good Environmental Status (GES) by 2020, through objectives for 11 high level descriptors in Annex I of the Directive. Descriptor 8 concerns *‘Concentrations of contaminants are at levels not giving rise to pollution effects’*. In coastal waters, the objectives of the MSFD are met through the WFD.

2.1.2 Sediments as part of nature conservation

There are a variety of different nature conservation designations, which have different levels of protection depending upon their conservation importance. At the European level, the Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitats Directive) promotes the maintenance of biodiversity within the EU by requiring Member States to take measures to maintain or restore natural habitats and wild species.

The Habitats Directive was initially transposed into UK national law via The Conservation (Natural Habitats &c) Regulations 1994, which were subsequently amended in 1997 and in 2000. The Conservation of Habitats and Species Regulations 2010 consolidate all previous amendments to the 1994 Regulations. The Regulations place a duty on Member States to designate sites of European conservation importance as Special Areas of Conservation (SACs). The Regulations also require the compilation and maintenance of a register of European sites, to include SACs and Special Protection Areas (SPAs) classified under Council Directive 2009/147/EC on the Conservation of Wild Birds (the Birds Directive – codified version). This Directive replaced Council Directive 79/409/EEC. Collectively, these sites form the Natura 2000 network. Under the Regulations, competent authorities have a general duty, in the exercise of any of their functions, to have regard to the Habitats Directive.

In addition, internationally important wetlands have been designated under the Ramsar convention. Ramsar sites in England are afforded the same level of protection as European designated sites. The majority of these sites are also SPAs, and terrestrial components are also Sites of Special Scientific Interest (SSSIs).

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[6] These are listed in EU Directive 2013/39/EU.

The objectives of the Habitats Directive require Member States to introduce a range of measures, some of which can relate to the management of in situ contaminated sediment where this is affecting the conservation status of a site, including:

- Maintain or restore European protected habitats and species listed in the Annexes at a favourable conservation status as defined in Articles 1 and 2;
- Ensure conservation measures are in place to appropriately manage SACs and ensure appropriate assessment of plans and projects likely to have a significant effect on the integrity of an SAC. Projects may still be permitted if there are no alternatives, and there are imperative reasons of overriding public interest. In such cases compensatory measures are necessary to ensure the overall coherence of the Natura 2000 network (Article 6);
- Member States shall also endeavour to encourage the management of features of the landscape that support the Natura 2000 network (Articles 3 and10); and
- Ensure strict protection of species listed on Annex IV (Article 12 for animals and Article 13 for plants).

The Wildlife and Countryside Act 1981, as amended, provides protection for SSSIs; sites identified for their wildlife or geological value at a national level. This Act was amended in 1985, 1991, 1995, 1998, 1999, and 2004 (Wildlife and Countryside Act 1981 (England and Wales) (Amendment) Regulations 2004). Schedule 9 of the Countryside and Rights of Way Act 2000 provides increased powers for the protection and management of SSSIs, including the possibility of prosecution for damaging a SSSI. Both acts also apply to National Nature Reserves (NNRs), which are SSSIs that have particular nature conservation importance. The Act contains measures for the protection and management of SSSIs. The objectives of a management scheme to address issues with in situ contaminated sediment would be undertaken to:

1. To conserve the flora, fauna, or geological or physiographical features by reason of which the land (or the part of it to which the scheme relates) is of special interest; or
2. Restoring them; or,
3. Both.

In terms of addressing existing issues of in situ contaminated sediment, the government's wildlife strategy, Biodiversity 2020 (see below), seeks to ensure that 50% of SSSIs reach favourable condition, while maintaining a combined level of at least 95% of sites in either favourable or unfavourable recovering condition. Where in situ contaminated sediment is affecting the condition of a SSSI, its remediation will help to achieve these targets.

The Marine and Coastal Access Act 2009 established a network of marine protected areas called Marine Conservation Zones (MCZs). These exist alongside SACs, SPAs and SSSIs to form an ecologically coherent network of protected marine habitats.

Local Nature Reserves (LNRs) are designated by local authorities under Section 21 of the National Parks and Access to the Countryside Act 1949, which was amended by Schedule 11 of the Natural Environment and Rural Communities Act 2006. These sites are of local importance for wildlife, geology, education or public enjoyment. In addition, other Local Wildlife Sites, such as Sites of Nature

Conservation Importance (SNCIs), Sites of Importance for Nature Conservation (SINCs) and Local Wildlife Sites are designated by local authorities and protected through the planning system.

In general, nature conservation legislation for designated sites such as SACs, SPAs, Ramsar sites, SSSIs, MCZs, NNRs, LNRs and Local Wildlife Sites means that:

- Sediment quality must not have (or be likely to have) a significant impact on the qualifying features (i.e. flora and fauna) for which nature conservation sites have been designated; and
- Sediment-associated contaminants must not result in water quality failing to meet the required standards for designated sites, or have a significant effect on qualifying features.

In addition to designated sites, nature conservation legislation also places a series of other targets that are relevant to in situ contaminated sediments. The Countryside and Rights of Way Act 2000 and the Natural Environment and Rural Communities Act 2006 place a duty on central and devolved government departments and other public bodies to have overall regard for biodiversity conservation in the delivery of their functions. This could include the remediation of in situ contaminated sediment or the control of sources of sediment-associated contaminants.

Furthermore, the UK Government joined a global agreement to take action to halt declines in biodiversity in October 2010. This was followed by the Natural Environment White Paper in June 2011, which outlined a shift in focus towards an integrated large-scale approach to conservation, with an emphasis on the valuing the natural environment to inform the decision making process. To adopt this new vision, Defra produced a new biodiversity strategy for England, Biodiversity 2020, which sits in the wider UK Post-2010 Biodiversity Framework. An important aim of the strategy is to deliver the UK Biodiversity Action Plan (UKBAP) in England. The UKBAP is a national program that covers terrestrial and marine species as well as migratory birds which spend a limited time in the UK or its offshore waters. The existing UKBAP identifies 1,150 species and 65 habitats in the UK that require conservation and greater protection. The requirements of the UKBAP mean that the relevant competent authorities have a duty to conserve these habitats and species, and as such this also includes pressures created by in situ contaminated sediments.

With respect to the Water Framework Directive, the Environment Agency has identified sensitive and critical habitats that are essential to support the status of a water body. Critical habitats could be those of unique importance or offering a rare combination of features that are critical to the ecological health of the water body. Sensitive habitats are those that are particularly sensitive to change from a pressure or modification. Contamination associated with sediments could affect these habitats through the mechanism previously described.

2.1.3 Point sources and sediment

The Water Resources Act 1991 regulates water resources, water quality and pollution, and flood defence. This legislation is relevant to sediment or activities that may disturb sediment as silt and soil from eroded areas are included in the definition of polluting material under the Act. Section 85 of the Act makes it an offence to cause or knowingly permit the release of contaminants into controlled waters. This Act may also provide a mechanism to deliver remediation works to address in situ contaminated sediments, since the river bed is included as part of the controlled waters. However, it should be noted that it may be difficult to enforce against pollution arising from a consented discharge if the operator has not breached the terms of the consent.

2.1.4 Marine/estuarine sediment contamination

The provisions of the Shellfish Waters Directive 2006/113/EC (which replaced Directive 79/923/EEC, and was repealed in 2013) were incorporated into the Water Framework Directive. These included aims to protect, and where necessary, improve the quality of shellfish waters in order to support shellfish life and growth and to contribute to the high quality of directly edible shellfish products. This is achieved by requiring Member States to designate shellfish waters and put in place specific measures to maintain and improve the quality of those designated waters to particular standards to support shellfish (bivalve and gastropod molluscs) as detailed in the Directive.

The Clean Seas Environmental Monitoring Programme (CSEMP) was designed to fulfil the UK's mandatory monitoring requirements under the OSPAR Strategy and also in support of EC Directives. The legislation outlined implements a broad range of sampling and monitoring in England related to sediment issues and related activities within marine and estuarine environments. Phase 2 of the CSEMP considers factors such as sediment chemistry, bioaccumulation and benthic communities within over a hundred stable depositional sites.

2.2 Control mechanisms

2.2.1 Point sources and sediment

Point source emissions into the aquatic environment can result in contaminants being stored in sediment reservoirs where they may accumulate. This can, in turn, impact upon aquatic biological communities, especially benthic invertebrates which may utilise sediments as a feeding resource and habitat. Under the WFD it is therefore important to consider point sources and their impacts in terms of altering sediment and water quality.

The Environmental Permitting Regulations 2010 came into force on 6th April 2010 and extended environmental permitting to include water discharge consents (previously issued under the Water Resources Act 1991). These regulations control industrial emissions and aim to reduce the release of chemicals into the environment.

Harbour Authorities have particular responsibilities and byelaw-making powers in relation to the safety of vessels and people within the harbour, efficient navigation and the protection of the port environment, as required by the Harbours Act, 1964 and The Merchant Shipping (Port State Control) Regulations, 1995.

2.2.2 Freshwater sediment contamination

In addition to the WFD, several other key pieces of legislation are relevant to the contamination of freshwater sediments. The Industrial Emissions Directive (IED), enacted in England through the Environmental Permitting (England and Wales) (Amendment) Regulations 2013 (EPR), replaced a series of directives including the Integrated Pollution Prevention and Control Directive 2008/1/EC (the IPPC Directive) in requiring industrial and agricultural activities with a high pollution potential to be permitted. This permit can only be issued if certain environmental conditions are met, so that the companies themselves bear responsibility for preventing and reducing any pollution they may cause. The IED is considered to be a fundamental measure under the WFD. As such, it should also protect sediment quality as well as water quality through requirements (as permit conditions) for pollution prevention using Best Available Techniques, as well as controls on discharges to water to achieve compliance with relevant EQS.

The Urban Wastewater Treatment Directive (91/271/EEC) (UWTD) addresses pollution incidents caused by direct urban wastewater discharges of excessive levels of nutrients (in particular phosphorus and nitrogen) into the freshwater environment. Sites can be designated as sensitive areas under the Directive, in which tertiary treatment facilities will be required. The UWTD is considered to be a fundamental measure under the WFD.

These pieces of national legislation, in conjunction with the Water Resources Act 1991, aim to restrict freshwater sediment contamination.

The Water Resources Act 1991 requires the input of dangerous substances into water to be controlled. The substances listed in List I and List II as having the potential to cause harm to aquatic life are regulated and monitored (via sediment or biota monitoring).

2.2.3 Marine/estuarine sediment contamination

In addition to the WFD, several other key pieces of legislation are relevant to the contamination of marine and estuarine sediments. The OSPAR Hazardous Substances Strategy aims to prevent pollution of the marine environment by continuously reducing discharges, emissions and losses of hazardous substances. The ultimate objective of the Strategy is achieving concentrations in the marine environment near background values for naturally occurring substances and close to zero for man-made synthetic substances.

2.2.4 Sediment as waste

The European Directive 1999/31/EC on the Landfill of Waste (Landfill Directive) aims to prevent or reduce as far as possible negative effects from the landfilling of waste on the environment. This is achieved by introducing technical requirements for waste and landfills. The requirements of the landfill directive were implemented by the revised Environmental Permitting Regulations 2010 (as amended) (EPR 2010). Waste classification is regulated under the Hazardous Waste Regulations 2005. Council Decision 2003/33/EC provides the framework for Waste Acceptance Criteria.

Directive 2008/98/EC (Waste Framework Directive) outlines waste management in terms of defining key variables and setting exceedance levels in terms of defining waste from by-products. The Directive sets some basic waste management principles, for example requiring that waste be managed without endangering human health and harming the environment, and in particular without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odours, and without adversely affecting the countryside or places of special interest. It should be noted that non-hazardous sediments that are relocated in surface waters without being brought onto land (for the purpose of managing waters or waterways or of preventing floods or mitigating the effects of floods and droughts or land reclamation) are not classed as waste under the Waste Framework Directive. The Waste (England and Wales) Regulations (2011) implemented much of the 2008 Waste Framework Directive, including the requirements for consideration of the waste hierarchy in reuse or disposal of arisings and updated requirements for waste Duty of Care.

A number of exemptions area available under the EPR 2010 which may be used for natural dewatering of sediments on the side of the watercourse from which it was dredged, or use of a limited quantity for construction.

The Definition of Waste: Industry Code of Practice, published by Contaminated Land: Applications in the Real Environment (CL:AIRE) also provides a mechanism whereby dewatered sediments can be used in construction, provided that they meet certain requirements (namely that they are suitable for their proposed use, that they will not present an unacceptable risk to human health or the environment; and that there is certainty that the material, and the volume of material proposed, will be required for reuse),

In tidal waters the requirements of the Waste Framework Directive are met through the marine licensing regime operated under the Marine and Coastal Access Act 2007 by the Marine Management Organisation. Sediment, in the form of dredged material, is permitted to be disposed of at a licensed marine disposal site subject to a review of any potential impacts to the environment and human health. As previously mentioned, if sediment is non-hazardous then it falls out of the Waste Directive.

The Land Drainage Act 1991 (as amended) also requires that a watercourse be maintained by its owner in a condition that flow conveyance of water is not impeded, taking into consideration upstream impacts such as waste input.

It should be noted that most sediments removed from rivers are exempt from landfill tax. In other areas of management of contaminated materials (e.g. remediation of contaminated land) rising landfill tax is regarded as having provided a driver for the development of treatment processes and mechanisms for reuse of material.

2.2.5 Sediments as land affected by contamination

Part 2A of EPA 1990 introduced regulations relating to contaminated land. In-channel sediments would not be included if the contaminants are deemed to be in contact with or already entered the water as a source below the water table. Floodplain sediments could be contaminated land if they were causing or there was a significant possibility of them causing significant harm to defined receptors as set out in Statutory Guidance.

The Environmental Liability Directive (ELD), transposed into English law by the Environmental Damage (Prevention and Remediation) Regulations 2009, aims to ensure that businesses focus on the environmental effects of their activities by encouraging operators to avoid causing environmental damage and to proactively remediate such damage rather than gambling on whether regulatory action will be taken once the damage occurs. The ELD covers environmental damage caused by, or resulting from, the occupational activities of operators to:

- Species and natural habitats protected under the 1992 Habitats Directive and the 1979 Wild Birds Directive;
- Waters covered by the WFD; and
- Land contamination that creates a significant risk of harming human health.

2.2.6 Sediments within planning

The National Planning Policy Framework (NPPF) sets out the Government's planning policies for England and how these are expected to be applied. Section 11 considers the conservation of the natural environment and states that, the planning system should contribute to and enhance the natural and local environment by:

- Protecting and enhancing valued landscapes, geological conservation interests and soils;
- Recognising the wider benefits of ecosystem services;
- Minimising impacts on biodiversity and providing net gains in biodiversity where possible, contributing to the Government's commitment to halt the overall decline in biodiversity, including by establishing coherent ecological networks that are more resilient to current and future pressures;
- Preventing both new and existing development from contributing to or being put at unacceptable risk from, or being adversely affected by unacceptable levels of soil, air, water or noise pollution or land instability; and
- Remediating and mitigating despoiled, degraded, derelict, contaminated and unstable land, where appropriate.

The jurisdiction of Local Authorities extends to Mean Low Water and therefore the intertidal sediments and therefore their management, falls within their remit (although in practice the MMO is likely to manage sediment issues in the inter-tidal zone).

2.2.7 Sediments within Environmental Impact Assessment

The EIA Directive (85/337/EEC) applies to a wide range of public and private projects, defined in Annexes I and II. All projects listed in Annex I require a Mandatory EIA due to being considered as having a significant effect upon the environment. The projects listed in Annex II require the discretion of Member States as to whether an EIA is required. This Directive was amended in 1997, 2003, 2009, and was most recently codified in 2011 (Directive 2011/92/EU). The provisions of The Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (Habitats Directive) also applies to sediments within an EIA context.

The Town and Country Planning (Environmental Impact Assessment) Regulations 2011 (which replaced earlier regulations from 1999) were developed in response to the EIA Directive. The Act prohibits the granting of planning permission without first considering the status of the environmental information supplied. The EIA has become a central vital tool used by Local Authorities in the determination of planning consent and permission. The environmental information presented with an

EIA enables all stakeholders in the development process to have concise information concerning the likely significant impacts on the environment of the proposed development should consent be granted.

The Marine Works (Environmental Impact Assessment) Regulations 2007 (as amended) puts into practice the EIA Directive in relation to marine licences. The Harbour Works (Environmental Impact Assessment) Regulations 1999 amends the Harbours Act 1964 to implement the EIA Directive in relation to harbour orders. The Marine Management Organisation (MMO) ensure the requirements of the EIA Directive in relation to marine licences and harbour orders. To meet the regulatory requirements, an assessment is made of the effect on the environment of projects requiring a marine licence or harbour order.

These pieces of legislation relate to potential sediment issues and activities by ensuring that planning authorities or government assess the significance of a projects likely environmental impact. Based of thresholds this assessment can be mandatory or discretionary. Environmental statements should consider the potential sediment issues associated with the proposed activities, for example the process, transport and disposal of contaminated sediment during dredging activities.

This section highlights the considerable variety of legislation that has some relevance to sediment. There are currently no sediment quality objectives that must be complied with. The requirement to mitigate or remediate in situ contaminated sediment will, therefore, depend upon the characteristics of each individual situation, the legal significance and any protection afforded to the impacted feature (local, national, European, etc.) and the weight of evidence supporting the contaminated sediment as being the cause of the observed impact. Unlike the legal provisions made for controlling risks from terrestrial contaminated land which is not being redeveloped under the planning regime (Environmental Protection Act, 1990, Part 2A, as amended), there is no regime in force which requires public bodies, landowners or other parties to identify, register and remediate contaminated sediment.

3 Conceptual model for in situ sediment contamination

Scope of task:

- To develop conceptual pollutant linkage model(s) using the principles established in technical guidance and based on the information on sources (contaminants, activities and industry types – including historical and current industrial uses of potential contaminants), pathways (management activities, physical and chemical processes) and receptors (human and ecological receptors including those represented by environmental objectives and quality standards). [*Note: contaminant types, characteristics and uses are discussed in* ***Section 5 and Appendix 1****.]*

- To consider, where appropriate, current controls on the uses of substances, for example where banned substances are no longer expected to contribute to replenishing concentrations in sediments (e.g. Tributyl Tin and PCBs). [*Note: this aspect is discussed in* ***Section 4****.]*

- To focus solely on linkages for release and / or dispersion of contaminants via in situ sediments on a catchment scale and encompass the freshwater environment, transitional and coastal/marine environment.

- To consider the following receptors: human health; aquatic ecology (i.e. those receptors for which the Environmental Quality Standards are protective); and, where relevant, other ecological receptors further up the food chain (e.g. certain species of internationally important fish or avian fauna protected under the Habitats and Birds Directives).

3.1 Introduction

3.1.1 Conceptual models

A conceptual model is a qualitative tool used to visualise the primary factors that influence contaminant fate and transport within a system. The system can be an individual site or land holding or a much wider area such as a river catchment or drainage basin. Current guidance (Environment Agency, 2004) recommends that a conceptual model is formulated based on the information available but that, as more information becomes available, the conceptual model should be updated.

In this case the conceptual model has been developed for a river catchment, its estuary and extending out into the near-shore marine waters (**Figure 3.1**).

3.1.2 Pollutant linkages

The model is based on the principle that, for contamination within soil or water to pose a risk, a pollutant linkage must be established. A pollutant linkage consists of three parts:

- A **source** of contamination;
- A **pathway** by which the contaminant is able to cause harm (or which presents a possibility of such harm being caused); and
- A **receptor** that is sensitive to an adverse impact from the contamination.

Where all three of these are present, a pollutant linkage exists. Conceptual models form a starting point of the understanding of the pollutant linkage system. Observations of contaminant behaviour can then be used to verify and refine the different pollutant linkages within the model (Environment Agency, 2001).

The detail used in the conceptual model will depend on the size and complexity of the system and reflects the balance between providing sufficient information to represent the real life situation and simplifying to a point where the model is readable and useable. In this case, a very simplified approach has been adopted in order to represent what are considered likely to be the main catchment processes associated with the release, movement, transportation and deposition of contaminated sediment and the impacts associated with contaminated sediments.

3.2 In situ contaminated sediments: Conceptual model

The conceptual model for in situ sediment contamination is presented in pictorial form in **Figure 3.1**, with an accompanying table that provides additional detail on each identified pollutant linkage (**Table 3.1**). Sources, pathways and receptors have all been colour coded for ease of use. Whilst agricultural pollution of sediments is outside the scope of this study, this source has been depicted in the model in order to provide a more complete picture of activities within a catchment which may result in contamination of sediments.

3.2.1 Assumptions and limitations

Given the uncertainties inherent in forming a conceptual model, it is important to consider what is known or understood about the system, what is not known or understood, any assumptions being made and anything which has been ignored or simplified in order to produce a readily understandable and useable representation (Environment Agency, 2001). In this case, broad assumptions have been made in order to produce a model of a ‘generalised catchment’ where all main pathways are active. This includes rock types that are susceptible to erosion and dissolution and the presence of a wide range of human activities including mining, farming, industry, dredging and fishing. In practice, not all of these activities may be present in all catchments. The relative importance of the pathways may also vary significantly between catchments and this is discussed in more detail in **Section 3.3**.

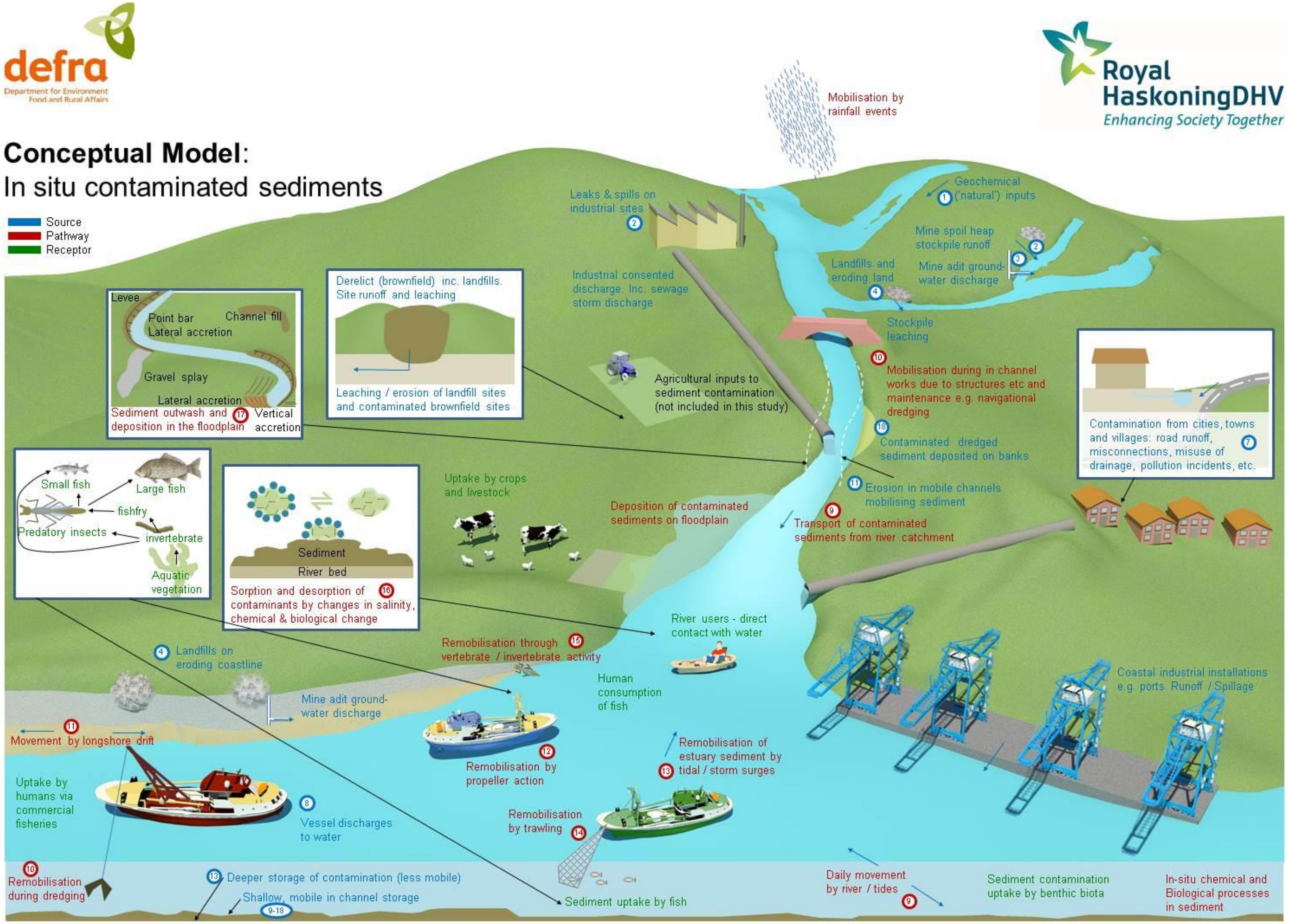

Figure 3.1: **Conceptual model of sources, pathways and receptors of in situ contaminated sediments**

Table 3.1: Conceptual site model – description table

Contaminant Linkage Number[1]	Source (2)	Contaminant types	Freshwater pathway	Marine/Estuarine pathway	Receptors	Influence of catchment type, channel and coastal mobility	Climate change implications
1	Natural deposits (geochemical inputs)	Inorganics	Direct erosion of mineral deposits from catchment geology, entrainment of enriched soils through surface runoff, chemical leaching of enriched deposits	Direct erosion of mineral deposits from coastal geology, entrainment of enriched soils through surface runoff, chemical leaching of enriched deposits	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Nature and quantity of inputs dependent on catchment/coastal geology	Increased rainfall volume and intensity is likely to increase runoff and entrainment of naturally enriched sediments. Increased long term saturation of soils may lead to an overall lowering in pH and more widespread anaerobic soil conditions, potentially leading to greater mobilisation of many (but not all) metal contaminants. Sea level rise (especially) and changes in storm and surge conditions are likely to increase erosion, entrainment and dispersion of naturally enriched sediments
2	Mine spoil heaps	Metalliferous mining: metals from primary minerals, metals from secondary minerals (gangue), acid mine drainage Coal mining: metals, acid mine drainage (iron hydroxides)	Direct erosion of spoil heaps by flowing water, entrainment by surface runoff, chemical leaching of enriched deposits, direct input of dissolved metals	Erosion of spoil-dumped beaches or spoil heaps adjacent to coastal areas	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river	Only relevant to catchments with mine workings. Acid mine drainage neutralised in limestone catchments	Increased rainfall volume and intensity is likely to increase runoff and entrainment of material from spoil heaps Increased long term saturation of soils may lead to an overall lowering in pH and more widespread anaerobic soil conditions, potentially leading to greater mobilisation of many metal contaminants. Sea level rise (especially) and changes in storm and surge conditions are likely to increase erosion of exposed (i.e. undefended) spoil-dumped beaches and spoil heaps adjacent to coastal areas (e.g. on cliff tops). Increase in temperature may increase rates of some geochemical processes, potentially promoting erosion
3	Mine adit discharges to surface and groundwater	Metalliferous mining: metals Coal mining: metals, acid mine drainage (iron hydroxides)	Direct discharge to surface flows, groundwater baseflow	Direct discharges to coastal environment	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish	Only relevant to catchments with mine workings. Acid mine drainage neutralised in limestone catchments	Increased rainfall volume and intensity could increase discharges from adits (although contaminants may be more diluted by increased volumes of uncontaminated water)
4	Landfills and contaminated land (including contaminated dredged material placed on canal and river banks and in disposal lagoons adjacent to rivers and fly tipped wastes)	Wide range of contaminants depending on nature of waste inputs/site activities	Natural bed and bank erosion, disturbance as a result of channel usage (e.g. navigation, management) and surface water runoff	Erosion of coastal contaminated sites by natural erosion processes and surface water runoff	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Erosion greater where river channels are highly mobile, river banks and coast lines are easily erodible (e.g. poorly cohesive), or banks are unprotected	Increased rainfall volume and intensity could increase river flows and energy, causing increased bed and bank erosion, erosion of surface materials and entrainment of sediments in surface runoff. Increased storminess could result in increased coastal erosion rates. Sea level rise (especially) and changes in storm and surge conditions are likely to increase erosion of exposed (i.e. undefended) landfills and contaminated land and increased erosion due to wave overtopping of defended landfills and contaminated land
5	Industrial sites (non-consented discharges)	Wide range of contaminants depending on nature of waste inputs/site activities	Leaks and spills (infiltration and surface water drains)	Leaks and spills in areas drained directly to coastal waters	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Could potentially apply to all catchment and coastal types. Likely to be a more significant issue in urbanised areas	More ‘flashy’ nature of rainfall events is likely to lead to more rapid discharge of leaks and spills into the environment before they can be contained

Contaminant Linkage Number[1]	Source (2)	Contaminant types	Freshwater pathway	Marine/Estuarine pathway	Receptors	Influence of catchment type, channel and coastal mobility	Climate change implications
6	Industrial consented discharges (including wastewater storm overflow discharges)	Wide range of contaminants depending on nature of waste inputs/site activities	Accumulation of contaminants downstream of consented outfalls	Accumulation of contaminants around estuarine and coastal consented outfalls (tidally influenced zone of contamination)	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Could potentially apply to all catchment and coastal types. Likely to be a more significant issue in urbanised areas	Increased potential for remobilisation of accumulated contaminants around outfalls as a result of increased river flooding or sea level rise / coastal storminess
7	Urban/built area diffuse inputs (road runoff, misconnections, misuse of surface water drains, pollution incidents, etc.)	Inorganics: metals, phosphates, nitrates and nitrites, Organics: petroleum hydrocarbons, polycyclic aromatic hydrocarbons, pesticides and herbicides	Surface water drains and combined sewer overflows	Diffuse inputs from coastal settlements	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Could potentially apply to all catchment and coastal types	Increased rainfall volume and intensity could increase discharges from the urban drainage system (although contaminants may be more diluted by increased volumes of uncontaminated water)
8	Vessel discharges - oily waste, grey water, ballast water and oil spill, erosion of anti-fouling paints	Inorganics: metals, phosphates Organics: petroleum hydrocarbons, surfactants	Direct discharge to water	Direct discharge to water	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Relevant to navigable waters	-
9	Existing contaminated in-channel and in-bank sediments (including current and historic estuarine and coastal licensed disposal sites)	Potentially wide range of contaminants depending on nature of inputs from catchment	Movement via river water under normal flow conditions	Movement by tides and wave action.	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Could potentially apply to all catchment and coastal types	Climate change could make normal river flows lower during summer months, with less energy to erode and remobilise contaminated sediments resulting in less baseflow transport of sediment. However, normal river flows in winter and peak river flows during storms will be likely to increase, causing greater erosion and transportation of contaminated sediment and bringing a greater 'seasonality' of effect. Sea level rise / coastal storminess could generally cause greater erosion and remobilisation of contaminated sediments from either the coast/estuary foreshore, the core of defence structures or the backing land (in the latter case due to wave overtopping)
10	Existing contaminated in-channel sediments	Potentially wide range of contaminants depending on nature of inputs from catchment	Mobilisation of in-channel sediments through river works (installing structures, maintenance, navigational dredging, weir removal)	Mobilisation via coastal and marine engineering works, maintenance and navigational dredging, capital dredging	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Could potentially apply to all catchment and coastal types	Increase in marine offshore renewable energy schemes to mitigate the effects of climate change through lower greenhouse gas emissions. Increased disturbance of contaminated sediments by associated construction / maintenance / repowering / decommissioning works

Contaminant Linkage Number[1]	Source (2)	Contaminant types	Freshwater pathway	Marine/Estuarine pathway	Receptors	Influence of catchment type, channel and coastal mobility	Climate change implications
11	Existing contaminated in-channel and in-bank sediments	Potentially wide range of contaminants depending on nature of inputs from catchment	Erosion and mobilisation by channel migration	Erosion and mobilisation via coastal processes and tidal action	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Erosion greater where river channels and coastlines are highly mobile and easily erodible (e.g. poorly cohesive), or where they are unprotected	Increased frequency of "geomorphologically active" floods[3] could increase the volumes of contaminated sediments that are remobilised through river channel migration. Increased storminess could also increase the volume of material remobilised through coastal erosion and tidal processes. Sea level rise / coastal storminess could generally cause greater erosion and remobilisation of contaminated sediments from either the coast/estuary foreshore, the core of defence structures or the backing land (in the latter case due to wave overtopping)
12	Existing in-channel contaminated sediments	Potentially wide range of contaminants depending on nature of inputs from catchment	Mobilisation by propeller action, and vessel wash	Mobilisation by propeller action and vessel wash	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Relevant to navigable waters	
13	Deep stored contaminated sediments	Potentially wide range of contaminants depending on nature of inputs from catchment	Mobilisation by fluvial flood events (deep scouring)	Mobilisation by coastal flood events (deep scouring) including erosion of floodplain salt marsh and mud flats and by capital dredging	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Greater effect in catchments/coastlines prone to significant flood events	Increased frequency of "geomorphologically active" floods could increase the volumes of contaminated sediments that are remobilised through river channel migration. Increased storminess could also increase the volume of material remobilised through coastal erosion and tidal processes and increased deposition of material in the floodplain. Sea level rise / coastal storminess could generally cause greater erosion and remobilisation of contaminated sediments
14	Existing in-channel contaminated sediments	Potentially wide range of contaminants depending on nature of inputs from catchment	-	Mobilisation through fishing e.g. beam trawling	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Relevant to navigable waters	
15	Existing in-channel contaminated sediments	Potentially wide range of contaminants depending on nature of inputs from catchment	Mobilisation by activity of aquatic or bank dwelling vertebrates and invertebrates (e.g. burrowing of invasive signal crayfish in river bed and bank collapse)	Mobilisation by activity of aquatic or coastal vertebrates and invertebrates (e.g. burrowing in sea bed and cliff collapse)	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	May occur in low energy systems where physical processes are less dominant.	Species diversity and populations may change due to direct changes in sea level (affecting submergence), changes in sea level / coastal storminess indirectly affecting suspended sediment concentrations and/or deposition/erosion patterns (in turn affecting turbidity of the water column and depth of burial of species), air or water temperature or salinity causing changes in nature and level of activity

Contaminant Linkage Number[1]	Source (2)	Contaminant types	Freshwater pathway	Marine/Estuarine pathway	Receptors	Influence of catchment type, channel and coastal mobility	Climate change implications
16	Existing in-channel contaminated sediments	Potentially wide range of contaminants depending on nature of inputs from catchment	Chemical and biological changes to contamination releasing additional contaminants or increasing availability of contamination (e.g. oxidation, reduction, degradation and concentration of contaminants by plants or animals)	Chemical and biological changes to contamination releasing additional contaminants or increasing availability of contamination (e.g. oxidation, reduction, degradation and concentration of contaminants by plants or animals)	Aquatic receptors (algae and plants, benthic invertebrates, fish, wildfowl, mammals); humans consuming fish/shellfish; human users of river or sea	Could potentially apply to all catchment and coastal types	Increased energy in aquatic systems could increase chemical/biological activity and/or favour aerobic processes over anaerobic due to physical disturbance of sediments. Potential for increase in water temperature to increase rates of chemical and biological processes. Changes in salinity may also alter these processes, particularly in the estuarine environment.
17	Existing in-channel contaminated sediments	Potentially wide range of contaminants depending on nature of inputs from catchment	Sediment outwash and deposition in the flood plain by fluvial flood events. River flood events may also deposit sediments in the estuary and navigation channels.	Sediment and deposition in the coastal floodplain by sea flooding events	Floodplain receptors - Humans, livestock, wildlife, crops, sensitive land uses such as arable gardens and allotments	Greater effect in areas with extensive floodplains and/or sensitive land uses in the floodplain (e.g. farming, residential, recreation)	Increased flood magnitude and frequency due to changes in rainfall and sea level / coastal storminess has the potential to increase geomorphological activity (i.e. erosion) within rivers and coasts/estuaries, thus remobilising greater volumes of contaminated sediment
18	Existing in-channel contaminated sediments	Potentially wide range of contaminants depending on nature of inputs from catchment	Contaminated dredged sediments deposited on banks	Contaminated dredged sediments deposited on shore	Floodplain receptors - Humans, livestock and wildlife	Greater effect in areas requiring frequent or widespread dredging	Increased flood magnitude and frequency has the potential to increase geomorphological activity (i.e. erosion) within rivers, thus a requirement for more frequent dredging. Increased sea level may result in generally higher levels of suspended sediment concentration and increased deposition, increasing the frequency with which dredging needs to occur

(1) Contaminant linkages 1 to 8 (in yellow) are regarded as contaminant input pathways – those which introduce contaminant load to the water body. Linkages 9-15 (in blue) are regarded as contaminant remobilisation pathways – those which can result in exposure of receptors to contaminants already present in sediments within the water body.

(2) Only non-agricultural sources of in-situ sediment contamination are discussed in this study. It is recognised however that a number of these pathways may also be relevant to exposure of receptors to agricultural diffuse pollution of sediments.

(3) Geomorphologically active floods are those resulting in sufficiently high flow velocities to cause sediment (particularly coarser sediment such as gravel) to move. Most erosion of river channels occurs during these higher flow events.

3.3 Relative importance of the contaminant linkages

Based on the complexity of a river catchment and the high level nature of the conceptual model presented in **Section 3.2**, it is possible only to discuss the relative importance of each of the pollutant linkages in broad, qualitative terms. A large quantity of detailed information (by observation and measurement) would be needed to confirm the importance of a given linkage in a particular catchment.

The importance of each linkage will vary depending on factors including:

- The nature and individual characteristics of the catchment;
- The stretch of the catchment under consideration; and
- The location of the sediments in the freshwater, estuarine and marine environments.

In **Table 3.2**, each linkage has been categorised based on where it is likely to be active within the system (within the upper river catchment, lower river catchment (lowland areas), estuary and/or marine environment. Each linkage has been categorised according to its likely relative importance in each water environment:

✓ This linkage is likely to have significant importance in this environment

(✓) This linkage is likely to have some (potentially limited) importance in this environment

✗ This linkage is likely to have very limited importance in this environment or the linkage may not be complete.

Comments have also been provided on the likely reasons for this and whether the linkage is likely to be present in all river catchments in England or restricted only to certain location or catchment types.

Table 3.2: Discussion of the relative importance of contaminant linkages

Contaminant Linkage	Presence				Comment
	Upper river catchment	Lower river catchment	Estuary	Marine waters	
Natural deposits (geochemical inputs)	✓	✓	✓	✓	All rivers and marine waters will receive geochemical inputs of (mainly) inorganic substances. These will vary widely depending on the geology present. The main areas of England where rivers are known to have significant inputs of potentially toxic substances via these pathways include the northern Pennines, the Lake District, parts of Derbyshire and western Shropshire, the Mendips, Devon and Cornwall.
Mine spoil heaps	✓	(✓)	(✓)	(✓)	Areas of England where sediment and water quality are influenced by historic mining activities are mainly associated with mineralised areas (e.g. the northern Pennines, the Lake District, Derbyshire, west Shropshire, the Mendips, Devon and Cornwall), as well as coastal coil spoil heaps in the north east of England. Hence this pathway is expected to be highly relevant in these areas but of minor importance elsewhere in England. In some small mined catchments, mine discharges drain directly into the sea, and some affect nearby estuaries (mainly in south west England).
Mine adit discharges to surface and groundwater	✓	(✓)	(✓)	(✓)	
Landfills and contaminated land (including contaminated dredged material placed on canal and river banks and in disposal lagoons adjacent to rivers and fly tipped wastes)	(✓)	✓	✓	✓	Landfilling and other activities which have contaminated land have historically been very widespread across England. Before the advent of comprehensive environmental controls, low-lying and marshy areas were often landfilled, resulting in extensive tips in areas which are prone to inundation and erosion. Although contaminated land may be more concentrated in industrial and/or urban areas, areas of landfilling are common in rural parts of England, particularly where land was quarried for clays and aggregates and then backfilled with wastes. This pathway is expected to be more concentrated in lowland areas as the majority of landfills are in lowland areas, although exceptions exist.

Contaminant Linkage	Presence				Comment
	Upper river catchment	Lower river catchment	Estuary	Marine waters	
Industrial sites (non-consented discharges)	(✓)	✓	✓	✓	Industrial sites often located in lowland/estuarine/coastal areas. Catchments will vary in the amount and nature of industrial activities and installations present. Industries vary widely in their use of, and discharges to, water.
Industrial consented discharges (including wastewater storm overflow discharges)	(✓)	✓	✓	✓	
Urban/built area diffuse inputs (road runoff, misconnections, misuse of surface water drains, pollution incidents, etc.)	(✓)	✓	✓	✓	The larger urban areas are more often located in lowland/estuarine/coastal areas although roads, villages etc. will be present to some extent throughout the catchment.
Vessel discharges - oily waste, grey water, ballast water and oil spill, erosion of anti-fouling paints	✗	✓	✓	✓	Navigable waters are likely to be present only in the lower catchment as well as estuarine and coastal areas.
Movement via river water under normal flow conditions	✓	✓	✓	✓	The volume and velocity of flow will vary through the catchment and under different weather/tidal conditions. The catchment will be made up of a series of erosional and depositional environments.
Mobilisation of in-channel sediments through river works (installing structures, maintenance, navigational dredging, weir removal)	✓	✓	✓	✓	Channel works may be undertaken in all parts of the river catchment and in coastal areas. Navigational dredging is likely to take place in the lower catchment as well as estuarine and coastal environments.
Erosion and mobilisation of floodplain sediments by channel migration	✓	✓	✓	✗	Natural channel migration occurs in response to the action of erosional processes on the banks of the channel. This can lead to the remobilisation of contaminants stored in the banks that are being eroded. These processes operate throughout the catchment, but are frequently most prevalent in higher energy reaches.
Mobilisation by propeller action and vessel wash	✗	✓	✓	✓	Navigable waters are likely to be present only in the lower catchment as well as estuarine and coastal areas
Mobilisation by fluvial flood events	✓	✓	✓	(✓)	Flood flows may affect all parts of the river, estuarine and marine environment to an extent. The erosional effects of flooding will depend on a variety of catchment features including geology, existing in-channel structures, channel modifications, etc. Some eroded material is likely to be redeposited on the floodplain surface as a result of overbank inundation.

Contaminant Linkage	Presence				Comment
	Upper river catchment	Lower river catchment	Estuary	Marine waters	
Mobilisation through trawling	✗	✗	✓	✓	Most trawling is outer estuary, coastal and offshore. It is widespread in the coastal zone reflecting the fish distribution.
Mobilisation by activity of aquatic or bank dwelling vertebrates and invertebrates (e.g. burrowing of invasive signal crayfish in river bed and bank collapse)	✓	✓	✓	✓	Aquatic vertebrates and invertebrates are expected to be found in all catchments, although invasive species may currently only be present in some areas.
Chemical and biological changes to contamination releasing additional contaminants or increasing availability of contamination (e.g. oxidation, reduction, degradation and concentration of contaminants by plants or animals)	✓	✓	✓	✓	Chemical and biological environments will vary amongst catchments and throughout a given catchment depending on a variety of factors including depth of contamination in the sediment column, turbulence, depth of water, presence of vegetation etc.
Deposition on the fluvial floodplain as a result of fluvial flooding events and deposition on the coastal floodplain by sea flooding events	(✓)	✓	✓	✓	Fluvial floodplains likely to be present in all but the steepest parts of the upper catchments . Coastal floodplains likely to be present mainly in low lying estuarine areas but also along low lying shorelines.
Contaminated dredged sediments deposited on banks/shore	✓	✓	✓	✓	Channel works may be undertaken in all parts of the river catchment and in coastal areas. Navigational dredging is likely to take place in the lower catchment as well as estuarine and coastal environments.

Scope of task:

- Establish qualitatively whether sediment management techniques might represent a pathway in their own right, or whether they may influence other pathways (including natural processes) in the conceptual model.
- Examine qualitatively the effects of flood events and the predicted effects of climate change, principally changes to erosion and transport of sediments.
- Discuss qualitatively the relative importance of the different pollutant linkages. *[Note: This is also discussed in Section 2.3.]*
- Examine, where possible, likely risks from contaminated sediments already transported into the floodplain including areas where erosion may cause redistribution of contaminants held within the floodplain using studies available on this topic (including the extensive literature associated with metal contamination from historical mining).

3.4 Mobilisation, dispersion and deposition of contaminants due to disturbance

3.4.1 Introduction

Many activities that are carried out within river catchments and coastal waters may affect the pathways identified in the conceptual model (**Table 3.1**).

Disturbance of sediments can leave sorbed contaminants exposed to a different geochemical environment, potentially resulting in desorption and transformation of contaminants into a more toxic and/or more bioavailable form (Eggleton and Thomas, 2004).

Processes which disturb sediments include:

- Capital and maintenance dredging programmes;
- Propeller action and vessel wash from ships, boats and other vessels;
- Construction activities (e.g. ports, weirs, offshore wind farms);
- Flood events;
- Tidal movements and storms;
- Commercial and recreational fishing;
- Other recreational activities, including water sports; and
- Feeding and burrowing of aquatic organisms (bioturbation).

Disturbance of sediment results in inflow of dissolved oxygen. In sediments containing sulphide, this leads to increased activity of sulphide-oxygenating bacteria which, in turn, causes a drop in pH. More acidic (low pH) conditions cause the release of metal contaminants from sediment into the water. The interactions and chemical transformations involved in suspension of sediments can be complex and involve changes in contaminant and substrate metal oxidation states as well as changes to the particles within the sediment to which the contaminants are sorbed. The changes may be dependent on how often or for how long the contaminants are mobilised (Eggleton and Thomas, 2004).

Dredging activities may have different effects on different types of contaminants. For example, metals have been shown not to be significantly mobilised, which is attributed to their being scavenged by iron and manganese oxides and hydroxides. Similarly, the larger PAH molecules may be associated with larger sediment particle sizes than the lower molecular weight PAHs (although the mechanism for this is not clear) and may therefore not be transported far before re-deposition (Eggleton and Thomas, 2004).

The sections below explore the different types of activities which may occur and their potential effects.

3.4.2 Influence of existing controls on sediment contamination processes

A number of methods have been developed with the aim of controlling contamination via the pathways listed in **Table 3.1**. This section identifies controls which may affect each individual pathway for sediment contamination; effects of source controls on contaminants found in sediment are discussed in **Section 5.4**. The controls identified for each pollutant linkage in the conceptual model are summarised in **Table 3.3**.

Table 3.3: Identified controls on sediment contamination processes

Contaminant Linkage	Controls identified
Natural deposits (geochemical inputs)	N/A – natural movement of sediments is encouraged under WFD
Mine spoil heaps	Erosion protection measures, including bioengineering to minimise bank erosion in areas adjacent to mine spoil Buffer strips adjacent to watercourses to minimise sediment ingress Sediment traps to reduce the spread of contaminated sediments from mined catchments Slope stabilisation techniques Note that spoil tips from historical metal mining may be considered to be of archaeological and landscape importance, particularly if they are archaeological features associated with a Scheduled Ancient Monument (protected under the Ancient Monuments and Archaeological Areas Act 1979). As such, direct interventions such as capping or removal may not be appropriate
Mine adit discharges to surface and groundwater	Active controls Reed beds and end of pipe controls
Landfills and contaminated land (including contaminated dredged material placed on canal and river banks and in disposal lagoons adjacent to rivers and fly tipped wastes)	Erosion protection measures Waste management and materials management using Environmental Permits, Waste Exemptions and Materials Management Plans Remediation of contaminated land under the Part 2A and planning frameworks

Contaminant Linkage	Controls identified
Industrial sites (non-consented discharges)	Environment Agency pollution prevention visits Environmental Permits
Industrial consented discharges (including wastewater storm overflow discharges)	UK water industry capital works to replace combined sewer overflows. Discharge Consent conditions providing regulatory controls on contaminant concentrations in consented discharges
Urban/built area diffuse inputs (road runoff, misconnections, misuse of surface water drains, pollution incidents, etc.)	Variety of source controls, pathway interventions and end of pipe engineering solutions
Vessel discharges - oily waste, grey water, ballast water and oil spill, erosion of anti-fouling paints	Source control (banning of some anti-fouling agents) International Convention for the Prevention of Pollution from Ships (MARPOL) Harbour/port byelaws and good practice guidance on discharges
Movement via river water under normal flow conditions	Natural movement of sediments is encouraged under WFD; however, discrete areas of contaminated sediment may be treated to avoid contaminant mobilisation (see Section 2.4.2)
Mobilisation of in-channel sediments through river works (installing structures, maintenance, navigational dredging, weir removal)	Construction phase pollution prevention measures e.g. coffer dams and sediment traps
Erosion and mobilisation by channel migration	Natural movement of sediments is encouraged under WFD; however, discrete areas of contaminated sediment may be treated to avoid contaminant mobilisation (see Section 2.4.2)
Mobilisation by propeller action and vessel wash	River traffic speed limits
Mobilisation by fluvial flood events (deep scouring)	Natural movement of sediments is encouraged under WFD; however, discrete areas of contaminated sediment may be treated to avoid contaminant mobilisation (see Section 2.4.2)
Mobilisation through trawling	-
Mobilisation by activity of aquatic or bank dwelling vertebrates and invertebrates (e.g. organisms burrowing into the river banks, causing destabilisation and collapse)	Work to control invasive species Natural movement of sediments is encouraged under WFD and natural activity of native biota is also encouraged; however, discrete areas of contaminated sediment may be treated to avoid contaminant mobilisation (see Section 2.4.2)
Chemical and biological changes to contamination releasing additional contaminants or increasing availability of contamination (e.g. oxidation, reduction, degradation and concentration of contaminants by plants or animals)	Natural movement of sediments is encouraged under WFD; however, discrete areas of contaminated sediment may be treated to avoid contaminant mobilisation (see Section 2.4.2).

3.4.3 Remediation techniques for contaminated sediment

A full review and assessment of sediment contamination management and mitigation will be undertaken in **Work Package 1B** of this study. However, an initial list of the principal management techniques has been identified as part of this work package. These include:

Activities in the water:

- Removal (dredging);
- In situ sediment stabilisation; and
- Sediment capping.

Activities on land:

- Engineering works to reduce sediment erosion;
- Ex situ stabilisation; and
- Ex situ sediment remediation (including stabilisation).

3.4.4 Sediment management techniques

A number of techniques are used routinely within catchments to control or influence the processes of sediment deposition and erosion within the system as well as extraction for commercial purposes (capital dredging of aggregates). The primary aim of these activities is to control the sediment itself rather than its contaminant loading, although they have significant overlap with the measures outlined above for remediation of contamination in sediments. These include:

Activities in the water:

- Dredging (capital or maintenance);
- Desilting; and
- Engineering structures to prevent or minimise or in some cases encourage siltation.

Activities on land:

- Engineering works to reduce sediment erosion;
- Setting back of flood defences to allow suspended sediment to deposit on the floodplain (it is noted that this intervention may introduce contaminants to the floodplain); and
- Beach replenishment.

In addition, activities are currently being undertaken within some catchments, as part of WFD implementation, to restore natural river processes. These include:

- Weir removal;
- Changes to the way in which structures are operated;
- Removal of culverts, setting back of flood embankments, removal of artificial structures and reinstatement of natural channels; and
- Other river restoration activities, including in-channel habitat enhancements and the reinstatement of natural geomorphological processes.

Note: Management of Natural Sediment Movements

It is important to recognise that sediment is a natural part of the fluvial, estuarine and coastal environment, and that sediment management needs to be undertaken in a sensitive way that is appropriate for the system in which it is being undertaken. Many aquatic plants, invertebrates, fish and other organisms are reliant on a relatively narrow range of conditions for different parts of their life cycle (e.g. adult lamprey species generally live in soft, fine sediments, but their eggs require clean gravels to hatch successfully), and any changes to the sediment regime could result in the degradation of habitat quality and adverse impacts to the ecology (on rare occasions impacts may be beneficial). In some scenarios, it could be possible for measures intended to address contaminated sediment issues to have unintended consequences by changing sediment dynamics in the catchment downstream. For example, a decrease in sediment supply as a result of desilting or measures to reduce bank erosion can increase the energy a river has, resulting in increased erosion downstream.

Conversely, an increase in sediment supply as a result of the removal of bank protection and barriers such as weirs and culverts can result in increased deposition further downstream.

3.4.5 Potential influence of management techniques on contaminant pathways

Activities that are aimed at controlling an individual pathway or natural sediment transport process may, by consequence, affect one or more other pathways. Source controls on contaminants are likely to affect all sediment transport processes by reducing the amount of the contaminant in the system. In some instances they may also reduce the quantity of sediment within the water body (e.g. by controlling erosion of mine spoil heaps). Some identified effects are summarised in **Tables 3.5** and **3.6**for selected key types of in-water and out-of-water activity. As illustrated in **Table 3.6**, some contaminant linkages are not expected to be directly influenced by the principal sediment management activities identified, e.g. erosion of mining stockpiles by surface water runoff is unlikely to be mitigated by in-water activities; however out-of-water activities such as the installation of reed beds to intercept the contaminated runoff, may prove to be highly effective .

Some activities that are likely to cause significant changes to natural processes have the potential to cause additional impacts on the sediment regime e.g. large scale dredging activities could reduce sediment availability and increase scour in sections of bank/coastline.

3.4.6 Influence of existing mechanisms and controls on chemical use

A number of factors are likely to have influenced the types of substances in use in England in, for example, industrial processes and domestic products, which may have made their way into water bodies and be present now as contaminants in sediment, including:

- Development of new chemicals (e.g. new pesticides which have been developed and released for commercial use);

- Controls on chemical usage (e.g. an EU ban on the presence of tributyl tin (TBT)-based antifouling paints on ship hulls in EU ports, which came into effect on 1st January 2008; phasing out of petrol containing lead additives; UK agreement to phase out use of PCBs by 1999); and
- Changes in behaviour which cause change in the use of chemicals (e.g. increased use of certain prescription medicines that may subsequently find their way into the environment).

When the use of contaminating substances is phased out using legislative powers, concentrations in effluent waters, and hence in water bodies, may decrease relatively rapidly depending on the efficacy of enforcement activities. However, contaminant levels in sediments may not closely mirror the decline in water concentrations (Förstner and Whittman, 1979; Salomons and Förstner, 1984). Longevity of contaminants in sediments and urban soils may result in substances which have been banned or are no longer widely used persisting in sediments in the medium- and long-term. This may be the case where contaminants are tightly bound to sediments and/or trapped at a depth where sediments are not often mobilised.

By contrast, contaminants which are degraded readily in anaerobic, but not in highly aerobic, environments may degrade more quickly in sediments than in the aerated water column.

It should also be noted that, implementation of a ban on production and use of a chemical may take a period of time to implement (and may be phased in), Producing using the substance may also remain the supply chain for a further period of time and users may have stocks of the product which are used over a prolonged period.

3.5 The potential impact of management activities in different scenarios

As described in **Section 3.4.6**, a wide range of activities can be used to manage sediment generally, and in situ contaminated sediments more specifically. The impacts that these management activities can have is often dependent upon the hydrological and geomorphological characteristics of the catchment in which they are undertaken. Some examples of the different impacts associated with selected sediment management activities in predominantly natural and extensively modified river catchments are explored in **Table 3.6**.

Table 3.4: Potential impacts of sediment management activities in different catchment/estuary/coastal scenarios

Scenario	Maintenance dredging and de-silting	Removal of water bodies structures	Introduction of flood defence embankments	Installation of bank reinforcement
Largely natural bed and banks and unregulated flow regime	• Reduction in sediment supply downstream • Direct disturbance of contaminated sediment • Potential for increased erosion and mobilisation of contaminated sediments stored in channel and floodplain downstream	• Reduction in sediment accumulation upstream • Increase in sediment supply downstream • Remobilisation of contaminated sediments upstream of weir • Potential for channel adjustment and remobilisation of contaminated sediments stored in channel and floodplain	• Reduction in volume of sediment stored on floodplain • Increased volumes of contaminated sediment transported downstream • Potential for increased contaminated sediment deposition in unprotected areas downstream	• Reduction in localised bank erosion • Reduction in localised remobilisation of contaminated sediment • Potential for increased erosion and remobilisation of contaminated sediment in unprotected areas downstream
Largely artificial bed and banks and regulated flow regime	• Reduction in sediment supply downstream • Direct disturbance of contaminated sediment	• Reduction in sediment accumulation upstream • Increase in sediment supply downstream • Remobilisation of contaminated sediments upstream of weir	• Reduction in volume of sediment stored on floodplain • Increased volumes of contaminated sediment transported downstream	• Reduction in localised bank erosion • Reduction in localised remobilisation of contaminated sediment

3.5.1 Effects of flood events and the predicted effects of climate change on erosion and transportation of sediments

The potential effects of climate change are examined for each pollutant linkage in **Table 3.1**. Different types of catchment, and different areas of sea bed and shoreline, will react differently to events such as flood flows or sea level rise. For example, predominantly urban river catchments may experience more flashy flood events and greater ‘first flush’ effects[7] than predominantly rural catchments. However, in catchments with abandoned mine workings, immediate discharges may result from mine adits, coupled with more delayed discharges from spoil heaps and the remobilisation of floodplain sediments in a

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[7] First-flush is the term given to the initial pulse of diffuse contamination mobilised into water bodies by a rainfall event following a dry period.

complex combination of processes. Similarly, coastal or estuarine areas with harder rock geology and limited surficial sediment cover will be relatively resistant to storm wave action and sea level rise, compared to ‘softer’ sedimentary areas. The potential influence of catchment type, river channel and sea bed/shoreline characteristics is also discussed for each linkage in **Table 3.1**.

In a Special Session discussion, SedNet (SedNet, 2011) identified the following catchment sediment processes which were expected to be influenced significantly by climate change. These spanned a range of catchment processes and wider activities within the catchment.

On the macro-scale:

- In highland catchments, more rapid snow melt and changes to rainfall patterns were expected to lead to increased erosion and fluctuating river discharges (although it is noted that, with climate change, the overall quantity of snow may decrease);
- In lowland catchments, more pronounced floods and drought periods were expected to lead to variation in water discharges and sediment loads, sediment transport patterns and contaminant loads;
- In estuaries, changes were expected to be seen in water discharges and sediment loads, tidal hydrodynamics, salinity gradients, exposure of intertidal areas and sedimentation/suspension patterns; and
- In the marine environment, changes were expected in sediment loads received from land, increased sea levels and changes in exposure of, and light intensity in, intertidal areas.

On the micro-scale:

- Changes to dissolved oxygen levels and pH, nutrient-fluxes, temperature, UV-light, salinity, contaminant fluxes, sediment fluxes and microbial activity which were expected to lead to changes in bioavailability, mobility/desorption/adhesion, toxicity and transport regime.

Potential secondary effects identified included:

- Changes in microbial populations and plankton blooms;
- Changes in the distribution and populations of invasive species (the UK Climate Change Risk Assessment: Government Report , Defra 2012) identified an increased prevalence of invasive non-native species, pests and pathogens as a risk);
- Changing food webs in given locations;
- Possible transport of pollutants in concentrations below the limit of detection (undetected contamination which may accumulate downstream); and
- Potential for changes in behaviour within the catchment, such as increased use of sun creams.

Sites with land contamination are also likely to be affected by climate change through processes including:

- Greater wind speeds increasing concentrations of wind-blown dusts;
- More intense rainfall increasing soil erosion, particularly following dry periods; and
- Damage to engineering containment systems under severe (wet/dry and free/thaw) weather conditions e.g. damage to cover systems (capping layers) and soils which have been stabilised or solidified with binding agents to immobilise contamination(CLAIRE, 2007):.

In addition, more intense rainfall and flood events are likely to affect transport of contaminated material, leaching of contaminants from soils (including through higher groundwater levels) and may also affect the integrity of some remedial solution (e.g. cover layers). Contaminant mobility and degradation may also be influenced by changes in temperatures.

Coulthard and Macklin (2003) used a cellular automaton fluvial catchment model to simulate the dispersal of contaminated sediment from metal mining in the River Swale catchment in North Yorkshire. This demonstrated that contaminated sediments are cycled very slowly through the fluvial system, with 70% of the metals released into the catchment remaining in the active channel sediments and stored in the floodplain more than 100 years after the cessation of mining. Under current climatic conditions, mining-related metals are likely to be cycled through the catchment for several thousand years. 10% and 25% increases in rainfall, which may be plausible under current climate change scenarios, do not result in a significant increase in conveyance. However, increases of 50% and 100% of rainfall increase erosion, raising the rate at which contaminants are cycled out of the system and reducing overall metal concentrations as a result of higher dilution from non-contaminated sources (Coulthard and Macklin, 2003). It should be noted that these contaminants will then be deposited in estuarine and coastal waters.

Sea level rise (especially) and changes in coastal storminess leading to more rapid deterioration and increased frequency / volume of wave overtopping of coastal protection and sea defence structures and increased erosion of undefended coastal and estuarine shores.

Table 3.5 Influence of in-water catchment/sediment management activities on contaminant pathways

Management Technique Contaminant linkage	Capital dredging	Maintenance dredging and desilting (e.g. for navigation and flood risk management)	Introduction of flood defence structures	Removal of river structures (e.g. weir removal and deculverting)	Remediation – treatment in situ (thermal, chemical, phytoremediation, use of binders, capping, removal via dredging, etc.)	Remediation – bank reinforcement
Direct erosion of mineral deposits, entrainment of enriched soils through surface runoff, chemical leaching of enriched deposits	×	×	×	✓	×	×
Direct erosion of mining spoil heaps by flowing water, entrainment by surface runoff, chemical leaching of enriched deposits, direct input of dissolved metals	×	×	×	×	×	×
Mine adit discharges to surface and groundwater	×	×	×	×	×	×
Erosion, disturbance and surface water runoff from landfills and contaminated land (including contaminated dredged material placed on canal and river banks and in disposal lagoons	×	×	✓ - reinforcement of banks may reduce erosion	✓ - deculverting may allow contaminated land to be eroded	×	×

Management Technique Contaminant linkage	Capital dredging	Maintenance dredging and desilting (e.g. for navigation and flood risk management)	Introduction of flood defence structures	Removal of river structures (e.g. weir removal and deculverting)	Remediation – treatment in situ (thermal, chemical, phytoremediation, use of binders, capping, removal via dredging, etc.)	Remediation – bank reinforcement
adjacent to rivers and fly tipped wastes).						
Leaks and spills from industrial sites	×	×	×	×	×	×
Accumulation of contaminants downstream of consented outfalls	×	×	×	×	×	×
Diffuse inputs Urban/built area (road runoff, misconnections, misuse of surface water drains, pollution incidents, etc.)	×	×	×	×	×	×
Vessel discharges - oily waste, grey water, ballast water and oil spill, erosion of anti-fouling paints	×	×	×	×	×	×

Management Technique Contaminant linkage	Capital dredging	Maintenance dredging and desilting (e.g. for navigation and flood risk management)	Introduction of flood defence structures	Removal of river structures (e.g. weir removal and deculverting)	Remediation – treatment in situ (thermal, chemical, phytoremediation, use of binders, capping, removal via dredging, etc.)	Remediation – bank reinforcement
Movement of existing contaminated in-channel and in-bank sediments via river water under normal flow/tidal conditions	✓ - dredging may expose older sediments and change sediment transport dynamics	✓ - dredging may re-suspend recently deposited contaminated sediments	✓ - flood defence structures may change sediment transport dynamics	✓ - weir removal may release accumulated contaminated sediments, deculverting may change sediment transport dynamics	✓ - in situ treatment is designed to reduce amount of contaminant or mobility. Dredging may expose older sediments and change sediment transport dynamics	✓ - may change sediment transport dynamics
Mobilisation of in-channel sediments through river works	✓	✓	✓	✓	✓	✓
Erosion and mobilisation of in-channel sediments by channel migration	✓ - dredging may change sediment transport dynamics and thereby alter channel mobility	✓ - dredging may change sediment transport dynamics and thereby alter channel mobility	✓ - flood defence structures may change channel mobility either restricting or encouraging it	✓ - deculverting may encourage channel migration if a natural channel is formed	×	✓
Mobilisation of in-channel sediments by propeller action, and vessel wash	✓ - dredging may expose older sediments and change sediment transport dynamics.	✓ - dredging may re-suspend recently deposited contaminated sediments. May change patterns of usage/ number of vessels.	✓ - flood defence structures may change sediment transport dynamics. May change patterns of usage/ number of vessels.	✓ - may change sediment transport dynamics. May change patterns of usage/ number of vessels.	✓ - in situ treatment is designed to reduce amount of contaminant or mobility. Dredging may expose older sediments and change sediment transport dynamics	✓ - bank enforcement may reduce erosion of contaminated material by vessel wash

Management Technique / Contaminant linkage	Capital dredging	Maintenance dredging and desilting (e.g. for navigation and flood risk management)	Introduction of flood defence structures	Removal of river structures (e.g. weir removal and deculverting)	Remediation – treatment in situ (thermal, chemical, phytoremediation, use of binders, capping, removal via dredging, etc.)	Remediation – bank reinforcement
Mobilisation of deep stored contaminated sediments by fluvial flood events (deep scouring) including erosion of floodplain salt marsh and mud flats	✓ - dredging may expose older sediments and change sediment transport dynamics.	×	✓ - dredging may expose older sediments and change sediment transport dynamics.	✓ - may change sediment transport dynamics.	✓ - in situ treatment is designed to reduce amount of contaminant or mobility. Dredging may expose older sediments and change sediment transport dynamics	✓ - may change sediment transport dynamics
Mobilisation of existing in-channel contaminated sediments through trawling	✓ - dredging may expose older sediments and change sediment transport dynamics.	✓ - dredging may re-suspend recently deposited contaminated sediments.	✓ - dredging may expose older sediments and change sediment transport dynamics.	×	✓ - in situ treatment is designed to reduce amount of contaminant or mobility.	×
Mobilisation of existing in-channel contaminated sediments by activity of aquatic or bank dwelling vertebrates and invertebrates (e.g. burrowing of invasive signal crayfish in river bed and bank collapse)	×	×	×	×	✓ - in situ treatment is designed to reduce amount of contaminant or mobility.	✓ - reduced effects of vertebrate activity on banks

Management Technique / Contaminant linkage	Capital dredging	Maintenance dredging and desilting (e.g. for navigation and flood risk management)	Introduction of flood defence structures	Removal of river structures (e.g. weir removal and deculverting)	Remediation – treatment in situ (thermal, chemical, phytoremediation, use of binders, capping, removal via dredging, etc.)	Remediation – bank reinforcement
Chemical and biological changes to existing contamination in channel releasing additional contaminants or increasing availability of contamination (e.g. oxidation, reduction, degradation and concentration of contaminants by plants or animals)	✓ - may change amount of oxygen available by uncovering contaminated sediments	✗	✗	✗	✓ - in situ treatment is designed to reduce amount of contaminant or mobility.	✗
Sediment outwash and deposition in the flood plain by fluvial flood events	✓ - dredging may expose older sediments and change sediment transport dynamics and capacity of river channel/frequency of outwash	✓ - dredging may expose older sediments and change sediment transport dynamics and capacity of river channel/frequency of outwash	✓ - dredging may expose older sediments and change sediment transport dynamics and capacity of river channel/frequency of outwash	✓ - removal of structures may change flow dynamics and frequency of outwash in particular stretches of the river catchment	✓ - in situ treatment is designed to reduce amount of contaminant or mobility.	✗
Contaminated dredged sediments deposited on banks	✗	✓ - dredged material may be deposited on banks	✗	✗	✓ - in situ treatment is designed to reduce amount of contaminant or mobility	✗

Table 3.6 Influence of out-of-water catchment/sediment management activities on contaminant pathways

Management Technique / Contaminant linkage	Beach replenishment	Ex-situ sediment remediation	Reed beds	Environmental permitting/pollution prevention regulation/invasive species control/source control	Improvements to sewerage infrastructure	River traffic speed limits
Direct erosion of mineral deposits, entrainment of enriched soils through surface runoff, chemical leaching of enriched deposits	×	×	(✓) - installation likely to be site specific to tackle a localised contamination problem	×	×	×
Direct erosion of mining spoil heaps by flowing water, entrainment by surface runoff, chemical leaching of enriched deposits, direct input of dissolved metals	×	×	(✓) - installation likely to be site specific to tackle a localised contamination problem	×	×	×
Mine adit discharges to surface and groundwater	×	×	(✓) - installation likely to be site specific to tackle a localised contamination problem	× - discharges likely to be unconsented	×	×

Management Technique Contaminant linkage	Beach replenishment	Ex-situ sediment remediation	Reed beds	Environmental permitting/pollution prevention regulation/invasive species control/source control	Improvements to sewerage infrastructure	River traffic speed limits
Erosion, disturbance and surface water runoff from landfills and contaminated land (including contaminated dredged material placed on canal and river banks and in disposal lagoons adjacent to rivers and fly tipped wastes).	✗	✗	(✓) - installation likely to be site specific to tackle a localised contamination problem	(✓) contaminated land regulation under planning regime or Environmental protection Act 1990, Part 2A	✗	✗
Leaks and spills from industrial sites	✗	✗	(✓) - installation likely to be site specific to tackle a localised contamination problem	✓	✗	✗
Accumulation of contaminants downstream of consented outfalls	✗	✗	(✓) - installation likely to be site specific to tackle a localised contamination problem	✓ (source control)	✓ (sewer outfalls)	✗
Diffuse inputs Urban/built area (road runoff, misconnections, misuse of surface water drains, pollution incidents, etc.)	✗	✗		✓	✓(sewer outfalls)	✗

Management Technique **Contaminant linkage**	**Beach replenishment**	**Ex-situ sediment remediation**	**Reed beds**	**Environmental permitting/pollution prevention regulation/invasive species control/source control**	**Improvements to sewerage infrastructure**	**River traffic speed limits**
Vessel discharges - oily waste, grey water, ballast water and oil spill, erosion of anti-fouling paints	✗	✗	(✓) - installation likely to be site specific to tackle a localised contamination problem	(✓) - variable depending on the contaminant.	✗	✗
Movement of existing contaminated in-channel and in-bank sediments via river water under normal flow/tidal conditions	✓ - provides a supply of clean sediment for transport	✓- reduces amount of contaminated sediment	(✓) - installation likely to be site specific to tackle a localised contamination problem	✗	✗	✗
Mobilisation of in-channel sediments through river works	✗	✓- reduces amount of contaminated sediment	(✓) - installation likely to be site specific to tackle a localised contamination problem	✗	✗	✗
Erosion and mobilisation of in-channel sediments by channel migration	✓ - provides a supply of clean sediment for transport	✓- reduces amount of contaminated sediment	(✓) - installation likely to be site specific to tackle a localised contamination problem	✗	✗	✗
Mobilisation of in-channel sediments by propeller action, and vessel wash	✓ - provides a supply of clean sediment for transport	✓- reduces amount of contaminated sediment	(✓) - installation likely to be site specific to tackle a localised contamination problem	✗	✗	✓

Management Technique / Contaminant linkage	Beach replenishment	Ex-situ sediment remediation	Reed beds	Environmental permitting/pollution prevention regulation/invasive species control/source control	Improvements to sewerage infrastructure	River traffic speed limits
Mobilisation of deep stored contaminated sediments by fluvial flood events (deep scouring) including erosion of floodplain salt marsh and mud flats	✓ - provides a supply of clean sediment for transport which may reduce deep scouring	✓- reduces amount of contaminated sediment	(✓) - installation likely to be site specific to tackle a localised contamination problem	✗	✗	✗
Mobilisation of existing in-channel contaminated sediments through trawling	✗	✓- reduces amount of contaminated sediment	✗	✗	✗	✗
Mobilisation of existing in-channel contaminated sediments by activity of aquatic or bank dwelling vertebrates and invertebrates (e.g. burrowing of invasive signal crayfish in river bed and bank collapse)	✓ - provides a supply of clean sediment for transport which may reduce deep scouring	✓- reduces amount of contaminated sediment	(✓) - installation likely to be site specific to tackle a localised contamination problem	✗	✗	✗

Management Technique / Contaminant linkage	Beach replenishment	Ex-situ sediment remediation	Reed beds	Environmental permitting/pollution prevention regulation/invasive species control/source control	Improvements to sewerage infrastructure	River traffic speed limits
Chemical and biological changes to existing contamination in channel releasing additional contaminants or increasing availability of contamination (e.g. oxidation, reduction, degradation and concentration of contaminants by plants or animals)	✓ - may change amount of oxygen available to contaminated sediments by covering	✓- reduces amount of contaminated sediment	(✓) - installation likely to be site specific to tackle a localised contamination problem	✗	✗	✗
Sediment outwash and deposition in the flood plain by fluvial flood events	✓ - provides a supply of clean sediment for transport which may reduce deep scouring	✓- reduces amount of contaminated sediment	✗	✗	✗	✗
Contaminated dredged sediments deposited on banks	✗ unlikely to be used where dredging required	✓- reduces amount of contaminated sediment	✗	✓	✗	✗

4 Substances of concern for in situ sediment contamination

Scope of the Task:

- To narrow down the contaminants of concern to those associated with sediments.
- To consider a wide range of contaminants which may cause harm to the critical receptors identified in Task 2.
- To identify the key substances that are controlled within the UK legislative framework including Priority Substances, Priority Hazardous Substances and specific pollutants defined in the WFD and those other contaminants considered likely to be of significant concern.
- To consider whether these substances are likely to cause harm when associated with sediments. It is noted that some of these contaminants may not have had assessment thresholds developed for them and for some contaminants the information available on their toxicity and behaviour in the environment may be minimal.
- To consider, where appropriate, the effects of combinations of contaminants on receptors
- To undertake a review of the key physical and chemical properties of each substance (including association with sediment, longevity in the environment, bioavailability and ecotoxicity), the sources of these substances (including natural occurrence and industrial processes), key environmental pathways (e.g. discharge into waters through natural erosion, release from industrial processes and other activities).

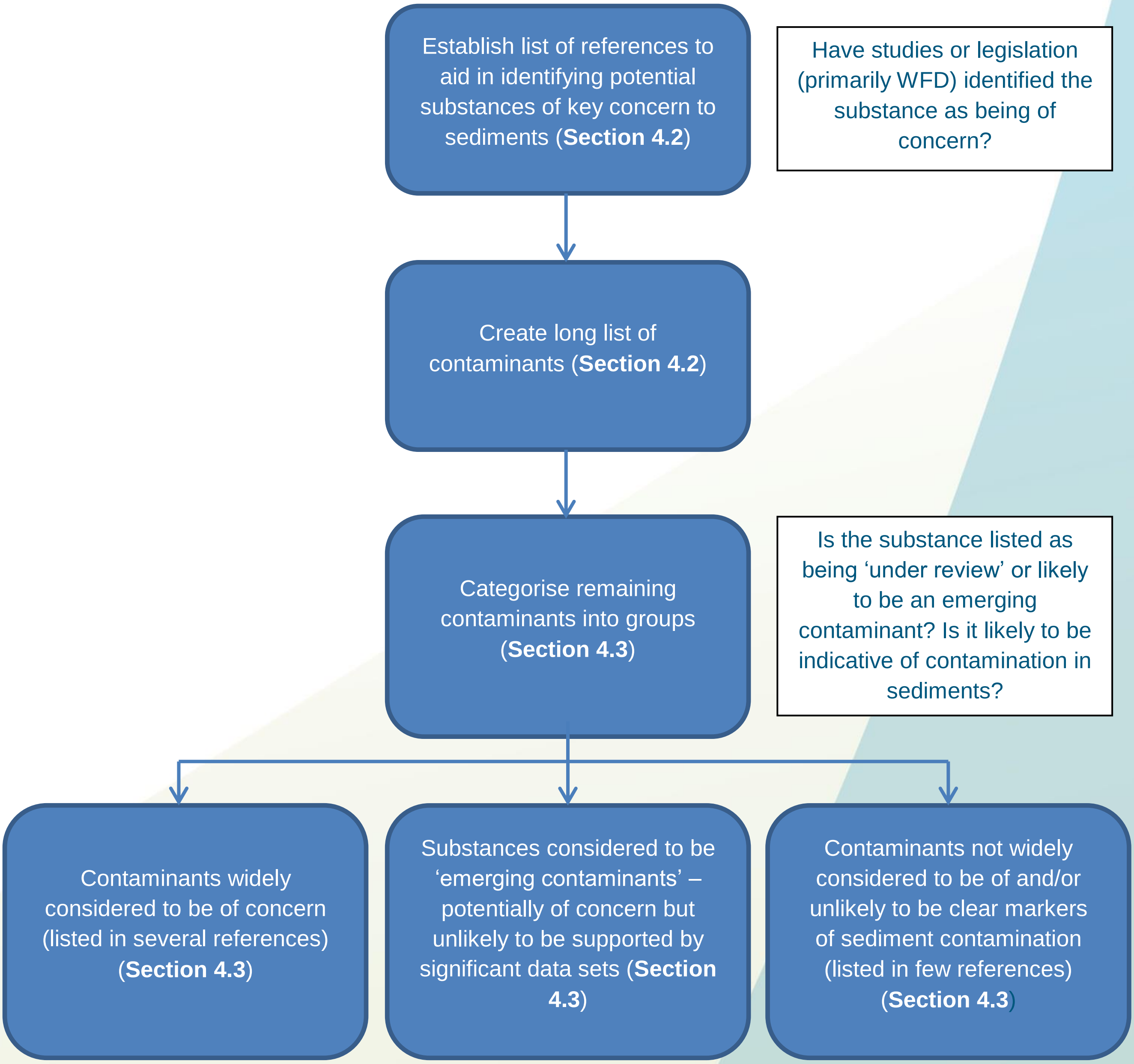
4.1 Identifying potential contaminants of concern

A wide range of contaminants have the potential to have been released into the aquatic and/or sedimentary environment through the processes shown in the conceptual model in **Figure 3.1** and **Table 3.1**. These include contaminants which have, historically, frequently been tested for in environmental water and sediment samples (e.g. as part of routine water or sediment quality analyses) and also emerging contaminants that are suspected to be present but have not historically featured in analytical testing suites.

Many contaminants are likely to be able to bind to sediments to some degree. Contaminants that are unable to bind to sediment particles or dissolve into the water column (e.g. asbestos fibres) may still contaminate sediments by physical mixing. This is discussed further in **Section 4.4**. In addition, some contaminants, such as TBT paint flakes, may be stored in sediments but release reactive contaminants on disturbance.

We have used a multiple stage process in order to identify a list of contaminants that could potentially be of concern in sediments; this is outlined in **Figure 4.1** and explained in more detail in the subsequent sections.

Figure 4.1 Process used to select contaminants of concern



4.2 Identifying a long list of contaminants of concern

As a starting point for identifying a broad spectrum both of well documented and emerging potential contaminants that are likely to be of concern in sediments, a range of sources were consulted and a list of nearly 550 contaminants and analytes drawn together. The sources included:

- The Environment Agency Contaminated Land Exposure Assessment model contaminant database. This model is used to model exposure of human receptors to soil contamination and the database has been populated by Royal HaskoningDHV to encompass contaminants with published Environment Agency human health assessment thresholds (Soil Guideline Values), those with Generic Assessment Criteria published by authoritative UK sources[8] and additional contaminants of concern to human health. It should be noted that the list of contaminants has been considered at this stage of the project, but the threshold values themselves have not been used;
- The EU Registration, Evaluation, Authorisation & restriction of Chemicals (REACH) Candidate List of Substances of Very High Concern for Authorisation (a list published in accordance with Article 59(10) of the EU REACH Regulation). Under REACH substances with certain hazardous properties are identified which may be of concern for human health and/or the environment. REACH identifies these substances with a view to subsequent regulation to ensure that the risks associated with the substances are properly controlled (http://echa.europa.eu/addressing-chemicals-of-concern, accessed July 2014);
- Environment Agency Pollution Reduction Plans which have been developed to help meet the requirements of the WFD for control of priority and priority hazardous substances in the environment;
- The Non-Agricultural Diffuse Pollution Substance and Impact Matrix (developed by Royal HaskoningDHV for Defra in 2006 and updated in 2010) in order to collate existing evidence of sources and pathways for non-agricultural diffuse pollution in England, Wales and Scotland;
- The British Geological Survey (BGS) Geochemical Baseline Survey of the Environment (G-BASE) which incorporates a nationwide survey of river sediments, surface and subsurface soils;
- The BGS report on Emerging contaminants in groundwater, Groundwater Science Programme Open Report OR/11/013, provides a review of organic micro-pollutants which can be found in the aquatic environment, which were considered to be, or to have the potential to become, emerging contaminants; and
- The Land Ocean Interaction Study (LOIS) - a Thematic Programme run by the Natural Environment Research Council (NERC) over six years. The aim was to “extend understanding of the movement of fluxes between the different components of the environment, particularly the land, air and ocean phases” (Centre for Ecology and Hydrology: LOIS homepage - http://www.nwl.ac.uk/~loissys/).

The list of 550 identified potential sediment contaminants is provided in **Table A1** in **Appendix 1**.

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[8] For example Soil Generic Assessment Criteria for Human Health Risk Assessment, CL:AIRE, January 2010 and Generic Assessment Criteria for Human Health Risk Assessment, 2nd Ed, LQM/CIEH, 2011

4.3 Potential key contaminants of concern for sediment

A smaller number of substances of concern for the aquatic environment and/or specifically for the sedimentary environment have then been highlighted for more detailed consideration during this project. The aims are to identify the key substances that are controlled within the UK legislative framework, to consider all contaminants which may cause harm to the critical receptors identified in the conceptual model, and to narrow down the contaminants of concern to those potentially associated with contamination in sediments.

However, a lack of collated, comparable and independently reviewed information on the wide range of contaminants identified in **Section 4.1** means that a review on the basis of toxicological and physico-chemical parameters of each substance has not been possible at this stage within the scope of this project. In order to prioritise contaminants for more detailed consideration, an approach has therefore ben taken whereby a number of sources have been consulted in order to identify those contaminants which have already been highlighted as of concern either at the UK or EU level.

These include the sources listed below:

- **Legislation**, including substances designated as Priority Substances or Priority Hazardous Substances under the WFD, substances listed as ‘of concern’ in the WFD and daughter directives but which have not yet been designated.
- **Existing lists of UK sediment thresholds**. For the purposes of this initial assessment the Draft Environment Agency Sediment Quality Guidelines and CEFAS Action Level lists have been used.
- **Recent UK studies** identifying contaminants of concern for surface water, which have used lists of contaminants agreed by regulators (the Environment Agency) and the UK water industry (the UK Water Industry Research Chemicals Investigation Programme (CIP) has been reviewed. Amongst the aims of CIP are to investigate the concentrations of substances in sewage effluents, the risks of them breaching statutory water quality standards and methods and priorities for controlling these risks.
- **Approaches and recent studies from other European countries**. Studies of contaminated sediment have been completed for a number of European river basins as part of the compliance monitoring required under the WFD. Based on research and dredging studies, some European countries have also developed their own national sediment contaminant of concern lists. The Dutch list has been used for comparison.

Details of the contaminants highlighted through each of the references listed above are provided in **Appendix 2**. Following the process for selecting contaminants shown in **Figure 4.1**, the initial list of contaminants was divided into three categories:

1. Contaminants widely considered to be of concern, supported by a wide range of references in the evidence base complied in **Section 4.2**.
2. Substances considered to be “emerging contaminants”, but with insufficient information in the current evidence base to determine the risk associated with them.
3. Contaminants not widely considered in the current evidence base to be of concern.

The following principles have been followed in this categorisation unless there were specific reasons to deviate from this (any deviations are explained in **Appendix 2 Table A2.11**).

Substances have been placed into **Category 1** if they are:

- Identified under the WFD as priority substances and specific pollutants, and those substances for which EQS have been derived; or
- Have a SQG derived specifically for the UK.

Substances with a SQG used in the UK but derived outside the UK have been placed provisionally in Category 1 (pending further investigation).

Substances have been placed into **Category 2** if they are:

- Under review under the WFD; or
- Investigated in the CIP UK water quality study but not identified in any of the other sources.

Substances have been placed into **Category 3** if they are:

- Investigated in European sediment quality studies but not identified in any of the other sources;
- Unlikely to be clear markers of sediment contamination (e.g. they will normally form part of the sediment substrate, such as aluminium and iron).

This process is summarised in **Appendix 2**, **Table A2.11** and the selected contaminants of concern are listed in **Table 4.1**. As this project progresses and detailed consideration of risk assessment methodologies is undertaken, it is likely that this list will be further refined through, for example, reference to particular toxicological benchmarks (such as Probable No Effect Concentrations) and use of marker compounds which are indicative of particular industries likely to have resulted in sediment contamination.

Contaminants excluded from the scope of this study (and therefore not selected as contaminants of concern) include:

- Agricultural pharmaceuticals; and
- Biological contaminants (e.g. faecal pathogens).

Invasive species have also been excluded.

Table 4.1: Contaminants of Concern

Contaminant Type	Contaminant
Polycyclic Aromatic Hydrocarbons	Acenaphthene
	Acenaphthylene
	Anthracene
	Benz(a)anthracene
	Benz(b)anthracene (2,3 - benzanthracene)
	Benzo(b)fluoranthene
	Benzo(k)fluoranthene
	Benzo(g,h,i)perylene
	Benzo(a)pyrene
	Chrysene
	Dibenzo (a,h) anthracene
	Fluoranthene
	Fluorene
	Indeno(1,2,3-cd)pyrene
	Naphthalene
	Alkylated naphthalenes (C1, C2 and C3-nathphthalenes)
	Perylene
	Phenanthrene
	C2-phenanthrene (alkylated phenanthrene)
	Pyrene
Pesticides	Aclonifen
	Alachlor
	Aldrin
	Atrazine

Contaminant Type	Contaminant
	Bifenox
	Chlordane
	Chlorfenviphos
	Chloropyrifos (chloropyrifos ethyl
	Cybutryne
	Cypermethrin
	Diazinon
	DBT
	DDD
	DDE
	DDT total
	Dieldrin
	2,4-dichorophenoxyacetic acid (2,4-D)
	Dichlorvos
	Dicofol
	Dimethoate
	Diuron
	Endosulfan
	Endrin
	Heptachlor/heptachlor epoxide
	Hexachlorocyclohexane (α-HCH, β-HCH, γ-HCH (lindane))
	Isodrin
	Isoproturon
	Linuron
	Malathion

Contaminant Type	Contaminant
	Mecoprop
	MBT (Monobutyltin)
	Permethrin
	Quinoxyfen (5,7-dichloro-4-(p-fluorophenoxy)quinolone)
	Simazine
	Terbutryn
	Tributyltin compounds, (Tributyltin-cation)
	Trifluralin
Metals	Arsenic
	Cadmium and its compounds
	Chromium (III and VI)
	Copper and its compounds
	Lead and its compounds
	Mercury and its compounds
	Nickel and its compounds
	Silver and its compounds
	Zinc and its compounds
Other Organic Pollutants	17 alpha-ethinylestradiol (EE2)
	17 beta-estradiol (E2)
	BDEs ("penta" congeners 28, 47, 99, 100, 153 and 154)
	Benzene
	Bis(2-ethylhexyl)phthalate (DEHP, Di(2-ethylhexyl) phthalate)
	Carbon tetrachloride
	Choroalkanes C10-C13
	1,2-dichloroethane

Contaminant Type	Contaminant
	Dichlofenac
	Dichloromethane
	2,4-dichlorophenol
	Dioxins and dioxin-like compounds
	Hexachlorobenzene
	Hexachlorobutadiene
	Hexabromocyclododecane (HBCDD)
	Nonylphenols
	Octylphenols
	Pentachlorobenzene
	Pentachlorophenol
	Perfluorooctane sulphonic Acid (PFOS)
	PCB
	Phenol
	Tetrachoroethylene (tetrachloroethene)
	Toluene
	Petroleum hydrocarbons
	Trichlorobenzenes
	Trichloromethane (chloroform)
	Trichloroethylene (trichoroethene)
Other inorganic contaminants	Unionised ammonia/ammoniacal nitrogen
	Cyanide

Potential contaminants have also been identified by examination of water bodies which are exhibiting impacts and investigating the potential causes of the impacts (including contamination of water and/or sediment). The Environment Agency has compiled a “Reasons for Failure” (RFF) database, which documents the results of monitoring and assessment under the WFD to identify water bodies that are failing their WFD objectives (those which are not achieving "good status"). This database contains information on water bodies in England and Wales.

From a review of the RFF database, several "pressures" on water bodies have been identified which are considered to be relevant to in situ contaminated sediments. These are summarised in **Table 4.2** and **Figure 4.1** based on information from the 2011 RFF data v.16.05.2011 (updated information was requested from the Environment Agency but was not available as a compiled national dataset at the time of writing). The RFF database records a total of 17,662 failures, and less than 2000 have been linked to in situ contaminated sediments. The number of failures for most of the pressures listed in **Table 4.2** is very small (<30), although ammonia and phosphates account for a larger proportion (470 and 1300, respectively).

It should be noted, however, that the RFF information is complex – there are several tiers of information explaining the cause attributed to each failure (if known) and there may be several pressures acting to produce a failure, all of which may not be readily identifiable. In addition, the pressures may be identified at different levels. For example some failures are attributed to non-agricultural diffuse pollution and others to zinc. However, non-agricultural diffuse pollution due to inputs from housing or mixed urban runoff may, in part, result from releases of zinc. The summary provided in **Table 4.2** therefore picks out only selected points from a large and complex database. It should also be noted that the information contained in the 2011 RFF data will be updated when the second River Basin Management Plans are published in January 2015.

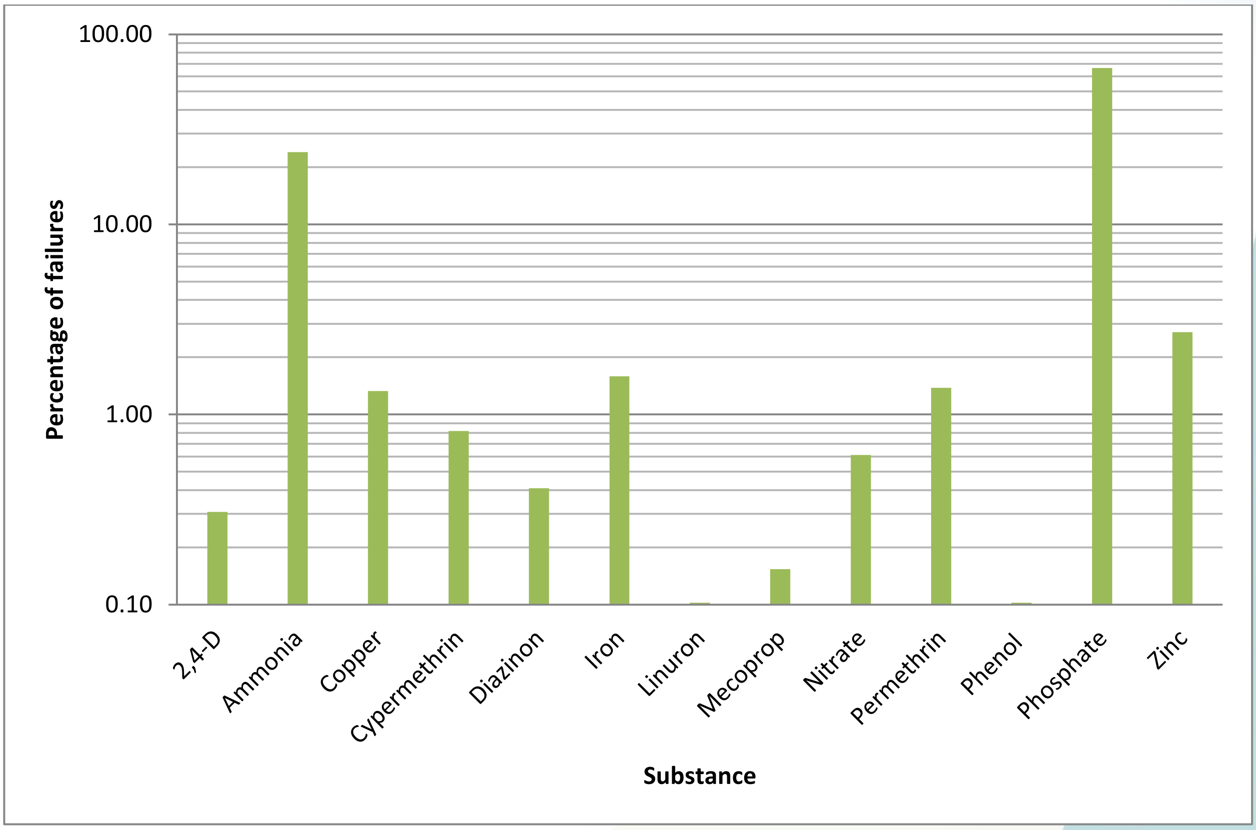
Table 4.2 Pressures relevant to in situ contaminated sediments

Pressure	Number of failures identified	Comment
2,4-D (2,4-Dichlorophenoxyacetic acid)	6 (5 affecting invertebrates and 1 affecting fish). 3 were from point sources and 3 from diffuse sources	Included in **Table 4.1**
Ammonia	Approx. 470 failures including urban runoff, storm discharges, contaminated land, point source sewage discharges and disused mine discharges	Included in **Table 4.1**
Copper	26 failures, mainly in NE Yorkshire and the southwest (Devon and Cornwall). Majority attributed to non-coal mining with some industrial discharges.	Included in **Table 4.1**
Cypermethrin	16 failures affecting either fish or invertebrates, nearly all from point source water industry discharges or trade effluent discharges. Majority in the	Included in **Table 4.1**

Pressure	Number of failures identified	Comment
	Humber river basin	
Diazinon	8 failures affecting invertebrates or fish, and attributed mainly to sewage discharges.	Included in **Table 4.1**
Iron	31 failures affecting fish or invertebrates and mainly in NW Yorkshire (Humber River Basin) or the south west (Devon and Cornwall). Attributed to disused mines and/or diffuse sources including natural mineralisation. Two failures attributed to contaminated land including land filling	Identified in the **Table A1** in **Appendix 1** but not a clear marker of sediment contamination as iron may be present in the substrate. It is noted that there are some distinct issues associated with mine-related discharge of iron oxides which may produce discrete WFD failures, but iron is likely to be prevalent in most sediments as an integral part of the geochemical matrix.
Linuron	2 failures affecting fish/invertebrates both in the River Colne (Humber River Basin) and attributed to a point source trade effluent discharge	Included in **Table 4.1**
Mecoprop	3 failures affecting fish or invertebrates in the River Colne (Humber River Basin). 2 attributed to trade effluent discharge and one water industry storm discharge	Included in **Table 4.1**
Nitrate	12 failures, affecting macroalgae, phytoplankton, macrophytes, invertebrates and fish. Majority attributed to diffuse agricultural sources. Over half of failures in transitional and coastal waters	May come from agricultural diffuse pollution sources as well as non-agricultural sources such as sewage outfall and areas of landfilling/contaminated land.
Permethrin	7 failures affecting fish/invertebrates. Attributed to point source discharges (water industry or trade effluent). All in either Humber or Anglian River Basins	Included in **Table 4.1**

Pressure	Number of failures identified	Comment
Phenol	2 failures affecting invertebrates. One confirmed to be from diffuse source contaminated sediments (in the Don and Rother catchment), the second suspected to be from a trade effluent discharge	Included in **Table 4.1**
Phosphate	Approx. 1300 failures, many from agricultural diffuse sources, but some attributed to point source sewage discharges, storm sewage discharges and some from urban runoff	May come from agricultural diffuse pollution sources as well as non-agricultural sources such as sewage outfall and areas of fertilizer factories.
Zinc	53 failures affecting fish/invertebrates, located in Northumbria , the Humber and the South west (Cornwall) as well as failures in Wales (Severn Uplands, and Western Wales)	Included in **Table 4.1**

Figure 4.1 Percentage of failures relevant to in situ contaminated sediments attributable to each substance



Based on the information presented in **Table 4.2** and **Figure 4.1**, no contaminants have been added to the list of 'contaminants of concern' for sediments in England provided in **Table 4.1**.

The Reasons for Failure database also identifies other pressures that could potentially be related to in situ contaminated sediments via the potential pollutant linkages described in the conceptual model (**Section 2**):

- **Sediment:** Sediment may constitute a pressure in a water body irrespective of its contaminant loading, depending on factors such as the river type, natural sediment regime, grain size characteristics and volume of sediment. It is therefore assumed that this pressure is related to sediment as a direct pollutant, and that contaminated sediment-related issues would not be included as part of this pressure; and
- **Invasive species:** Although some invasive species may effect sediment transport (e.g. burrowing by signal crayfish or erosion of bare banks during the winter die-back of Himalayan balsam), it is assumed that this pressure is related to direct biological issues rather and that indirect contaminated sediment-related issues would not be included as part of this pressure.

4.4 Risks from chemically inert contaminants

As noted in **Section 4.2,** contaminants which are not able to bind to sediment particles may still pose a risk when physically mixed with sediments. These include:

- Metal fragments – particles of potentially toxic metals such as lead may be washed into a water body and mix with sediments. Although these may not be in a form where they are able to physically or chemically react with the sediment, they may be transported along with the sediment load and may pose a risk via ingestion of sediment; and
- Unreactive fibres in sediment, such as asbestos, which cause harm mainly via inhalation, may present a risk if sediments are dredged and deposited on land where they are able to dry and release fibres into the air. In addition, wind erosion of contaminated sediment may lead to fibres being distributed away from the deposited sediment.

4.5 Summary

The contaminants selected represent a well-established list of substances. Although a much larger number have been researched, there is not considered to be a sound justification for including additional contaminants at this stage. Whilst there are some differences in the potential contaminants of concern for freshwater and coastal/estuarine environments (e.g. TBT is primarily of concern to coastal and estuarine waters due to the presence of shipping lanes, boat repair yards etc.), the majority of contaminants in the list are considered to have the potential to pose a risk to both types of environment.

5 Processes that affect contaminant mobility in sediments

Scope of task:

- To undertake a review of the physical and chemical processes which define how they behave in fluvial and coastal sediment.
- To highlight, qualitatively, any particularly high impact management activities that may have an effect on the movement or availability of contaminated sediments prior to a detailed review of management activities in Work Package 1B [*See Section 2.4.5*].
- Where possible, to discuss high impact management activities in the context of different catchment scenarios (recognising that such activities may produce a significant impact within certain catchments but not others).

5.1 Contaminant mobility and behaviour in sediments

5.1.1 Chemical characteristics

Potential pathways for exposure of sensitive receptors to sediment contamination are discussed in the conceptual model presented in **Section 3**. Each pathway will have a series of component processes. For example:

- Binding to a river sediment; and
- Dissolving back into the river water downstream and being taken up by fish; or
- Remaining bound to the sediment and being ingested by fish or invertebrates feeding on the river bed.

A number of the characteristics of individual contaminants may affect how they interact with sediments, the overlying water column and the air, should the sediments be exposed to this. Some of the principal pathways and the properties of contaminants which are likely to influence how receptors (such as fish and invertebrates) are exposed to the contaminant are summarised in **Table 5.1** and discussed in detail below.

Table 5.1: Contaminant properties linked to receptor exposure

Intake / uptake pathway	Relevant contaminant properties
Direct ingestion of sediment	Oral toxicity and bioaccumulation factors
Plant uptake	Bioaccumulation factors and ecotoxicity
Indirect ingestion (consumption in the food chain)	Bioaccumulation factors
Aquatic uptake (consumption of water or respiration of water by aquatic organisms)	Partition coefficients, water solubility and persistence (half lives in aerobic and anaerobic environments)
Dermal contact	Dermal toxicity and dermal absorption coefficients
Inhalation	Inhalation toxicity

Each of the parameters in **Table 5.1** is described (below) to highlight the key characteristics of relevance to the risk of exposure from in-situ contaminated sediments. . Toxicity benchmarks have not been included in this analysis, since toxicity is highly dependent on the species of the receptor and exposure pathway. This discussion is considered too detailed for this stage of the project. However, it is noted that bioavailability of contaminants may vary depending upon factors such as pH, redox conditions and the constituents of the sediment matrix. Contaminants may not be available in the water column but may still be bioavailable when sediment is ingested by the organism.

Bioaccumulation Factor (BCF)

The BCF provides a measure of how much a contaminant will concentrate from water into the tissue of aquatic organisms such as fish. This is calculated (experimentally) as the ratio of the pollutant concentration in fish to that in the water. Experimental values are not always available and estimates are frequently quoted which have been derived using K_{ow}.

Partition coefficients and water solubility

Many contaminants are likely to be able to bind to sediments to some degree. Contaminants which are unreactive and unable to bind to sediment particles or dissolve into the water column (e.g. asbestos fibres) may still contaminate sediments by physical mixing (however these contaminants are beyond the scope of this study). Partition coefficients are often used as indicators for the degree to which a substance is likely to desorb from a substrate (e.g. soil or sediment) and dissolve into water which is in contact with the soil, for example, the octanol-water partition coefficient (K_{ow}) or the organic carbon-water partition coefficient (K_{oc}) for organic contaminants and the substrate-water partition coefficient (K_d) for inorganic substances (including metals). The higher the K_{ow}, the less polar the contaminant and the less likely it is to dissolve preferentially into the (polar) water.

Although highly soluble contaminants may be more likely to desorb from sediments and be available for uptake by aquatic organisms through ingestion or respiration of water, contaminants with high K_{ow}, whilst likely to remain bound to sediment, are also likely to bioaccumulate in the food web if the sediments are ingested by fish or other receptors[9].

The use of partition coefficients to predict contaminant behaviour in the environment is limited by a number of factors:

- Published coefficients are for equilibrium (where conditions are stable over time). In practice many parts of a river or marine system may be highly dynamic (not at equilibrium);
- Contaminants may also be bound to suspended solids (sediment particles which have not settled out of the water column) rather than in the settled/consolidated sediments (European Chemicals Agency, 2013); and
- Partition coefficients span a wide range of values (they are therefore often presented on a logarithmic scale).
- Partition coefficients are difficult to derive for sediments due to the variability in the nature of the substrate (see **Section 5.1.3**).

The more soluble and volatile contaminants, although likely to be found in sediments if there is an ongoing source, are also likely to be removed by water movement or released more readily into the air by evaporation (Calvin et al., 2004) and are therefore, generally, likely to be found in sediments in lower concentrations and/or limited extents.

Where sediments are exposed to air, or in shallow water where evaporation of contaminants may be an important pathway, other partition coefficients such as the soil-air and air-water coefficients may be relevant.

Aerobic and anaerobic aqueous degradation half lives

The concentrations of contaminants reduce with the time spent in the environment. The time taken for a contaminant concentration to reduce to half its original concentration is known as its ‘half-life’. The reduction could be through degradation, volatilisation or other loss processes. The shorter the half-life, the quicker the contaminant concentration reduces in the environment and the shorter the period of time during which it is likely to pose a risk to sensitive receptors in the form of the parent contaminants. However, it should be noted that the breakdown products of contaminant degradation may also pose a risk to receptors (for example, tributyl tin and its breakdown products dibuyltin and monobutyl tin).

A contaminant may degrade, or its concentration reduce, more quickly in an aerobic environment (where air is present) or an anaerobic environment (with little air present), depending on the nature of the chemical and biological processes involved. Within sediments, the environment is frequently anaerobic; as the sediments accumulate and compress, they force air and oxygenated water out. However, in some shallow, turbulent waters, aerobic conditions may be dominant.

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[9] K_{ow} is also linked to bioaccumulation since octanol has the non-polar characteristic of the fatty tissues in receptor organisms. Bioaccumulation from sediment is expressed as Biota-Sediment Accumulation Factors (BSAF)

The interstitial spaces within in situ sediment deposits (the spaces between sediment particles) have an important role in determining the level of oxygenation in the sediment. Coarse sediments on a channel bed with open interstices are more likely to be aerobic than finer sediments or mixed deposits where the interstitial spaces between coarse particles are filled with finer material.

5.1.2 Properties of the Identified Contaminants of Concern

The Contaminants of Concern list presented in **Table 4.1** encompasses a number of different types of chemical. Selected properties are summarised in **Table A3.1** in **Appendix 3** and discussed below:

- **Metals** do not degrade as organic substances do, but may be transformed by chemical or biological processes into different compounds which may also have different oxidation states. Some oxidation states of metals may, for example, be more likely to bind to sediments or desorb into the water column or precipitate out of the water. Compounds of metals in one oxidation state may also be more be more toxic than in another. For example, chromium (VI) compounds are generally more reactive and more toxic to humans than chromium (III) compounds. **Table A3.1** in **Appendix 3** shows that K_d for chromium (VI) is 18 whereas that of chromium (III) is 4800. This indicates that chromium (III) is far more likely to remain bound to the sediment than chromium (VI) which will partition more freely in to water in contact with the sediment. Metals are shown, in **Table A3.1**, to have generally much higher water solubility than the organic compounds, due to their ionic (highly polar) nature. However, solubility is likely to be highly dependent on the chemical compounds of the metal present in the sediment and at the original source of contamination;
- **Polycyclic Aromatic Hydrocarbons** (PAHs) are a group of organic contaminants which generally have low solubility and a high log K_{ow} indicating that they are likely to remain bound to the organic fraction in sediment rather than partition into water. This is more pronounced in the heavier (higher molecular weight) molecules, with the lightest molecules (e.g. naphthalene) having higher solubility and lower log K_{ow}. PAHs as products of incomplete combustion are often found in ashy deposits;
- Some of the **pesticides** in the Contaminants of Concern list have relatively lower log K_{ow} values and higher solubilities (e.g. lindane which has log K_{ow} of 3.67 and solubility of 7.3mg/L at 25^oC). None of the substances in the list have a negative log K_{ow}, which would indicate strong preference to be dissolved in water rather than remaining in sediment; however, dibutyl tin (as dibutyltindichloride) has a reported log K_{ow} of 0.97 indicating that this is likely to partition significantly into the water; and
- Of the Persistent Organic Pollutants, **PCBs** are noted to have generally very low solubility and these are therefore highly likely to remain in sediments and/or bioaccumulate in the food web. All **Persistent Organic Pollutants** are resistant to environmental degradation (“persistence” is defined by the length of the concentration half-life for a contaminant in particular types of waters or sediments, UNEP, 1998); and
- The shortest half-lives (most readily degradable contaminants in the list) are found for the pesticides chlordane, dieldrin and heptachlor epoxide (a metabolite of the pesticide heptachlor) under anaerobic conditions. There are therefore likely to degrade in sediments. However, heptachlor itself has a longer half-life of between 60 and 260 days before this can degrade to the

epoxide. The high end estimates for the anaerobic half-lives of some of the PAHs are over 2000 days.

5.2 Sediment substrate characteristics

Parameters of the substrate are also likely to have a pronounced effect on contaminant sorption. These include:

- Particle size distribution;
- Specific surface area;
- Cation exchange capacity;
- Partition coefficients;
- pH;
- Organic matter content and type; and
- Mineral constituents (Delle Site, 2001).

The United States Geological Survey (USGS) reports that sediment organic matter is in general less polar than soil organic matter, leading to differences in sorption (USGS, 2000). Partition coefficients based on sorption to soil may not therefore be wholly appropriate to sediments; however, given the potential difference in sediment characteristics, it may not be possible to obtain a sediment partition coefficient which is suitable for a given site.

5.3 The role of natural processes in distributing and remobilising contaminated sediments

The availability of a contaminant to affect a receptor is not only dependent on the properties of the contaminant itself but also on its surroundings. River catchments and marine waters are complex systems in terms of the physical and chemical conditions they support. Changes in the sediment and water environment can cause chemicals to bind more to sediment particles or dissolve more into the water as they travel through a catchment, through an estuary or within marine waters. They may also undergo other chemical or physical changes.

5.3.1 Metals and inorganic contaminants

Partitioning of metals and ionic inorganic contaminants between soil or sediment and water may be dependent on a number of factors including:

- pH;
- Oxidising or reducing (redox) conditions;
- Temperature;
- Salinity (ionic strength of solution);
- Concentration of the substance in solution and sorbed;
- Concentrations of the main metal complexing agents[10] (including dissolved organic carbon) which may make the metal more stable in the water phase);

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[10] Complexing agents are ions or molecules which bind to metal ions and make them more stable in solution.

- The availability of specific types of sediment (organic content of the substrate and other sorbing materials present); and
- Sediment particle size.

Many metals bind onto particulates such as:

- Clay minerals;
- Iron and manganese oxides or hydroxides;
- Carbonates;
- Organic substances such as humic acids; and
- Biological materials such as algae and bacteria (USEPA, 2005; Eggleton and Thomas, 2004).

The availability of these may change through a river catchment or across a marine water body.

The bioavailability of metals may be dependent not only on their partitioning behaviour (as noted in **Section 5.1.1** more tightly bound contaminants are likely to be less available for uptake by aquatic biota) but also on factors such as salinity. Cadmium is known to be less bioavailable in saline conditions since it binds to chloride; whereas calcium and magnesium ions tend to bind preferentially to organic materials. Copper, however, is indicated to be more bioavailable in seawater (Eggleton and Thomas, 2004).

5.3.2 Organic contaminants

Factors affecting the partitioning of organic contaminants, other than the properties of the contaminant, may include:

- Sediment particle size;
- Type and amount of organic matter present;
- Length of time the chemical has been bound to the sediment (“resistant desorption”);
- pH;
- Redox potential; and
- Salinity.

These parameters are likely to vary significantly between catchments and also within catchments. Within the tidal reaches of rivers, the salinity of the water (and in terms of ions other than salt, the ionic concentration of the water) will fluctuate with the tidal cycle, meaning that some contaminants may be released from sediments in pulses with the tide. Changes in salinity may also affect bacterial activity. For example, highly saline water may inhibit bacterial activity and prevent bacteria from converting ammonium to nitrate or vice versa (Rysgaard et al., 1999).

Organic and organometallic contaminants (such as tributyl tin oxide) tend to sorb to organic matter in sediments and dissolved organic matter in sediment pore waters (interstitial waters), where the conditions such as the availability of dissolved organic matter, redox, pH and temperature may be different from that of the overlying water column. It has been noted (Eggleton and Thomas, 2004) that contaminant concentration in pore water may influence the overall toxicity of sediment more than the total concentration of the contaminant in the bulk sediment.

5.4 The behaviour of metals in fluvial sediments

5.4.1 Physical and chemical controls of metal behaviour

A number of physical characteristics, including particle size, surface area, specific gravity, surface charge, and bulk density, influence the behaviour of metals within sediment (Horowitz, 1991). Of these, the closely related parameters of grain size and surface area are considered to be the most important. Fine sediments have a much greater surface area than coarser particles of the same weight (Jones and Bowser, 1978), and a positive correlation between increasing surface area and decreasing grain size has been recorded (Horowitz and Elrick, 1987). As a result, fine particles, especially clay minerals (the flat structure of which means that they have a high sorption potential), organic matter and iron hydroxides, are able to adsorb large quantities of metals through cation exchange processes (Förstner and Wittmann, 1979; Salomons and Förstner, 1984). This means that metal concentrations are usually greatest in the clay size fraction, while the lowest concentrations are usually observed in the quartz-dominated silt and fine sand fractions (Horowitz, 1991).

A number of chemical factors also influence the accumulation and retention of metals in fluvial sediments, including:

- Adsorption onto fine-grained sediment. Adsorption is the sorption of metals from solution onto the surface of soil and sediment particles (Kabata-Pendias and Pendias, 2001). Adsorption is controlled by the cation exchange capacity of the sediment, the pH of the sediment and solution, and the oxidation-reduction potential of sediment;
- Precipitation of metals from solution as a result of changes in pH, oxidation-reduction potential or dissolved metal concentrations (Salomons and Förstner, 1984);
- Co-precipitation with iron and manganese oxides. Iron and manganese oxides are excellent scavengers of metals from solution, and often form a coating on mineral grains and other fine particles (Salomons and Förstner, 1984). Dissolved metals co-precipitate with the iron and manganese oxides, and therefore become concentrated on the surface of fluvial sediments (Horowitz, 1991);
- Association with organic matter by adsorption or organometallic bonding. Organic molecules transported within the fluvial sediment load act as a focus for the accumulation of metals (Gibbs, 1973). Metals are bound to organic molecules by a variety of processes, including adsorption, chemical bonding and physical trapping; and
- Incorporation in crystalline minerals. Metals can become incorporated into crystalline minerals through the process of substitution, where an element within the crystal structure is replaced with another from solution outside it. This reaction is more common in solid solutions that in sediment-water interactions, and may not play a major role within fluvial sediments under most conditions (Horowitz, 1991).

Metals may not be stable in the fluvial sediments, and may transfer to and from solution if chemical conditions are altered. The distribution of metals between solution and particulate-bound phases is influenced by chemical form, interactive processes such as precipitation, dissolution, sorption and desorption, and the concentration and composition of particulates (Förstner and Kersten, 1988).

5.4.2 Metal transport in fluvial sediments

The fate of metals in the fluvial system is governed by sediment transport processes, which themselves are controlled by factors such as discharge, stream power and the physical and chemical properties of the sediment.

Sediment-associated metals can be transported as part of the bed load of the river, or in suspension. Bed load moves in near-continuous contact with the river bed, through processes such as saltation, rolling and basal sliding, while the suspended load is transported within the water column. Sediments transported as bed load generally consist of sands and gravels, although finer sediment may also be transported in this way. In contrast, the suspended load is generally dominated by clays, although silt and fine sand is frequently carried in suspension. These differences in grain size between each load mean that metals associated with bed load generally remain static during low flows, and are cycled during periods of higher discharge (e.g. Bradley, 1988; Ciszewski, 2001). Metals in the suspended load are transported more continuously, although the total volume of metals transported in river sediments increases markedly during periods of high discharge (Horowitz, 1995).

5.4.3 Metal storage in fluvial sediments

Metal-rich sediment is subject to the same storage processes as the remainder of the fluvial sediment load. A significant proportion of metals associated with fluvially transported sediments become incorporated into the floodplain through overbank deposition and lateral accretion processes (e.g. Rang and Schouten, 1989; Macklin et al., 1992). Metal dispersal patterns within floodplain sediments are therefore dictated by the predominant style of sedimentation that operates within an individual reach.

In historically stable river channels, vertical accretion is the dominant process of floodplain formation, with metal concentrations reflecting the history of metal production in the vertical sediment record (e.g. Swennen et al., 1994). This relationship is attributable to the addition of metals as a thin veneer across the floodplain surface, and therefore the age of the overbank deposit increases with increasing depth. This leads to considerable variation in metal concentrations with depth, and allows the direct comparison between known phases of fluvial activity and peaks in metal concentrations in floodplain sediments (e.g. Macklin et al., 1994; Swennen et al., 1994). However, local variations in metal deposition across the floodplain surface complicate this simple relationship, so that it may only be possible to distinguish between mining-age and pre-mining sediments. Such variations have been attributed to localised flooding as a function of irregular bank heights, leading to overbank deposition in discrete areas on the floodplain surface (Swennen et al., 1994). Variations in metal concentrations in vertically accreted floodplain sediments have also been attributed to spatial differences in precipitation intensity. Variable precipitation patterns across a catchment can lead to variations in sediment source area and changes in the degree of mixing with uncontaminated sediments.

Significant variation in the lateral distribution of metals in historically stable reaches has also been reported. In many mined river systems, metal concentrations are greatest in sediments adjacent to the channel (Graf et al., 1991; Macklin, 1996;). This trend has been attributed to the increased incidence of flooding in near-channel zones and the receipt of more highly contaminated sediment during small floods (Middelkoop, 2002). Metal concentrations in suspended sediment decrease with increasing discharge due to dilution effects from clean sediment (Leenaers, 1989). Higher floodplain surfaces are only inundated during periods of high discharge, which suggests that they only receive diluted sediments (Rowan et al., 1995). Conversely, lower floodplain units are inundated more frequently with less diluted sediment, causing them to receive greater volumes of contaminant metals (Leenaers, 1989; Graf et al., 1991). In addition, in situations where metals are closely associated with coarse sediment, they are generally deposited closer to the channel as a result of gravitational effects (Macklin, 1996). Conversely, in situations where metals are most concentrated in silt and clay-sized sediment, contaminants are generally dispersed evenly across the floodplain surface as a thin veneer. In such conditions, areas subject to the preferential deposition of fines, such as palaeochannels, may become foci of metal accumulation (Lewin et al., 1977). This suggests that grain size variations play an extremely important role in determining the lateral dispersal patterns of metals in overbank sediments (Macklin, 1996).

In historically unstable channels, floodplain development is generally dominated by lateral accretion processes. Progressive reworking of the floodplain in such reaches can result in abrupt changes in metal concentrations across the valley floor (e.g. Macklin and Lewin, 1989). Furthermore, metal concentrations are defined by the intensity of mining operations at the time of deposition, resulting in further variability between units of different ages (Macklin and Lewin, 1989). A direct relationship between floodplain age and metal concentrations does not always exist, however, since changes in flood frequency and magnitude in relation to mining activities can be more dominant in dictating patterns of metal dispersal across the floodplain (Brewer and Taylor, 1997). Floodplain surfaces deposited during the peak of mining activities may not be the most highly contaminated if the incidence of flood events was low at the time of their formation.

As a result of the storage processes outlined above, soils that develop on a river floodplain can become highly enriched with metals. Many of these metals have long residence times within floodplain soils (Salomons and Förstner, 1984). The duration over which metals remain stored within the floodplain is dependent on a range of factors, such as the rates of physical, chemical and biological remobilisation, and the geomorphology of the reach in which they are stored. In stable reaches, metals can remain stored for hundreds to thousands of years (e.g. Macklin et al., 1992; Miller et al., 1996). In temperate soils in stable reaches, metals are gradually depleted by leaching and plant uptake. Cd can remain for up to 380 years, Hg for between 500 and 1000 years, and Ag, Cu, Ni, Pb and Zn for between 1000 and 3000 years (Salomons and Förstner, 1984; Kabata-Pendias and Pendias, 2001). In unstable reaches, however, residence times may be considerably shorter, with the cycling of metals accelerated by increased erosion rates (Macklin et al., 1992).

5.4.4 Remobilisation of metals

The depletion of metals in floodplain storage is linked to natural leaching and biological uptake, and, crucially, the chemical and physical remobilisation of such elements from the floodplain. The importance of the latter is considerably enhanced during periods of high discharge, when greater amounts of material are eroded from the bed and banks of the river channel (Leenaers, 1989; Middelkoop et al., 2002).

Furthermore, spoil tips are also likely to be ‘activated’ as sources of metals during high flow events, through erosion by surface runoff and direct fluvial erosion (Leenaers, 1989). Metal-rich floodplain sediments are therefore an important diffuse source of metals to the fluvial system (Macklin, 1992). Indeed, two thirds of the Pb entering the channel of the River Geul, the Netherlands, are thought to have been derived from the banks of the river (Leenaers, 1989).

The remobilisation of metal-rich sediments from floodplain stores has been identified as a potentially serious environmental problem (Stigliani et al., 1991; Konsten et al., 1993). The release of large volumes of sediment-bound contaminants can severely damage the aquatic ecosystem and, if deposited overbank further downstream, cause problems for floodplain-surface activities such as agriculture. Such releases of metal-rich sediment can occur during extreme events such as large floods (e.g. Middelkoop, 2000; Dennis et al., 2003) and tailings dam failures (e.g. Hudson-Edwards et al., 2001; Macklin et al., 2003), or, perhaps more commonly, as a result of longer-term geomorphological responses to changes in discharge or sediment load (Graf, 1985; Macklin, 1996). These changes may be attributable to variations in general climatic conditions that accelerate floodplain erosion (Stigliani et al., 1991), or anthropogenic changes such as the construction of flood protection schemes.

Activities such as farming may also alter the characteristics of the floodplain soils/sediments, for example altering pH, redox conditions and organic content which may, in turn, lead to changes in contaminant mobility.

Case Study: The River Swale catchment in North Yorkshire

The River Swale catchment in North Yorkshire is heavily mineralised. There is a long history of metal mining in the catchment, resulting in high concentrations of lead, zinc and cadmium in in-channel and floodplain sediments in the main river and its tributaries (Dennis et al., 2009). Some of the most intensively mineralised tributaries which formed the centre of the mining industry, including Gunnerside Beck, Barney Beck and Arkle Beck, display concentrations in excess of 20,000 mg kg^{-1} lead in fine-grained in situ sediments (Dennis et al., 2009).

A heavily mined reach of Barney Beck, showing extensive mine workings and spoil tips that are directly eroded by the river

Despite the long legacy of mining, the River Swale and its tributaries appear to support healthy fish populations, including trout, grayling and barbell. According to the draft version of the second Humber River Basin Management Plan, many of the water bodies in the upper catchment are at Moderate Ecological Status, although they support good fish and macrophyte populations. No data are presented for invertebrate populations, and it is possible that they are under pressure from sediment-associated contaminants. Furthermore, the water bodies in the upper catchment, which include centres of historic mining such as Gunnerside Beck, Barney Beck and Arkle Beck, fail to reach the required Chemical Status due to high concentrations of lead, zinc and cadmium. However, it is possible that the relatively high pH in the Swale system, a result of the extensive limestone bedrock, effectively reduces bioavailability for many aquatic communities.

Despite that fact that some of the WFD quality elements are not affected by the legacy of mining, there is clear evidence that sediment associated metals pose a risk to livestock. A study by Stewart and Allcroft (1956) in Arkle Beck found high concentrations of lead in herbage and sheep faeces from riparian fields where lambs were prone to lameness and premature mortality. Furthermore, lead concentrations were also greatly elevated in blood and liver tissue from lambs born to healthy ewes in floodplain pastures.

In addition, high concentrations of mining-related zinc in floodplain soils may also lead the suppression of copper intake in sheep, causing a variety of health problems (Hatch, 1977). Many farmers in Swaledale are obliged to provide copper supplements for their livestock, suggesting that this is a tangible problem in parts of the catchment.

5.4.5 Uptake of sediment-associated contaminants in floodplains

Sediment-associated contaminants may pose a hazard to the overall health of plants and animals in several ways. Plant health is primarily affected through the direct uptake of contaminants from near-surface and subsurface soils (Thornton, 1983).

Mechanisms for impacts upon animal health are more complex, and include:

- The intake of contaminants contained within plant material (i.e. substances that have been taken up from the soil); and
- Through the ingestion of metal-rich sediment, whether directly or in the form of a fine coating of dust derived from surface soils (Thornton, 1983).

It is likely that the soil-animal transfer of metals is more important than the transfer of metals from plants to animals (Abrahams and Steigmajer, 2003). Indeed, up to 97 % of the daily intake of Pb by sheep grazing on mining-affected floodplains may be attributable to soil ingestion. Ingestion rates are especially high during winter and spring months, possibly as a result of shorter vegetation and enhanced rain-splash effects (Abrahams and Steigmajer, 2003). Contaminants taken up by crops or ingested by livestock may travel up the food chain to affect humans who consume these.

6 Current Understanding of the nature and scale of in situ sediment contamination in England

Scope of task:

- To collate sediment quality and information on sediment sampling techniques from sites in England, building on Defra's existing work on Contaminated Dredged Marine Sediments: Developing a Management Framework
- To provide the outputs in a spread sheet format with geographical references to enable development of GIS mapping in later work packages.
- Where possible, to identify background concentrations within this data for use in **Work Package 2A.**

6.1 Collation of existing sediment contamination data for England

6.1.1 Introduction

A targeted literature review encompassing key databases from regulatory and research bodies, scientific publications and 'grey' literature has been undertaken using the project team's in house libraries, academic databases and references provided by the project's steering panel.

Information on sediment quality and sampling techniques has been collected in a spread sheet format with geographical references to enable development of GIS mapping in later work packages. Where possible, background concentrations within this data set have been identified.

6.1.2 Methodology

To provide an overview of in situ sediment contamination in England, various databases were searched and sources of information selected for analysis which fell into two categories:

1. Peer reviewed journal articles; and
2. National databases.

The national databases incorporated were:

- WIMS (Water Information Management System; Environment Agency, which also contains sediment analysis data);
- CDMS (Contaminated Marine Sediments Database; hosted on the Cefas website);
- CRT (Canal and Rivers Trust) 'NTC' and 'Leeds 1992' spread sheets;
- Norfolk Broads data; and
- G-Base data (British Geological Survey).

In addition, whilst water samples for metals and PCBs were collected as part of the LOIS (Land Ocean Interaction Study) programme these were excluded because only sediments are considered in this report. LOIS sediment data from journal articles have been summarised.

The nature of these data sets (reasons and methodologies of their collection) is discussed further in **Section 7.1**.

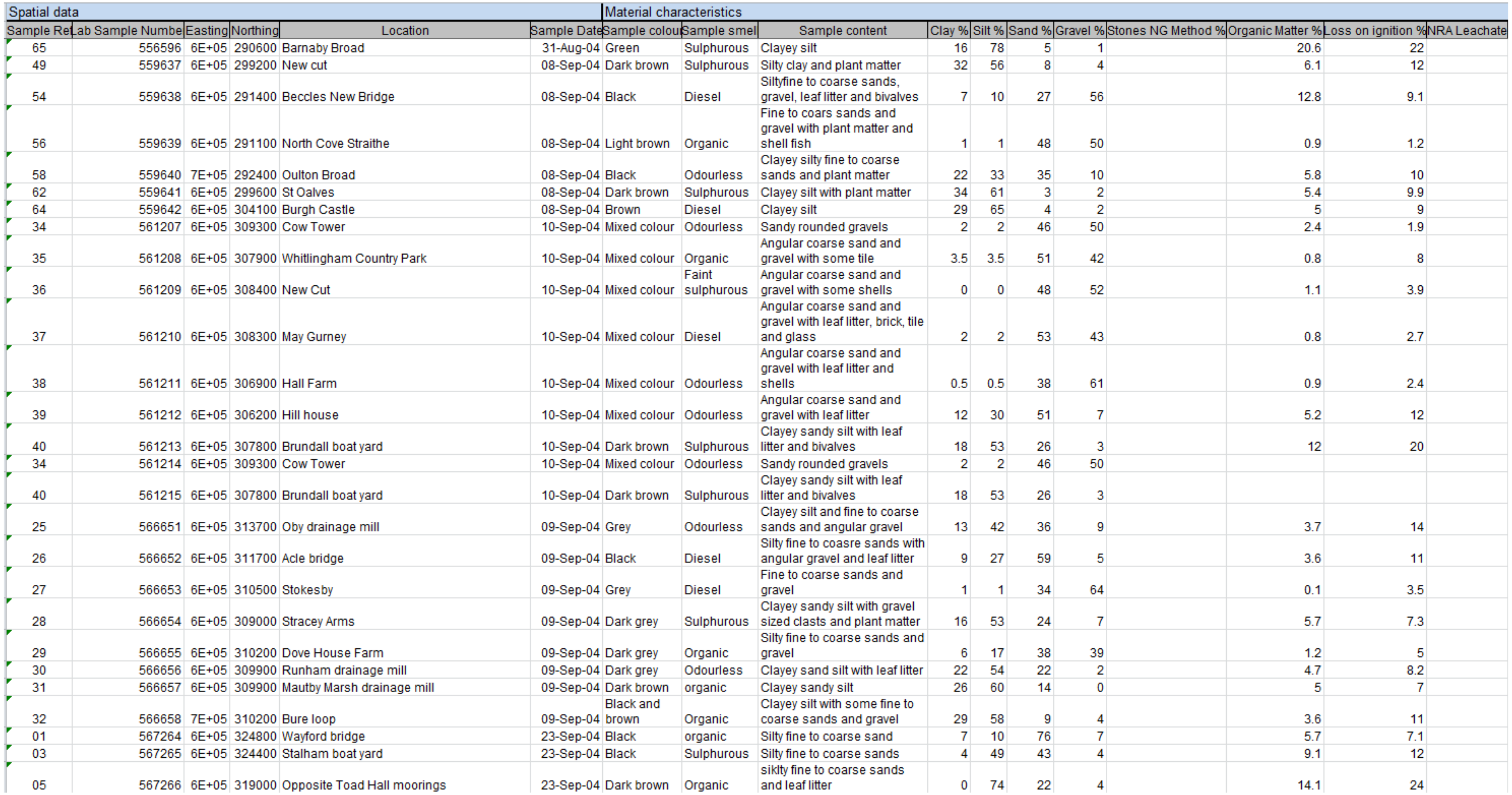
All data were extracted and entered into the Excel spreadsheet that accompanies this report. The spreadsheet was designed to include spatial data (e.g. river catchment, NGR), sampling and analysis data (e.g. sampling method, digest procedure), concentration data (concentrations of organic and inorganic pollutants), referencing details, and confidence rating.

The following headings were used in the database:

- Location;
- Sample collection date;
- Catchment;
- Easting;
- Northing;
- Water body identification;
- Depositional environment;
- Grain size;
- Sample size;
- Sample depth;
- Sampling method(s);
- Analytical technique(s);
- Digest; Accuracy/recovery;
- Concentrations;
- Mining affected catchment(s);
- Author; Journal; Year; Volume;
- Pages; and
- Confidence rating (see **Table 6.1**).

These fields were chosen as they include key data that can be used in **Work Packages 2A** (Developing methods for risk assessment and data collection), **3A** (Phase 1 national risk assessment to establish locations of concern), **4A** (Developing the case for action on in-situ contaminated sediment, including assessment of significant management issues), and **5A** (Developing options and guidance for further investigation). **Figure 6.1** provides an illustration of the database format.

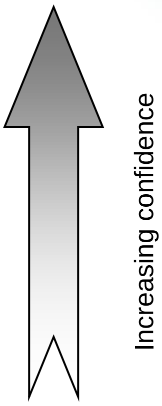
Figure 6.1 Illustration of Database Structure



Spatial data						Material characteristics										
Sample Re	Lab Sample Numbe	Easting	Northing	Location	Sample Date	Sample colou	Sample smel	Sample content	Clay %	Silt %	Sand %	Gravel %	Stones NG Method %	Organic Matter %	Loss on ignition %	NRA Leachate
65	556596	6E+05	290600	Barnaby Broad	31-Aug-04	Green	Sulphurous	Clayey silt	16	78	5	1		20.6	22	
49	559637	6E+05	299200	New cut	08-Sep-04	Dark brown	Sulphurous	Silty clay and plant matter	32	56	8	4		6.1	12	
54	559638	6E+05	291400	Beccles New Bridge	08-Sep-04	Black	Diesel	Siltyfine to coarse sands, gravel, leaf litter and bivalves	7	10	27	56		12.8	9.1	
56	559639	6E+05	291100	North Cove Straithe	08-Sep-04	Light brown	Organic	Fine to coars sands and gravel with plant matter and shell fish	1	1	48	50		0.9	1.2	
58	559640	7E+05	292400	Oulton Broad	08-Sep-04	Black	Odourless	Clayey silty fine to coarse sands and plant matter	22	33	35	10		5.8	10	
62	559641	6E+05	299600	St Oalves	08-Sep-04	Dark brown	Sulphurous	Clayey silt with plant matter	34	61	3	2		5.4	9.9	
64	559642	6E+05	304100	Burgh Castle	08-Sep-04	Brown	Diesel	Clayey silt	29	65	4	2		5	9	
34	561207	6E+05	309300	Cow Tower	10-Sep-04	Mixed colour	Odourless	Sandy rounded gravels	2	2	46	50		2.4	1.9	
35	561208	6E+05	307900	Whitlingham Country Park	10-Sep-04	Mixed colour	Organic	Angular coarse sand and gravel with some tile	3.5	3.5	51	42		0.8	8	
36	561209	6E+05	308400	New Cut	10-Sep-04	Mixed colour	Faint sulphurous	Angular coarse sand and gravel with some shells	0	0	48	52		1.1	3.9	
37	561210	6E+05	308300	May Gurney	10-Sep-04	Mixed colour	Diesel	Angular coarse sand and gravel with leaf litter, brick, tile and glass	2	2	53	43		0.8	2.7	
38	561211	6E+05	306900	Hall Farm	10-Sep-04	Mixed colour	Odourless	Angular coarse sand and gravel with leaf litter and shells	0.5	0.5	38	61		0.9	2.4	
39	561212	6E+05	306200	Hill house	10-Sep-04	Mixed colour	Odourless	Angular coarse sand and gravel with leaf litter	12	30	51	7		5.2	12	
40	561213	6E+05	307800	Brundall boat yard	10-Sep-04	Dark brown	Sulphurous	Clayey sandy silt with leaf litter and bivalves	18	53	26	3		12	20	
34	561214	6E+05	309300	Cow Tower	10-Sep-04	Mixed colour	Odourless	Sandy rounded gravels	2	2	46	50				
40	561215	6E+05	307800	Brundall boat yard	10-Sep-04	Dark brown	Sulphurous	Clayey sandy silt with leaf litter and bivalves	18	53	26	3				
25	566651	6E+05	313700	Oby drainage mill	09-Sep-04	Grey	Odourless	Clayey silt and fine to coarse sands and angular gravel	13	42	36	9		3.7	14	
26	566652	6E+05	311700	Acle bridge	09-Sep-04	Black	Diesel	Silty fine to coasre sands with angular gravel and leaf litter	9	27	59	5		3.6	11	
27	566653	6E+05	310500	Stokesby	09-Sep-04	Grey	Diesel	Fine to coarse sands and gravel	1	1	34	64		0.1	3.5	
28	566654	6E+05	309000	Stracey Arms	09-Sep-04	Dark grey	Sulphurous	Clayey sandy silt with gravel sized clasts and plant matter	16	53	24	7		5.7	7.3	
29	566655	6E+05	310200	Dove House Farm	09-Sep-04	Dark grey	Organic	Silty fine to coarse sands and gravel	6	17	38	39		1.2	5	
30	566656	6E+05	309900	Runham drainage mill	09-Sep-04	Dark grey	Odourless	Clayey sand silt with leaf litter	22	54	22	2		4.7	8.2	
31	566657	6E+05	309900	Mautby Marsh drainage mill	09-Sep-04	Dark brown	organic	Clayey sandy silt	26	60	14	0		5	7	
32	566658	7E+05	310200	Bure loop	09-Sep-04	Black and brown	Organic	Clayey silt with some fine to coarse sands and gravel	29	58	9	4		3.6	11	
01	567264	6E+05	324800	Wayford bridge	23-Sep-04	Black	organic	Silty fine to coarse sand	7	10	76	7		5.7	7.1	
03	567265	6E+05	324400	Stalham boat yard	23-Sep-04	Black	Sulphurous	Silty fine to coarse sands	4	49	43	4		9.1	12	
05	567266	6E+05	319000	Opposite Toad Hall moorings	23-Sep-04	Dark brown	Organic	siklty fine to coarse sands and leaf litter	0	74	22	4		14.1	24	

Table 6.1: Scale of confidence rating

Nature of reference	Confidence rating
Peer Reviewed Journal or Book	1
Report by Industry Body, Regulator or Consultant	2
Unpublished / internal data from Industry Body, Regulator or Consultant; Conference papers (not peer reviewed)	3
Academic Thesis	4
Personal Communication	5



Individual studies were selected for inclusion based on the following criteria:

- **Spatial coverage**: To give a comprehensive overview, studies were selected from major river systems in each region of England (e.g. NE England, NW England). Where possible, the broadest study (in terms of spatial coverage) per catchment was used (review style publications; e.g., Woodhead et al., 1999);
- **Range of contaminants**: Studies were selected that investigated a wide range of potentially hazardous metals and organic substances. Some studies were included that reported a limited number of potential contaminants if there was little other material available for a given area (e.g. Hg, River Yare; Birkett and Lester, 2005); and
- **Depositional environment**: Studies that investigated a range of sedimentary environments, such as channel bed sediments, flood sediments and floodplain sediments were selected (e.g. Dennis et al., 2003; Brewer et al., 2005).

In reality very few studies meet all of these criteria, with the exception of several well studied catchments in northern England. Key limitations of many studies (principally those conducted in southern England) include:

- A propensity to concentrate on estuaries, with little information available for inland areas. Estuarine contamination reflects the ‘end point’ of sediment transfer and there is likely to be contaminated sediment stored upstream of the tidal limit;
- Investigation of a limited range of depositional environments and processes. The majority of studies investigate active channel sediments (refer to the ‘depositional environment’ field of the database). Although useful, these data need to be combined with sediment core data to provide a context for contaminants stored at depth. Furthermore, flood events are important in liberating contaminants and they are crucial for understanding potential impacts of climate change and more frequent flooding; very few studies report these kind of data;
- Details of sampling and analysis procedures not fully recorded in some databases. This relates primarily to several large data sets (e.g. CRT, WIMS) Details which do not always accompany the sediment analyses include: sample collection method and depth, grain size sampled, sedimentary context, background concentrations, digestion procedure and accuracy;

- Variable consistency of data recording. As above (3), this relates to large data sets (such as the CRT NTC data set). Specifically, within the NTC data stored in Excel, column headings for many substances have multiple options; for Zn alone there are 15 different options (e.g., ‘Zinc’, ‘Zinc (Total)’, ‘Zinc (Tot)’, ‘Zinc as Zn’, ‘Zinc, Total as Zn’). This is likely to have been the result of combining previously separate data sets or from changes over time in the way that analyses are performed or procured.

Once selected, data were screened with reference to Environment Agency sediment quality guidelines (SQGs) for metals (**Table 6.2**) and organic pollutants (**Table 6.3**). For metals, best practice sediment quality guidelines for Natura 2000 sites in England (Habitats Directive Technical Advisory Group on Water Quality, 2004) were used. These interim sediment quality guidelines are based on the Environment Canada “threshold effect level” (TEL) and “probable effect level” (PEL) approach; the TEL is the concentration below which sediment-associated contaminants are not considered to represent significant hazards to aquatic organisms; the PEL represents the lower limit of the range of concentrations associated with adverse biological effects (Hudson-Edwards et al., 2008). Screening for contamination associated with organic pollutants focused on the two most widely reported groups of potentially harmful substances (PAHs and PCBs). Threshold values were taken from Burton (2002) and include TEL and PEL thresholds and ‘effect range low’ (ERL) guidelines; concentrations greater than ERL indicate that adverse toxicological effects can be detected (Kanzari et al., 2014).

Table 6.2: Interim Environment Agency freshwater sediment quality guidelines used to assess metal contamination of in situ sediment.

Metal	TEL (mg kg^{-1})	PEL (mg kg^{-1})
As	5.9	17
Cd	0.596	3.53
Cr	37.3	90
Cu	36.7	197
Pb	35	91.3
Ni	18	35.9
Zn	123	315

Table 6.3: Sediment quality guidelines used to assess organic contamination of in situ sediment associated with total PAHs (ΣPAHs), total PCBs (ΣPCBs) and six PAHs that are known to be carcinogenic to mammals (as reported by Woodhead et al., 1999)

Substance (µg kg^{-1})	EA marine sediment quality guidelines		EA draft freshwater sediment quality guidelines	
	TEL	PEL	TEL	PEL
ΣPAHs	N/A	N/A	N/A	N/A
ΣPCBs	21.5	189	34.1	277
Benz[a]-Anthracene	74.8	693	31.7	385
Benzo[a]-Pyrene	88.8	763	31.9	782
Benzo[b]-Fluoranthene	N/A	N/A	N/A	N/A
Benzo[k]-Fluoranthene	N/A	N/A	N/A	N/A
Chrysene	108	846	57.1	862
Dibenz[ah]-anthracene	6.22	135	N/A	N/A

Normal background concentrations (NBCs) in UK soils have been assessed by the British Geological Survey; these data are shown in **Table 6.4**. NBCs are shown for urban, mineralised, 'principal' areas or 'domains' (the latter are located outside major/towns cities and mining areas). Several minor areas (ironstone, Peak District, chalk south) are also included. NBCs include anthropogenic inputs, such that '*normal background concentrations are a combination of both natural and diffuse anthropogenic contributions*' (BGS, 2014; emphasis added). In this sense, BGS NBCs do not truly represent background concentrations. This is reflected in the NBC data (**Table 6.4**); e.g. the NBC for Pb in mineralised areas is approximately 26 times greater than the EA freshwater guideline PEL. The 'principal' domain values, are therefore expected to be much closer to undisturbed/pre-industrial concentrations.

The BGS NBC Final report explains the methodology for dividing values into domains in the following way:

"*The term "domain" has been used by this project to identify areas of England to which high concentrations of a contaminant can be attributed as a result of readily distinguishable controlling factors. Such regions are defined by a boundary derived from a soil's underlying parent material, an urbanisation index, or an area of non-ferrous metalliferous mineralisation with associated mining activities. The area remaining outside domains defined by these controlling factors is referred to as the Principal Domain."*

Table 6.4 British Geological Survey Normal Background Concentrations (NBCs) in English Soils (mg kg^{-1})

Metal	Principal	Urban	Mineralised	Ironstone	Peak District	Chalk South
As	32		290	220		
Cd	1.0	2.1	2.9-17			2.5
Cu	62	190	340			
Hg	0.5	1.9				
Ni	42			230	120	
Pb	180	820	2400			

6.2 In situ contamination by metals in England

6.2.1 Catchments affected by historical metal mining

The evidence for pervasive and chronic in situ sediment contamination in English river catchments, as a result 18th, 19th and early 20th century metal mining, is unequivocal (see Hudson-Edwards et al., 2008 and **Table 6.5**). Some of the most contaminated rivers in England (Tyne, Wear, Tees and Yorkshire Ouse system), in terms of sediment quality, drain the Pennines and associated orefields (**Figure 6.2**; **Table 6.5**). Metal concentrations in active channel sediments, floodplain sediments and overbank flood sediments are typically characterised by Pb and Zn concentrations that exceed the Environment Agency interim sediment quality guidelines (developed for the Habitats Directive Water Quality Technical Advisory Group, 2004) by one to two orders of magnitude. Furthermore, many floodplains in northern England have been found to be contaminated to such an extent that concentrations are higher than those associated with European tailings dam failure ‘disasters’ (Macklin et al., 2006).

Figure 6.2: UK metal mining areas

Table 6.5: Summary metal concentrations in catchments affected by historical metal mining (Values in bold exceed interim sediment quality (PEL) thresholds. All data listed below are included in the accompanying database)

River system	As mg/kg	Cd mg/kg	Cu mg/kg	Pb mg/kg	Zn mg/kg	Source
Yorkshire Ouse catchment						
Rivers Swale and Ure at Myton-on-Swale, n=4	6-10 (8)	nr	18-30 (24)	**192-932** (**500**)	198-**472** (307)	1
River Nidd at Kirk Hammerton, n = 5	5-7 (6)	nr	12-25 (19)	**283-1,100** (**602**)	102-284 (201)	1
River Ouse at York, n = 6	4-17 (9)	nr	15-37 (23)	**108-1,050** (**522**)	105-**701** (198)	1
River Wharfe at Tadcaster, n = 5	9-**19** (15)	nr	33-55 (40)	**196-1,690** (**830**)	188-**803** (**451**)	1
River Aire at Beal	**125-175** **(140)**	nr	81-**227** (162)	**130-314** (**237**)	206-**424** (254)	1
River Swale 2000 flood < 63 µm overbank sediments, n = 35		1.2-**29.1**		**174-19,370**	275-**13,920**	2
River Swale 2000 flood < 63 µm channel edge sediments, n = 35		0.6-**29.5**		49-**20,310**	55-**6,500**	2
River Swale floodplain sediments: surface (0-20 cm) < 2 mm, n = 297		0-**40**		75-**8,052**	50-**3,885**	3
River Swale floodplain sediments: surface (0-20 cm) < 2 mm, n = 147		0.4-**66**		54-**11,990**	60-**4,050**	3
Tyne catchment						
River Nent upstream of Blagill, < 2 mm overbank sediment, n = 24	nr	nr	nr	**224-15,800** (**5,262**)	**4,360-38,000** (**16,320**)	4
River South Tyne, floodplain sediment	nr	nr	nr	15-**10,490**	130-**15,270**	5
South Tyne and Tyne < 2 mm overbank sediment, n = 93	nr	2.3-**116.9** (**14.0**)	8-**384** (57)	**410-9,798** (**2,834**)	**590-16,520** (**5,504**)	6
South Tyne < 2 mm in-channel sediment, n = 21	nr	nr	nr	max **6,200** (**1,192**)	max **8,799** (**1,885**)	7
Wear catchment						
Upper River Wear, < 150 µm channel sediment, n = 107	<10-**65**	nr	<10-**340**	20-**15,000**	40-**1,500**	8

River system	As mg/kg	Cd mg/kg	Cu mg/kg	Pb mg/kg	Zn mg/kg	Source
Catchment-wide survey, n = 145	nr	nr	nr	56-**18,358**	nr	9
Tees catchment< 2 mm overbank sediment, n = 15		0.95-**5.95** (2.2)	19.5-76.9 (37)	**522-6,880** (**2170**)	**404-1,920** (**836**)	10
Axe catchment						
River Axe at Wookey Hole Cave, < 2 mm overbank sediment, n = 24	nr	nr	3-27 (14)	**226-25,124** (**2,642**)	89-**660** (245)	11
Trent catchment						
Hamps and Manifold rivers < 2 mm floodplain and channel sediment, n = 61		0.25-**21.86** (2.33)	11.4-**5,318** (**560.3**)	15.5-**1,107.7** (**162.8**)	92**-6,391** (**667**)	12
River Derwent at Darley Dale, < 2 mm overbank sediment, n = 157		0.08-**12.5** (2.5)	2.9-64 (17.2)	**131.4-1,179** (**620**)	9.3-**1,696** (194)	13
Fal catchment						
Inter tidal sediments, n = 405	13-**2,803**	nr	21-**5,073**	16-**902**	97-**6,600**	14
Inter tidal sediments, <2 mm, n = 25	nr	nr	30-**4,210**	**141-3,620**	nr	15
Tamar catchment						
Channel sediment, <2 mm, n = 25	**800-25,000**	nr	nr	nr	nr	16

Sources: 1 - Hudson-Edwards et al., 1999a; 2 - Dennis et al. 2003; 3 - Brewer et al. 2005;
4 - Macklin, 1986; 5 - Macklin and Lewin 1989; 6 - Macklin and Smith, 1990;
7 - Passmore and Macklin, 1994; 8 - Lord and Morgan, 2003; 9 - Shepherd et al., 2009;
10 - Hudson-Edwards et al., 1997; 11 - Macklin, 1985; 12 - Bradley and Cox, 1986;
13 - Bradley and Cox, 1990; 14 - Pirrie et al., 2003; 15 -Rainbow et al., 2011;
16 - Rieuwerts et al., 2014

Previous studies have found that, typically, the most polluted river sediment is stored within alluvial units that were formed during the peak period of mining (Macklin, 1986), or in discrete sedimentation zone 'hot spots' that experience frequent inundation (Brewer et al., 2005). Alluvium buried at depth is often more polluted than surface sediments, reflecting flooding during the peak period of mining and subsequent burial by post mining alluvium. In lowland areas, the most contaminated material will often be located between flood embankments, which trap fine-grained sediment (Hudson-Edwards et al., 1999). This study, based on detailed sampling and analysis of 379 sediment samples recovered from 32 core or trench profiles across seven catchments in the Yorkshire Ouse basin, showed that floodplain metal storage has been ongoing for 2000 years but has been greatest since c. 1750. These patterns are related to Pb and Zn mining in the Yorkshire Dales dating back to Roman times and to c. 250-300 years of industrial and urbanization activity around Leeds and Bradford. The in situ sediments database which this report accompanies collates studies which, as discussed above, were chosen in part for their spatial extent, in order to build a picture of sediment quality across England. More detailed but localised studies such as Hudson-Edwards et al. (1999) provide an additional level of detail and insight into the processes at work in a given catchment.

The vast scale of in situ sediment contamination in northern England is demonstrated by an estimate that 28% of the Pb extracted in the Swale catchment (155,000 tonnes) remains stored in floodplains (Dennis et al., 2009). In the entire Yorkshire Ouse basin there is an estimated 640 million tonnes of stored Zn (Hudson-Edwards et al., 1999), and for the Swale catchment alone the residence time of this material is several thousands of years (Coulthard and Macklin, 2003; Dennis et al., 2009).

In others parts of England the degree of in situ sediment contamination as a result of historical metal mining is less well studied. Where investigations have taken place (e.g. Axe catchment, Trent catchment; Macklin, 1985; Bradley and Cox, 1986, 1990), results show a similar degree of contamination (**Table 6.5**). Despite the small number of studies, contamination is probably more widespread than reported. For example, the River Trent drains approximately 470 abandoned metal mining sites (Mayes et al., 2013). Significant ore extraction (Cu and Pb) also took place in parts of the Lake District. The majority (90%) of Pb ore in the Lake District was extracted from Greenside Mine above Ullswater (Hudson-Edwards et al., 2008) and Grayson and Plater (2009) reported lake sediment Pb concentrations of ca. 10,000 to 35,000 mg kg^{-1} in upper Ullswater, near Greenside. Although no data are available for stream sediment, channel and floodplain sediments within small mined catchments that feed lake systems are likely to be contaminated. The same applies to catchments draining into Lake Coniston, where Cu ore was extracted and typical lake bed sediments contain up to 10 000 mg kg^{-1} of Cu (Davison, 1985).

In southwest England, Devon and Cornwall are characterized by a very high density of historical metal mines (Mayes et al., 2013). Investigations of in situ contamination in the southwest have focused almost exclusively on inter tidal mudflats and estuarine environments, and few studies have investigated flood processes or contamination at depth within floodplain soils. Unlike northern England, where the main pollutants are Pb and Zn, the primary metals of concern in the southwest are As, Cu and Sn. Arsenic and copper concentrations are spectacularly high in some locations; intertidal sediments on the rivers Tamar and Fal contain Cu concentrations up to 25 000 mg kg^{-1} (Pirrie et al., 2003; Rieuwerts et al., 2014). The highest concentrations in stream sediments recorded in the Tamar equal or exceed those reported in similar mining areas around the world (e.g. the Rio Tinto; Rieuwerts et al., 2014) and maximum levels of contamination in Cornish estuaries are comparable with geochemical data for sulphidic mine waste tailings (Pirrie, 2003).

6.2.2 Catchments affected by heavy industry and urban diffuse pollution

In river catchments unaffected by historical metal mining the main sources of metal pollution originate from heavy industry and urban diffuse pollution (UDP) from residential areas and highways (Ellis and Mitchell, 2006). In all English catchments, the percentage of urban cover is a significant predictor of catchment outlet flux for all metals (Mayes et al., 2013). Estuaries are key areas of in situ sediment contamination due to specific discharges associated with the congregation of anthropogenic activity (Emmerson et al., 1997). Before the 1960s and 1970s many urban watercourses were highly contaminated, and have been described as ‘essentially lifeless open sewers’ (Attrill and Thomes, 1995). **Table 6.6** shows typical concentrations of metals in estuarine sediments in England and **Tables 6.7** and **6.8** show concentrations in canal sediments.

Table 6.6 Summary metal concentrations (mg kg-1) in estuarine surface sediments in England

Catchment	As	Cd	Cu	Cr	Hg	Ni	Pb	Zn	Source
Blackwater	-	<0.10-2.51	1-130	13-**334**	<0.10-1.22	2-**106**	7-**231**	21-293	1
Medway & Swale	-	-	9-103	-	0.019-1.30	-	8-**203**	20-**392**	2
Thames [11]	15 (**45**)	1.3 (**9.8**)	61 (**348**)	59 (**240**)	0.60 (5.70)	34 (**157**)	**179** (**1634**)	219 (**1,050**)	3
Mersey	4.5-**44.7**	0.01-**155**	0.1-**240**	0.5-**155**	0.01-9.2	0.91-**364**	1-**741**	0.8-**1,200**	4
Yare	-	-	-	-	0-33	-	-	-	5
Broads rivers [12]	<1.0-**25** (11.3)	<0.5-2.9 (1.16)	<2.5-**250** (33)	<5.0-**100** (24)	<0.2-6.2 (0.84)	<2.5-**65** (20.5)	7.6-**1,700** (**98**)	7.7-**960** (140)	6
Plym	-	0.57-0.97	98.5-**2,230**	5.9-38.8	-	11.1-31.1	**98.5-163**	129-**916**	7
Severn	-	0.1-1.4	2-48	9-**92**	-	3-34	9-**92**	30-335	8
Humber [5]	**49.8**	0.48	54	77	0.55	**39**	**113**	252	9
Solent [5]	14.1	1.85	50	49	0.81	26	**96**	165	9
Hamble [5]	**18.4**	0.34	31	37	0.43	19	56	105	9
Avon [5]	13	0.08	18	28	0.12	23	68	82	9
Axe [5]	4.8	0.17	12	27	0.20	14	26	76	9
Rother [5]	12.4	0.13	11	29	0.09	15	20	46	9
Solway [5]	6.4	0.23	7	30	0.03	17	25	59	9
CDMS[4]	0-**243** (**17.3**)	0-**12** (0.5)	0-**4211** (51)	0-**1206** (35)	n.r.	0-**285** (21)	0-**6445** (81.2)	0-**7659** (181)	10

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[11] Mean and (max) concentrations.
[12] Range and (mean) concentrations
[5] Mean concentrations

Note: Values in bold exceed Environment Agency interim sediment quality PEL thresholds. Unless stated otherwise (footnotes 4, 5 and 6) concentrations show range values.

Sources: 1 - Emmerson et al. (1997); 2 - Spencer et al. (2006); 3 - Attrill & Thomes (1995);
4 - Harland et al. (2000); 5 - Birkett & Lester (2005); 6 - Internal communication;
7 - Singh & Turner (2009); 8 - Duquesne et al. (2006); 9 - Bryan & Langston (1992); 10 – internal communication.

Table 6.7: Summary metal concentration data from sediment samples collected by the Canal and Rivers Trust in 1992

Metal	% samples >PEL	Range (Mean) mg kg^{-1}	Location of maximum concentration	Number of samples
As	45	1-877 (26)	BCN - Walsall Canal	2066
Cd	37	0.05-687 (9.1)	Trent & Mersey Canal	1611
Cr	22	0.25-4150 (146)	BCN - Icknield Port Loop	2169
Cu	25	1.55-15,900 (399)	BCN - Icknield Port Loop	2258
Hg	n/a	0.02-1100 (2.58)	Weaver Navigation	2188
Ni	61	1-43,400 (117)	Grand Union Canal	2238
Pb	58	2-12,400 (260)	Leeds & Liverpool Canal	2165
Sn	n/a	2-1120 (29)	Birmingham Canal	1625
Zn	52	0.02-57,500 (907)	Birmingham & Black Country Canal	2327

Note: Raw data are available in the accompanying database.

Table 6.8: Summary metal concentration data (range and mean) from sediment samples collected by the Canal and Rivers Trust (NTC data).

Metal	Dry weight (mg kg-1)	Element (mg kg^{-1})
As	<0.1-330 (25)	1-389 (23)
Cd	<0.5-206 (NA)	<0.5-335 (5)
Cr	<2-10,200 (133)	<0.1-5064 (102)
Cu	2-26,600 (336)	<0.1-16,960 (317)
Hg	<0.5-627 (NA)	<0.5-515 (NA)
Ni	<4-2030 (71)	<0.1-5646 (70)
Pb	4-48,400 (247)	<0.5-81,000 (421)
Sn	<1-1960 (NA)	<1-760 (NA)
Zn	4-27,100 (803)	<0.5-9616 (571)

Note : For some metals (Cd, Hg, Sn), the majority of samples are characterized by very low concentrations (e.g. reported in original data as ‘<0.5’). For these metals averages are not available. The ‘dry weight’ and ‘Element’ columns reflect the original data supplied by the CRT; it is unclear how the latter were analysed.

Key points concerning in situ sediment contamination resulting from industrial activity and UDP are listed below. All studies referenced below have been used in the accompanying database.

- Despite significant improvements in water quality, primarily due to legislation such as the Water Act 1973, Control of Pollution Act 1974 and Environmental Protection Act 1990, river sediments remain contaminated above interim sediment quality guidelines in many areas, especially for Pb;
- Typically, a wider range of metals in high levels can be found adjacent to and downstream of urban and industrial areas, including Cr, Hg and Ni, as well as Cd, Cu, Pb and Zn (Bryan and Langston, 1992; Emmerson et al., 1997);
- Sediment contamination 'plumes' can be traced downstream from point sources, such as Sewage Treatment Works (Birkett and Lester, 2005) and storm drains (Attrill and Myles Thomes, 1995; Ellis and Mitchell, 2006). There may be problems of chronic accumulation of potentially toxic sediment adjacent to and below storm water outfalls (Ellis and Mitchell, 2006); for example, 'road dusts' that are washed into drains following rainfall may contain up to 3000 mg kg^{-1} Zn and 6600 mg kg^{-1} Cu, as well as a range of other metals (Charlesworth et al., 2003);
- Decadal-scale improvements in surface (0-5 cm) sediment quality can be easily reversed by erosion of contaminated sediment buried at depth (Harland et al., 2000);
- Sediment has a long residence time in estuaries and provides a continuing source of contamination (e.g., CDMS data in **Table 6.6**). Often, contaminants can only be washed to the open sea during extreme wet weather or on large spring tides (Martino et al., 2000);
- In brackish and saline environments there may be appreciable metal desorption from sediment to the overlying water column (Martino et al., 2002).
- Metal concentrations in canal sediments widely exceed PELs, especially for As, Cr, Pb and Zn; the most contaminated canals are those located near large industrial centres (e.g. Birmingham, Liverpool, Leeds; CRT, 1992, NTC (**Tables 6.7** and **6.8**).
- Metals may accumulate in estuarine sediments sourced from fuels and antifouling paints associated with pleasure boating (Singh and Turner, 2009); this may explain some of the high Cu and Zn concentrations in sediments of the Norfolk Broads rivers and lakes.
- Atmospheric deposition of metals also contributes to catchment metal loads. Cave et al. (2005) reported dry deposition in the Humber Estuary of 0.1 t yr^{-1} for As and Cu, 0.7 t yr^{-1} for Zn and 0.2 t yr^{-1} for Pb.

Despite improving surface sediment quality in catchments affected by heavy industry and UDP, evidence suggests that further improvements could potentially be difficult to achieve due to the erosion of contaminated sediments buried at depth. For example, Harland et al. (2000) reported that erosion of a saltmarsh in the Mersey estuary added ca. 2.5 t of Hg to the river system, causing a reversal in improving sediment quality. In the Thames catchment, despite improvements in recent years, the estuary remains chronically contaminated with a range of metals, due to the driving role of sediments in controlling metal levels through re-suspension and partitioning to the overlying water column (Pope and Langston, 2011). These examples provide an indication of scenarios that are likely to be very widespread because metals will have been accumulating in sediments since the beginning of the Industrial Revolution and, as a result, there is the potential for appreciable in situ metal storage and remobilisation as a result of the release of contaminants from urban and industrial sources.

There are likely to be differences between the locations of in situ metal contaminated sediment related to mining activity and industrial and urban diffuse pollution. In catchments affected by mining, ore extraction and processing usually took place in upland areas, creating a catchment wide contamination problem as metals were propagated downstream. In contrast, locations contaminated by heavy industry and UDP tend to be in lowland estuarine areas. As a result, some of the most contaminated catchments are likely to be those characterised by historical mining operations in headwater areas and heavy industry in lowland/estuarine settings (e.g. northern England).

6.2.3 In situ contamination associated with persistent organic pollutants and priority substances in England

Sediments are important reservoirs for a range of organic pollutants including APEs (alkylphenol ethoxylates) PAHs (polycyclic aromatic hydrocarbons), PCBs (polychlorinated biphenyls), OCPs (organochlorine pesticides) and dioxins and dioxin like compounds, some of which are carcinogenic and mutagenic (Woodhead et al., 1999; Bigus et al., 2014). Similar to the behaviour of metals in river catchments, the bulk burden of organic pollutants in the environment resides in soils and sediments (especially where organic matter is abundant) due to their hydrophobic and lipophilic nature (Jones and de Voogt, 1999; Ying et al., 2002). Storage of these high toxicity and persistent pollutants in sediments means that even after many substances have been banned, they remain at high levels in sediments that can be remobilised by large floods and cause further contamination (Hilscherova et al., 2007).

Table 6.9 shows concentrations of the most commonly reported organic pollutants in English river catchments (PCBs and PAHs). There are no EA guidelines for the majority of PAHs in freshwater sediments, but most of the upper range values in **Table 6.9** exceed the effect range low (ERL) reported by Burton (2002), especially in catchments with a strong industrial heritage (NE England: Tyne, Wear, Tees; NW England; Mersey). **Figure 6.3** shows the toxicity (expressed as “toxic units”[13]) of PAHs for each estuary reported in Woodhead et al. (1999), as well as predicted mortality rates for amphipods (an order of crustacean). The most toxic areas are those associated with heavy industry such as ship building (Tyne) and chemical works (Teesside). Estuaries of the NE coast experience PAH concentrations at levels likely to be acutely toxic to certain sediment dwellers (Woodhead et al. 1999). Studies reviewed during compilation of the database concluded that, in a global context, English rivers are contaminated with persistent organic pollutants and priority substances to ‘intermediate’ levels, similar to other industrial areas with similar histories, but lower than the most contaminated sites reported in the literature (e.g. Rhine: Camacho-Ibar & McEvoy, 1996; Meharg et al., 2003). **Table 6.10** shows concentrations in estuarine sediments for six PAHs which are known to be carcinogenic (Woodhead et al., 1999); most estuaries exceed EA guidelines, in some cases by an order of magnitude.

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[13] Toxic Units are a measure of relative toxicity of the PAHs. These are defined as the pore water concentration of the PAH compound divided by the 10-d LC501w (the concentration which is lethal to have the sample population of the test organism after 10 days).

Table 6.9: Concentrations of organic pollutants in estuarine surface sediments in England.

Catchment	ΣPCBs (µg kg^{-1})	ΣPAHs (µg kg^{-1})	APEs (µg kg^{-1})	Source
Solway		660-28,520		1
Blyth		11,458-12,130		2
Tyne		260-43,470		2
Wear		205-31,715		2
Wear		612-26,377		1
Tees		8,606-26,549	Up to 76	2, 3
Humber	1-84	1,349-11,149; 3,372-7,041		1, 2, 4
Aire & Calder		4.0-53.8	15-76	3, 5
Great Ouse		1,259-2,431; 2,997-10,032		1, 2
Blackwater		9,793-4,603		2
Crouch		1,153-1,439		2
Thames	120 (max)	122-6,519		2, 6
Mersey	7.4-1409;	626-3,766; 664-11,229; 6-6,230	6-11	1, 2, 3, 7; 8
Southampton Water		398-705; 1,062-89,305		1, 2
Poole Harbour		624-1,694		2
Tamar		4,929-7,410		2
Exe		42-5,889		2
Plymouth Sound		3,753		2
Orwell		581-11,608		1
Hamble		1497-9,737		1
Fowey		1141-22,316		1
Severn		5,425-5,472		2
CDMS	PCB-25 0.00498 - 10794 PCB-ICES8 0.00262– 5298.5	2.2 – 2,833,776		9

Sources:

1 - Rogers (2002). PAH analysed were: naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, 2,6-dimethylnaphthalene, acenaphthalene, acenaphthene, 2,3,5-trimethylnaphthalene, fluorine, phenanthrene, anthracene, 2-methylphenanthrene, fluoranthene, pyrene, 1-methylpyrene, benzo[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, indeno[1,2,3-*cd*]pyrene, benzo[*ghi*]perylene , dibenzo[a,h]anthracene;
2 - Woodhead et al. (1999). PAH analysed were: Naphthalene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene Benz[a]anthracene, Chrysene, Benzo[e]pyrene, Benzo[b]fuoranthene, Benzo[k]fuoranthene, Benzo[a]pyrene, Dibenz[ah]anthracene, Benzo[ghi]perylene;
3 - Blackburn et al. (1999);

4 - Tyler & Millward (1996); 5 - Meharg et al. (2003); 6 - Scrimshaw and Lester (1995) . Congeners included in Total PCB concentrations not specified;

7 - Vane et al. (2007). PAH analysed were : Naphthalene, Acenaphthylene. Fluorene. Phenanthrene. Anthracene. Fluoranthene. Pyrrene. Benz[a]anthracene, Chrysene. Benze[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenzo[ah]anthracene, benzo[ghi]perylene, indeno[123cd]pyrene;

8 - Fox et al. (2001). PCBs analysed were the ICES congeners : No. 28 (2,4,4’trichlorobiphenyl), No. 52 (2,2’,5,5$_{0}$-tetrachlorobiphenyl), No. 101 (2,2’,4,5,5’ pentachlorobiphenyl), No. 118 (2,3’,4,4’,5-pentachlorobiphenyl), No. 138 (2,2’,3,4,4’,5’hexachlorobiphenyl), No. 153 (2,2’,4,4’,5,5’-hexachlorobiphenyl) and No. 180 (2,2’, 3,4,4’,5,5’-heptachlorobiphenyl).

9 – Contaminated Dredged Marine Sediments database hosted by Cefas. PAHs analysed are 2,3 – benzanthracene, acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[e]pyrene, benzo[ghi]perylene, benzo[k]fluoranthene, C1-naphthalenes, C1-naphthalenes, C2-naphthalenes, C3-naphthalenes, chrysene, dibenz[ah]anthracene, fluoranthene, fluorene, indeno[123-cd]pyrene, naphthalene, perylene, phenanthrene, pyrene.

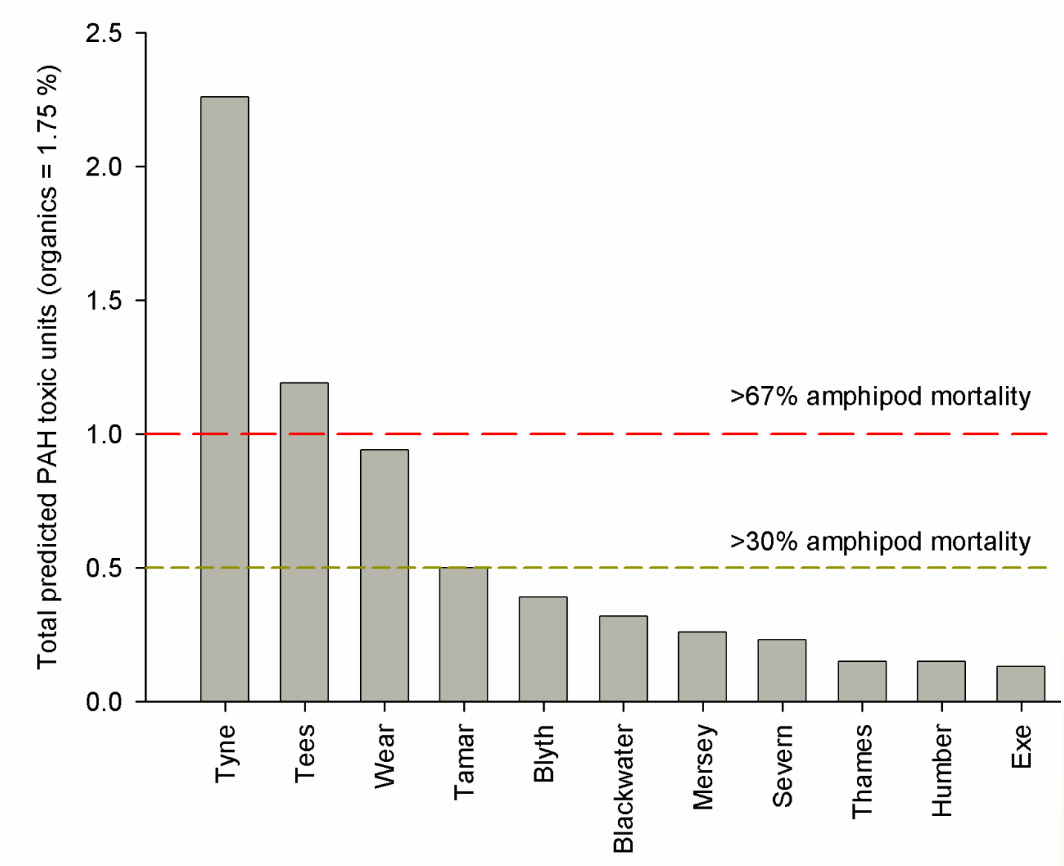

Figure 6.3: Toxicity (PAH) of estuarine sediments in England. Summed values for each river have been taken from Table 5 of Woodhead et al. (1999)

Table 6.10: Concentrations of six carcinogenic PAHs (as reported by Woodhead et al., 1999) in sediments from some of the most polluted English estuaries

Substance (µg/kg)	Tyne	Blyth	Wear	Tees	Mersey
Benz[a]anthracene	16-**4,130**	**2,050-2,490**	10-**2,050**	72-**3,880**	<3-**1,240**
Benzo[a]pyrene	16-**3,310**	533-694	11-**2,070**	23-**1,730**	2-587
Benzo[b]fluoranthene	16-1,960	457-718	7-2,380	38-2,140	<3-571
Benzo[k]fluoranthene	8-2,170	103-221	6-1,020	35-894	<1-257
Chrysene	20-**3,410**	**860-863**	14-**1,800**	22-**1,420**	<2-350
Dibenz[ah]anthracene	<3-**195**	110-**475**	26-**233**	<3-**345**	<3-**350**

Note: Values in bold exceed the EA PELs shown in Table 6.3). Noted that there are no threshold guidelines for benzo(b)fluoranthene or benzo(k)fluoranthene.

Analysis of the database shows that the main issues relating to in situ sediment contamination from organic pollutants include the following:

- Strong correlations between PCBs, PAHs and organic matter content and fine-grained sediment, especially where oils and fatty sewage deposits accumulate (Tyler & Millward, 1996) and dredged material is deposited (Camacho-Ibar and McEvoy, 1996).
- High concentrations are usually located near chemical works and sewage outfalls (Vane et al., 2007), enclosed harbours and docks and road bridges (Rogers, 2002). The latter tend to accumulate combustion residues.
- Suspended sediment may be more contaminated than bed sediment due to the presence of organics, which can lead to elevated concentrations in floodplain sediment (Meharg et al., 2003).
- Surface sediment concentrations in some estuaries are higher than may be expected for a suite of substances that were discontinued in the 1970s (Fox et al., 2001).
- Contamination profiles may cover the upper 1 m of alluvium (Fox et al., 2001; Vane et al., 2007). Some cores may show little change in contamination through time due to extensive sediment reworking and resuspension.

7 Preliminary risk screening

Scope of task:

- To compare sediment contaminant concentrations collated to published CEFAS action level and unpublished Environment Agency quality guidelines for freshwater sediments.
- Where possible to identify evidence of harm occurring or other ‘top down’ effects and note any “unexplained impacts” which may not be captured in the sediment contamination data set or, depending on the data available, consider alternative approaches to the screening, for example based on the mobility of the river within the catchment and therefore the likelihood of remobilisation of sediment.

To identify:

- Any particular types of environment which are of concern (e.g. sets of circumstances in a catchment or stretch of coastal water where in situ sediment contamination is likely to be of concern).
- Any particular locations where there is a clear risk of harm and action is very likely to be needed (i.e. that this is clear before the risk assessments in later Work Packages have been completed).
- Any gaps in the existing literature and sediment contamination data set and make recommendations for further work where there is a clear benefit to this. Using the Environment Agency Reasons for Failure Database, we will examine areas where there are particularly noticeable gaps in the data available and, where possible provide a qualitative discussion on whether processes related to in situ contaminated sediment might be responsible for failures.

7.1 Preliminary risk screening methodology

As an initial risk screening exercise, the sediment quality data have been compared against threshold values comprising the Cefas Action Levels, Environment Agency Draft Marine Sediment Quality Guideline values for coastal and marine sediments and the Environment Agency Draft Freshwater Sediment Quality Guideline values for freshwater sediments. As noted in **Section 6.1.2**, the Environment Agency SGQ are the same as the Canadian TEL and PEL threshold value.

Where a Cefas Action Level 2 is available, this has been used. In the absence of an Action Level 2, the Action Level 1 has been applied.

Note: Current application of sediment threshold values

The threshold values applies in the initial screening have been chosen in absence of authoritative and agreed levels for the assessment of overall risk from sediment contamination in England.

Cefas Action Levels

The Cefas Action Levels are known to be in widespread use specifically for the assessment of sediments which are proposed to be dredged, in order to assess the viability of their disposal at sea.

The original set of action levels was implemented in 1995, based on concentrations of contaminants in dredged material from England and Wales, with limited use of toxicological information. The action levels were revised in 2003, with additional levels being added for individual PAHs. Provisional action levels for some additional contaminants have been proposed but are not yet implemented. Cefas provide the following information on use of the current action levels in their note on Use of Action Levels in Dredged Material Assessments:

"*Action Levels are used as part of a 'weight of evidence' approach to assessing dredged material and its suitability for disposal to sea. These values will be used in conjunction with a range of other assessment methods e.g. bioassays, as well as historical data and knowledge regarding the dredging site, the material's physical characteristics, the disposal site characteristics and other relevant data, to make management decisions regarding the fate of dredged material. We are currently in the process of testing sediment bioassays to provide further information on the characteristics of dredged material. This integrated approach is in line with recent discussions regarding weight of evidence approaches to environmental management of sediments. It considers balancing multiple lines of evidence concerning ecological assessment as an aid to decision making.*
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."

Environment Agency Draft SQGs

The Environment Agency SQGs, however, are currently in draft form and it is less well documented how the TEL and PEL levels are currently applied and the weight that is given to the different levels. These thresholds are known originally to have been developed for use in assessing contaminant risk in Canada and the US Great Lakes region. They are understood not to be routinely applied currently in a regulatory context in England; however, the Draft SQGs were originally selected for application to sediment assessment in European protected sites.

For the purposes of this exercise, freshwater sediments have been defined as those above Mean High Water Springs (MHWS) level, with coastal and marine sediments being all those below this level.

Table 7.1 summarises the thresholds applied to each data set. For the purposes of this preliminary risk screening exercise, it has been assumed that contaminant concentrations above the relevant guideline level indicate a risk to sensitive receptors from sediment contamination. The basis of risk assessment for sediment contamination will be examined in more detail in later Work Packages of this project.

In order to analyse the data, the results have been imported into the ArcGIS Geographical Information System (GIS) software package using the following process:

- A sub-set of the chemical results within the databased described in **Section 6** was created, by selecting only those contaminants with either an Environment Agency Draft Sediment Quality Guideline value, or a Cefas Action Level.
- The chemical results, which often included several names for the same analyte, were rationalised using a standard chemical name list;
- Data were imported into a template file with a unique identification reference, easting, northing and chemical breakdown;
- Results stored as text were converted into numbers;
- Results below the laboratory limit of detection were set equal to the limit of detection;
- Results that were recorded as ranges were set to the mean of that range;
- The data were loaded into the GIS using the easting and northing grid coordinates;
- The data were split into two groups; those above MHWS and those below;
- The grouped data were linked into a template GIS where they were displayed using the appropriate sediment quality guidelines for marine and freshwater sediments;
- Each data sheet is represented in its own layer and grouped by sediment quality guideline;
- An additional layer has been included to show all data points. This allows an understanding of the spatial location for each dataset, irrespective of contaminant.

Table 7.1: Thresholds applied to each sediment quality dataset

Dataset	Cefas Action Levels[14]	EA Draft Marine SQG	EA Draft Freshwater SQG	Notes
WIMS	✓ (locations below MHWS)	✓ (locations below MHWS)	✓ (locations above MHWS)	Freshwater and coastal data set
CRT NTC	×	×	✓	Freshwater data set. One point noted to be below MHWS. Assumed not to be in continuity with marine waters

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[14] As detailed in the 'Note' box above, the draft SQG identified by the Environment Agency were derived from Canadian sediment quality guidelines.

Dataset	Cefas Action Levels[14]	EA Draft Marine SQG	EA Draft Freshwater SQG	Notes
Metals	×	×	✓	Freshwater data set.
POPs	N/A	N/A	N/A	This data set contains no grid references and hence has been excluded from the preliminary risk assessment.
Leeds 1992 (from CRT)	×	×	✓	Freshwater data set. Small number of data points noted to be below MHWS. Assumed not to be in continuity with marine waters
G-Base Stream	×	×	✓	Freshwater data set. One point noted to be below MHWS.
G-Base Surface Soils	×	×	✓	Freshwater data set. Small number of data points noted to be below MHWS.
G-Base Subsurface Soils	×	×	✓	Freshwater data set. Small number of data points noted to be below MHWS.
CDMS	✓	✓	×	Coastal and marine sediment data set
Broads	✓ (locations below MHWS)	✓ (locations below MHWS)	✓ (locations above MHWS)	Freshwater and coastal data set

As an initial high level screening exercise, on the national scale, the results have been categorised into three levels based on the number of exceedances (analysed by visual inspection of the results – see **Section 7.1.4**). It should be noted that the initial screening exercise represents a very high level consideration of sediment contamination and, even where the results across England have been categorised as having limited incidence of SQGs being exceeded, there may be individual areas with a far higher concentration of exceedances. As noted above, later Work Packages will examine methodologies for sediment contamination risk assessment in detail and this is likely to include statistical treatment of the analytical data. This brief evaluation is intended only to highlight areas of concern and to aid discussion of whether further works is needed to quantify risk from sediment contamination in England.

7.1.1 Targeted and non-targeted data sets

Based on the organisations which collected them, the reason for their collection and the sampling methodologies, the sediment quality data are considered likely to comprise a combination of highly targeted, semi-targeted and spatial distribution (untargeted) data (targeted in this context indicating targeting based on contamination concentrations). Detailed information on the reason for the sampling and analysis has not, in the main, been available for review; however the assumptions summarised in **Table 7.2** have been made in order to allow the datasets to be categorised and their results assessed accordingly. Targeted and untargeted sampling regimes can yield very different pictures of the spread of any contamination and these have therefore been discussed separately to avoid masking localised issues which have been the subject of targeted sampling.

Table 7.2 Assumptions on Targeting of Sediment Sampling

Highly Targeted	Semi-Targeted	Mainly Untargeted
WIMS – collected by the Environment Agency. Likely to be mainly targeted towards areas of perceived pollution.	**Metals and POPs worksheets**– collation of studies chosen for wider spatial coverage but concentrated in catchments with known environmental issues e.g. from mining.	**CRT and Leeds 1992** – Canal and Rivers Trust data sets covering the whole CRT network to support maintenance activity. May include some level of targeted sampling towards areas of concern.
-	**CDMS** – likely to be weighted towards areas of dredging activity and therefore around industrial activities (predominantly port and harbours)	**G-Base Stream, Surface Soils and Subsurface soils** – sampling for spatial distribution across sections of England
-	-	**Broads Authority** data set covering the Broads network to support maintenance activity. May include some level of targeted sampling towards areas of concern.

The G-Base data is divided into three separate databases:

- G-Base Stream: Samples taken mainly from 1st or 2nd order streams avoiding any contamination that may lie upstream. The sampling method involved removing the oxidised layer from the stream bed, retrieving the sediment sample and passing through a coarse and fine sieve to collect the fine fraction.
- G-Base Surface Soils: Samples taken by auger from a depth of 5-20cm below ground level.
- G-Base Sub-surface Soils: Samples taken by auger from a depth of 35-50cm below ground level (http://www.bgs.ac.uk/gbase/sampling.html, accessed October 2014).

It has been assumed that, in most river systems, the top 20cm of floodplain soils will represent the material that has recently accreted during overbank floods, and as such is representative of what is currently being transported in the channel (this depends on geomorphological processes such as vertical and lateral accretion rates, floodplain connectivity, bank stability and cohesiveness, but has been adopted as a general principle). The subsurface sediments (35-50cm) are therefore considered to be more representative of what has formerly been transported, and as such represent a form of "background". However, there is a strong likelihood that this material will itself be contaminated in some way by anything that has been transported by the river since the Industrial Revolution (or, in some rivers, for many centuries before this time). For example, in rivers located in historically mined catchments, floodplain contamination can extend several metres down, with peak concentrations at depth (reflecting a post-mining decrease in contaminant loadings). The floodplain has been delineated using the Environment Agency's Flood Zone 2 boundaries, which represent a major flood with a 0.1% chance of occurring each year (also known as the 1:1000 year flood).

7.1.2 Limitations of data sets for preliminary risk assessment

As discussed in **Section 6**, the data sets have been compiled by different organisations over potentially prolonged periods of time and hence a number of differences and limitations in the data are apparent when these are compiled and interrogated as one data set. These include:

- Some obvious errors in the coordinates attached to a small number of data points e.g. Broads data should appear, when mapped, in a small area of East Anglia but points are shown in the North Sea; one point in Kent; and one point off the coast of Cornwall. In other data sets it may be less evident if coordinates have errors since these cover much wider and less clearly delineated areas.
- The contaminants have been analysed in a number of ways e.g. metals analysed by X-ray Fluorescence (XRF), Optical Emission Spectroscopy (OES) and other methods, the results of which are not strictly comparable.
- Some contaminants for which the thresholds are defined for a group of species have not always been analysed in a way which is directly comparable with the threshold. For example, PCBs have been recorded as separate congeners or totals of different congener combinations. This has resulted either in a tentative comparison being made or some results not, at this stage, been compared to a threshold value.
- Units are not always provided clearly in the data sets; in some cases, the units have been assumed based on professional judgement.
- The criterion of above or below Mean High Water Springs level has been applied to differentiate between freshwater and marine sediment samples; however this is recognised as a very crude assumption as it relies on the grid reference being within or outside the MHWS area as mapped by the Ordnance Survey and not on the individual sample location or nature of the water body from which it was taken.
- G-Base stream metals data was derived by XRF and therefore likely to encompass concentrations from the geochemical sediment matrix as well as adsorbed contaminants. There were no untargeted, systematic data sets identified for organic contaminants.

- At this scale, some data points are overlain by others and this may affect the visual assessment of exceedances to some extent.

Based on the limitations outlined above, it is considered that only very broad conclusions can be drawn from this exercise, which has been carried out prior to the development of a national risk assessment methodology.

7.1.3 Spatial extent of data sets

Spatial extent and sample density varies significantly between data sets. The greatest coverage over England is provided by the BGS G-Base data sets; however, these do not extend to the whole of England and provide only analyses of metals. **Figures 7.1** to **7.4** show the spatial distribution of results in selected targeted and non-targeted data sets. It should be noted that some areas of the country are not covered by any of the data sets or have a very low density of results.

The results of the preliminary risk screening exercise are presented in **Tables 7.3** to **7.6** and discussed in **Section 7.2**. In some instances, the spatial distributions of exceedances were noted to be widespread and/or scattered (**Figure 7.6**); whereas in other cases, the exceedances are broadly concentrated in selected geographical areas (**Figure 7.7**). In these figures, red indicates an exceedance and green represents a result below the threshold.

Figure 7.1: Data points from the WIMS dataset (highly targeted)

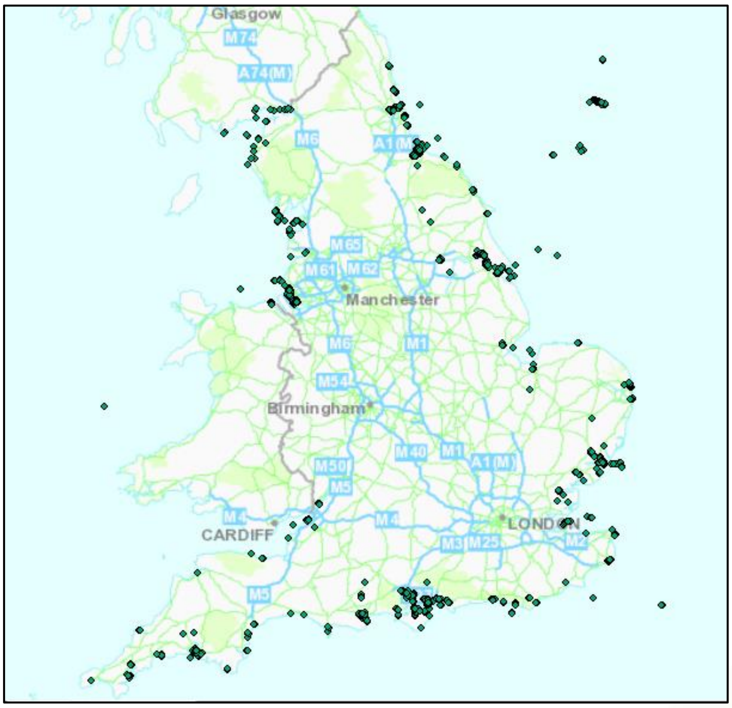

Figure 7.2: Data points from the CDMS dataset (semi-targeted)

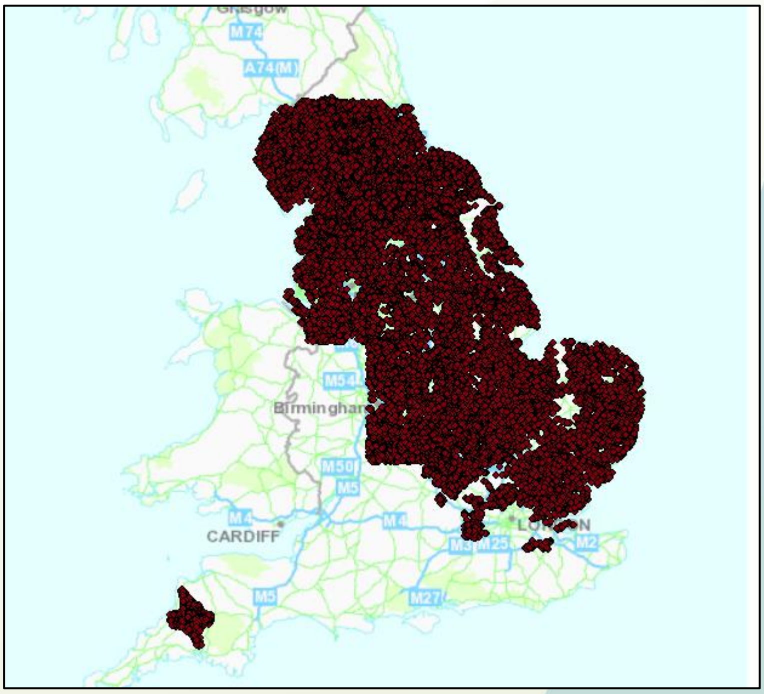

Figure 7.3: Data points from the G-Base stream sediment dataset (mainly untargeted)

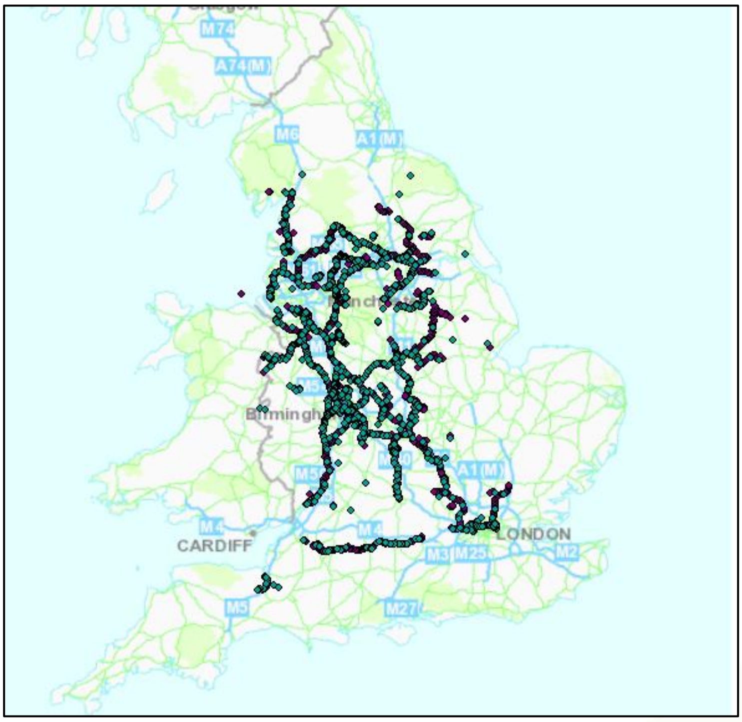

Figure 7.4: Data points from Canal and Rivers Trust datasets (mainly untargeted)

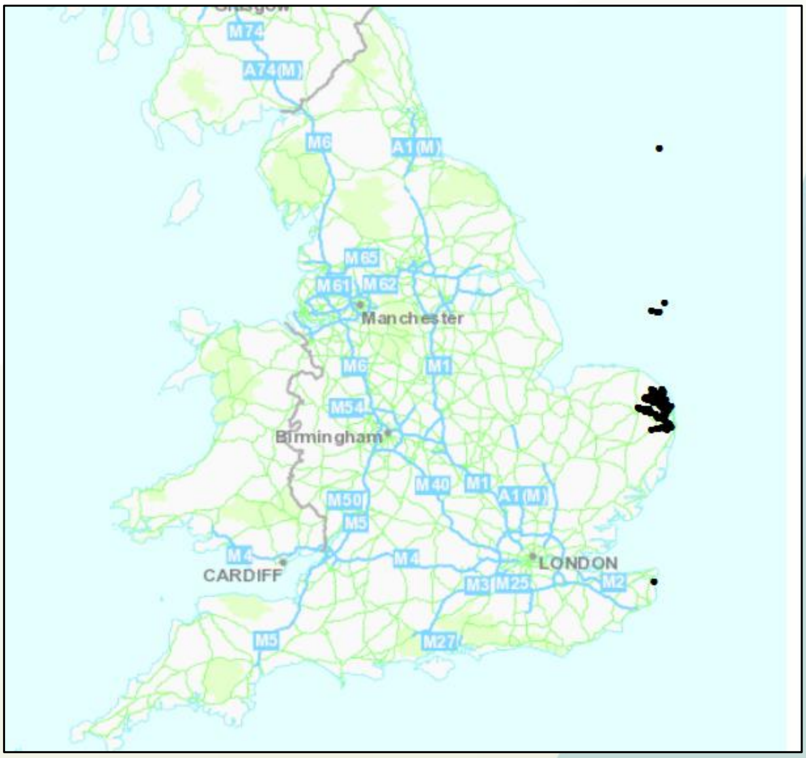

Figure 7.5: Data points from the Broads Authority dataset (mainly untargeted)

Note: results from this dataset with grid references off-shore have been excluded from the assessment

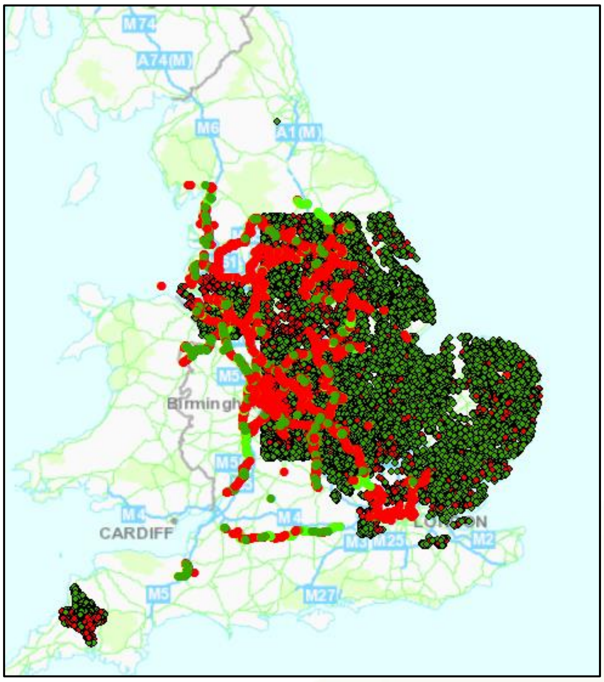

Figure 7.6 Copper concentrations compared to the Environment Agency Freshwater TEL SQG in the untargeted datasets (green < threshold; red > threshold)

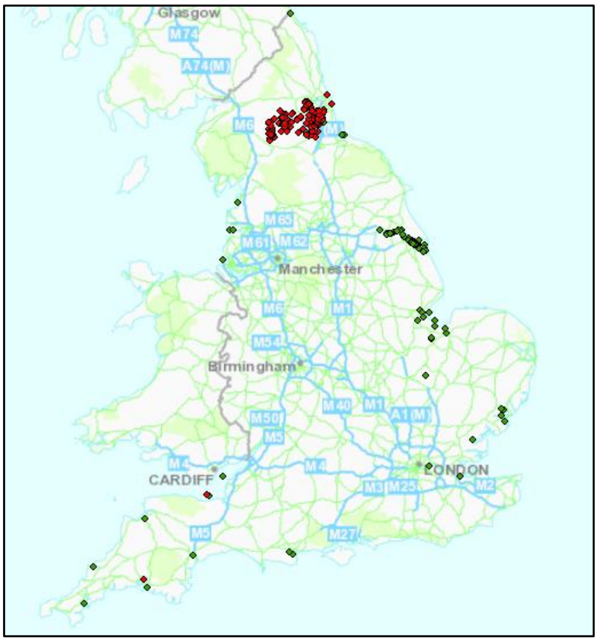

Figure 7.7 Lead concentrations compared to the Environment Agency Freshwater PEL SQG in the targeted datasets (green < threshold; red > threshold)

7.1.4 Summary of results

As an initial high level screening exercise, on the national scale, the results have been categorised into the following three levels by visual inspection of the results mapped in GIS format:

Green	Limited exceedances (estimated <25%)
Yellow	Estimated 25%-75% exceedances
Red	Widespread exceedances (estimated >75%)

Table 7.3: Threshold Exceedances in Targeted and Semi-Targeted Data Sets (WIMS, Metals and CDMS) (where green = <25% exceedance, yellow = 25-75% exceedance, and red = >75% exceedance)

Contaminant Group	Contaminant	Freshwater		Marine and Coastal			Notes
		EA (TEL)	EA (PEL)	Cefas Action Level	EA (TEL)	EA (PEL)	
Metals	Arsenic	🟨	🟨	🟩	🟨	🟨	
	Cadmium	🟩	🟩	🟩	🟩	🟩	
	Chromium	🟩	🟩	🟩	🟩	🟩	
	Copper	🟩	🟩	🟩	🟨	🟩	
	Lead	🟥	🟨	🟩	🟨	🟩	
	Mercury	🟨	🟨	🟩	🟨	🟩	
	Nickel	🟨	🟨	🟩	🟨	🟩	
	Silver	No threshold			-		2 data points
	Zinc	🟨	🟩	🟩	🟨	🟩	
	TBT DBT MBT	No threshold			No threshold		Compared to AL2
POPs	PCB's, sum of ICES (101; 118; 138; 153; 180; 28; 52)	No threshold		🟨	No threshold		Compared to AL1 (no AL2). WIMS POPS data not correctly formatted for comparison to threshold – CDMS data only
	PCB's, sum of 25 congeners	No threshold		🟩	No threshold		WMS POPs no marine PCB analysis – CDMS only
	PCBs, Total	🟩	🟩	No threshold	🟨	🟨	Data in WIMS only ; few data points
	pp-DDD	No data	No data	No threshold	No data	No data	
	pp-DDE	No freshwater data	No freshwater data	No threshold	🟩	🟩	Data in CDMS only. Few data points
	pp-DDT	No freshwater data	No freshwater data	No threshold	No threshold		Compared to AL1 (no AL2). Data in CDMS only. Few data points

Contaminant Group	Contaminant	Freshwater		Marine and Coastal			Notes
		EA (TEL)	EA (PEL)	Cefas Action Level	EA (TEL)	EA (PEL)	
	DDT, Total	No data	No data	🟨	🟨		
	Dieldrin	No freshwater data	No freshwater data	🟩	🟨	🟩	Compared to AL1 (no AL2). CDMS only. V few results
	Endrin	No freshwater data	No freshwater data	No threshold			No data in any of the data sets
	Chlordane	No data	No data	No threshold	No data	No data	No data in any of the data sets
	Lindane	No freshwater data	No freshwater data	No threshold	🟨	🟩	CDMS only. Few data points
	Bis(2-ethylhexyl)phthalate	No data	No data	No threshold	No data	No data	No data in targeted data sets
	Heptachlor epoxide	No freshwater data	No freshwater data	No threshold			
PAHs	Acenaphthene	No threshold		🟩	🟨	🟩	Compared to AL1 (no AL2).
	Acenaphthylene	No threshold		🟩	🟨	🟩	Compared to AL1 (no AL2).
	Anthracene	No threshold		🟨	🟨	🟩	Compared to AL1 (no AL2).
	Benz[a]anthracene	🟩	🟩	🟥	🟨	🟩	Compared to AL1 (no AL2). Little freshwater data
	Benzo[a]pyrene	No data	No data	🟨	🟨	🟩	Compared to AL1 (no AL2).
	Benzo[b]fluoranthene	No threshold		🟥	No threshold		Compared to AL1 (no AL2).
	Benzo[e]pyrene	No threshold		🟨	No threshold		Compared to AL1 (no AL2).
	Benzo[ghi]perylene	No threshold		🟨	No threshold		Compared to AL1 (no AL2).
	Benzo[k]fluoranthene	No threshold		🟨	No threshold		Compared to AL1 (no AL2).
	C1-naphthalenes	No threshold		🟨	No threshold		Compared to AL1 (no AL2).
	C1-phenanthrene	No threshold		🟨	No threshold		Compared to AL1 (no AL2).
	C2-naphthalenes	No threshold		🟨	No threshold		Compared to AL1 (no AL2).
	C3-naphthalenes	No threshold		🟨	No threshold		Compared to AL1 (no AL2).

Contaminant Group	Contaminant	Freshwater		Marine and Coastal			Notes
		EA (TEL)	EA (PEL)	Cefas Action Level	EA (TEL)	EA (PEL)	
	Chrysene	-	-	🟨	🟨	🟩	Compared to AL1 (no AL2). 3 freshwater data points
	Dibenzo[ah]anthracene	No threshold		🟥	🟥	🟨	Compared to AL1 (no AL2).
	Fluoranthene	-	-	🟨	🟨	🟨	Compared to AL1 (no AL2). 5 freshwater data points
	Fluorene	No threshold		🟨	🟨	🟨	Compared to AL1 (no AL2).
	Indeno[123-cd]pyrene	No threshold		🟨	No threshold		Compared to AL1 (no AL2).
	Naphthalene	No threshold		🟨	🟨	🟨	Compared to AL1 (no AL2).
	Perylene	No threshold		🟥	No threshold		Compared to AL1 (no AL2).
	Phenanthrene	No data	No data	🟨	🟨	🟨	Compared to AL1 (no AL2).
	Pyrene	🟩	🟩	🟥	🟨	🟩	Compared to AL1 (no AL2). 6 freshwater data points
	2-methylnaphthalene	No threshold		No data	No data	No data	No data
Petroleum Hydrocarbons	Petroleum hydrocarbons*	No threshold		🟥	No threshold		Compared to AL1 (no AL2). CDMS only

*It is noted Note that hydrocarbons are often analysed in different ways and for different molecular weight fractions depending on the reason for the analysis. All hydrocarbon results may not be comparable to the available petroleum hydrocarbon thresholds (in this case the Cefas Action Level 1 for Total Hydrocarbons).

Table 7.4: Threshold Exceedances in Mainly Non-Targeted Data Sets – sediments (CRT NTC and Leeds 1992, G-Base Stream, Broads) (where green = <25% exceedance, yellow = 25-75% exceedance, and red = >75% exceedance)

Contaminant Group	Contaminant		Freshwater		Marine and Coastal (Broads data only)*			Notes
			EA (TEL)	EA (PEL)	Cefas (AL2)	EA (TEL)	EA (PEL)	
Metals	1	Arsenic	🟥	🟨	🟩	🟨	🟩	
	2	Cadmium	🟨	🟨	🟩	🟩	🟩	
	3	Chromium	🟥	🟨	🟩	🟩	🟩	
	4	Copper	🟨	🟩	🟩	🟥	🟩	
	5	Lead	🟨	🟨	🟩	🟥	🟩	
	6	Mercury	🟨	🟨	🟩	🟥	🟨	Little G-Base coverage
	7	Nickel	🟥	🟨	🟩	🟨	🟩	
	8	Silver	No threshold			-	-	2 data points for marine sediments
	9	Zinc	🟨	🟨	🟩	🟨	🟩	
	10	TBT DBT MBT	No threshold		No data	No threshold		No data
POPs	11	PCB's, sum of ICES (101; 118; 138; 153; 180; 28; 52)	No threshold		No data	No threshold		Compared to AL1 (no AL2).
	12	PCB's, sum of 25 congeners	No threshold		No data	No threshold		
	13	PCBs, Total	No data	No data	No threshold	No data	No data	Some individual PCB ICES-7 analyses in NTC data set
	14	pp-DDD	No data	No data	No threshold	No data	No data	No data
	15	pp-DDE	No freshwater data	No freshwater data	No threshold	No data	No data	Data in CDMS only. Few data points
	16	pp-DDT	No freshwater	No freshwater	No data	No data	No data	Data in CDMS only. Few data points
	17	DDT, Total						
	18	Dieldrin	No freshwater	No freshwater	No data	No data	No data	Compared to AL1 (no AL2). CDMS only.

Contaminant Group	Contaminant		Freshwater		Marine and Coastal (Broads data only)*			Notes
			EA (TEL)	EA (PEL)	Cefas (AL2)	EA (TEL)	EA (PEL)	
	19	Endrin	No freshwater	No freshwater	No threshold			No data in any of the data sets
	20	Chlordane	No data	No data	No	No	No data	No data in any of the data sets
	21	Lindane	No freshwater	No freshwater	No	No data	No data	CDMS only.
	22	Bis(2-ethylhexyl)phthalate	No data	No data	No	No	No data	No data in targeted data sets
	23	Heptachlor epoxide	No freshwater	No freshwater	No threshold			
PAHs	24	Acenaphthene	No threshold		🟥	🟥	🟥	Compared to AL1 (no AL2).
	25	Acenaphthylene	No threshold		🟥	🟥	🟥	Compared to AL1 (no AL2).
	26	Anthracene	No threshold		🟥	🟥	🟥	Compared to AL1 (no AL2).
	27	Benz[a]anthracene	🟥	🟨	🟥	🟥	🟩	Compared to AL1 (no AL2).
	28	Benzo[a]pyrene	🟥	🟨	🟥	🟥	🟩	Compared to AL1 (no AL2).
	29	Benzo[b]fluoranthene	No threshold		🟥	No threshold		Compared to AL1 (no AL2).
	30	Benzo[e]pyrene	No threshold		No data	No threshold		Compared to AL1 (no AL2).
	31	Benzo[ghi]perylene	No threshold		🟥	No threshold		Compared to AL1 (no AL2).
	32	Benzo[k]fluoranthene	No threshold		🟥	No threshold		Compared to AL1 (no AL2).
	33	C1-naphthalenes	No threshold		No data	No threshold		Compared to AL1 (no AL2).
	34	C1-phenanthrene	No threshold		No data	No threshold		Compared to AL1 (no AL2).
	35	C2-naphthalenes	No threshold		No data	No threshold		Compared to AL1 (no AL2).
	36	C3-naphthalenes	No threshold		No data	No threshold		Compared to AL1 (no AL2).
	37	Chrysene	🟥	🟨	🟥	🟥	🟩	Compared to AL1 (no AL2).
	38	Dibenz[ah]anthracene	No threshold		🟥	🟥	🟥	Compared to AL1 (no AL2).
	39	Fluoranthene	🟥	🟨	🟥	🟥	🟩	Compared to AL1 (no AL2).
	40	Fluorene	No threshold		🟥	🟥	🟥	Compared to AL1 (no AL2).
	41	Indeno[123-cd]pyrene	No threshold		🟥	No threshold		Compared to AL1 (no AL2).
	42	Naphthalene	No threshold		🟥	🟥	🟥	Compared to AL1 (no AL2).

Contaminant Group	Contaminant		Freshwater		Marine and Coastal (Broads data only)*			Notes
			EA (TEL)	EA (PEL)	Cefas (AL2)	EA (TEL)	EA (PEL)	
	43	Perylene	No threshold		No data	No threshold		Compared to AL1 (no AL2).
	44	Phenanthrene	🟨	🟨	🟥	🟥	🟨	Compared to AL1 (no AL2).
	45	Pyrene	🟥	🟨	🟥	🟥	🟨	Compared to AL1 (no AL2).
	46	2-methylnaphthalene	No threshold		No data	No data		Compared to AL1 (no AL2).
Petroleum Hydrocarbons	47	Petroleum hydrocarbons	No threshold		🟩	No threshold		Compared to AL1 (no AL2). CDMS only

** Only the Broads data set has marine data. Therefore this is a limited data set in number and spatial distribution

*** Laboratory limit of detection for many of the PAHs exceeds the marine sediment thresholds for many results in the Broads data set. Where the limit of detection is lower than the thresholds, some of the results do not exceed, indicating that the analysis of the current results may show an overestimation of the risk.

Table 7.5: Threshold Exceedances in Mainly Non-Targeted Data Sets – G-Base Surface and Subsurface Soils within Flood Zone 2 (data available for metals only and freshwater environment only) (where green = <25% exceedance, yellow = 25-75% exceedance, and red = >75% exceedance)

Contaminant	Freshwater		Notes
	EA (TEL)	**EA (PEL)**	
Arsenic	🟥	🟨	
Cadmium	🟨	🟩	
Chromium	🟥	🟨	
Copper	🟨	🟩	
Lead	🟨	🟨	
Mercury	🟨	🟨	Less spatial coverage than for other metals
Nickel	🟨	🟨	
Silver	No threshold		
Zinc	🟨	🟩	

Table 7.6: Threshold Exceedances in Mainly Non-Targeted Data Sets – G-Base Surface and Subsurface Soils outside Flood Zone 2 (data available for metals only and freshwater environment only) (where green = <25% exceedance, yellow = 25-75% exceedance, and red = >75% exceedance)

Contaminant	**Freshwater**		**Notes**
	EA (TEL)	**EA (PEL)**	
Arsenic	🟥	🟨	Indicated greater density of failures of PEL in subsurface soils
Cadmium	🟨	🟩	
Chromium	🟥	🟨	Indicated greater density of failures of PEL in subsurface soils
Copper	🟩	🟩	
Lead	🟨	🟩	
Mercury	🟨	🟨	Less spatial coverage of surface soils. No subsurface soils results
Nickel	🟨	🟨	
Silver	No threshold		
Zinc	🟨	🟩	

7.2 Discussion of results

7.2.1 Targeted and semi-targeted data

The targeted results set was initially expected to show the greatest proportion of threshold exceedances, because sampling was deliberately targeted at areas that were likely to contain sediment-associated contaminants. However, it is noted that even targeted investigations often include the analysis of a wide range of contaminants, some of which may be present at lower or even background levels.

The most widespread exceedances (approximately <75%) in the targeted and semi-targeted data sets were for:

- EA Freshwater TEL for lead;
- Cefas AL1 for benzo(a)pyrene, benzo(b)fluoranthene, diebnzo(ah)anthracene, perylene, pyrene and petroleum hydrocarbons; and
- EA Marine and Coastal TEL for dibenzo(ah)anthracene.

There were also approximately 25%-50% exceedances for a much wider range of contaminants, notably:

- EA Freshwater PEL for arsenic, lead, mercury, and nickel; and
- EA Marine PEL for arsenic, PCBs total, dibenzo(ah)anthracene, fluoranthene, fluorene, naphthalene, and phenanthrene.

7.2.2 Mainly non-targeted data

The non-targeted data sets were designed to cover a broad spectrum of sedimentary environments, and as such should be expected to reflect a proportion of contaminated sediments (e.g. as a result of natural enrichment and anthropogenic contamination) in addition to uncontaminated and background concentrations. As a result, these were found to have more contaminants exceeding the freshwater thresholds than the targeted data sets. Approximately >75% of results exceeded the:

- EA Freshwater TEL for arsenic, chromium, nickel, benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene and pyrene.

Between approximately 25% and 75% of results exceeded the:

- EA Freshwater TEL for cadmium, copper, lead, mercury, zinc and phenanthrene; and
- EA Freshwater PEL for arsenic, cadmium, chromium, lead, mercury, nickel, zinc, benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene and pyrene.

The Marine and Costal thresholds were exceeded by many contaminants. However, the highly localised Norfolk Broads data were the only non-targeted data set that contained coastal results below MHWS. These results are therefore unlikely to be representative of conditions across England.

7.2.3 Surface and subsurface soil data within the floodplain

Data for floodplain soils have been identified using the Environment Agency Flood Zone 2 boundaries. As these areas are generally above MHWS, they have (in the initial risk screening exercise and for direct comparison against results from the targeted and non-targeted sediment data sets) been compared to the EA freshwater SQG. However, it is noted that these are out-of-channel sediments and therefore likely to be in contact with terrestrial rather than aquatic receptors. It may therefore be necessary in later, more detailed phases of assessment, to compare these results against human health and/or terrestrial ecological risk assessment thresholds. It should also be noted that the sediments, once deposited on the floodplain, may be exposed to a variety of contamination sources which are unrelated to sediment contamination (e.g. direct contamination from industrial spills and urban runoff).

Within Flood Zone 2, surface or near surface soils are expected to contain sediments derived from overbank deposition from water bodies. Outside the flood zone boundary (and, by inference, the floodplain boundary), this is considered to be less likely.

Within Flood Zone 2, as in the mainly non-targeted data:

- The TEL thresholds for arsenic and chromium were exceeded by >75% of samples. None of the metals tested had approximately >75% exceedances of the PEL thresholds.
- Approximately 25%-75% exceedances of the TEL threshold were found for six out of eight metals tested. Five of the eight metals also exceeded the PEL threshold in approximately 25% to 75% of samples tested.

The results for soils outside Flood Zone 2 were very similar, the only differences being that there were approximately <25% copper exceedances of the TEL level and approximately <25% exceedances of the lead PEL level. Any influence from overbank sediments on surface soil contamination levels in the floodplain is therefore not evident at this level of assessment.

7.2.4 Background concentrations

An important factor in interpreting the data on current sediment quality is the identification of concentrations which can be described as “background levels”, as differentiated from elevated concentrations caused by human activity. As noted in the conceptual model in **Section 3**, natural geochemical inputs constitute one pathway by which “contaminants” can enter a river or coastal system. Furthermore, all of the datasets discussed above have the potential to incorporate some “background” sediment concentrations.

In **Section 6.1.2**, the Normal Background Concentrations (NBCs) published by the BGS were discussed. However, as noted in **Section 6.1.2**, some of the NBCs exceed the thresholds used in the preliminary risk screening exercise and hence even the expected geochemical background concentrations are likely to show as a ‘risk’ in the initial risk screening exercise. These exceedances are summarised in **Table 7.7**. **Section 6.1.2** also notes that the NBCs include both natural and diffuse anthropogenic contributions but that the Principal Domain values are likely to represent the closest approximation to geochemical background.

Table 7.7: Exceedances of the Risk Screening Thresholds by Normal Background Concentrations

Metal	Threshold Exceeded by NBC (Principal Domain)					
	Cefas AL1	Cefas AL2	EA Marine SQG TEL	EA Marine SQG PEL	EA Freshwater SQG TEL	EA Freshwater SQG PEL
Arsenic	Yes	No	Yes	No	Yes	Yes
Cadmium	Yes	No	Yes	No	Yes	No
Copper	Yes	No	Yes	No	Yes	No
Mercury	Yes	No	Yes	No	Yes	Yes
Nickel	Yes	No	Yes	No	Yes	Yes
Lead	Yes	No	Yes	Yes	Yes	Yes

As noted in **Section 7.1**, the Cefas Action levels are currently applied for assessing the suitability of dredged material for disposal at sea. The EA SQGs are understood not to be routinely applied currently in a regulatory context in England and the weight, in terms of risk assessment which is currently assigned to the TEL and PEL levels is uncertain. It is therefore difficult to establish the impact on regulation of contaminated sediments which the exceedance of the thresholds by many of the Principal Domain SQGs may have. However, the most significant exceedances are expected to be of the AL2 and PEL levels (the less stringent thresholds). In the Marine environment, the EA Marine SQG was exceeded at the PEL level only by the lead NBC and none of the metal NBC exceeded the Cefas AL2. In the Freshwater environment, the exceedances were more widespread, with arsenic, mercury, nickel and lead exceeding.

7.2.5 Indications of environments of particular concern

In order to target resources (either in terms of further investigation or intervention) towards the areas of most need, it is important to be able to identify particular types of environment which are of concern (e.g. sets of circumstances in a catchment or stretch of coastal water where in situ sediment contamination is likely to be of concern).

In terms of river and estuarine systems in general, those areas most at risk from receiving sediment-associated contaminants are likely to include:

- The active channel. This transports contaminated sediments that are currently being released (e.g. by direct discharge or as a result of catchment runoff), and also remobilises contaminants through bed and bank erosion processes.
- The active floodplain, which receives the contaminated sediments from the channel during periods of high flow. Contaminated sediments typically form through vertical accretion under these circumstances. Within the floodplain, particular areas will be at greater risk if they are re flooded more often and/or in a highly depositional environment. These are likely to be, for example, lower terrace units, historical channels and depressions where water is trapped as the floodplain drains and preferentially deposits sediment.
- The parts of the valley floor that were most regularly inundated while the sources of contamination were at their most active. Although these areas represent the currently active

floodplain in many catchments (see above), in some catchments they may be disconnected from the current channel as a result of incision (i.e. they are now higher than the active floodplain) or lateral migration (i.e. the channel has moved and they are no longer so well connected).

- Areas of the floodplain that have been reworked since the source has been actively releasing contaminants. The accumulation may be by vertical or lateral accretion.

Wide, low energy delta-type estuaries are also likely to be subject to significant deposition of sediment. Whether this material is readily redistributed will depend on whether the erosional regime is stable or fluctuating in that part of the river/coastal system.

In terms of contaminant types and geographical locations of concern, the most detailed information is available for metal contamination and for selected (former mining) catchments which have been characterised in detail, such as the Yorkshire Ouse and Tyne systems in north east England. Although extremely high concentrations of metals such as Pb, Zn and Cd have been recorded in historically mined tributaries, floodplain deposits, active channel sediments and overbank flood sediments (often several orders of magnitude greater than the SQGs), this does not necessarily correspond to a failure to comply with WFD targets. This may be a result of a lack of bioavailability (see the case study about the River Swale in **Section 5.4.4**), and is also likely to reflect the comparatively narrow range of indicators used to assess WFD compliance.

The preliminary risk screening exercise has been conducted at a national level and, as such, has not yet identified individual catchments of concern. Recommendations for next steps are provided in **Section 8.2**.

The Environment Agency RFF data (version v.16.05.2011) identifies a very small percentage (only 42 water bodies or 0.24% of the total) where the failure was attributed to “confirmed - diffuse source contaminated sediments” or “suspected - diffuse source contaminated sediments”. These are summarised in **Table A4.1** in **Appendix 4**. These can be interpreted as indicating an existing impact on identified receptors from contaminated sediments (either confirmed or suspected). The locations identified in England are in the following Environment Agency Regions:

- North East;
- Anglian;
- North West; and
- South West.

The information provided on possible sources of the contamination includes inputs from agriculture, contaminated land, industry, urban runoff, mine discharges and sewage discharges.

It should be noted that the information presented in this section is based on Reasons for Failure data that accompanied the first River Basin Management Plans, and that many of these initial classifications were based on expert judgement and an often incomplete evidence base. An extensive investigations programme has been undertaken since the first RBMPs were published, and as a result large numbers of water bodies have been reclassified in the draft second RBMPs that are currently being consulted upon. For instance, the heavily mined tributaries in the upper Swale catchment (see case study in

Section 5.4.4) were all assigned Good Ecological Status in the first RBMP, but have been downgraded to Moderate Ecological Status and failed Chemical Status. A repeat of this analysis on the updated Reasons for Failure dataset (not available at the time of writing) may show a greater proportion of sediment-associated failures.

It is also possible that sediment-associated contamination is a contributing pressure to the failure of a much higher number of water bodies, but it is not recorded in the dataset. This could potentially occur when other, more easily identifiable pressures (including other physico-chemical pressures that are identified during routine testing, and hydromorphological modifications) are recorded as the main reason for failure for a water body.

7.2.6 Identification of fundamental gaps in the current datasets

A number of clear gaps have been identified. These include the following:

- **Spatial extent of current sediment quality data**: The CDMS data set provides a reasonable scatter of data points along the whole of the English coastline, with higher concentrations in some areas than in others. By contrast, the G-Base datasets provide a very dense coverage of large parts of the country but is entirely absent from others. **Figure 7.3** shows that the G-Base stream sediment dataset covers almost all of northern, central and eastern England and one area of south west England. The remainder (west midlands, central southern England, south east and most of the south west) remains unsurveyed.
- **Extents of studies examined**: Many studies which have been examined as part of this Work Package, especially those located outside northern England, have focused almost exclusively on estuaries and shallow sediments; few studies report pollutant concentrations in flood sediments or floodplain cores. These sedimentary contexts are critical for understanding the dispersal and storage of contaminants due to increasing flood frequency. The focus on surface sediments therefore takes no account of contaminants stored at depth and may give a misleading impression of improving sediment quality; several studies show that improvements in sediment quality can be easily reversed by a large flood or storm that liberates pollutants buried at depth. Finally, estuaries are often regarded as the end point of contaminant flux and there is likely to be further contamination above the tidal limit that may not always be recorded; a ‘source to sea’ sampling approach is required.
- **Analytes**: Whilst many of the “established” contaminants such as the heavy metals and PAHs are well represented in the data sets, for others there is scarcely any data available. For example:
    - Organics are absent from many datasets. The G-Base data provides detailed coverage only for selected metal compounds, but there are no such high density analyses for organic compounds;
    - Silver is very rarely tested, as this has a threshold only in the Environment Agency Marine SQG list;
    - Pesticides such as DDD, DDE, DDT and Dieldrin are typically not tested in freshwater data; and

  - Selected PAHs, such as Benzo[e]pyrene are rarely tested outside the CDMS dataset, as they only have a threshold in the Cefas Action Levels list.

- **Consistency of analysis**: Although some contaminants, or groups of contaminants such as PCBs, are represented in the dataset that has been compiled for this Work Package, the data are difficult to assess as a whole due to variation in the analyses undertaken.
- **Uncertainty in the Reasons for Failure Data**: The Reasons for Failure database shows that there are a considerable number of locations for which there is uncertainty over the pressure (**Table 7.8**). For some of these, there is also uncertainty over whether there is a WFD failure; for others, the information recorded in the database indicates evidence of an impact has been observed but the pressure responsible for this has not been defined (also see discussion in **Section 7.2.5**).

Table 7.8: Examples of areas of uncertainty within the RFF database[1]

Information on Pressure	Number of records in the RFF database	% of total number of failures
Pressure listed as “unknown” ,of which:	866	4.9%
The Tier 1 source was listed as “diffuse source”	178	1.0%
'X2009_RFF - 'Unknown - reasons for failure unknown	84	0.5%

[1] 2011 RFF data v.16.05.2011

7.3 Studies highlighted for possible ‘top-down’ evidence of harm

The risk screening exercise in **Section 7.2** has evaluated primary data (concentrations of contaminants in sediment samples) against guideline values which have been derived based on ecotoxicological effects. Such thresholds are often calculated in a precautionary way in order to take account of, for example, intra-species or inter-species variability. They are also often derived through laboratory methods using exposure of receptors to the pure contaminant. Responses to contaminants bound to sediment and/or present as part of a mixture of contaminants, may therefore vary from the predicted responses. Where widespread exceedances of thresholds are present, there may not necessarily be an obvious ecological impact.

In order to address this, case studies have also been sought which document an impact (e.g. deterioration of an ecosystem) where it is either proven or suspected that contamination in sediments may be playing a significant role. The complexities of environmental conditions can make it difficult to prove a causal link between an effect observed in the field and a source contaminant or a particular contaminant pathway. However, several studies and reviews have been highlighted in this section which report indications of harm to aquatic receptors which are attributed (although in most cases tentatively) to contamination and, in some cases, specifically sediment contamination. In addition, impacts of out-washed sediments on livestock grazing in the floodplain is highlighted in **Section 5.4.4**.

It should be noted that these studies provide a snapshot in time at each of the locations studied. Since then, conditions may have changed for a variety of reasons including industrial sites closing, new controls on discharges, natural attenuation and any active remediation undertaken, perhaps in response to the study's findings.

Document 1: Assessment of the risk posed by toxic contamination to waterbirds on Special Protection Areas (SPAs) English Nature Research Report No 703, 2006

Main Aim of Study: Carry out a screening risk assessment using new measurements of concentrations in prey to determine the key contaminants which could have toxic effects on waterbirds in Poole Harbour and the Severn Estuary.

Evidence of Harm in the Environment? No direct evidence indicated (potential likelihood of harm modelled by reference to toxicological benchmarks).

Causal Link to Sediments? Inconclusive – contaminant concentrations were tested in *Nereis* spp. (invertebrates) rather than directly from sediment therefore uptake could have been from sediment or the water column. However, the report concludes that "It appears likely, however, that lead and mercury contamination of both estuaries is dominated by historic rather than current sources" indicating that it may be more closely associated with sediments than the dissolved phase.

Document 2: Endocrine disrupters and European Marine Sites in England English Nature Research Reports No 531, 2001

Main Aim of Study: Provides a review of evidence relating to the prevalence and effects of suspected endocrine disrupter (ED) compounds as well as a preliminary risk assessment for UK Special Areas of Conservation and Special Protected Areas in terms of exposure to ED substances.

Evidence of Harm in the Environment? *Notes that:*

- "TBT in sediments (generally at concentrations above 0.02 g/g dry wt) has been demonstrated to have adverse effects on benthic communities, including direct and indirect effects on species other than molluscs, although the extent to which these effects are caused by endocrine disruption has not been established (Rees et al., 1999; Waldock et al., 1999)". Location of harm not provided in the review.
- "Female flounder (*Platichthys flesus*) held for 3 years on harbour sediment contaminated mainly with PCBs and PAHs showed elevated testosterone and oestradiol titres which could have been due to decreased steroid clearance via the cytochrome P450 system (Janssen et al., 1997). Correct interpretation of this type of data should take into consideration the natural cycles of sex steroids in fish, which vary with the seasons." Location of harm not provided in the review.
- "Nagler and Cyr (1997) have shown that male flatfish held on naturally ED -contaminated sediments produce sperm which are less effective in producing viable larvae, although it is not certain that this effect was indeed an example of ED." Not clear if this was laboratory or field evidence.

Causal Link to Sediments: The report provides preliminary risk assessments based on evidence including potentially contaminative discharges, analysis of water, sediment and tissue samples and evidence of harm (such as feminisation of fish) for the following locations:

- Berwickshire and North Northumberland Coast SAC
- Teesmouth and Cleveland Coast SPA
- Flamborough Head SAC
- Humber Flats, Marshes and Coast SPA
- Wash and North Norfolk Coast SAC
- Essex Estuaries SAC
- Thames Estuary and Marshes SPA
- Thanet Coast SAC
- Solent SAC
- Isle of Wight SAC
- Pool Harbour SPA
- Chesil and the Fleet SAC
- Plymouth Sound and Estuaries SAC
- Fal and Helford SAC
- Scilly Isles SAC

Document 2: Endocrine disrupters and European Marine Sites in England English Nature Research Reports No 531, 2001 (ctd.)

- Lundy SAC
- Severn Estuary SPA/pSAC
- Dee Estuary SPA
- Mersey Estuary SPA
- Ribble and Alt Estuaries SPA
- Morecombe Bay SAC
- Duddon Estuary SPA
- Solway Firth SAC

For many of these European Protected Sites, it was concluded either that they were unlikely to be highly contaminated or that there was insufficient evidence of contamination or harm available. However for selected sites, indications of harm tentatively attributed to contamination were presented. These are summarised in **Case Studies 1** to **7**.

Evidence of Harm Case Study 1: Teesmouth and Cleveland Coast SPA

(Source: Endocrine disrupters and European Marine Sites in England English Nature Research Reports No 531, 2001)

The report notes that “male Flounder from the Tees are amongst the most highly feminised fish to have been caught around the UK coastline as a result of oestrogenic substances discharged within the estuary (Allen et al. 1999a). Much of the oestrogenic contamination is located in sediments, but although a proportion has been identified as being of steroidal or industrial origin, the majority remains to be identified (EDMAR programme, unpublished data).”

“In 1998, NP {nonylphenol] concentrations in Tees sediments ranged from 0.2 to 42mg/kg, showing that historically contaminated sediments may be a significant source of this material (Cefas unpublished data). However, NP only appears to be a minor contributor to the total oestrogenicity of Tees sediments (EDMAR Programme unpublished data). Historical mining operations have resulted in elevated lead levels in sediments within the estuary (Plater et al, 1998).”

Cd, Hg and Pb levels were described as “elevated above background” with medians of 6.6 mg/kg, 0.32mg.kg and 39.5mg.kg respectively. It was noted that a proportion of this would be “associated with metalliferous minerals and therefore expected to be relatively unavailable to biota. A single mammal sample sowed a moderately high level of PCBs (54.7mg/kg) but the few organics measured in sediments (n=2) were not markedly elevated”.

The study concluded that “there is evidence for strong oestrogenic activity in the Tees estuary, probably caused by a variety of domestic and industrial sources, and it is to be expected that this is causing some adverse effects in the immediately adjacent SPA.” However, further research was recommended to confirm this.

Evidence of harm in the Environment:	Yes
Causal link to sediments:	Tentative

Evidence of Harm Case Study 2: Essex Estuaries SAC

(Source: Endocrine disrupters and European Marine Sites in England English Nature Research Reports No 531, 2001)

The report notes that "low or medium levels of oestrogenic substances probably enter these estuaries via sewage discharges, and some male flounder caught in the lower reaches of the Crouch were moderately feminised…(Allen et al, 1999b)."

The report summarises the data available as follows "contaminant data examined were sparse, but they do not indicate a serious problem. However, the fact that sewage discharges in the Crouch are causing a moderate feminisation in male flounder (probably through discharge of steroids) suggests that these estuaries are not in optimal condition. "

Evidence of harm in the Environment:	Yes
Causal link to sediments:	Not considered specifically in the review

Evidence of Harm Case Study 3: Severn Estuary SPA/pSAC

(Source: Endocrine disrupters and European Marine Sites in England English Nature Research Reports No 531, 2001)

The Estuary is noted to have large discharge inputs including sewage discharges and a relatively small proportion of industrial discharges. These are balanced by the large dilution capacity. The report notes that the data available for seawater and sediment analyses is sparse. Organochlorine contaminants and concentrations of most metals were noted to be low.

Evidence of harm in the Environment:	The report states that "the only other available information (EDMAR programme, unpublished data) originates from two flounder individuals caught in the Severn (Swash Channel) in 1999, one of which was a male showing mild feminisation. A risk to fish (possibly including the rare species found in this system) from endocrine disrupters may therefore exist, although its degree of severity is impossible to judge on the available evidence."
Causal link to sediments:	Not discussed in the review

Evidence of Harm Case Study 4: Mersey Estuary SPA

(Source: Endocrine disrupters and European Marine Sites in England English Nature Research Reports No 531, 2001)

The report notes that the Mersey Estuary is both highly populated and highly industrialised resulting in large volumes of discharged effluent. It also notes that, although there is a high volume to shipping movements, relatively low sediment concentrations of TBT were recorded in very limited sampling (median of 0.12mg/kg from 5 samples). Metal concentrations in fish and sediment were noted to be generally low organochlorine concentrations were described as “not high” in fish but PCBs were elevated.

Evidence of harm in the Environment:	The report states that “despite these sparse monitoring data the information that is available shows that the Mersey is one of the most contaminated UK estuaries (Matthiessen et all, 1993, NRA, 1995, Fox et al, 1999) and it is to be expected that endocrine disruption is occurring. Indeed, Allen et al (1999 a & b) have shown that male flounders from the Mersey are among the most strongly feminised in the UK”.
Causal link to sediments:	Tentative. The report states that “it seems likely that some Mersey wildlife in addition to fish is potentially experiencing endocrine disruption. However, whether birds are at risk from effects on their prey, or through direct biomagnification of residues in the food chain, is impossible to say based on the recent review”. The report recommended further research.

Evidence of Harm Case Study 5: Humber Flats, Marshes and Coast SPA

(Source: Endocrine disrupters and European Marine Sites in England English Nature Research Reports No 531, 2001)

The report notes a number of large sewage and industrial discharges. The habitats are described as essentially terrestrial but intermittently flooded.

Evidence of harm in the Environment:	"Feminisation of male flounder in the area is, only moderate, probably because of the large dilution available in the estuary (Allen et al, 1999a)."
Causal link to sediments:	Not specifically discussed in the review

Evidence of Harm Case Study 6: Solent SAC

(Source: Endocrine disrupters and European Marine Sites in England English Nature Research Reports No 531, 2001)

A complex of estuaries and harbour with large domestic and industrial discharges and heavy shipping traffic. The report notes that some TBT persists in sedimentary sinks (Cefas, 2000).

Evidence of harm in the Environment:	"Allen et al (1999a) found moderate feminisation of male flounder in Southampton Water, probably related to sewage discharges." The report notes that "no chemical monitoring were obtained for this review…However, the substation discharges in the area, coupled with the relatively poor dilution available in Southampton Water and, to a lesser extent in the Solent, suggest that endocrine disruption may be occurring , and it has indeed been demonstrated in flounder.
Causal link to sediments:	No sediment testing reviewed. The report recommended further research.

Evidence of Harm Case Study 7: Seal Sands

(Source: Assessment of the Value of Biological Effects Measures within the EU Habitats and Birds Directives and Habitat Regulations. Background to and Project Plan for the Seal Sands Case Study. R&D Technical Report, WRc 2014)

The estuary is described as “a complex system that is characterised by being highly stratified with low flushing rates” and forms part of the Teesmouth and Celveland Coast SPA/RAMSAR site (see Case Study 1)

“ Tees Estuary has a history of being heavily polluted from inputs of sewage and industrial effluents. In recent years the situation has improved by a concerted action on the part of industrial and municipal stakeholders to reduce inputs of ammonia and toxic substances such as cyanide, mercury, chloroform and 1,2 dichlorethane and substances that increase the BOD load. Most recently the Bran Sands sewage treatment complex operated by Northumbrian Water has been expanded and as a consequence no untreated sewage now enters the estuary.” This has improved the aquatic environment but pollutant inputs continue.

Pollutants including heavy metals, organotins, PCBs and chlorinated hydrocarbons have been monitored for 10 years. Endocrine disruptors have been detected.

The study investigated several effluent discharges for toxicity and indications of harm to aquatic organisms.

Evidence of harm in the Environment:	“Concentrations of nonylphenol have been found to exceed 80µg l^{-1} in the lower estuary. This is four times the threshold concentration at which feminisation of trout has been observed. Studies, co-ordinated by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) have provided unequivocal evidence of endocrine disruption in the viviparous blenny and some morphological changes have been detected in the sand goby, although these have yet to be verified as an ED response.”
Causal link to sediments:	“As part of the National Marine Monitoring Programme the Environment Agency assessed sediment toxicity at a number of sites on the Tees Estuary including Seal Sands using two acute whole sediment tests: 1. the 10 day polychaete *Arenicola marina* test which measures cast formation and lethality ; 2. the 10 day amphipod *Corophium volutator* test which measures lethality”. The data from whole sediment tests with *Arenicola marina* and *Corophium volutator* on samples taken in vicinity of the one of the investigated discharges indicated that toxic effects are evident.

The study produced the following conclusions to key questions:

1. Do the discharges identified as having a likely significant effect exhibit toxicity?

The discharges exhibited varying degrees of toxicity in oyster embryo-embryo-larval development bioassay - indicated that in some effluents to be due in part to the certain heavy metals and non-polar organic chemicals.

2. Is any observed effluent toxicity due to the consented/authorised chemical determinands based on the available concentration data and ecotoxicological information on the toxicity of the identified chemicals to the bioassay species?

The data for Daphnia magna indicated that the measured toxicity was not wholly explained by the toxicity of concentrations of consented/authorised determinands in the effluents.

3. Does hydrodynamic modelling of effluent discharges predict exceedances of EQSs of key contaminants (metals, PAHs and pesticides) in the water column?

Exceedances not expected.

4. Does hydrodynamic modelling of the dispersion of the discharge toxicity under ‘worst-case’ conditions predict that the discharge toxicity could impact on the SSSI (alone or in combination with other discharges)?

Modelling indicated potential impacts on the SSSI (potential for the toxicity threshold of the “combined effluent” to be exceeded) in one area.

5. Do measured concentrations of key contaminants in the water column exceed current EQSs?

At all the 19 receiving water locations sampled the EQSs for aluminium, copper and zinc were probably exceeded whilst the EQS for silver was exceeded at most locations. Other heavy metals did not exceed relevant EQSs. Key PAHs and pesticides were generally below the limit of detection at all locations.

6. Are biological effects evident at sites showing exceedances of EQSs?

Limited biological effects (abnormal development in the oyster embryo-embryo-larval bioassay) were shown in the receiving waters. Metals and non-polar organics were indicated to be responsible in part for the observed toxicity.

1. Do measured concentrations of key contaminants in the sediments exceed current Threshold Effect Levels (TELs) and/or Predicted Effect Levels (PELs) from the Environment Agency Interim Guidance on Sediment Quality Guidelines and are they linked to releases from particular discharges?

Measured concentrations of heavy metals and PAHs exceeded Environment Agency Interim SQG TEL and/or PEL levels

2. Are elevated levels of contaminants in the sediments linked to accumulation in polychaete worms and resulting biological effects?

Statistically significant effects on lugworm cast formation and growth (as weight gain) were evident at a number of locations. Concentrations of heavy metals and certain organic contaminants increased in the test organisms but only by a factor of 2-3 relative to background levels in animals at the start of the test.

3. Do sediment bound contaminants bioaccumulate in polychaete worms to levels that may harm the worms or cause potential effects on predator (bird) species that feed on them?

Potential risks identified to Dunlin (as a surrogate for all shorebirds) from uptake of contaminants in food items such as polychaete worms. Risk indicated to be mainly from uptake of arsenic and zinc in worms, although additive toxicity from other metals may also exist.

4. Is the pattern of abundance and distribution of polychaete worms measured at the Seal Sands SSSI linked with the observed biological effects measured in the water column and/or sediments or with other factors?

Overall the results of multivariate analysis suggest that Enteromorpha cover is the primary determinant of polychaete densities in Seal Sands.

“With regard to the application of biological effects measures within the EU Habitats and Birds Directives and Habitat Regulations the data indicate that...The potential risks are primarily from arsenic and zinc, although additive toxicity from other metals may also exist and deserve further investigation to determine whether mitigating factors, such as bioavailability, species-specific toxicity, or bird behaviour reduce these risks to an acceptable level. The data from the case study indicate that the source of the heavy metals may be largely historical and not due to current releases.”

7.3.1 Summary

As noted in **Section 7.3**, proving causal links from contamination in the aquatic environment can be very difficult due to the huge number of factors influencing the river or coastal system. This is borne out in the studies outlined above, where despite detailed investigation and analysis, the conclusions drawn tend to be tentative, particularly over the role of contaminated sediment in any observed impacts. However, it is clear from some of these studies that, although controls on the identified point source discharges may have improved in recent years, there are ongoing issues not only from the residual contaminant loadings from the discharges themselves but also from contaminants stored in the estuaries. It is considered highly likely therefore that sediment is playing a role in storing, transporting and re-releasing contaminants in some locations.

8 Conclusions and recommendations

8.1 Conclusions

This study has drawn together and examined key existing information on sediment quality. A large amount of work has already been undertaken to understand what contaminants exist in sediments in England, their fate and transport in the aquatic environment. However, currently, many sediment analysis studies report different grain size fractions, which makes comparison between studies and contamination thresholds difficult and are also produced using different sample preparation and analytical techniques, which further limits the comparability of results.

It is clear that there will be current differences between catchments and differences over time which will affect which pollutant linkages are active for exposure of receptors to contamination in sediment. These include variations in land uses and the response of the catchment or coastal system to climate change.

Analysis of the results compiled in the sediment quality database have shown that in situ sediment contamination, as a result of historical metal mining, heavy industry and urban diffuse pollution, is a pervasive and locally chronic problem in England. The highest levels of metal contamination are found in river catchments in north east (lead, zinc, cadmium and copper) and south west (arsenic, copper and tin) England. The main source of metals in these areas has been indicated by previous studies, to be diffuse pollution from contaminated floodplains and old mine workings.

In all catchments that have experienced historical mining, metal concentrations exceed interim sediment quality guidelines by at least one order of magnitude. Most large rivers that have a concentration of heavy industry and large urban centres in their catchments are also contaminated, primarily in estuarine areas, with a range of metals and organic pollutants (PAHs, PCBs; e.g. Thames, Mersey, Trent). Some estuaries are characterised by concentrations of persistent organic pollutants that are likely to be acutely toxic to aquatic ecosystems if there is a high degree of bioavailability.

Despite improvements in water quality over recent decades, high levels of floodplain contamination form a significant store of unregulated pollutants that constitute a limiting factor to further improvements in river system health within some catchments. Several studies demonstrate the potential for flood remobilisation of contaminants and these problems are likely to intensify due to climate change and/or human intervention (e.g. dredging).

Analysis of sediment quality data for England against freshwater and coastal/marine Action Levels and SQGs has indicated significant numbers of exceedances for some contaminants (e.g. arsenic, cadmium and some PAHs) as well as a lack of data for other contaminants (e.g. silver and pesticides). On the national scale, differences between surface soils inside and outside the floodplain were difficult to identify.

In some case studies, although controls on the identified point source discharges may have improved in recent years, there appear to be ongoing issues not only from the residual contaminant loadings from the discharges themselves but also from contaminants stored in the estuaries. It is considered highly likely therefore that sediment is playing a role in storing, transporting and re-releasing contaminants in some locations.

Break Point 1A: Evidence that there is an issue to address

Based on the preliminary risk screening results presented in **Section 7**, it is considered that there is a potential risk to sensitive receptors from selected contaminants. In some cases, this risk may be localised and in other cases potentially more widespread. However, in order to produce a robust, transparent and defensible national risk assessment, further investigation and assessment is considered to be necessary.

8.2 Recommendations

Two key questions that are considered to require further detailed consideration in subsequent work packages are:

1. Whether ongoing human activities and future effects due to climate change are likely to mobilise in-situ contamination and increase the risk of status deterioration occurring in the future (to provide supporting information for whether the 'no deterioration' objectives are likely to be met); and
2. Whether in situ contaminated sediments pose a problem in terms of compliance of WFD objectives and other nature conservation objectives, notably conservation objectives for Sites of Special Scientific Interest (SSSI), Special Protected Areas (SPA), Special Areas of Conservation (SAC) and Marine Conservation Zones (MCZ), and that there is a need to take action in order to achieve compliance.

The following actions are recommended in order to provide an improved understanding of in situ sediment contamination in England, although outside the current scope of this project:

1. Adoption of a standardised framework for sample collection, analysis and reporting by organisations undertaking sampling, particularly for regional or national sampling projects. Further areas where standardisation is necessary include digestion procedure and analytical techniques; if these methods cannot be standardised then accuracy results obtained from analysing standard reference material should be reported. When reporting results, data should be stored in a clear and simple format that is easily understood by a third party.
2. Development of a set of national guidelines for sediment sampling, to ensure that contamination is identified in a coherent and comprehensive way. These should include recommendations for sample collection from a range of sedimentary environments, ideally to include suspended sediments, active bed sediments, deposits from palaeochannels and other depositional hollows and floodplain cores.
3. Research to address the evidence gap in demonstrating causal links between sediment contamination and harm in the environment previously identified in Task 6 of the Defra Contaminated Dredged Marine Sediments: Developing a Management Framework project. The outputs to this study recommended an increased understanding of bioavailability to enable realistic action levels to be derived. In order to fully understand contaminant linkages involving contaminated sediment, it is considered that the following aspects would need to be addressed:

1. Isolation of the contaminant linkages from other environmental factors (as discussed within this report, this is made difficult by the complexity of river or coastal systems);
2. Evaluation of toxicity of the contaminant in the site-specific context (compared to results of laboratory toxicity tests) and toxicity to the particular receptor species of concern for the site;
3. Demonstration of harm to key features of the site.

It is noted that only a select number of reports containing information on evidence of harm could be reviewed as part of this report. It is recommended that this review be extended to include additional studies including the following, recommended by Cefas:

- Assessing and Managing Contaminated Sediments: Part II, Evaluating Risk and Monitoring Sediment Remedy Effectiveness, Apitx, S.E. et al., Integrated Environmental Assessment and Management, Volume 1, Number 1—pp.e1–e14, 2005;
- Ecological Risk Assessment of Polycyclic Aromatic Hydrocarbons in Sediments: Identifying Sources and Ecological Hazard, Neff, J.M et al., Integrated Environmental Assessment and Management, Volume 1, Number 1, pp.22–33, 2005; and
- Contaminants and their effects on estuarine and coastal organisms in the United Kingdom in the late twentieth century, Matthiessen, P., and Law, R.J., Environmental Pollution 120, 739-757, 2002.

In addition, the following points provide suggestions for further analysis of the sediment quality database which may be possible following completion of the national risk assessment methodology. These suggestions have been made here for consideration in the subsequent work packages of this project:

1. Following completion of the national risk assessment methodology, the sediment quality database may be examined in more detail at a catchment scale, for example by considering the concentrations of each contaminant within the catchment boundary using GIS methods. This would allow management catchments and/or water bodies with a high concentration of exceedances of the applied thresholds to be highlighted as potential areas of concern.
2. Compare the Environment Agency's latest Reasons for Failure data to the outputs of the national risk assessment using catchment boundaries to examine potential correlations between failures and high sediment contaminant concentrations. Where possible consider SSSI, SPA, SAC and MCZ boundaries where failures of environmental objectives are reported and their proximity to water bodies.
3. Examine the WFD status of water bodies of concern (derived from point 3) in light of the new draft RBMP 2 for increases in diffuse pollution and/or sediment contamination-related failures to establish the current trend in water body status.
4. Apply the WFD data and river typology information to assign a (qualitative) measure of river energy and likelihood of remobilisation of sediments in the catchments of the water bodies of concern.

5. At this stage, the data sets have been formatted to allow them to be viewed using GIS software for the purposes of the preliminary risk screening exercise. This could be further developed to facilitate access to, and interrogation of, the data through development of:
    - An online or free standing database allowing importing and exporting of data, reporting /querying and the ability to convert values to different units.; or
    - A data viewer with:
        - Online web maps with customisable banding for contaminants ranges.
        - Ability to produce interpolated heat maps
        - Links to other web mapping services such as EA WFD data.
        - Query and selection of attributes.

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