REPORT

In Situ Contaminated Sediments Project

Work Package 4A Report

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Table of Contents

Table of Tables

Appendices

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 national risk assessment approach. This process is intended ultimately to 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 the regulation and protection of water quality. This knowledge will enable these bodies to make evidence-based decisions for funding priorities 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.

Details of the project scope, definition of *in situ* contaminated sediments and project structure are provided in the Work Package 1A Report (Royal HaskoningDHV, 2015).

1.2 Objectives of Work Package 4A

Work Package 4A (WP4A) was initially intended to use the risk assessment methodology agreed in Work Package 3A (WP3A) to examine risk on a scale of significance of impact on the identified environmental management objectives (e.g. environmental protection, human health, etc.).

The outputs to the Hazard Screening exercise presented in the WP3A report were mainly qualitative and were considered not, at this stage, to be suitable for developing a methodology for prioritisation based on magnitude of exceedance or trigger levels. A further step would be needed in order to complete a full risk assessment for contaminated sediments. It is likely that any further risk assessment stage would need to be performed at a different scale to the hazard screening assessment (e.g. at water body or site scale).

The objectives to be addressed in WP4A, replacing those in the original brief are:

1. Refinement of the hazard screening assessment as outlined in **Section 1.3**, including separation of assessments for the two Biological Quality Elements and a less conservative approach to sediment quality guidelines (SQG) exceedance, in order to narrow down the number of areas in the highest hazard category.
2. Following refinement, selection of two areas in the highest hazard category. These would be chosen as indictors for validation of the national scale risk assessment for further study; that is, they would be representative of different situations (e.g. a coastal area and an upland freshwater area). The two areas would also be selected where it is known that site-specific data on risk from contaminated sediments are available. The data would be collated and assessed in order to inform the methodology for use in Work Package 5A Option 2 (should this be taken forward), which is intended to produce a contaminated sediments assessment and management tool for regulators to use 'on the ground'.

1.3 Recommendations from WP3A

For WP4A, the intention was that the trigger levels of risk at which action is required would be discussed with reference to trigger levels used in the risk assessment frameworks reviewed in WP3A. As part of the risk assessment methodology, the WFD principle of technical feasibility and disproportionate costs would need to be applied. Two tasks would be completed:

1. Identification of approaches to trigger levels, drawing from information collated and reviewed in WP3A.

2. Identification and presentation of potential options for trigger levels: The existing approaches to the application of trigger levels would be evaluated for their applicability for use in England (e.g. whether similar approaches have already been applied in England in other environmental contexts). An agreed preferred approach would be trialled by application to the WP3A mapping outputs.

The conclusions of WP3A have focussed WP4A on revisions to the National Hazard Screening Assessment due to significant data gaps including:

- Lack of available data sets (e.g. for historic contaminated areas, quality and substrate data for lake and reservoir sediments);
- Gaps within data sets (e.g. areas not currently covered by the British Geological Society's (BGS) G-Base sampling data and areas where the Biological Quality Elements are not currently classified under WFD);
- Lack of SQG and sediment quality data for a number of potential contaminants of concern (predominantly organic contaminants);
- Lack of consistency between sediment quality results (discussed in Work Package 1A); and
- Lack of information to link negative effects in WFD biological quality elements and designated habitat condition to sediment contamination.

This has led to a low confidence rating in the assessment of risks from historic contamination and the comparison of in-channel sediment concentrations with surface soil concentrations. Further information is needed to assess these areas in greater detail. WP4A is focussed on filling gaps in data and reducing uncertainty; and narrowing down the number of areas in the highest hazard category.

Proposed revisions to the National Hazard Screening Assessment include:

- Separate out the assessment of **WFD Biological Quality Element Classifications** and reassess using the individual elements;
- Include the **Industrial and Environmental Permitting Regulations (EPR)** records data, combined with the Defra Trading Estates project, and reassess Assessments 1 and 2 with this new information;
- Update Assessments 1 and 3 with newly licensed **G-Base data** to significantly increase the resolution of metals data that can be used to inform the assessments;
- Using expert judgement, assign **land adjacent to transitional waters** the WFD classification details of the transitional or coastal waters into which those unclassified areas drain. This should change the results of the assessment in the landward side of the coastal zone (areas of central London, isolated from the coast but in the Tidal Thames operational catchment, are also not associated with any river water bodies. These areas would also be assigned the characteristics of the adjacent transitional water body); and
- Re-run Assessment 1 with a less conservative approach through **Application of SQGs**. For example, multiple exceedances of the SQC_{upper} for different contaminants in a single sample could be required in order for the likelihood to be classified as 'high'.

1.4 Report structure

The WP4A report provides an update to the results and conclusions drawn in WP3A. To avoid repeating the results and conclusions of WP3A in this report, it is recommended that this report is read in conjunction with the WP3A report to enable comparison of the updated results.

WP4A Assessment 1, 2 and 3 results are reported in comparison to the WP3A results and therefore if no significant changes are identified from the updated results then no additional reporting is included herein.

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

- **Section 2**: National Hazard Screening Assessment update;
- **Section 3**: Re-testing and application of the Phase 1 National Hazard Screening Assessment Methodology;
- **Section 4**: Re-testing the influence of flood events and climate change;
- **Section 5**: Case studies; and
- **Section 6**: Conclusions and recommendations.

2 National Hazard Screening Assessment Update

2.1 Introduction

Several additional pollutant source data sets have been included in this revision of the hazard screening assessment, with the aim of narrowing down areas of potential concern from contamination in sediments. As in the first iteration of the assessment, undertaken in WP3A, areas with more identified potential sources of pollution are considered to have a greater likelihood of sediments becoming contaminated than those with fewer potential sources.

2.2 Additional Pollution Source Data Sets

2.2.1 Industrial and Environmental Permitting Regulations (EPR) data set

The first version of the assessment included the following potential pollutant sources:

- Discharge consents;
- Urban areas; and
- Mining.

Table 3.7 in the WP3A report details how each of these pollutant sources has been categorised for a given location in terms of the likelihood of pollution, and how they have been combined to produce an overall hazard level.

In this report, scales of likelihood of pollution have been applied to the following data sets to refine the assessment:

- Trading estates (see **Table 2.1**);
- Landfill sites (see **Table 2.2**); and
- Environmental Permit Compliance (see **Table 2.3**).

Table 2.1 Likelihood – pollutant sources (trading estates)

Category	Likelihood Example Definitions
High	Worst case trading estate scores 100 – 125
Medium	Worst case trading estate scores 75 – 99.5
Low	Worst case trading estate scores 50 – 74.5
Very Low	Worst case trading estate scores 25 – 49.5
Remote	Worst case trading estate scores < 25 or no trading estate

Table 2.2 Likelihood – pollutant sources (landfill sites)

Category	Likelihood Example Definitions
High	Multiple historic landfills < 250m from watercourse
Medium	Historic landfill < 250m from watercourse
Low	Only currently authorised landfills < 250m from watercourse
Very Low	Landfill present but > 250m from watercourse
Remote	No landfills present

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Table 2.3 Likelihood – pollutant sources (Environmental Permit compliance)

Category	Likelihood Example Definitions
High	Permitted installations present which score 1 – 2 stars
Medium	All permitted installations score 3 stars or above
Low	All permitted installations score 4 stars or above
Very Low	All permitted installations score 6 stars
Remote	No permitted installations present

2.2.2 Potential overlap and double counting of additional pollution source data sets

It is acknowledged that there is likely to be overlap and, therefore, an element of double counting of potential pollution sources in the assessment if all of these data sets are included with equal weighting. For example:

Discharge consents

- Urban areas are likely to contain a large number of sites for which discharge consents are held.
- Many authorised landfill sites are likely to hold discharge consents, for example, for treated leachates. However, discharges from the majority of historic landfills are unlikely to be regulated in this way, particularly for non-engineered landfills where discharged may comprise diffuse leaching into groundwater and shallow surface water.
- The vast majority of installations regulated using an Environmental Permit will have a discharge consent for any discharges made to water.
- There are likely to be discharge consents associated with ongoing mining activities and some closed mines which are being actively managed; however, many orphaned historical mines may not have discharge consents although they may still discharge to surface water courses through adits.
- Many trading estates may have businesses which hold discharge consents; however, many other estates may not have consented discharges.

Environmental Permits

- Trading estates may have some businesses which are regulated using Environmental Permits; however, many of the small businesses on trading estates are unlikely to fall under the Environmental Permitting Regulations.
- Authorised landfill sites are regulated using Environmental Permits; however, historic landfill sites will not have an associated permit.

The relationships and potential overlaps between pollution source data sets are summarised in **Figure 2.1**. The greatest degree of overlap is with the consented discharges data set. If this were to be removed from the assessment, the amount of identified double counting would be much reduced (**Figure 2.2**). However, there are expected to be a large number of potentially polluting discharges which are not captured by the remaining data sets. These include:

- Domestic sewage discharges (e.g. from cess pits, septic tanks and domestic sewage treatment plant) if these meet the relevant General Binding Rules.
- Water company sewage treatment works discharges.

- Trade effluent discharges such as from hotels, garden centres, golf courses and restaurants which are not in urban areas.
- Discharges from military sites where no Environmental Permit is held.

Due to the potential for significant numbers of discharges to be excluded from the assessment, the discharge consent data set has not been removed.

Figure 2.1 Expected overlap of pollutant source data sets

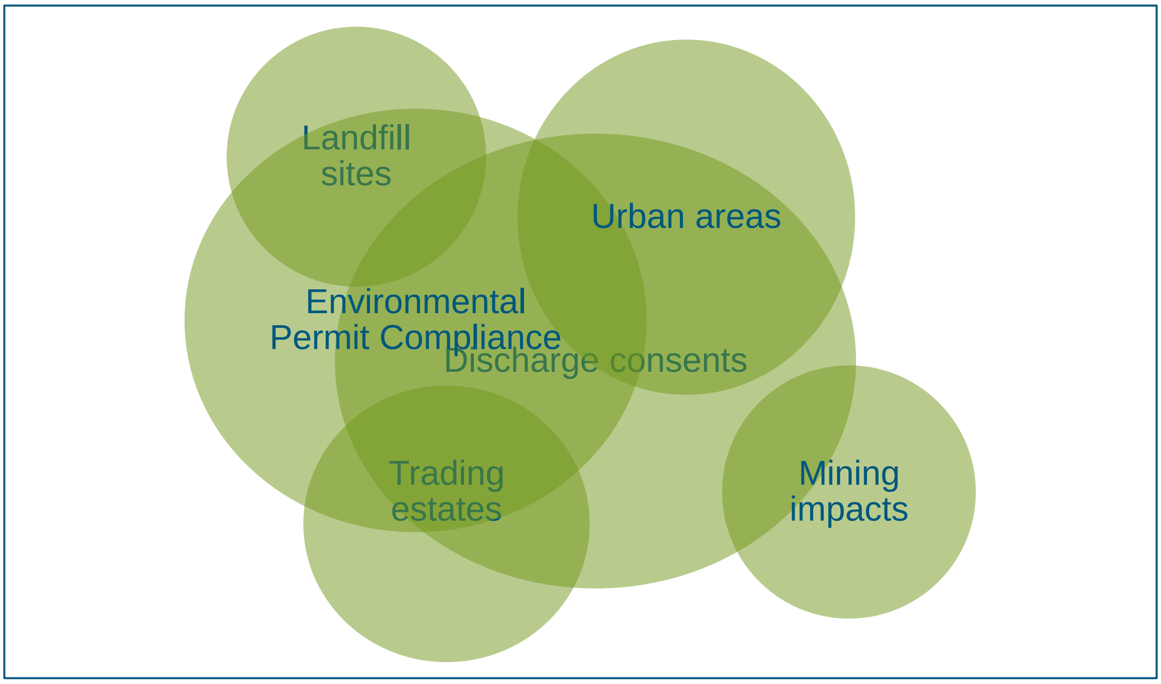
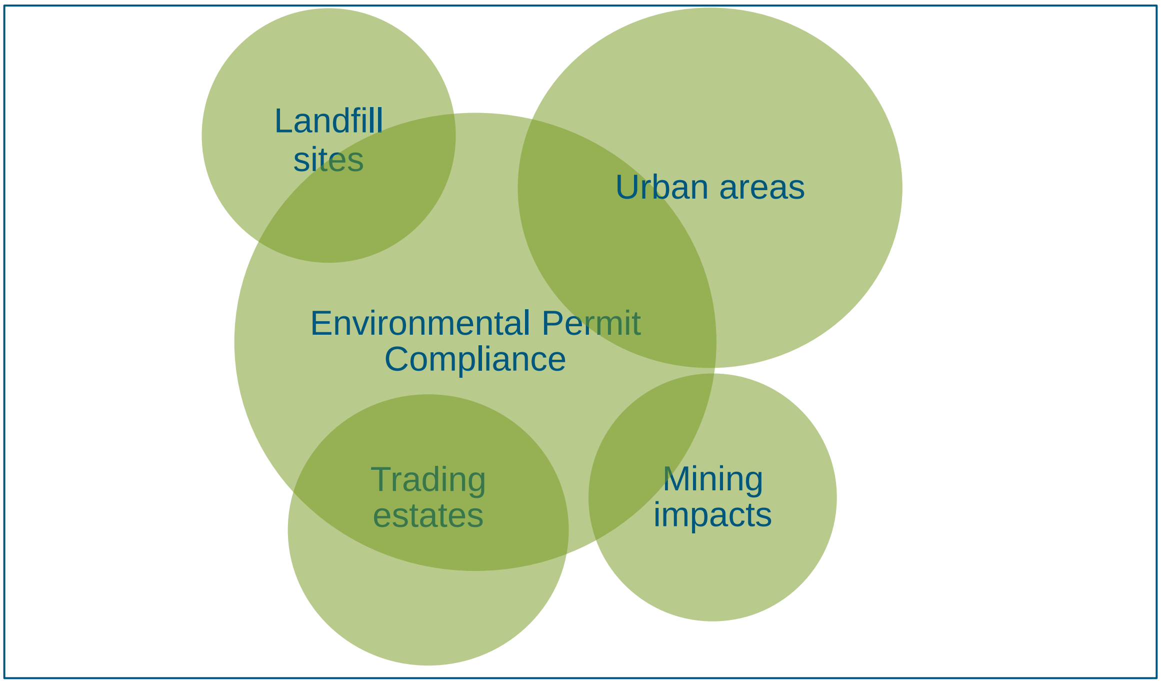


Figure 2.2 Overlap of pollutant source data sets with removal of discharge consents



2.2.3 Additional pollution source data sets not included in the assessment

Contaminated land sites that are not classified as historic landfills, or mining sites, do not have an environmental permit, are not on a trading estate and do not fall within an urban area have not been identified in this assessment. This could include, for example, a historic factory site in a rural location. Contaminated land information is not held nationally, so it has not been possible to obtain a data set for this on the national scale. In addition, any such data set would be likely to overlap significantly with those described in **Section 2.2** above.

2.3 Updated G-Base Data

BGS provided an updated data set to Defra, which was provided for inclusion to this project on 14 April 2016.

WP3A separated out the assessment of hazards arising from ongoing and historic sediment deposition due to historical (e.g. mining) contamination although the floodplain may now be protected from new contaminated sediment input. However, there may be ongoing hazards from sediment contamination in floodplains in certain areas and this update provides a further step in considering this.

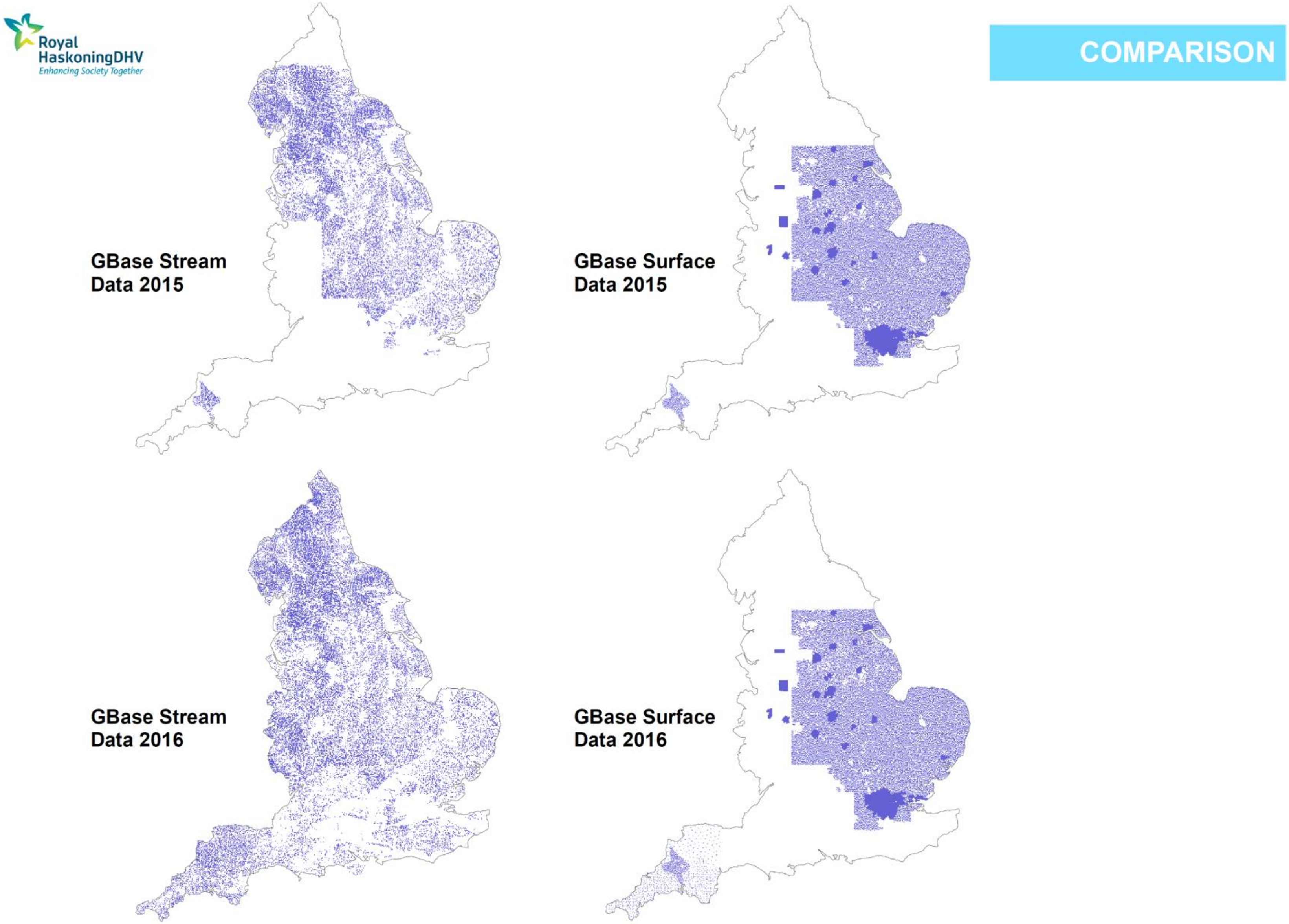
Figure 2.3 displays a comparison of the increased coverage of the update G-Base data set compared to the previous exercise in WP3A.

The coverage as displayed in **Figure 2.3** demonstrates that there is a still a lack of suitable identified data sets to complete a full assessment. This report has updated the comparison of mean concentration in the in-channel sediments against the mean concentration in surface soils to establish whether an influx of sediments will increase the metal concentrations in the floodplain soils.

It is noted that the G-Base data is available only for metals and only for some catchments in England. Although the coverage has improved for the updated data set, this improvement of coverage is predominantly for catchments in south-west England (Cornwall, Devon and Somerset) but significantly increases the resolution of metals data that can be used to inform these assessments.

The results of the updated G-Base data are presented in Assessment 1 and 3 (**Section 3.2** and **Section 3.4**).

Figure 2.3 **Update G-Base data set coverage**

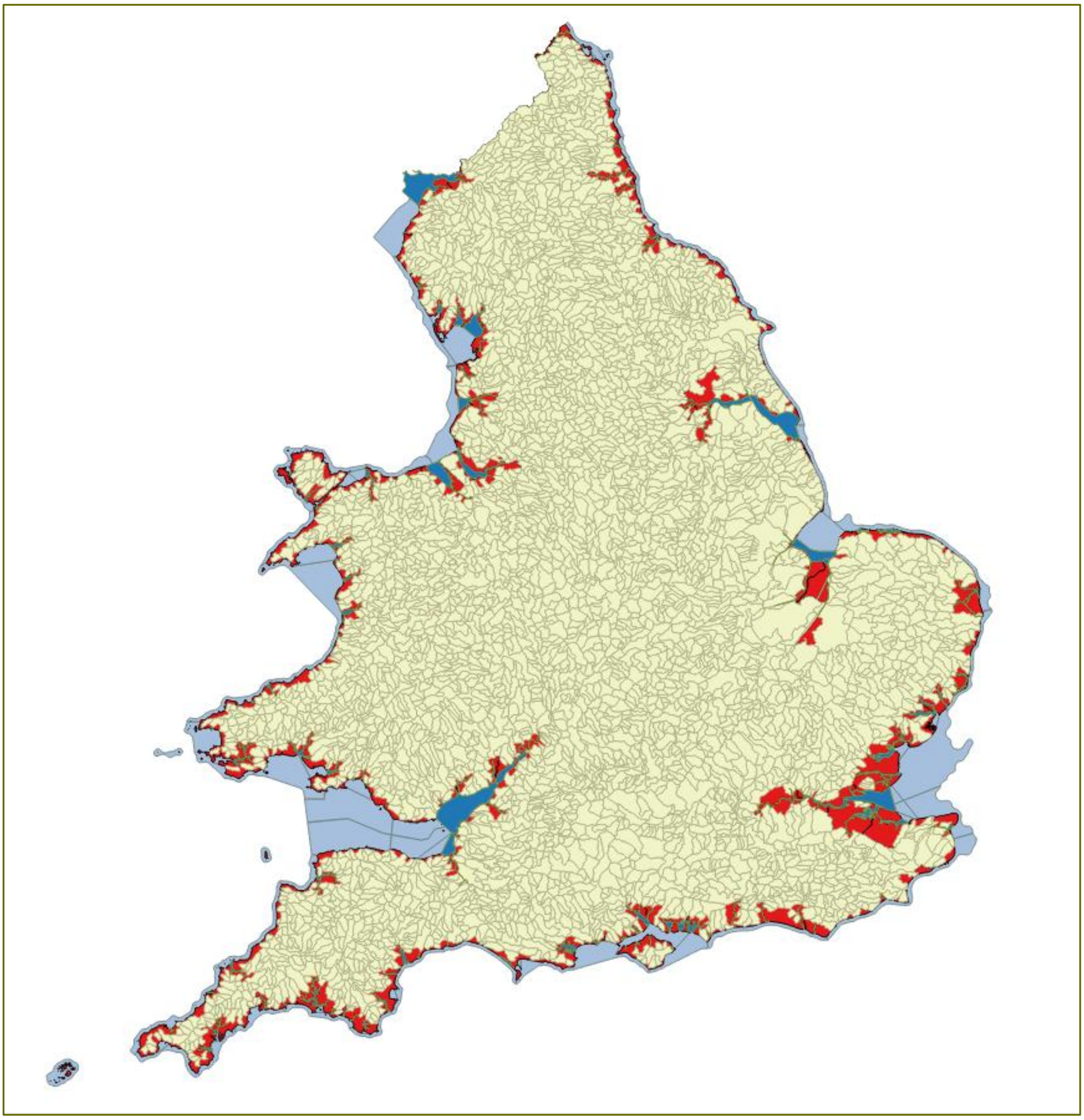


2.4 Reclassification of land adjacent to transitional waters

The revisions in the second River Basin Management Plan (RBMP2) created coastal areas that fringe the coastal zone that are no longer considered to be river water bodies. Although these areas are included in the Environment Agency's management catchments and the smaller operational catchments, they have not been assigned any classification data in the RBMP2 shapefiles because they are no longer located within a river water body.

These areas are shaded in red in **Figure 2.4** (with river water bodies in pale yellow, transitional water bodies in dark blue and coastal water bodies in pale blue).

Figure 2.4 Unclassified areas in England and Wales (source: Environment Agency RBMP2 shape files)



These areas do not include any water body classification data (e.g. for fish and micro invertebrates), and therefore were assigned a low consequence of contamination in Assessment 1 in WP3A. This means that they were also assigned a low level of hazard from in situ contaminated sediments. It was decided in WP3A that this was not an accurate reflection of the level of hazard that would be expected; for example, several of these areas are adjacent to river, transitional and coastal water bodies that have all been classified as having a high level of hazard.

2.4.1 WP4A update

The unclassified areas that contain low gradient watercourses and coastal marsh systems have been assigned the WFD classification details of the transitional or coastal water into which they drain. In the instances where more than one water body is connected, expert judgement has identified which water body characteristics should be assigned. A new shapefile has been generated using the outlines of the river water bodies and transitional and coastal water bodies.

A set of rules was established for assigning water body characteristics:

1. If a transitional water body is present in the unclassified area then that area is assigned the same water body characteristics as the transitional water body;
2. If more than one transitional water body is present in the unclassified area then that area is assigned the transitional water body characteristics of the water body with the longest connecting boundary;
3. If no transitional water body is present in the unclassified area then that area is assigned the water body characteristics of its adjacent coastal water body; and
4. If no coastal or transitional water body is adjacent to an unclassified area then this is likely a mistake in the mapping of the WFD RBMP2 catchments and requires closer scrutiny.

The WFD RBMP2 data has reassigned these unclassified areas for the rerunning of Assessment 1 and the Flood & Climate Change Analysis. The updated results are discussed in **Section 3.2** and **Chapter 4**.

2.4.2 Additional reclassifications

In addition, areas of central London isolated from the coast but in the Tidal Thames operational catchment have also been assigned the characteristics of the adjacent transitional water body. Similarly, the small unclassified catchment south of the Wash in East Anglia, between the Old Bedford and Middle Level and Cam and Ely Ouse catchments has been assigned the WFD classification of the adjacent Old West River and/or Ely Ouse (South Level) water bodies.

2.5 Application of SQGs

SQGs were applied in WP3A (Section 3.2.1) as a contributory part in a 'weight of evidence' approach to assessing potential hazards from contaminated sediments. **Table 2.4** summarises the proposed likelihood categories using sediment type and SQG exceedance.

Table 2.4 WP3A likelihood sediment type / sediment quality data

Likelihood level	Likelihood description
High	Fine sediment present in all/nearly all of water body and concentrations confirmed by any sediment quality concentrations* greater than SQG_{upper}
Medium	Fine sediment present in over half the water body area and concentrations confirmed by any sediment quality test results* being between SQG_{lower} and SQG_{upper}
Low	Some fine sediment present but majority of substrate coarse grained, any sediment quality concentrations* between SQG_{lower} and SQG_{upper}
Very Low	Substrate all/nearly all coarse grained, contaminant concentrations not confirmed by data

* Assessment of reliability of sediment quality test results would be based on professional judgement

The approach in WP3A was highly conservative, highlighting as 'higher hazard' areas those where there is a single exceedance of a SQG_{upper} level for any contaminant. This resulted in a large number of assessment grid squares across the country being classified as having 'potentially unacceptable hazards'.

The updated Assessment 1 in WP4A has been re-run with a less conservative approach to identify more specific areas for focus. To do this, for the likelihood to be classified as 'High' then areas must have **three** exceedances of the SQG_{upper} for differing contaminants in a single sample.

The selection of exceedances reduces the highly conservative nature of the assessment. The upper limit of three exceedances was discussed and agreed with the project board during the teleconference on 10th March 2016.

Table 2.5 WP4A likelihood sediment type / sediment quality data

Likelihood level	Likelihood description
High	Fine sediment present in all/nearly all of water body and concentrations confirmed by **at least three** sediment quality concentrations* greater than SQG_{upper}
Medium	Fine sediment present in over half the water body area and concentrations confirmed by any sediment quality test results* being between SQG_{lower} and SQG_{upper}
Low	Some fine sediment present but majority of substrate coarse grained, any sediment quality concentrations* between SQG_{lower} and SQG_{upper}
Very Low	Substrate all/nearly all coarse grained, contaminant concentrations not confirmed by data

* Assessment of reliability of sediment quality test results would be based on professional judgement

The suggested SQCs for aquatic receptors and for PAH compounds remain the same as per WP3A.

2.6 WFD Biological Quality Element Classifications

The WP3A Assessment 1 was carried out using combined classification information for two WFD Biological Quality Elements. These were considered to have the greatest potential at risk from contamination in sediments: benthic invertebrates and fish.

The WP4A assessment is carried out using these two classifications individually. This has provided greater clarity on potential indications of biological effects from contaminated sediments.

Two sets of results are produced following this update:

- Worst case of fish classification and designated habitat condition; and
- Worst case of benthic invertebrates and designated habitat condition.

Results of Assessment 1 are presented in **Section 3.2**.

2.7 Refinement of Assessment 3 (floodplain assessment)

Following the update of G-Base data (**Section 2.3**), it is possible to refine the floodplain assessment undertaken in WP3A Assessment 3.

For this exercise, the BGS G-Base Stream (in-channel) and Surface Soil (out of channel) data sets were used. This enabled comparison of contaminants observed in in-channel and out of channel sediments within the assessment grid squares in order to gauge whether sediments washed out of watercourses and onto nearby land increased contaminant concentrations on surface deposits.

As per WP3A, the WP4A assessment has been restricted to metal contaminants and has used the following eight metals:

- Arsenic;
- Cadmium;
- Chromium;
- Copper;
- Lead;
- Nickel;
- Silver; and
- Zinc.

Despite the update, the spatial coverage of the two data sets is incomplete and the two data sets are not coincident in large parts of the country. This means that the comparison is only possible for certain regions of England (Central and East Midlands, extending to north of the Humber, East Anglia and the South West). Accordingly, all other areas have been excluded from the WP4A assessment.

Refinement of the WP4A assessment has focussed on the comparison between the in-channel and out of channel data sets. Categorisation of high, medium and low hazard categories was mapped to Flood Zone (1 in 100 year events).

Table 2.6 WP4A likelihood sediment type / sediment quality data

Hazard level	Ratio description
High	Stream concentration ten times **greater** than surface soil concentration (i.e. >10:1)
Moderate	Stream concentration between ten times greater and ten times less than surface soil concentration(i.e. between <10:1 and >1:10)
Low	Stream concentration ten times **less** than surface soil concentration (i.e. <1:10)

Ratios of ten were used to identify those areas where in-situ contaminants carry the greatest potential to deposit on to the floodplain. This ratio was discussed as an appropriate starting point for testing of the assessment sensitivity at the board meeting on 10th March 2016. The ratio can be reviewed upon interpretation of the results. Results for the comparison are presented in **Section 3.4**.

3 Re-Testing and Application of the National Hazard Screening Assessment

3.1 Introduction

As outlined in **Section 1.3**, the WP3A assessment recommended updates to the National Hazard Screening Assessment to identify the following:

- Areas of lowest concern, for which further action is considered to be a low priority;
- Those areas with a high level of uncertainty associated with the potential hazards from sediment contamination; and
- Areas with a potentially unacceptable hazard level.

Therefore, the WP4A assessment is divided into three parts:

1. Assessment of potential hazards to aquatic receptors from in-channel sediment contamination (see **Section 3.2**);
2. Assessment of potential hazards arising from the erosion of buried historic contaminated sediments as a result of climate change (see **Section 3.3**); and
3. Assessment of potential hazards to floodplain receptors (see **Section 3.4**).

As per the WP3A assessment, the WP4A assessment is performed on a 1km x 1km grid. The assumptions and methodology for the WP4A assessment remain the same as WP3A assessment, bar the amendments as outlined in **Chapter 2**.

For the purposes of this report, the results focus on differences between the WP3A assessment results and the WP4A assessment results.

3.2 Assessment 1

3.2.1 Purpose of the assessment

Assessment 1 focuses on risk to aquatic receptors from in-channel sediments. This assessment brings together potential sources of contamination in sediments with information on the nature of the sediment.

The results of the updated WP4A assessment are compared to the previous WP3A results in the subsequent sections.

3.2.2 Pollutant sources

There are no significant changes to the pollutant sources as mapped in WP3A following the updates. This refers to urban areas; discharge consents; and mines and mineralisation (**Appendix A Pollutant Source: Urban Areas**, **Pollutant Source: Discharge Consents**, and **Pollutant Source: Mines** maps).

The WP4A exercise considered three additional potential sources of sediment-associated contaminants: landfills (including currently permitted and historic landfills), trading estates and EPR compliance.

A large proportion of England has no landfill present within 250m of a WFD surface water body (**Appendix A Pollutant Source: Landfill**). Areas with multiple historic landfills or historic landfills within less than 250m of a WFD river water body are concentrated in south east England (particularly London and the Home Counties), the West Midlands (around Birmingham), the north west (including Liverpool, Manchester, Leeds and Sheffield) and the north east (including Newcastle-upon-Tyne and Middlesbrough). The map for landfills correlates closely to the map for Pollutant Source: Urban Areas map, suggesting a strong relationship between these two pollutant sources. This is probably because landfills are frequently located close to the urban centres in which waste is generated.

The majority of England has a worst case trading estate score of less than 25 or no trading estates present (**Appendix A Pollutant Source: Trading Estates**). There are minimal instances of a worst case trading estate score of 75 or above. The highest instance occurrences are in the north west (Liverpool and Manchester). Medium and low densities of trading estate scores of more than 25 do not appear to be localised, although there are greater densities around the urban areas as identified in the Pollutant Source: Urban Areas map, suggesting a potential relationship between these two pollutant sources

Again, a large proportion of England has no permitted installations present (**Appendix A Pollutant Source: EPR Compliance**). Instances of permitted installations that score 3 or fewer stars are dispersed across medium and low densities, with some localisation of greater densities in the south east, West Midlands, north west and north east regions. This suggests an unlikely relationship between pollutant sources from urban areas (**Appendix A Pollutant Source: Urban Areas**) and EPR compliance, as also shown in the landfill mapping (**Appendix A Pollutant Source: Landfill**).

3.2.3 Sediment quality

The updated SQG categorisations and coverage provide a better output for the WP4A assessment than for the WP3A assessment (**Appendix A Sediment Quality map**). The large parts of England that previously did not have data now have coverage, and this reinforces that areas seem to have at least one sediment quality concentration that is greater than the lower sediment quality guideline limit. Areas that have at least three sediment quality concentrations in excess of the upper guideline limits are distributed across the country but are prevalent in the Lake District, Lancashire, around Birmingham and across the West Midlands, and in the south west. These are areas closely associated with mineralisation and heavy mining, with the areas around Birmingham and the West Midlands also tied closely to urbanisation. A significant difference from the WP3A assessment mapping is the heavy density band of sediment quality concentrations in excess of the upper guideline limits to the north of the River Thames. This band of upper exceedances correlates closely with the urban areas and landfill maps.

Overall, although the WP4A assessment includes updated SQG categorisations and coverage, its results in both the freshwater and coastal environments do not differ significantly from the results generated by the WP3A assessment.

3.2.4 Overall likelihood of contamination

Under the WP4A assessment, the overall likelihood of contamination (**Appendix A Overall Likelihood** map) is defined by co-occurrence of likely hazards arising from the maps of substrate type (**Appendix A Substrate**), sediment quality (**Appendix A Sediment Quality**) and combined pollutant source (**Appendix A Pollutant Source**).

The resulting overall likelihood maps for the WP4A assessment differ significantly from the equivalent maps for the WP3A assessment.

The maps for the WP4A assessment identify relatively few areas of high likelihood of contamination compared to the maps for the WP3A assessment, which identify large areas of high likelihood across England.

In addition, the maps for the WP4A assessment identify areas as:

- Areas of predominantly remote or very low likelihood in the freshwater environment and in less urbanised areas;
- Areas of predominantly low likelihood in urban areas;

- Localised areas of medium or high likelihood in Milton Keynes and north London, respectively; and
- Localised areas as high likelihood, which are predominantly in coastal areas mainly associated with ports and estuaries such as Falmouth, Plymouth, Teignmouth, Poole, Lymington, Southampton, Portsmouth, the Thames Estuary, Harwich and Felixstowe, the Humber, Tees, Tyne and Mersey estuaries.

Despite the significant updates to the mapping regarding the overall increased likelihood across England, the overall trends regarding which areas are of most significance remain from WP3A.

3.2.5 Overall consequence of contamination

Under the WP4A assessment, the overall consequence of contamination (**Appendix A Overall Consequence** map) is defined by the worst case benthic invertebrate and fish classification (**Appendix A Benthic Invertebrates** & **Appendix A Fish** map) and condition of designated habitats (**Appendix A Environmental Designations** map). The overall consequence therefore represents the lowest of the WFD classifications and designated site conditions.

The WP4A assessment includes individual assessments of the consequences of contamination for fish and benthic invertebrates, and thereby provides more detail on the principal areas of concern. Nevertheless, the consequences of contamination still increase as WFD status decreases. Areas of higher consequence for fish (medium – severe) are distributed throughout the country, with areas focussed around London, Suffolk, the Lake District and Peak District, East Yorkshire, Lancashire, Humberside and the north east. Areas of higher consequence for benthic invertebrates are more clearly defined with areas focussed around London, Berkshire, Norfolk, Birmingham, Liverpool, Manchester, Leeds, the Humber and the north east.

In the coastal environment, the consequences of contamination for fish are negligible, as would be expected, and the consequences for benthic invertebrates are high (medium – severe) along the Lincolnshire and South Humberside, Mersey, Exmouth and North Devon coastlines. No areas of coastline were classified as severe.

3.2.6 Overall hazard

Under the WP4A assessment, the overall hazard associated with each grid square (**Appendix A Overall Hazard** map) is a product of the overall likelihood and the overall consequence: the hazard increases as likelihood and consequence increase.

The WP4A assessment finds that the majority of England falls into a low overall hazard (i.e. potentially acceptable hazard level). Also, the WP4A assessment finds very few areas of high overall hazard (i.e. potentially unacceptable hazard level), which differs from the WP3A assessment's findings. For fish, the areas of high overall hazard are:

- Near Tehidy, North Cornwall;
- Southampton Harbour;
- North and north east London;
- South west of Shrewsbury;
- Liverpool Estuary; and
- Humber Estuary.

For benthic invertebrates, the areas of high overall hazard are:

- Near Tehidy, North Cornwall;

- North London;
- Norfolk Broads;
- Liverpool Estuary;
- Humber Estuary; and
- York.

In order to focus the WP4A assessment on aquatic receptors in individual water bodies, the results are shown on the **Assessment 1 Overall Hazard within Flood Zone 3** map in **Appendix B** only for land within Flood Zone 3. Land within Flood Zone 3 is defined by the Environment Agency as being at 'high risk 'of flooding and, therefore, is most closely associated with the adjacent water body.

The WP4A assessment finds very few numbers of water bodies lying in high overall hazard areas. This finding correlates closely with the Overall Hazard map, and represents a significant change from the WP3A assessment's Overall Hazard map. It is believed that the increased coverage of the BGS G-Base stream data gives extra confidence to the WP4A assessment's findings compared to the WP3A assessment's findings.

3.3 Assessment 2

3.3.1 Purpose of the assessment

This assessment focused on potential hazards from historic buried contaminants being mobilised by higher rainfall, sea level rise and storm surges predicted by current climate change modelling (provided by the UKCP09 project).

The results of the updated WP4A Assessment 2 are compared to the previous WP3A results in the subsequent sections.

3.3.2 Overall likelihood of contamination

There are no significant differences between the Coastal Erosion Risk and Fluvial Erosion Risk maps in WP3A and WP4A. However, the updates have altered the overall likelihood across England. Areas are mostly downgraded in their likelihood between the WP3A results and WP4A results, where the majority is now classified as 'remote'. Areas of 'high' likelihood are now isolated in Leeds, the Mersey (Liverpool) Estuary, the Severn Estuary, north London, Berkshire and south west Birmingham (**Appendix C Overall Likelihood**). In WP3A, these typically related to areas of medium erosion risk but high likelihood of pollutant sources as a result of urban pollution. Similar clusters of Cornwall and the northern Pennines combine medium erosion risk with a high likelihood of mining-related pollutants.

3.3.3 Overall consequence of contamination

There are no significant differences between the Consequence (Fluvial) and Consequence (Coastal) maps for WP3A and WP4A (**Appendix C Consequence (Fluvial)** and **Appendix C Consequence (Coastal)** maps).

As per WP3A, the highest levels of consequence in the freshwater environment are shown mainly to be in the west of England, the south of England and London. Only two significant areas of severe consequence were highlighted by this exercise: one between the Torridge and Taw estuaries near Barnstaple in north Devon, and one between the Rivers Tyne and Wear in the Jarrow/Sunderland area. Additional smaller areas were also highlighted, for example in the centres of Birmingham and Bristol.

No areas of coastline were classified at the 'severe' consequence level; however, the majority of south west coast (reaching as far as Gloucestershire and Hampshire, with the western coast of the Isle of

Wight also included) were classified at the 'medium' consequence level. The eastern coast and north west coast we classified as the 'negligible' or 'minor' consequence level.

3.3.4 Overall hazard

The lowering of the likelihood classifications for contamination in WP4A has affected the overall hazard maps (**Appendix C Overall Hazard**) by similarly reducing the classifications compared to WP3A. Areas with high levels of urbanisation or significant mining influence are at the medium (uncertain) hazard levels. There are no areas with the highest hazard level.

As per WP3A, areas of potentially unacceptable hazard level are restricted to individual stretches of river (**Appendix C Assessment 2 Overall Hazard within Flood Zone 3** map). Potentially acceptable levels are prevalent along large parts of the coast, with medium hazard levels in those areas identified in WP3A (south coast (from Dungeness in the east to Paignton in the west) plus the north coast of Devon, Felixstowe, the Severn and Medway estuaries and parts of the south west, north west and north east).

3.4 Assessment 3

3.4.1 Purpose of this assessment

Concentrations of contaminants observed in in-channel and out of channel sediments have been compared within the assessment grid squares, in order to gauge whether sediments washed out of watercourses and onto nearby land are likely to increase contaminant concentrations in the surface deposits. Those grid squares where the concentration of stream contaminants is ten times the ratio of the soils contaminants provides an indication of those areas where there is the greatest risk of in situ sediment spreading to the floodplain.

As per WP3A, the use of the G-Base data set has restricted the comparison to metals only (no organic contaminants were analysed for). The comparison has been made using eight metals: arsenic, cadmium, chromium, copper, lead, nickel, silver and zinc.

The results of the updated WP4A assessment are compared to the previous WP3A results in the subsequent sections.

3.4.2 Spatial coverage

The updated Gbase data is still an incomplete picture of England (see **Figure 2.3**), particularly regarding the soils data, although the stream data has significantly increased coverage. As per WP3A, the comparison is only possible for certain regions of England (Central and East Midlands, extending to north of the Humber, East Anglia and one area of the South West).

3.4.3 Results of concentration comparison

The results for arsenic show no clear trend (as per WP3A) although there are greater concentrations in East Anglia and around Yorkshire / central Midlands. These identified areas were discussed in WP3A where stream concentration were higher than soil concentrations. Lead mapping had a similar lack of trends with areas of higher concentration in East Anglia and west Midlands.

Cadmium concentrations are quite localised though central Midlands, the north west, northern East Anglia and across the south west. It is noted that there is also a balance of soil sediment concentrations of cadmium having a much greater ratio than the stream concentration in the Tamar catchment. This may be a result of the historic mining in the region. Results for copper, lead and nickel follow a similar distribution as cadmium.

Chromium concentrations are minimal, with only two localised instances in south west London and near Doncaster.

Zinc concentrations show no clear trend but are localised in a similar way to cadmium, copper, lead and nickel results but with increased coverage in those areas and also localised distributions of higher concentrations in north and west London, Berkshire and across south Yorkshire.

Results for silver are distributed more evenly than the other metals for instances of high concentrations. As noted in WP3A, there is a clear divide between the Midlands and South Yorkshire region and the south west that has a reversal of concentrations. WP3A noted that this is likely a result of methods of data gathering and on this basis the results for silver are considered to remain unreliable.

4 Re-testing the Influence of Flood Events and Climate Change

The individual assessments of the water body characteristics in Assessment 1 for fish and benthic invertebrates creates two separate assessments for looking at the likely implications of climate change effects on *in situ* contaminated sediments for aquatic receptors (**Appendix F Influence of Climate Change (Benthic Invertebrates)** and **Appendix F Influence of Climate Change (Fish)** maps).

Despite having results for these two assessments, when focussed on land within Flood Zone 3 at the national scale (**Appendix F Influence of Climate Change in Flood Zone 3 (Fish) & (Benthic Invertebrates)** maps) the split assessments show similar trends in the results. There are potentially stronger influence areas in the north of England, particularly towards the north east and north west coasts, also in isolated inland areas in central England – related to upland areas – and areas in the south near the North and South Downs, and some areas in the south west. The trends identified in the WP4A assessment are not significantly different from those as identified in the WP3A assessment.

5 Case Studies

5.1 Purpose of catchment-scale testing

Two areas have been selected for analysis based on their differing characteristics (i.e. upland freshwater in the north east of England and lowland coastal in the south west of England). The chosen catchments are the Upper Swale in North Yorkshire and the Lower Tamar on the border of Cornwall and Devon.

The purpose of these case studies is to test the National Hazard Screening Assessments against areas where on-the-ground knowledge is available to ensure that the assessments are considering the appropriate triggers and data sources. The catchment-scale testing enables conclusions on the validity and further recommendations for the utilisation and updates / amendments required to ensure the assessments are applicable as a tool.

5.2 The River Swale catchment

The River Swale is the northernmost tributary of the River Ouse, and is located in North Yorkshire. The river rises in the Yorkshire Dales, from where it flows eastwards. The river passes through the major settlements of Richmond and Catterick, downstream of which it flows southwards before joining the River Ure and subsequently the Ouse in the Vale of York. The catchment is largely rural in nature, with pastoral agriculture dominating the upper catchment and arable agriculture becoming more widespread in the lower parts of the catchment.

The upper parts of the Swale catchment are underlain by a series of Carboniferous limestones and sandstones which make up the Askrigg Block formation. The rocks of the Askrigg Block are heavily mineralised with fluorite (CaF_2) and barite ($BaSO_4$) and associated metalliferous minerals such as galena (PbS) and sphalerite (ZnS). As a result of this extensive mineralisation, the upper catchment has a long history of metalliferous mining (largely for lead). Mining commenced at some point before the Roman period, and emerged as a significant industry by the late eighteenth century. Available records suggest that at least 550,000 tonnes of lead ores were extracted.

The lead ores were processed (dressed, crushed and smelted) at surface sites that were typically adjacent to watercourses. This was a relatively inefficient process (with maximum recovery of lead estimated to be between 60-70%), resulting in widespread contamination of sediments in the catchment. Indeed, detailed geochemical investigations have reported extensive contamination of in-channel and floodplain sediments throughout the upper Swale catchment, including the main river corridor and tributaries such as Gunnerside Beck and Barney Beck (e.g. Dennis et al., 2003; Dennis, 2005; Dennis et al., 2009). These sediments contain high concentrations of sediment-associated lead, zinc and cadmium, which occur generally occur as particulates or absorbed onto the surface of sediment particles.

5.2.1 Current state of the environment

This case study is focussed on the intensively mined upper Swale catchment, which is located in the Upper Swale operational catchment. The operational catchment is divided into fourteen separate water bodies, which make up the main River Swale and its tributaries (**Appendix G Catchment Status** and **Table 5.1**). According to the most recent water body classification data presented on the Environment Agency's Catchment Data Explorer (Environment Agency, 2016), contamination from historical metal mining is at least partly responsible for five water bodies in the upper catchment failing to reach Good Ecological Status:

Table 5.1 Status of river water bodies in the Upper Swale operational catchment (water bodies failing due to mining pressures highlighted in bold)

Water body	Water body ID	Overall water body status	Failing elements (and status)	Reasons for failure	Description
Arkle Beck from Source to River Swale	**GB104027069170**	**Moderate**	Fish (Moderate)	Barriers to fish migration	No sector responsible
			Zinc (Moderate)	**Abandoned mine**	**Non-coal mining**
			Cadmium and its Compounds (Fail)	**Abandoned mine**	**Non-coal mining**
Barney Bk/Hard Level Gill from Source to R Swale	**GB104027069080**	**Moderate**	**Zinc (Moderate)**	**Abandoned mine**	**Non-coal mining**
			Cadmium and its Compounds (Fail)	**Abandoned mine**	**Non-coal mining**
			Lead and its Compounds (Fail)	**Abandoned mine**	**Non-coal mining**
Birkdale Beck from Source to River Swale	GB104027069110	Moderate	pH (Moderate)	Other (not in list)	Agriculture and rural land management
Gill Beck/Black Beck from Source to River Swale	GB104027068980	Poor	Macrophytes and Phytobenthos Combined (Moderate)	Sewage discharge (continuous)	Domestic General Public
			Dissolved oxygen (Moderate)	Unknown (pending investigation)	Sector under investigation
Great Sleddale Beck from Source to River Swale	GB104027069040	Good	-	-	-
Gunnerside Beck from Source to River Swale	**GB104027069090**	**Moderate**	**Invertebrates (Moderate)**	**Abandoned mine**	**Non-coal mining**
			Zinc (Moderate)	**Abandoned mine**	**Non-coal mining**
			Cadmium and its Compounds (Fail)	**Abandoned mine**	**Non-coal mining**

Water body	Water body ID	Overall water body status	Failing elements (and status)	Reasons for failure	Description
			Lead and its Compounds (Fail)	**Abandoned mine**	**Non-coal mining**
Marske Beck from Source to River Swale	**GB104027069140**	**Moderate**	Dissolved oxygen (Moderate)	Unknown (pending investigation)	Sector under investigation
			Zinc (Moderate)	**Abandoned mine**	**Non-coal mining**
			Cadmium and its Compounds (Fail)	**Abandoned mine**	**Non-coal mining**
			Lead and its Compounds (Fail)	**Abandoned mine**	**Non-coal mining**
Muker Beck Catchment from Source to River Swale	GB104027069030	Good	-	-	-
Stonesdale Bk from Source to River Swale	GB104027069150	Poor	Hydrological Regime (Does not support good)	N/A	N/A
Swale Birkdale/Gt Sleddale Bks to Whitsundale Bk	GB104027069050	Good	-	-	-
Swale from Muker Beck to Clapgate Beck	**GB104027069121**	**Moderate**	Dissolved oxygen (Moderate)	Unknown (pending investigation)	Sector under investigation
			Zinc (Moderate)	**Abandoned mine**	**Non-coal mining**
			Cadmium and its Compounds (Fail)	**Abandoned mine**	**Non-coal mining**
Swale from Stonesdale Bk tp Muker Bk	GB104027069100	Good	-	-	-
Swale from Whitsundale Bk to	GB104027069070	Moderate	Dissolved oxygen	Unknown (pending	Sector under

Water body	Water body ID	Overall water body status	Failing elements (and status)	Reasons for failure	Description
Stonesdale Bk			(Moderate)	investigation)	investigation
Whitsundale Beck from Source to River Swale	GB104027069130	Moderate	pH (Moderate)	Natural conditions – other	N/A

- GB104027069170: Arkle Beck from source to River Swale.
- GB104027069080: Barney Beck / Hard Level Gill from source to River Swale.
- GB104027069090: Gunnerside Gill from source to River Swale.
- GB104027069140: Marske Beck from source to River Swale.
- GB104027069121: River Swale from Muker Beck to Clapgate Gill.

The majority of these failures are for physico-chemistry (Specific Pollutants: zinc) or chemistry (Priority Substances: lead and its compounds; Priority Hazardous Substances: cadmium and its compounds), although the biological failure (invertebrates) in Gunnerside Beck is also attributed to contamination from abandoned mines. This means that, although the legacy of sediment-associated contamination resulting from historical lead mining is resulting in failure to reach WFD standards in parts of the upper catchment, the majority of failures are associated with physico-chemistry or chemistry and impacts on biology appear to be more limited.

Parts of the upper Swale catchment are located within the North Pennine Moors Special Area of Conservation (SAC) and Special Protection Area (SPA), and the North Pennine Dales Meadows SAC. In addition, there are several Sites of Special Scientific Interest (SSSI) located within the catchment, including Arkle Beck Meadows and Shaw Beck Gill in Arkle Beck, Muker and Healaugh Meadows in Swaledale, and Arkengarthdale, Gunnerside and Reeth Moor in the uplands to the north of the main river. A large proportion of the designated habitats are in favourable or unfavourable recovering condition.

5.2.2 Results of Assessment 1

Assessment 1 investigates the potential hazards to aquatic receptors (benthic invertebrates and fish) from in-channel sediment contamination. The main findings of the assessment are summarised in **Tables 5.2** to **5.5**.

Table 5.2 Upper Swale Assessment 1 – Likelihood of effect

Likelihood	Description of results
Pollutant source **(Appendix G Assessment 1)**	The pollutant source analysis categorises the majority of the formerly mined tributaries of the River Swale as low. The main river is also low downstream of these tributaries, although parts of intermediate reaches are classified as very low. The results of this assessment are likely to reflect the predominantly rural nature of the upper Swale catchment; urban development is limited and there are few consented discharges. However, the assessment does not appear to adequately reflect the degree of mineralisation and historical metal mining that has occurred in the upper Swale. Gunnerside Beck, Barney Beck, Arkle Beck and Marske Beck are all correctly identified as being impacted by mining in the mining pollutant source data, and these tributaries correspond to the centre of the historical mining industry. However, less extensively mined (but still mineralised) tributaries such as Whitsundale Beck and Stonesdale Beck are not recognised as such. This could indicate that the mining and mineralisation source data do not adequately reflect the intensity of mining in the catchment. Furthermore, it is likely that mining-related sources of pollution have not been given sufficient weighting in the pollution source assessment, and the low pollutant score reflects the lack of urbanisation, trading estates, discharge

Likelihood	Description of results
	consents and landfills in the upper Swale catchment.
Substrate **(Appendix G Assessment 1)**	The tributaries are typically classified as having primarily coarse substrates, while the main river is classified as supporting a higher proportion of fine sediments. In reality, the tributaries are dominated by cobbles and gravels, while the main channel is dominated by gravels and sands. This assessment is therefore supported by available field-based geomorphological data (e.g. as reported in Dennis, 2005).
Sediment quality **(Appendix G Assessment 1)**	The assessment identifies contaminant concentrations in historically mined tributaries such as Whitsundale Beck, Stonesdale Beck, Gunnerside Beck, Barney Beck, Arkle Beck and Marske Beck as high, with at least one (and in many cases three) SQG upper value exceeded in part of each catchment. These are coincident with the areas of extensive mining-related contamination reported in the literature (e.g. Dennis, 2005; Dennis et al., 2009), although previous studies have found more widespread enrichment of metals such as Pb, Zn and Cd in stream sediments. This potential disparity can be explained by the use of the BGS G-Base stream sediment data set, which involved fewer samples and different analytical techniques than the intensive investigations described in the literature. In the main River Swale, there are large areas where contaminant concentrations are below the SQG lower values. However, they are between the upper and lower SQGs downstream of Arkle Beck, and higher than at least one SQG downstream of several of tributaries such as Gunnerside Beck and the headwater tributaries such as Whitsundale Beck and Stonesdale Beck. This pattern partially reflects trends in metal concentrations recorded in in-channel sediments, which show high concentrations of Pb, Zn and Cd in peaks downstream of each mined tributary (Dennis et al., 2003; Dennis, 2005). However, the assessment does not appear to reflect the level of sediment-associated contamination observed in the literature. As with the tributary results, this can potentially be explained by differences between the source data for this assessment (BGS G-Base stream sediment data) and the data reported in the literature.
Overall likelihood **(Appendix G Assessment 1)**	The likelihood of contamination is classified as very low or remote in the majority of the upper Swale water bodies. This overall likelihood strongly reflects the predominance of coarse substrates found in the catchment and the lack of pollutant sources in comparison to more urbanised areas. The results of this assessment do not, therefore, appear to assign the likelihood that may be expected given the high concentrations of sediment-associated metals that have been reported in in-channel sediments in the historically mined tributaries and along the main channel of the River Swale

Likelihood	Description of results
	(cf. Dennis et al., 2003; Dennis, 2005; Dennis et al., 2009).

Table 5.3 Upper Swale Assessment 1 – Consequence of effect

Consequence	Description of results
Benthic invertebrate classification **(Appendix G Assessment 1)**	Benthic invertebrates are typically at high or good status in large parts of the upper Swale catchment, including the main River Swale and heavily mined tributaries such as Barney Beck, Arkle Beck and Marske Beck. This suggests that benthic invertebrate populations have not been significantly affected by historical metal mining in the upper Swale catchment. However, benthic invertebrates are at moderate status in Gunnerside Beck, and the Environment Agency has identified historical mining as the likely cause of this failure. Given the high concentrations of particulate metals observed in this tributary, coupled with the high pH of the catchment and low concentrations of metals in the dissolved phase, it is therefore likely that sediment-associated contamination is responsible for the impacts on benthic invertebrates in Gunnerside Beck.
Fish classification **(Appendix G Assessment 1)**	The status of fish populations has not been assessed in large parts of the upper Swale catchment. However, they are at high status in Barney Beck and good status in Birkdale Beck and Whitsundale Beck. Fish populations are at poor status in Stonesdale Beck and moderate status in Arkle Beck. However, neither of these failures are attributed to metal contamination in the WFD classification data. This suggests that fish have not been significantly affected by historical metal mining in the upper Swale catchment.
Overall consequence (benthic invertebrates) **(Appendix G Assessment 1)**	The overall consequence for benthic invertebrates is generally minor throughout the catchment, although Stonesdale Beck has a negligible consequence. Birkdale Beck, Whitsundale Beck and the main river in between are all classified as minor consequence for benthic invertebrates, as is the majority of Gunnerside Beck. The overall consequence for benthic invertebrates is a product of the benthic invertebrate WFD classification data for the second River Basin Management Plan described above and environmental designations (e.g. SAC, SPA and SSSI) for the catchment. The results of this assessment reflect the good (or better) status of benthic invertebrates in the catchment and the largely favourable condition of the designated sites adjacent to the river.
Overall consequence	The overall consequence for fish is negligible along the majority of the main

Consequence	Description of results
(fish) **(Appendix G Assessment 1)**	River Swale, with the exception of a short reach downstream of Gunnerside Beck, where it is minor, and parts of the headwaters between Birkdale Beck and Whitsundale Beck. These tributaries and the river in between all have a mild consequence for fish. Gunnerside Beck also has a predominantly mild consequence. However, Arkle Beck has a moderate consequence for fish, while Stonesdale Beck and the main River Swale immediately upstream and downstream have a severe consequence. The results of this assessment strongly reflect the results of the WFD water body classification for fish described above and the largely favourable condition of the designated sites adjacent to the river.

Table 5.4 Upper Swale Assessment 1 – Hazard

Hazard	Description of results
Overall hazard **(benthic invertebrates)** **(Appendix G Assessment 1)**	The results of the assessment suggest that the overall hazard for benthic invertebrates is low across the entire upper Swale catchment. The only exception is a small reach of Gunnerside Beck, where the hazard level is uncertain. Since the hazard levels for benthic invertebrates have been derived from the likelihood and consequence assessments described in **Tables 5.3** and **5.4**, the results of the hazard assessment reflect the coarse substrate and relative lack of pollution sources, and the good WFD status of benthic invertebrates. However, the WFD failure for invertebrates in Gunnerside Beck does not appear to be adequately represented in this assessment; a higher level of hazard may be expected because there is evidence of an adverse biological response to mining-related contaminated sediments.
Overall hazard (fish) **(Appendix G Assessment 1)**	The results of the assessment suggest that the overall hazard for fish is generally low across the catchment. However, the hazard is uncertain in Stonesdale Beck, a small reach of Gunnerside Beck, and several small reaches of Arkle Beck. As described above, this assessment reflects the coarse substrates, relative lack of pollution sources and WFD status of fish populations.

Table 5.5 **Upper Swale: summary of WFD water bodies, failing parameters and outcome of the national risk assessment for benthic invertebrates and fish**

Water body	Water body ID	Overall water body status	Failing elements (and status)	Outcome of national risk assessment (benthic inverts)	Outcome of national risk assessment (fish)
Arkle Beck from Source to River Swale	GB104027069170	Moderate	Fish (Moderate); Zinc (Moderate); Cadmium and its Compounds (Fail)	Low	Low – Uncertain
Barney Bk/Hard Level Gill from Source to R Swale	GB104027069080	Moderate	Zinc (Moderate); Cadmium and its Compounds (Fail); Lead and its Compounds (Fail)	Low	Low
Birkdale Beck from Source to River Swale	GB104027069110	Moderate	pH (Moderate)	Low	Low
Gill Beck/Black Beck from Source to River Swale	GB104027068980	Poor	Macrophytes and Phytobenthos Combined (Moderate); Dissolved oxygen (Moderate)	Low	Low
Great Sleddale Beck from Source to River Swale	GB104027069040	Good	-	Low	Low
Gunnerside Beck from Source to River Swale	GB104027069090	Moderate	Invertebrates (Moderate); Zinc (Moderate); Cadmium and its Compounds (Fail); Lead and its Compounds (Fail);	Low (1 km^2 grid square uncertain)	Low (1 km^2 grid square uncertain)
Marske Beck from Source to River Swale	GB104027069140	Moderate	Dissolved oxygen (Moderate); Zinc (Moderate); Cadmium and its Compounds (Fail); Lead and its Compounds (Fail)	Low	Low
Muker Beck Catchment from Source to River Swale	GB104027069030	Good	-	Low	Low

Water body	Water body ID	Overall water body status	Failing elements (and status)	Outcome of national risk assessment (benthic inverts)	Outcome of national risk assessment (fish)
Stonesdale Bk from Source to River Swale	GB104027069150	Poor	Hydrological Regime (Does not support good)	Low	Predominantly Uncertain
Swale Birkdale/Gt Sleddale Bks to Whitsundale Bk	GB104027069050	Good	-	Low	Low
Swale from Muker Beck to Clapgate Beck	GB104027069121	Moderate	Dissolved oxygen (Moderate); Zinc (Moderate); Cadmium and its Compounds (Fail)	Low	Low
Swale from Stonesdale Bk tp Muker Bk	GB104027069100	Good	-	Low	Low
Swale from Whitsundale Bk to Stonesdale Bk	GB104027069070	Moderate	Dissolved oxygen (Moderate)	Low	Low
Whitsundale Beck from Source to River Swale	GB104027069130	Moderate	pH (Moderate)	Low	Low

Assessment 1 therefore suggests that in situ contaminated sediments do not pose a hazard to benthic invertebrates and fish in the upper Swale catchment (**Table 5.5**). Although this is broadly concordant with the observed WFD classification data for these aquatic receptors, the moderate status for benthic invertebrates in Gunnerside Beck does not appear to be reflected in the results of the hazard assessment.

The results of the overall hazard assessment do not appear to reflect the high concentrations of sediment-associated metals reported in the literature and the chemical and physico-chemical status failures observed in several water bodies for lead, zinc and cadmium. However, it is likely that the elevated metal concentrations are not generally bioavailable due to the low pH of the system, which means that metals are retained in the sediments and not easily accessible to biota (cf. Dennis, 2005). The high status classifications for fish and benthic invertebrates reported for Barney Beck in the Environment Agency's 2015 water body status assessment (Environment Agency, 2016) support this assertion. Although the river water body is sufficiently impacted by historical mining to fail to reach Good Ecological Status as a result of high concentrations of zinc, and fail to reach Good Chemical Status as a result of high concentrations of lead and cadmium, this is not reflected in a response in the biological quality elements. However, it should be noted that fish and/or benthic invertebrate data are absent from some of the mined sub-catchments, and the WFD classifications may not, therefore, truly reflect conditions on the ground.

5.2.3 Results of Assessment 2

This assessment investigates the potential hazards arising from the erosion of buried historic contaminated sediments as a result of climate change. The main findings of the assessment are summarised in **Table 5.6**.

Table 5.6 Upper Swale Assessment 2

Likelihood	Description of results
Pollutant source **(Appendix G Assessment 2)**	The pollutant source analysis categorises pollutant sources along the main River Swale and in the majority of its tributaries as remote. Gunnerside Beck, Barney Beck, Arkle Beck and Marske Beck are all classified as low, which may reflect the legacy of intensive metal mining in these sub-catchments compared to other water bodies in the upper Swale. As described in Assessment 1 (**Table 5.2**), the low pollutant sources identified in this assessment do not appear to adequately reflect the intensity of mining in the catchment. This indicates that that mining-related sources of pollution have not been given sufficient weighting in the pollution source assessment. Note that minor variations between this assessment and the Assessment 1 pollutant sources are a product of slight differences in the classification boundaries adopted for each assessment.
Erosion risk **(Appendix G Assessment 2)**	The risk of erosion in the majority of the upper Swale catchment is classified as very low. This suggests that the bank forms observed in the River Habitat Survey (RHS) data are largely stable, and/or that RHS data is absent from large parts of the catchment. This finding that erosion risk is very low does not necessarily reflect the level of erosion and sediment mobilisation that would typically be expected in a high energy, steep gradient upland river

Likelihood	Description of results
	system of this type, and the level of channel planform change, bank erosion and sediment remobilisation that has been observed along the main river and its active upland tributaries. However, erosion is reported to be sporadic and largely confined to higher winter flows (e.g. bankfull discharges) in the upper catchment (cf. Dennis et al., 2003; Dennis, 2005). Small reaches of the main river and its tributaries (Whitsundale Beck, Stonesdale Beck, Barney Beck and Arkle Beck) have a high risk of erosion. These areas are likely to correspond to reaches where erosion is recorded in the RHS data, and occur in steep tributaries where high levels of erosion would typically be expected.
Overall likelihood **(Appendix G Assessment 2)**	The overall likelihood of contamination from the erosion of buried contaminated sediments is typically remote along the main channel of the River Swale and its tributaries, reflecting the apparent stability of the banks and the low pollutant sources identified in the assessment. Parts of the main river (e.g. downstream of Stonsedale Beck and Barney Beck) have a low likelihood, as do small reaches of Whitsundale Beck and Stonesdale Beck. Short reaches of Barney Beck and Arkle Beck are predicted to have a medium likelihood. Parts of the catchment with a higher likelihood of contamination from buried sediments are generally located where higher levels of contamination are coincident with enhanced risk of bank erosion. However, as discussed above, geomorphological investigations in the catchment suggest that the likelihood of erosion may be higher than predicted, while the intensity of mining operations suggest that pollutant sources are high. This implies that the overall likelihood of contamination as a result of the erosion and remobilisation of buried sediments should be higher than predicted in this assessment. Indeed, evidence from the literature (e.g. Dennis et al., 2003; Dennis, 2005) suggests that parts of the catchment are active and that considerable quantities of contaminated sediment are eroded from the floodplain through bank erosion processes during high flows, remobilised in the water column and transported downstream.
Overall consequence **(Appendix G Assessment 2)**	The consequence of contamination as a result of the erosion of buried contaminated sediment was assessed with reference to the likely response of the catchment to climate change. The entire upper Swale catchment (including the main river and its tributaries) has a mild level of consequence, with the exception of a short reach of Arkle Beck which is minor. This suggests that the catchment is at moderate risk of increased precipitation, and is expected to respond moderately quickly with moderately high flows. This prediction is concordant with other studies of the hydrology of the catchment reported in the literature.

Likelihood	Description of results
Overall hazard (Appendix G Assessment 2)	The majority of the River Swale and its tributaries have been assigned a low level of overall hazard. However, parts of the main river downstream of Stonsedale Beck and Barney Beck have an uncertain level of hazard, as do short reaches of Whitsundale Beck, Stonesdale Beck, Barney Beck and Arkle Beck. This pattern strongly reflects the overall likelihood of contamination described above; this would be expected because the overall consequence does not appear to be a differentiating factor between the different parts of the catchment.

Assessment 2 therefore suggests that the remobilisation of buried historic contaminated sediments as a result of climate change is unlikely to present a significant hazard in the upper River Swale catchment. This conclusion does not necessarily correspond to the very high concentrations of metals that have been observed in floodplain sediments and recorded in suspended and overbank deposits during large floods (cf. Dennis et al., 2003; Dennis, 2005). Indeed, detailed modelling by Coulthard and Macklin (2003) suggests that climate change is likely to result in an increase in the supply of contaminants to the channel. These studies also consider the effects of contaminant remobilisation from wider catchment sources (hillslopes, surface runoff, erosion of spoil tips) and do not solely consider bank erosion, which may exaggerate the risks in comparison to the methodology used for Assessment 2.

5.2.4 Results of Assessment 3

G-Base surface soils data are not available for the upper Swale catchment, so it has not therefore been possible to undertake Assessment 3 in this catchment.

5.2.5 Conclusion: Implications of these results

This case study demonstrates that in situ contaminated sediments do not pose a significant hazard to benthic invertebrates or fish in the upper Swale catchment. This conclusion is supported by the WFD classification data for the catchment; although several water bodies fail to reach the required standards for physico-chemistry or chemistry due to high concentrations of cadmium, lead and zinc, only a single river water body fails to reach Good Ecological Status as a result of impacts on biological quality elements (in this case, benthic invertebrates in Gunnerside Beck). However, the methodology does not appear to highlight the increased hazard in Gunnerside Beck that might be expected from the WFD classification data; a low level of hazard is predicted for all but a short reach of the river water body.

The results of Assessment 1 may be skewed by the apparent lack of pollutant sources (other than mineralisation and mining) identified in the catchment. It would appear that the assessment understates the importance of mineralisation and historical metal mining as a source of contaminants, and too strongly reflects the otherwise uncontaminated nature of the catchment, which contains little in the way of the other pollution sources that were considered in this assessment (e.g. urbanisation, consented discharges landfills and trading estates).

This case study also indicates that the remobilisation of buried contaminated sediments as a result of climate change is not a major hazard in the catchment. This conclusion does not appear to correspond to the data available in the literature, which suggests that contaminated sediments are readily cycled through the catchment, a trend that is likely to increase as a response to increased rainfall in the future. There are two potential factors that could be responsible for this apparent discrepancy:

- The classification of pollutant sources as low, which is likely to underplay the significance of historical metal mining as a source of sediment-associated contaminants.
- The classification of erosion risk in the catchment as low, which may not accurately reflect patterns of erosion reported in the literature. However, the literature is not entirely clear, and despite evidence of considerable sediment transport, measured rates of bank erosion in the upper catchment are relatively low.

This therefore suggests that the classification of pollutant sources is likely to be the primary factor between the apparent discrepancies observed in the results of Assessment 2. The assessment methodology does not consider the severity or volume of pollution derived from any single source (e.g. a single mine or an outfall that discharge large volumes of contaminants) and instead favours multiple sources of pollution. Since this appears to be a limiting factor in the results of both Assessment 1 and Assessment 2, it is possible that a change in the way in which mining is weighted or considered in the assessment (at least in historically-mined catchments such as the Swale) could produce more accurate results.

5.3 The Tamar Estuary system and Lower Tamar catchment

This site has been selected to test Assessment 1 of the National Risk Assessment on the basis that it is known that sediment quality within the estuary and contributing freshwaters experience very variable quality, specifically related to heavy mineralisation of the upstream soils where mining has historically been undertaken for centuries. Other additional pressures within the catchment include the heavy urbanisation associated with the City of Plymouth, and agriculture contributing to elevated nutrient concentrations within the catchment.

The area of study captures a relatively large spatial area, incorporating the catchment of the River Tamar, the River Tavy and the River Lynher, and also includes the waters of the Tamar Estuary complex. The area of study is described collectively as the Tamar Estuary system and Lower Tamar catchment. In addition to the major rivers there are also a number of smaller creeks and streams which discharge into the estuary complex. The estuary complex is described as a ria, a partially submerged river valley (South Devon and Dorset Coastal Advisory Group, 2011), which has been flooded as a result of rising sea levels since the Holocene marine transgression (circa 10,000 years BP).

The geology surrounding the Tamar predominantly consists of upper Devonian rocks, with lower Devonian rocks at the mouth of the estuary complex at Plymouth Sound (Thomas, 2001). To the north-west of Gunnislake, in the heart of the Tamar catchment area, Carboniferous rocks are dominant (Thomas, 2001). The geology of the south-west region (and the varying resistance of the geology to erosion) is one of the biggest contributing factors to the geomorphological nature of the coastline.

As already noted, particular pressures on the study area include the highly urbanised nature of the surrounding hinterland by the City of Plymouth and upstream pressures associated with highly mineralised soils and agricultural farming. It is repeatedly reported that river catchments in Devon and Cornwall, including the Tamar valley, are characterised by a very high density of historical metal mines (Mayes et al., 2013) and the primary metals of concern are arsenic, copper and tin. Langston *et al*.

(2003), note that mining for deposits of tin, copper, lead, silver, iron, arsenic, zinc, tungsten and manganese has taken place in the Tamar and Plym valleys for at least nine centuries.

A detailed characterisation of the Tamar catchment undertaken in 2003 by the British Geological Survey on behalf of the Environment Agency (Rawlins *et al*., 2003) highlighted the following key points relating to mining in the study area:

- Significant arsenopyrite (FeAsS) deposits had been obtained from nearly all of the mines located to the east of the Hingston Down granite outcrop.
- The mining workings identified were mainly shafts, with some adits and opencast mines. More than 60% of these were located in the Kit Hill/Gunnislake and Tamar valley areas (BGS, 2003).
- The highest concentrations of arsenic and copper are found in the area around the Devon Great Consols mine. This is located on the east bank of the River Tamar in the Tavistock district.
- To the north of the mineralised zone, concentrations of arsenic and copper in soil were found to be below the median values for the catchment and not significantly above typical values for UK soils.
- Very high environmental concentrations of various metals in this area are partly related to the bedrock mineralisation, as well as to the ground disturbance, mine waste and pollution associated with smelting activities.

5.3.1 Current state of the environment

This case study is focussed on the Lower Tamar catchment (see **Appendix H Catchment Status**) which is divided into seven operational catchments. This study also considers the Tamar Estuary and Plymouth Coast operational catchments. A total of twelve separate water bodies, which make up the Lower River Tamar and its tributaries, are considered in this study (**Table 5.7**).

Table 5.7 Lower Tamar: Water body Water Framework Directive (Cycle 2 2015) Information

Operational catchment	Water body	Water body ID	Overall water body status	Failing elements (and status)	Reasons for failure	Description
Tamar Estuary	Plymouth Sound	GB650806230000	Moderate	Dissolved Inorganic Nitrogen (Moderate)	Mixed agriculture	Agriculture and rural land management
	Plymouth Tamar	GB520804714300	Moderate	Mitigation Measures Assessment (Moderate or less)	-	-
Plymouth Coast	Plymouth Coast	GB620806110003	Good	-	-	-
Plym	Lower River Plym	GB108047004040	Good	-	-	-
	Meavy	GB108047003660	Good	-	-	-
Tavy	Walkham	GB108047007870	Good	-	-	-
	Lower River Tavy	GB108047007840	Moderate	Hydrological Regime (Does not support good)	Surface water abstraction	Other
				pH (Moderate)	-	-
	Lumburn	GB108047007850	Good	-	-	-
Tamar and Lower Inny	Lower River Tamar	GB108047007860	Moderate	Macrophytes and Phytobenthos Combined (Moderate)	-	-
				Hydrological Regime (Does not support good)	Groundwater abstraction	Cement and other minerals

Operational catchment	Water body	Water body ID	Overall water body status	Failing elements (and status)	Reasons for failure	Description
				Copper (Moderate)	-	-
	Cotehele Stream	GB108047004070	Moderate	Fish (Moderate)	-	-
				Invertebrates (Moderate)	-	-
				Hydrological Regime (Does not support good)	Surface water abstraction	Agriculture and rural land management
				Phosphate (Moderate)	-	-
				Copper (Moderate)	-	-
Lynher	Lower River Lynher	GB108047007670	Moderate	Zinc (Moderate)	-	-
	Tiddy	GB108047003890	Moderate	Fish (Moderate)	Unknown (pending investigation)	Sector under investigation

5.3.2 Results of Assessment 1

Assessment 1 investigates the potential hazards to aquatic receptors (benthic invertebrates and fish) from in-channel sediment contamination. The main findings of the assessment are summarised in **Tables 5.8** to **5.11**.

Table 5.8 Lower Tamar Assessment 1 – Likelihood

Likelihood	Description of results
Pollutant source (Appendix H Assessment 1)	There are very limited areas of medium risk level associated with overall pollutant sources around the head of the estuary. This is perhaps surprising given the urbanisation of the City of Plymouth and the surrounding area. In addition, the risks are identified as predominately low and very low in upstream parts of the catchment where historic mining activities are known to have occurred. This would not be expected given the relatively high density of old mines and evidence of mining activities such as spoil heaps and adits present. Although the source data identifies the extent of mining in most parts of the catchment, it fails to identify Cotehele Stream as being impacted. This is unexpected because the stream has been highlighted as being heavily contaminated with metals associated with historic mining activity. This result suggests that the mining and mineralisation source data used to inform the assessment is incomplete and/or does not fully reflect the distribution or production of historical mines in the catchment. Furthermore, the low or very low risk levels also indicate that mining may not be weighted sufficiently in this assessment.
Substrate (Appendix H Assessment 1)	The estuary is classified as having primarily fine sediments, while much of the surrounding area does not have data available. The finer sediments identified supports the continued requirement for maintenance dredging within the estuary by a number of port and harbour activities and the information found in the literature (Widdows *et al*., 2007 for example). Further up the catchment sediments are identified as being coarser in nature, which would be expected in a naturally functioning river system such as the Tamar. The results of the assessment agree with the information presented in the literature.
Sediment quality (Appendix H Assessment 1)	The assessment identifies contaminant concentrations in historically mined tributaries such as Cotehele Stream, around Gunnislake Weir, much of the Lynher and Tiddy and parts of the Meavy, Plym and Walkham, with at least one (and for Gunnislake area three) SQG upper value exceeded in part of each catchment. These are coincident with the areas of extensive mining-related contamination reported in the literature and support the G-Base stream sediment plots for the area. However, in some areas (primarily Cotehele Stream), it would be expected that all samples would have exceeded the SQG upper due to the historical intensity of metal mining. This may reflect that fact that there are limited data

Likelihood	Description of results
	(i.e. fewer than three samples) within the sub-catchment and therefore applying the category for three samples exceeding SQG upper is not possible. There are also areas of the estuary where at least three samples exceed the SQG upper within the 1km square. This fits with the understanding of the quality of the estuary sediments in that it is known that levels of arsenic, for example, exceed SQG upper in a number of locations within the estuarine sediments. It should be noted that there is a large area for which data are not available.
Overall likelihood **(Appendix H Assessment 1)**	Overall likelihood of contamination is generally very low or remote across the whole study area in the flood zone 3 outputs. The exceptions are very small areas in the Lynher, at Gunnislake and around the Plym and estuary. The latter is also shown in the 1km square plot output, which shows areas of medium and low likelihood coincide with parts of the catchment where at least three samples exceed SQG upper. Higher up in the catchment, the overall likelihood of contamination is predominantly very low or remote. This does not appear to reflect the mineralisation of the catchment and historic mining activity in this area, but is likely to reflect a lack of sediment quality data and/or the low weighting assigned to mining-related contamination in parts of the catchment where there are relatively few other pollution sources.

Table 5.9 Lower Tamar Assessment 1 – Consequence

Consequence	Description of results
Benthic invertebrate classification **(Appendix H Assessment 1)**	Only the Cotehele Stream is identified as having issues associated with invertebrates under the WFD status classifications, although no cause has been identified by the Environment Agency.
Fish classification **(Appendix H Assessment 1)**	Only Cotehele and Tiddy are identified as having issues associated with fish under the WFD status classifications, although no cause has been identified by the Environment Agency.
Overall consequence (benthic invertebrates) **(Appendix H**	The majority of the estuary in the 1km square output is identified as mild with much of the surrounding area classified as negligible. The Cotehele Stream is identified as medium. This supports the WFD information within the classification status categories for these water bodies. However, the results of this assessment do not necessarily reflect the high levels of sediment-

Assessment 1)	associated contaminants and the intensity of historical metal mining reported in the literature.
Overall consequence (fish) **(Appendix H Assessment 1)**	Much of the study area shows very low or negligible consequence in the 1km square output. This ties in with the WFD water body classifications, which only identify issues with fish in the Tiddy and Cotehele Stream. Both these areas are identified within the overall consequence output as being at mild and medium respectively.

Table 5.10 Lower Tamar Assessment 1 – Hazard

Hazard	Description of results
Overall hazard (benthic invertebrates) **(Appendix H Assessment 1)**	The majority of the study area is identified as being at low hazard, with a limited number of areas at uncertain hazard level within the estuary, Lynher River and in the Cotehele Stream catchment. However, the WFD failure for invertebrates in the Cotehele Stream does not appear to be adequately represented in this assessment; a higher level of hazard may be expected because there is evidence of an adverse biological response.
Overall hazard (fish) **(Appendix H Assessment 1)**	The majority of the study area is identified as being at a low hazard level, with a limited number of areas of uncertain hazard within the estuary, River Tavy, Lynher River and in the Cotehele Stream catchment. However, the WFD failure for fish in the Tiddy (low hazard level) and Cotehele Stream (uncertain hazard level) do not appear to be adequately represented in this assessment; a higher level of hazard may be expected because there is evidence of an adverse biological response.

Assessment 1 suggests that although issues with sediment quality are highlighted in some areas in relation to SQG values, in situ contaminated sediments do not pose a hazard to benthic invertebrates and fish in the study area. This is broadly concordant with the observed WFD classification data for these aquatic receptors.

However, the moderate status for benthic invertebrates in the Cotehele Stream and for fish in the Tiddy and Cotehele Stream is not highlighted in the assessment. The WFD status classification produced by the Environment Agency does not provide a definitive explanation for these failures, but the impact of historical metal mining cannot be ruled out (and indeed may be expected given the concentrations of contaminants observed in the water bodies). Conversely, investigations may show that another parameter, not accounted for in the assessment (such as abstraction), is the cause in which case the national risk assessment is correct in its output. A level of understanding regarding the pressures within the catchment is therefore important in order to verify the output of the risk assessment.

Table 5.11 **Lower Tamar: summary of WFD water bodies, failing parameters and outcome of the national risk assessment for benthic invertebrates and fish**

Water body	Water body ID	Overall water body status	Failing elements (and status)	Outcome of national risk assessment (benthic inverts)	Outcome of national risk assessment (fish)
Plymouth Sound	GB650806230000	Moderate	Dissolved Inorganic Nitrogen (Moderate)	Mild	Negligible
Plymouth Tamar	GB520804714300	Moderate	Mitigation Measures Assessment (Moderate or less)	Considerable percentage of water body mild. Some km squares negligible	Negligible
Lower River Plym	GB108047004040	Good	-	Minor	Mild
Meavy	GB108047003660	Good	-	Minor	Medium
Walkham	GB108047007870	Good	-	Minor	Medium
Lower River Tavy	GB108047007840	Moderate	Hydrological Regime (Does not support good), pH (Moderate)	Minor	Mild
Lumburn	GB108047007850	Good	-	Minor	Negligible
Lower River Tamar	GB108047007860	Moderate	Macrophytes and Phytobenthos Combined (Moderate),Hydrological Regime (Does not support good), Copper (moderate)	Minor	Negligible
Cotehele Stream	GB108047004070	Moderate	Fish (Moderate), Invertebrates (Moderate), Hydrological Regime (Does not support good), Phosphate (mod) Copper (mod)	Medium	Medium
Lower River Lynher	GB108047007670	Moderate	Zinc (Moderate)	Mild	Mild
Tiddy	GB108047003890	Moderate	Fish (Moderate)	Minor	Mild

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5.3.3 Results of Assessment 2

This assessment investigates the potential hazards arising from the erosion of buried historic contaminated sediments as a result of climate change. The main findings of the assessment are summarised in **Table 5.12**.

Table 5.12 Lower Tamar Assessment 2

Likelihood	Description of results
Pollutant source **(Appendix H Assessment 2)**	Pollutant sources in the catchment are primarily classified as very low or low, reflecting the largely rural nature of the catchment. Increased risks are associated with extensive urbanisation in Plymouth. As described in Assessment 1 (**Table 5.11**), the low pollutant sources identified in this assessment do not appear to adequately reflect the intensity of mining in parts of the catchment. This indicates that that mining-related sources of pollution have not been given sufficient weighting in the pollution source assessment. Note that minor variations between this assessment and the Assessment 1 pollutant sources are a product of slight differences in the classification boundaries adopted for each assessment.
Erosion risk **(Appendix H Assessment 2)**	The risk of erosion shows considerable variation across the catchment. Risks are high in the lower reaches of the Plym and Walkham, with smaller areas of high risk in the Meavy, Inny and Lunher. The remaining parts of each watercourse are typically low or medium. Although some areas of medium risk appear to coincide with highly sinuous sections of channel, there are no clear spatial trends in the data. These results are likely to represent the variable nature of the catchment, which contains high energy upland streams and low energy lowland rivers. The data may also indicate that there are considerable variations in underlying superficial geology and bank material, which could also help to explain variations in bank erosion risk.
Overall likelihood **(Appendix H Assessment 2)**	The likelihood of contamination from the remobilisation of buried contaminants is typically remote or very low cross the catchment, and there are no areas identified as having a high likelihood. The rivers on the eastern side of the catchment appear to have the greatest proportion of low or medium risk, including parts of the Meavy, Plym, Walkham and Tavy. Areas with a higher likelihood of contamination from buried sediments are generally located where higher levels of contamination are coincident with enhanced risk of bank erosion.
Overall consequence	Although there are no areas of high consequence in the catchment, a large

Likelihood	Description of results
(Appendix H Assessment 2)	proportion of the lower reaches of the Tavy, Plym, Lynher and Tamar sub-catchments have a medium consequence. The upper parts of each catchment are generally mild or minor, with no areas of negligible consequence identified in the assessment. This suggests that the upper parts of each catchment are at a lower risk of increased erosion as a result of climate change than the lower reaches. This pattern is likely to reflect the proportionally greater impact of tidal storm surges (which only affect the lower reaches) than increased fluvial flows.
Overall hazard **(Appendix H Assessment 2)**	The majority of the catchment has been assigned a low or uncertain level of hazard, with the exception of parts of the lower Tavy. This pattern reflects the overall likelihood of contamination described above, with the spatial distribution of hazard more closely reflecting the trends displayed by likelihood than consequence.

Assessment 2 therefore suggests that the remobilisation of buried historic contaminated sediments as a result of climate change could potentially pose a hazard in parts of the Tamar catchment. Although the hazard is low in a significant proportion of each sub-catchment, it is uncertain in a large proportion of the Lunher, Meavy and Plym, and either uncertain or high in much of the Tavy.

5.3.4 Results of Assessment 3

This assessment considers potential hazards to floodplain receptors as a result of the deposition of contaminated sediments from the active channel by comparing metal concentrations in G-Base surface soils with concentrations of the same metals observed in G-Base stream sediments (note that this comparison is restricted to metals because the G-Base dataset does not consider any other substances).

The results of this assessment for eight key metals (including the metalloid arsenic) are summarised in **Table 5.13**.

Table 5.13 Lower Tamar results of Assessment 3

Metal	Description of results
Arsenic **(Appendix H Assessment 3)**	The ratio of arsenic in stream sediments to that in floodplain soils is typically between 10:1 and 1:10 in the majority of the catchment. A single location on the main River Tamar near Gunnislake has a ratio of less than 1:10, while a single location on the River Lynher near Trevigro has a ratio of greater than 10:1.
Cadmium **(Appendix H Assessment 3)**	The ratio of cadmium in stream sediments to that in floodplain soils is typically between 10:1 and 1:10 in a large proportion of the catchment. However, there is a large cluster of samples with a ratio of less than 1:10 in the Tamar catchment around Downgate, Gunnislake, Calstock and Bere Alston. There is also a small area where the ratio exceeds 10:1 in the lower Lynher between

Metal	Description of results
	Trevigro and Callington.
Chromium **(Appendix H Assessment 3)**	The ratio of chromium in stream sediments to that in floodplain soils is between 10:1 and 1:10 across the entire lower Tamar catchment.
Copper **(Appendix H Assessment 3)**	The ratio of copper in stream sediments to that in floodplain soils is between 10:1 and 1:10 in the majority of the Tamar catchment. However, two samples situated to the south of Gunnislake in the Tamar and single samples to the west of Callington and the north of Pensilva in the Lynher catchment have a ratio of greater that 10:1.
Lead **(Appendix H Assessment 3)**	The ratio of lead in stream sediments to that in floodplain soils is between 10:1 and 1:10 in the majority of the Tamar catchment, with the exception of a single site near Bere Alston on the Tamar estuary where the ratio is less that 1:10.
Nickel **(Appendix H Assessment 3)**	The ratio of nickel in stream sediments to that in floodplain soils is between 10:1 and 1:10 across the entire lower Tamar catchment.
Silver **(Appendix H Assessment 3)**	The ratio of silver in stream sediments to that in floodplain soils is between 10:1 and 1:10 in a large proportion of the catchment. However, there is a cluster of samples around Downgate and Gunnislake which have a ratio of less than 1:10.
Zinc **(Appendix H Assessment 3)**	The ratio of zinc in stream sediments to that in floodplain soils is between 10:1 and 1:10 in the majority of the Tamar catchment. A single site near Bere Alston on the Tamar estuary has a ratio of less than 1:10, and the ratio exceeds 10:1 in the lower Lynher between Trevigro and Callington.

The results of this assessment demonstrate that the ratio of metals in in-channel sediments to floodplain soils is between 1:10 and 10:1 in the vast majority of the catchment. This suggests that contaminated in-channel sediments are a moderate hazard to floodplain receptors throughout the Tamar. However, metal concentrations in in-channel sediments exceed metal concentrations in floodplain soils by a ratio of more than 10:1 in very localised parts of the Tamar catchment (most notably near Trevigro and Callington in the Lynher sub-catchment). This indicates that contaminated in-channel sediments pose a high level of hazard to floodplain receptors in this area. Conversely, the ratio between in-channel sediments and floodplain soils is less than 1:10 in the main Tamar near Downgate, Gunnislake and Bere Alston, which suggests that contaminated in-channel sediments are present a low level of hazard to floodplain receptors in this area.

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5.3.5 Conclusion – Implications of these results

The results of Assessment 1 may be affected by the apparent discrepancy between the known distribution and production of mines in the catchment, and the low risk of pollutant sources highlighted in the assessment. The is likely to reflect the typically rural characteristics of the mineralised and historically mined sub-catchments, which contain few other pollution sources (e.g. urbanisation, landfills, discharges) other than mining. The low or very low risk levels may also indicate that mining may not be weighted sufficiently in this assessment.

There may also be issues where data are limited to one or two sediment samples in a particular river water body, in which case assessing the more serious categories such as exceedance of three or more samples is impossible. A future update of the national risk assessment may therefore benefit from the incorporation of additional data sets if they become available.

The results of Assessment 2 are not conclusive, inasmuch as they indicate that the level of hazard resulting from the remobilisation of buried contaminated sediment as a result of climate change is highly variable across the catchment. Areas with a high hazard are restricted to parts of the lower Tavy, and a large proportion of the remainder have been assigned a low hazard level. However, the hazard in significant parts of each river is uncertain, which suggests that improvements to the method may be required to increase certainty.

The results of Assessment 3 may be affected by the breadth of the moderate hazard category, which encompasses all sites where the ratio between contamination levels in in-channel sediments and floodplain soils is between 1:10 and 10:1. Although the predominantly moderate classification of hazard in the majority of the catchment may fairly reflect reality (cf. the results of Assessment 1), it may be more appropriate to refer to the hazard in this category as “uncertain”, since changes to the upper or lower ratio would result in an increase in high and low hazard levels. However, it may be very difficult to make any changes to the ratios without adding further subjectivity to the assessment (unless complex statistics are used to identify groups within the data).

6 Conclusions and Next Steps

6.1 Conclusions

6.1.1 National Hazard Screening Assessment update

The National Hazard Screening Assessment presented in Work Package 3A has been updated to:

- Include trading estates, Environmental Permit compliance and landfill sites as potential pollutant sources, alongside discharge consents, urban areas and mining that were considered in the first assessment;
- Include the most recent (2016) G-Base data set, which has greater coverage of stream sediments and surface soils for the south west of England;
- Account for changes in the way small water bodies adjacent to transitional and coastal water bodies are classified;
- Use a less conservative approach to the use of SQGs to define hazard;
- Provide separate assessments of risk for benthic invertebrates and fish; and
- Improve the way in which the risk of contamination to floodplain soils is assessed.

The influence of these changes on the overall results of the analysis are summarised in the subsequent sections.

6.1.2 Re-testing and application of the Phase 1 National Hazard Screening Assessment Methodology

As a result of the updates described in **Section 6.1.1**, Assessment 1 now demonstrates that large areas of England appear to have at least one sediment quality concentration that exceeds the lower SQG, and most sites where at least three concentrations exceed the upper SGQ are associated with mining and urbanisation. The overall likelihood and consequence of contamination in in situ sediments appear to be broadly the same as that identified in Work Package 3A, although the separate consequence of contamination outputs for benthic invertebrates and fish provide a clearer indication of the location of areas of greatest concern. When these factors are combined, the majority of England appears to have a low hazard level for benthic invertebrates and fish, and there are very few areas with a high level of hazard.

The revised Assessment 2 shows that the overall likelihood of contamination from historic buried contaminants is typically classed as remote across the majority of England. Areas of high likelihood are generally confined to large urban areas or heavily mined sites with a medium risk of erosion. The overall consequence of contamination is broadly the same as that identified in Work Package 3A, with the greatest consequence in London, southern and western England. Furthermore, there are very few areas of severe contamination. The changes to the likelihood of contamination mean that the overall hazard from historic buried contaminants has reduced, with the greatest hazard now classified as medium (associated with large urban centres).

The updated Assessment 3 now includes a slightly wider spatial coverage, but the results are limited to metals and confined to areas where the G-BASE surface soils data have been published. The same trends that were reported in Work Package 3A remain apparent.

6.1.3 Influence of flood events and climate change

Flood events and climate change are likely to have a stronger influence in upland areas rather than lowlands. In addition, the north east and north west coastal zones are also likely to be significantly affected.

6.1.4 Case studies

The case studies described in **Section 5** demonstrate that the national risk assessment generally works well, with the level of hazard concordant with evidence of biological response and observed patterns in each catchment. However, there are several implications for the national risk assessment methodology presented in this report.

In both case studies, the importance of mining and mineralisation as a pollutant source is understated, with intensively mined sub-catchments not identified as significant pollutant sources in either Assessment 1 or Assessment 2. Although this may be partially due to the inaccuracies in the source data, this trend is likely to reflect the predominance of a single source and a comparative lack of other pollutant sources. The assessment considers the presence or absence of potential sources of pollution rather than the scale of potential outputs of pollution from these sources, which means that large numbers of sources are weighted more heavily than mining, which is considered on a presence or absence basis.

The implication of this apparent discrepancy in the identification of pollutant sources is not conclusive in the case studies. Hazards across both catchments are predicted to be low in both Assessment 1 and Assessment 2. In the Tamar catchment, there are several failures for WFD biological quality elements, but the status classification produced by the Environment Agency does not provide a definitive explanation for these failures. The impact of historical metal mining cannot be ruled out, however, and may be expected given the concentrations of contaminants observed in parts of the catchment. If it is assumed that at least some of these failures are attributable to mining, this means that the risk assessment has not correctly identified these hazards. There are several chemical and physico-chemical failures as a result of mining-related contamination in the Swale catchment, but only a single biological failure is attributed to mining. This broadly supports the low hazard classification for the catchment, although the failing water body is not highlighted as having a high level of hazard in the assessment due to the lack of pollutant sources identified for this sub-catchment.

It was only possible to test the results of Assessment 3 against observed data in the Tamar case study, because the G-Base data on which this is reliant is not currently available for the Swale catchment. The results of Assessment 3 are likely to be affected by the breadth of the moderate hazard category, which encompasses all sites where the ratio between contamination levels in in-channel sediments and floodplain soils is between 1:10 and 10:1. Although the results may be broadly similar to what would be expected, it may be more appropriate to refer to the hazard in this category as “uncertain” rather than “moderate”, since changes to the upper or lower ratio could result in an increase in high and low hazard levels.

It is important to note that it is unreasonable to expect the national scale assessment to measure a high degree of accuracy with the catchment scale. Confidence in the identified patterns and trends is good, but demonstrates that ground-truthing is required to indicate the next level of investigation and any potential recommendations for remediation.

6.2 Next steps

The previous sections have demonstrated that the national scale assessment has successfully identified areas where contaminated sediments are likely to pose a hazard to aquatic and terrestrial receptors, including significant areas of London, Merseyside, and Humberside (among others). When the results are studied in detail at a local level, the results appear to be broadly concordant with observed evidence of biological impact (i.e. WFD biological quality element classifications), although they underplay the significance of major pollutant sources such as mining. This suggests that the assessment is most effective at the national scale because the limitations inherent in the source data on which the assessment is based are highlighted more clearly at a local (catchment) scale.

The outputs of the national hazard assessment process are therefore likely to benefit from the following amendments and refinements:

- Improvements in the way in which mineralisation and mining are considered in the assessment methodology. This will help to ensure that the risk posed by potentially significant sources of contamination such as historical metal mines are not understated in the risk assessment. The incorporation of more accurate spatial data (e.g. mine locations or proportion of a river water body that is mineralised) in place of the simple presence-absence data used in this assessment is likely to have the greatest benefit, although it is acknowledged that these data may not be easy to obtain.
- Incorporation of additional data sets that may indicate the presence of contamination when they become available, including national coverage of surface soils from the BGS G-Base data set and other data sets that include non-metals.
- Further trialling of the method in alternative study catchments to ensure that the existing case studies have not missed any significant limitations in the methodology. Catchments with more varied pollution sources may be particularly useful. However, the assessment of results is dependent upon real catchment level data and this task may therefore be very difficult to progress.
- Amendments to the method to allow the degree by which SQGs are exceeded to be considered in the assessment, rather than the number of exceedances. The spatial distribution of exceedances (and the statistical significance of these exceedances in terms of number of samples in relation to overall sample size) could also be considered. However, it should be noted that since many SGQs were not derived for the use in the UK, the benefits of this may be limited. It may be possible to use the concentration of a sediment-associated contaminant that is required to cause a water quality problem (e.g. identified through the use of published partition coefficients) or biological response (e.g. identified through the use of published toxicology data). This may provide an indication of “harm” at a national scale, although it should be noted that these parameters are likely to be highly variable in response to site specifics.

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