THE UNIVERSITY OF HULL

# Developing an Estuarine Planning Support System: A Case Study for the Humber Estuary, UK.

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by

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## Declaration

I hereby declare that the work presented in this thesis is my own, except where otherwise stated, and that it has not been previously submitted for any other degree at any other educational institution in the United Kingdom or overseas.

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## Publications

The publications that are a result of this thesis are provided below (the chapters the papers are based on are provided in unlined text after the reference):

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## Presentations

The below are the oral presentations and posters presented at national and international conferences.

- Lonsdale, J-A., Elliott, M., Weston, K. 2016. Development of an Estuarine Planning Support System, Oral Presentation presented at University of Essex, Penryn Campus, MBA Post-Graduate Conference 25th April 2017, Penryn, UK.
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- Lonsdale, J-A., Elliott, M., Weston, K., Birchenough, A. 2017. Developing an Estuarine Planning Support System: An integrated tool to managing contaminated sediments in coastal and estuarine environments. Presentation at Dioxins 2017, Vancouver, Canada.

## Abstract

Estuaries are often challenging to manage, as management must strike a balance between the needs of the users and the ecological and economic values within the context of multiple legislative drivers. To help facilitate integrated management, a novel Estuarine Planning Support System (EPSS) framework, using the Humber Estuary in Eastern England as a case study, has been developed. This integrated EPSS framework goes beyond previous approaches as it brings together the legislative drivers, management tools and other mechanisms for controlling plans (formal/legal management, action or work plans (e.g. shoreline management plans) and projects (a new structure or activity such as extending a port). It thereby enables managers and users to assess and address both the current environmental state, and the way in which the new project could impact an estuary in an accessible and understandable tool. This study has been primarily completed by desk based research using peer reviewed literature, technical and research reports, marine licence applications and legislation, with correspondence to several sources to determine the baseline information and existing knowledge gaps. Further to the framework, an EPSS tool was developed to provide a practical application of these requirements. The GIS-based tool ensures that the information is accessible for regulators, managers, the scientific community, developers and the public. Whilst the tool is adaptable for regions within and outside the United Kingdom (UK), the research presented in this thesis focussed on the Humber Estuary. The successful application of the tool for a complex socio-economic and environmental system such as the Humber Estuary shows that the tool can efficiently guide users through the complex administrative requirements needed to implement a management plan, and therefore support sustainable development. In addition, the tool can be used as a scoping mechanism to identify potential stressors which are to be addressed in an environmental impact assessment (EIA). The tool was validated against four case studies and was also tested by a number of stakeholders to determine the utility and accuracy of the tool. The tool was subsequently updated to reflect feedback from the stakeholders. This project should be viewed as a 'proof of concept' in that its primary purpose is to demonstrate the potential for developing and operationalizing an approach in the field. The method has the potential to integrate highly technical knowledge from scientists, and the views of non-scientists, to make better-informed management and planning decisions and to provide reasonable assurance to justify those decisions. The tool can be used to prevent conflicts among stakeholders and/or between uses and users and the environment, and makes it possible to integrate all the existing background data in thematic maps and identifies the human activities that use

the areas, resources and services. The EPSS tool can save time and resources, aid in the decision-making process and make the decision process more transparent and consistent. It has the potential to make the governance of the marine area more logical, simple, fast and therefore more cost effective. The tool has been developed to be flexible in its approach, this means that it can be easily adapted to be used internationally and to allow for it to be adaptable to future changes. It combines the many aspects required for a holistic approach to marine management, from the inclusion of governance and stakeholder views, to the need for, and use of, monitoring information. In marine management, there will always be a need for robust and scientifically and legally defendable science to inform management. The increasingly large spatial scales that are addressed by policy makers, and the reduction in funding, means that new methods are needed to provide the evidence base which this tool helps to provide, and can be applied worldwide. The developed toolbox is an important step towards such an integrated, holistic ecosystem based approach for marine management, demonstrating that a single tool can bring together the legislative, environmental and economic considerations. The tool is a method to undertake the assessments that are currently being carried out by separate organisations, to combine in a single process that is consistent and transparent and on a quicker timescale helping to reduce costs.

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# 1. Introduction

The marine environment is affected by both natural and anthropogenic pressures and drivers of change; these tend to increase in number and intensity as the population and economic growth increases, leading to much of the marine ecosystem being affected (Arbo and Thuy, 2016; Prestrelo and Vianna, 2016; Oinonen *et al.*, 2016; Woods *et al.*, 2016; Borja *et al.*, 2013b; 2010a; Halpern *et al.*, 2008; Varghese *et al.*, 2008; Berger and Hodge, 1998; Fabbri, 1998). Marine planning has been developed to anticipate future changes (UNESCO IOC MSP[1] programme), and balance the varying needs of the sectors, to this end the UK has adopted a legal requirement to develop marine plans under the Marine and Coastal Access Act 2009.

Sustainable management of terrestrial and marine stressors through the application of impact assessment (including cumulative impact assessment) and thresholds are needed to ensure that the ecosystem services and societal goods and benefits are available for future generations, and for the long-term survival of ecosystem functions that are currently being degraded (Perminova *et al.,* 2016; Elliott and Whitfield, 2011; Counsell and Haughton, 2006; Cicin-Sain and Belfiore, 2005; Cooper and Sheate, 2002; Shriberg, 2002; Turner *et al.*, 1996). In the UK, the main legislative driver for providing more sustainable use of marine resources is currently provided by the Marine and Coastal Access Act 2009 and through the development of Marine Spatial Plans (MSP) (Defra, 2013b) but it does not, as yet, implement a fully holistic view of the sustainable use of an area or ecosystem such as envisaged by the Marine Strategy Framework Directive (Directive 2008/56/EC), Marine and Coastal Access Act and the UK Marine Plans. The aim of the presented work was, therefore to analyse and interrogate the management of a complex and urbanised estuary with a view to providing a toolbox for aiding decision makers in taking a holistic approach to that management.

## 1.1 Marine, Estuarine and Coastal Management in the UK

The UK Government acknowledges that it is important to protect, and where possible, enhance the marine environment (here the term 'marine' is taken to include sea, estuarine and coastal), while, at the same time, enabling marine industries to prosper (Defra, 2013b). To achieve this, robust evidence on the state of the environment and its sensitivity to various impacts is essential. As increased use and development of marine resources increases, ecosystem services could be impacted, so an integrated planning support system would assist to ensure that the current ecosystem condition is understood and sustained by the

[1] http://msp.ioc-unesco.org/ [viewed 15/8/17]

current generation, so the goods and services are available for future generations. It can also allow effective future scenario assessments to be undertaken to ensure that a development will not have a detrimental impact on the current and future status of the system (Cooper and Sheate, 2002).

Recent marine and estuarine management throughout Europe has focussed on a set of concepts and tools related to specific planning applications (see list below) (Elliott *et al.*, 2017; Torresan *et al.*, 2016; Whitfield *et al.*, 2012; Elliott and Whitfield, 2011; Atkins *et al.*, 2011; Svarstad *et al.*, 2008; Counsell and Haughton, 2006). These however are not currently interlinked despite being central to the integrated implementation of several EU directives and national governance mechanisms (see 2.1) (Borja *et al.*, 2013a; Borja *et al.*, 2011; Townsend *et al.*, 2011; Borja *et al.*, 2010b; Hering *et al.*, 2010; Mee *et al.*, 2008; Borja and Elliott, 2007; Apitz *et al.,* 2006). The currently available concepts and tools for managing estuarine, coastal and marine areas include:

- Conservation designations (sections 2.1.6 and 2.2.3);
- sectoral management schemes (Environment Agency, 2008a; 2008b; Apitz *et al.*, 2006; Fujii, 2007) (section 2.1);
- the DAPSI(W)R(M) framework (Elliott *et al.*, 2017) (section 3.1);
- ecosystem services and societal goods and benefits, (Elliott and Whitfield, 2011; Atkins *et al.*, 2011; Austen *et al.*, 2009; Beaumont *et al.*, 2007) (section 3.5);
- environmental integrative indicators (Ware *et al.*, 2010; Aubry and Elliott, 2006) (section 4.7);
- limits of acceptable change (also referred to as thresholds or benchmarks) (Aubry and Elliott, 2006; Cole and Stankey, 1997, Stankey *et al.*, 1985) (Chapter 7);
- the integrated socio-ecological system (Borja and Elliott, 2013), and
- The 10-tenets (Elliott, 2013; Atkins *et al.*, 2011) and 17 goals (Cormier and Elliott, 2017; United Nations, 2015) for successful and sustainable management (section 3.4).

Each of these concepts and tools have been developed individually for different inshore, estuarine and marine areas (Torresan *et al.*, 2016; Elliott and Whitfield, 2011; Elliott and Ducrotoy, 2010; Aubry and Elliott, 2006; Counsell and Haughton, 2006; Lee, 2006; Islam and Tanaka, 2004; Harris, 2003). However, so far, there is not one tool that integrates the various planning and management concepts and regulations, to produce a fully developed and integrated planning support system.

To develop such a tool, it is essential to demonstrate its value through the practical application by ensuring all relevant policies (including directive and legislative tools) and stakeholders are taken into consideration, and that the confidence and/or uncertainty of the evidence is taken into consideration (Townsend *et al.*, 2011).

For an ecosystem management and strategic assessment to be successful, there are multiple management levels that must be accommodated i.e. international directives, national legislation and regional plans (Apitz *et al.,* 2006). The various water and land uses, including functions and values must be identified and assessed within and across different disciplines (Barbier *et al.*, 2011; Townsend *et al.*, 2011; Katsanevakis *et al.,* 2011; Gross, 2003).

## 1.2 Aims, Objectives and Research Questions

The overall aim of the research presented in this thesis was to develop an integrated system to simplify the process of assessing and managing an ecosystem (in its current state and possible future states) and in determining an application to undertake an activity or policy (e.g. MSFD, WFD) (Counsell and Haughton, 2006). The EPSS builds on previous work for estuarine management, enhancing these initial planning tools for the area (Lonsdale, 2013; García-Alonso *et al.*, 2011; Fujii, 2007; Mazik *et al.*, 2007; Boyes *et al.*, 2006; Elliott *et al.*, 2006).

Management tools have been recently developed to aid in environmental management, however given the potential for overlap in activities, potential conflicts, and policy objectives, having these as separate tools can still leave gaps in knowledge for developers and decision makers. There is currently no universal tool that can guide a developer/decision maker through the process and highlight where receptors, activities, legislative requirements etc. are in relation to a development. The thesis aims to answer the research question of 'can one tool be developed to bring in the multi-disciplinary nature of managing an estuarine environment together?'.

The objectives of this study are:

1. To summarise the knowledge and understanding of the baseline(s) of the estuary with regards to the current environmental condition. (Chapter 2);
2. To investigate the different management schemes and frameworks and integrate these into a novel framework (Chapter 2);
3. To develop an EPSS framework for managers to assess the current baseline and future projects (Chapter 3);

4. To develop a tool that provides a practical application of the EPSS framework (Chapter 4 and 5);
5. To further develop the tool to include a cumulative impact assessment technique (Chapter 4 and 5);
6. To identify the current level and extent of ecosystem services and societal goods and benefits provided by the Humber Estuary, including a review of appropriate indicators (Chapter 4 and 5);
7. To test the tool with several stakeholders and decision makers, on a consented project within the Humber Estuary and update the tool based on the received feedback (Chapter 6);
8. To determine if the application of standard indicators or thresholds for change are appropriate in estuarine management (Chapter 7);
9. To provide an integrated toolbox to assess the current state and the way in which a new development impacts the estuary (Chapter 8).

## 2. Need for an Estuarine Planning Support System

An EPSS is a framework by which to define a clear planning or management process and to identify the tools and management options that are available to support that process. It is a representation of a generic integrated estuarine management process, and is not a replacement for expert judgement. Its aims are to aid and support the decision-making process and developers when proposing to develop conservation, public or private infrastructure and policies, by applying a holistic approach (Quilliam, 2015). An EPSS aims to help developers identify which activities are taking place and where, and identifies any connections and/or conflicts between uses and informs of where priorities should be placed, both in the short and long term (Juda, 1998).

In the following sections, the different legislations and management tools of the Humber Estuary that are available will be explored and developed into an EPSS framework. The Humber estuary was chosen as a study area to test the benefit and validity of using an EPSS tool as guidance for decision-makers when determining new projects or policies.

### 2.1 Governance

Juda (1998) defines governance as "*the formal and informal arrangements, institutions, and more[s] which determine how resources or an environment are utilized; how problems and opportunities are evaluated and analysed; what behaviour is deemed acceptable or forbidden; and what rules and sanctions are applied to affect the pattern of resource and environmental use*", or simply, the law, administrations, policies and politics. Management therefore incorporates stakeholders, businesses, non-governmental organisations and academic/ research institutions (supported by Galler *et al.*, 2016; Freire-Gibb *et al.*, 2014) and governments. It is identified that the environmental status of an ecosystem or receptor does not change, nor do the potential impacts stop at the maritime boundary of two states, therefore consultation with stakeholders in neighbouring jurisdictions is essential (Borja *et al.*, 2013a; b). It is important to recognise that decisions made by one country, state or region may affect the management strategies of another, either positively and negatively.

Given the large area of the Humber catchment (approximately 24,240km$^2$ (Cave *et al.*, 2003)), it is monitored and managed by different agencies with specific functions and remits or responsibilities, which makes monitoring transboundary potential effects difficult (Table 1 and Figure A1).

Table 1 The different agencies and organisations that manage parts or all of the Humber Estuary ("-"denotes that the group/organisation does not fall under the "type" category).

| **Area of Responsibility** | **Group/ Organisation** | Advisory | Private Utility | Executive Non-Departmental Public Body | Formal agreements | Forum | Government Body | Harbour Authority | HGO Expertise | Landowner/ manager and NGO Pressure | Lobby | Partnership | Land Management | Promotion | Statutory | Stakeholder |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Quality | Environment Agency (Environment Agency) | - | - | Y | - | - | - | - | - | - | - | - | - | - | Y | - |
| | Water Companies | - | Y | - | - | - | - | - | - | - | - | - | - | - | - | Y |
| Nature Conservation | Defra | - | - | - | - | - | Y | - | - | - | - | - | - | - | Y | - |
| | Natural England | - | - | Y | - | - | - | - | - | - | - | - | - | - | Y | - |
| | Environment Agency | - | - | Y | - | - | - | - | - | - | - | - | - | - | Y | - |
| | Royal Society for the Protection of Birds | - | - | - | - | - | - | - | - | Y | - | - | - | - | - | - |
| | Lincolnshire Wildlife Trust | - | - | - | - | - | - | - | - | Y | - | - | - | - | - | - |
| | Yorkshire Wildlife Trust | - | - | - | - | - | - | - | - | Y | - | - | - | - | - | - |
| | Yorkshire Naturalists Union | - | - | - | - | - | - | - | Y | - | - | - | - | - | - | - |
| | Spurn Heritage Point | - | - | - | - | - | - | - | - | - | - | Y | - | - | - | - |
| | Humber Nature Partnership | - | - | - | - | Y | - | - | - | - | - | - | - | - | - | - |
| Shipping and Ports | Marine Management Organisation | - | - | Y | - | - | - | - | - | - | - | - | - | - | Y | - |
| | ABP Humber Estuary Services | - | - | - | - | - | - | Y | - | - | - | - | - | - | Y | - |
| | Humber Sea Terminals, APT, Conoco Philips | - | - | - | - | - | - | Y | - | - | - | - | - | - | Y | - |
| | British Waterways | - | - | - | - | - | - | - | - | - | - | - | - | - | Y | - |
| Development | Local Planning Authorities | - | - | - | - | - | - | - | - | - | - | - | - | - | Y | - |
| | Associated British Ports | - | - | Y | - | - | - | - | - | - | - | - | - | - | Y | - |
| | Environment Agency | - | - | Y | - | - | - | - | - | - | - | - | - | - | Y | - |
| | Humber Local Enterprise Partnership | - | - | - | - | - | - | - | - | - | - | Y | - | - | - | - |
| Flood Protection | Defra | - | - | - | - | - | Y | - | - | - | - | - | - | - | Y | - |
| | Humber Estuary Coastal Authority Group | Y | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Environment Agency | - | - | Y | - | - | - | - | - | - | - | - | - | - | Y | - |
| | Local Planning Authorities | - | - | - | - | - | - | - | - | - | - | - | - | - | Y | - |
| | Internal Drainage Boards | - | - | - | - | - | - | - | - | - | - | - | - | - | Y | - |
| | Local Landowners | - | - | - | - | - | - | - | - | - | - | - | - | - | - | Y |
| Tourism | Visit Hull and East Yorkshire, Visit Lincolnshire | - | - | - | - | - | - | - | - | - | - | - | - | Y | - | - |
| Fishery | North Eastern Inshore Fisheries and Conservation Authority | - | - | - | - | - | - | - | - | - | - | - | - | - | Y | - |

| Area of Responsibility | Group/ Organisation | Advisory | Private Utility | Executive Non-Departmental Public Body | Formal agreements | Forum | Government Body | Harbour Authority | HGO Expertise | Landowner/ manager and NGO Pressure | Lobby | Partnership | Land Management | Promotion | Statutory | Stakeholder |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Environment Agency | - | - | Y | - | - | - | - | - | - | - | - | - | - | Y | - |
| | Fishing/ Sea Angling Clubs | - | - | - | - | - | - | - | - | - | - | - | Y | - | - | - |
| | National Federation of Fisherman's Organisations | - | - | - | - | - | - | - | - | - | Y | - | - | - | - | - |
| Wildfowling/ Hunting | Local wildfowling clubs, Upper Humber wildfowling committee, Humber wildfowl refuge committee | - | - | - | - | - | - | - | - | - | Y | - | Y | - | - | - |
| Agriculture | National Farmers Union (North East Region), Country Landowners Association (Yorkshire) | - | - | - | - | - | - | - | - | - | Y | - | - | - | - | - |

### 2.1.1 European Directives and National Strategies

The Humber Estuary, like many other coastal and estuarine environments that stretch over a large area, has numerous European Directives and national strategies in place for the management of discreet areas i.e. on a town-by-town basis, and the ecosystem (Figure 1 and Figure 2). These different directives and strategies are provided in Boyes and Elliott (2015) and those relevant to the Humber Estuary are reviewed below.

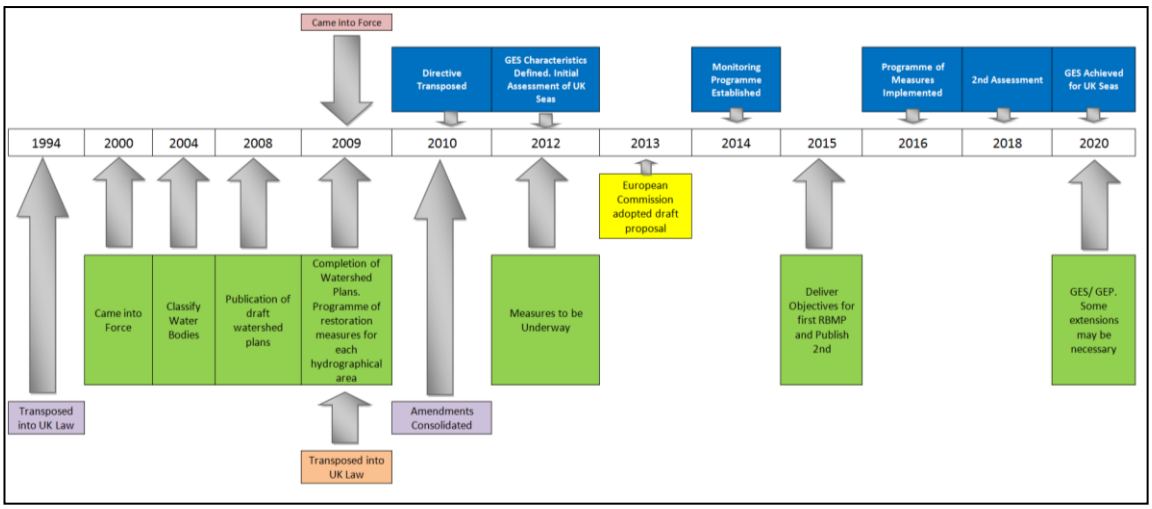



Figure 1 The timelines of the different directives and regulations of when they were implemented and the deadlines for the consultations. From the top down: pink relates to Marine and Coastal Access Act 2009; blue relates to the Marine Strategy Framework Directive; yellow relates to the proposed [2]Marine Spatial Planning and Integrated Coastal Management; green relates to the Water Framework Directive; purple relates to the Habitats Regulations; and orange relates to the Wild Birds Directive.

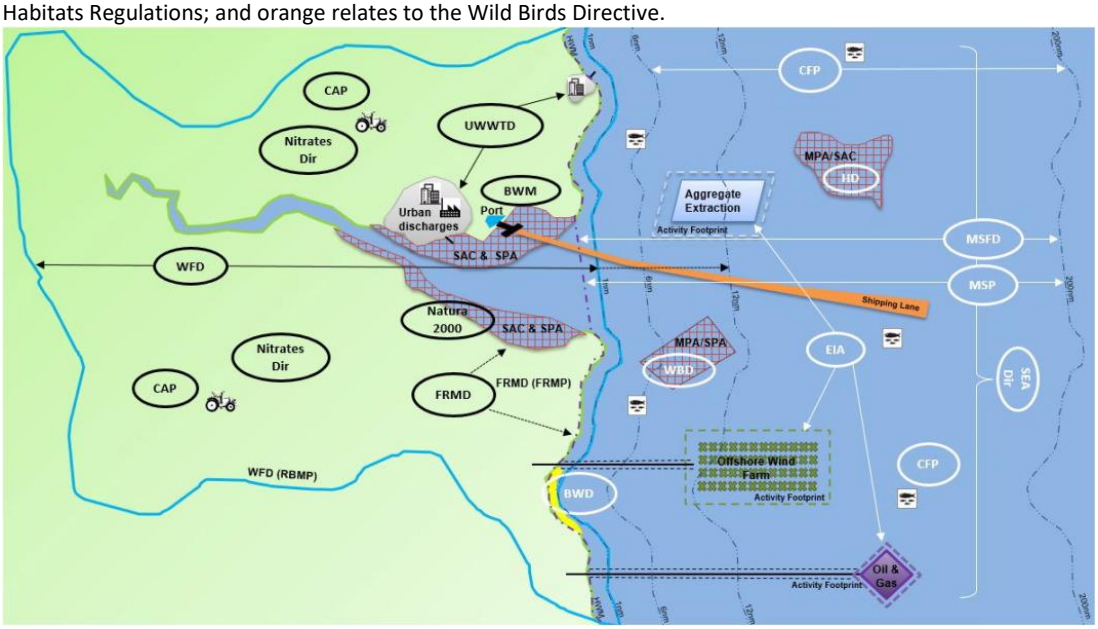



Figure 2 The boundaries of the different directives and legislation that are in place to enable the sustainable management of the Humber Estuary (from Boyes *et al.*, 2016). Detailed jurisdictions of the different English marine organisations are provided in Boyes and Elliott (2015) (Not to scale)

The Directives and regulations are designed to ensure that the environment is managed sustainably (c.f. Boyes and Elliott, 2015). Whilst some are framework directives (e.g. WFD) where the aim is clear but the methods to reach it differ between the different Member States, others are mandatory, whereby the requirements are clear e.g. the Habitats Directive. The directives and legislative tools are not weighted and therefore there is a need to identify an effective balance and compliance with all their requirements.

[2] The Marine Spatial Planning Directive came into force in 2014 but UK legislation for marine planning pre-dates the Directive under the Marine and Coastal Acess Act, 2009.

Due to the overlapping duties and functions within the marine environment, a review was carried out by the Department for Business Innovation and Skills in 2012 which highlighted that businesses found it difficult to understand and deal with overlaps between marine regulators. In response Defra published a Coastal Concordat (Defra, 2013c) which "*aims to provide a framework within which the separate processes for the consenting of coastal developments in England can be better coordinated, and provides applicants with a single point of entry spanning all of the many regulatory systems*" (Boyes and Elliott, 2015). The Coastal Concordat approach can be applied to any application that crosses the intertidal areas (including both estuaries and along the coast) that require multiple consents from multiple regulatory bodies. Whilst none of the Local Authorities that border the Humber Estuary have adopted the coastal concordat (correct as of October 2018) it is a measure that could be introduced for new developments or management options.

### 2.1.2 Water Framework Directive

The WFD applies to waters out to one nautical mile from which the territorial waters are drawn (Apitz *et al.*, 2006) and uses the bay closing line as that limit for estuaries (see Figure 2 above). The aim of the WFD, as outlined in Article 1, paragraph 27 (Official Journal of the European Commission, 2000), is to achieve "*concentrations in the marine environment near background values for naturally occurring substances and close to zero for man-made synthetic substances*".

The Directive aims to protect and improve the chemical and ecological status of water bodies through the process identified in Figure 3 (Borja *et al.*, 2006, 2008; Borja, 2005). The purpose of the WFD Assessment is to determine whether an individual dredging or disposal activity needs further assessment to establish if it complies with the WFD. There may be some activities that can be exempted from the WFD Assessment, however it is recommended that all projects are screened, and a record/audit should be kept and provided to the Licensing Authority to aid the decision-making process (Environment Agency 2012a; b; c; d; e).

It is important that the EPSS identifies projects that could potentially impact the WFD status of a waterbody and therefore provide guidance on the assessment. A concept model of the WFD is provided in Figure 3 and will be incorporated into the EPSS.

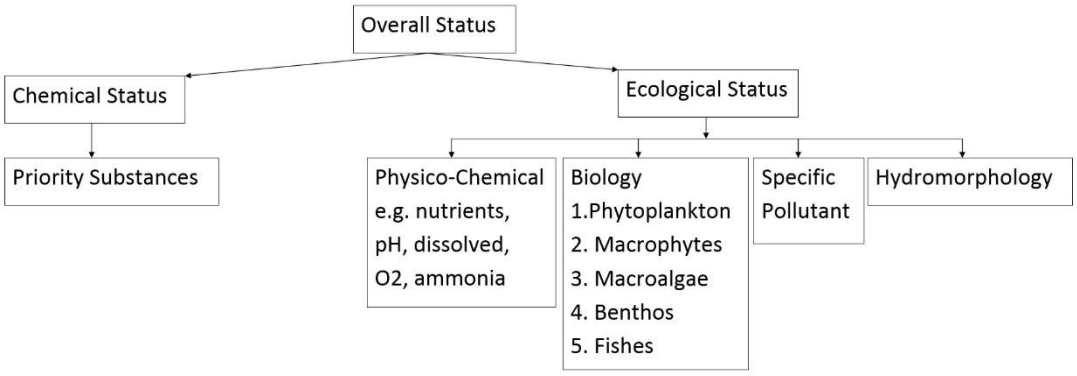



Figure 3 Conceptual model of the WFD.

### 2.1.3 Humber River Basin Management Plan

In the UK, the Environment Agency monitors the progress of water bodies against the objectives of the WFD through the implementation of the River Basin Management Plans (RBMP). The Humber RBMP (Environment Agency, 2015) was prepared under the WFD by the Environment Agency and covers 26,109km$^2$, including the Humber Estuary but ranges from the North Yorkshire Moors to Birmingham, Pennines to the North Sea and Stoke on Trent to Rutland (Figure A 2). It is the Environment Agency's remit to ensure the plan is managed and carried out.

The ecological status is based on the status of the biological, hydromorphological and physio-chemical quality elements (Borja, 2007). The process of developing and reviewing a RBMP is shown below (Figure 4) and will be incorporated into the EPSS to ensure the RBMP is taken into account when developing a new project or policy. This will guarantee the decision-making process is iterative and make sure there are feedback loops to ensure any management plans are appropriate if any future developments occur.

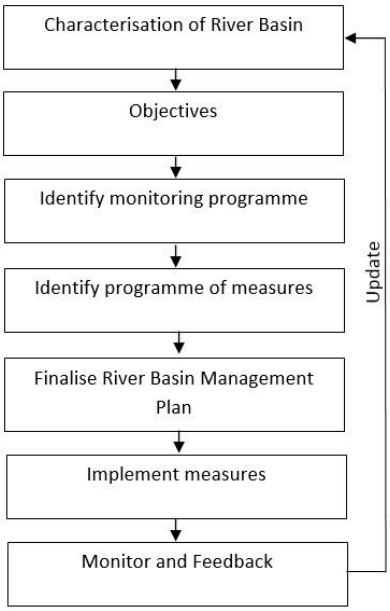



Figure 4 An overview of the HRBMP process.

### 2.1.4 Marine Strategy Framework Directive

The Marine Strategy Framework Directive (MSFD) is transposed into UK law by the Marine Strategy Regulations 2010. The Directive lists several obligations its member states must fulfil by 2020 and incorporates the 'precautionary principle'[3]. This allows, where insufficient evidence is presented, for the regulatory authority to decide in the favour that the project will have a significant adverse effect on the environment. Although the MSFD does not extend into the Humber Estuary, the approaches identified within the directive can be adapted to the management of the Humber Estuary within the EPSS.

The MSFD requires member states to take measures to achieve and/or maintain good environmental status of the marine environment by 2020 by considering the structure, function and processes of marine ecosystems (Borja *et al.*, 2013b). Member states are required to adopt marine strategies that must apply an ecosystem based approach i.e. natural and anthropogenic aspects, to the management of the ecosystem. The MSFD sets out a list of 11 descriptors, which summarise the way in which the whole system functions alongside criteria and indicators (HM Government, 2012a). To ensure countries achieve good environmental status, the managers of the Humber Estuary (identified in Table 1 ) need to identify and understand the inputs, outputs and spatial control measures and management measures which may affect the MSFD (Figure 5).

[3] See: http://jncc.defra.gov.uk/default.aspx?page=2519 for more information. [accessed 05/02/2017].

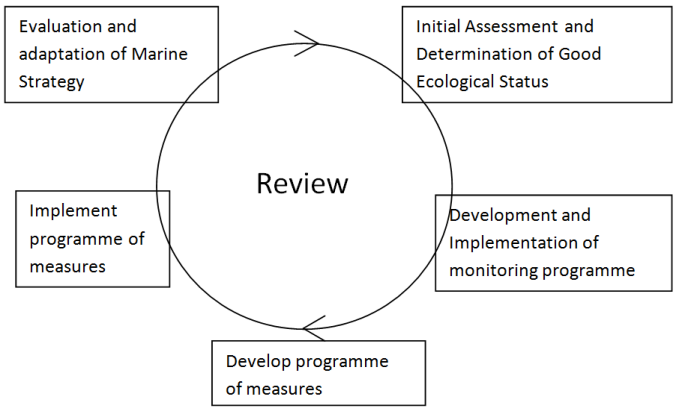



Figure 5 An overview of the MSFD process.

### 2.1.5 EU Directive for Maritime Spatial Planning

Marine Spatial Planning (MSP) promotes sustainable development by trying to achieve a balance between environmental, social, economic and cultural objectives with the aim of sustainable development and sustainable ecosystem services and societal benefits (Diedrich *et al.*, 2010; Mateus and Campuzano, 2008; Varghese *et al.*, 2008; Pickaver *et al.*, 2004; Shriberg, 2002; Turner and Schaafsma, 2015). The EU Directive for Maritime Spatial Planning (adopted in August 2014 (Boyes and Elliott, 2015)) was established to help create marine plans and promote sustainable growth of maritime and coastal activities, and the sustainable use of resources (Diedrich *et al.*, 2010; Mateus and Campuzano, 2008; Varghese *et al.,* 2008). In the UK, the Marine and Coastal Access Act provides the legal basis for MSP, including the current and potential use of UK seas (Defra, 2011) and establish marine planning authorities and publish marine plans, the effectiveness of which are to be monitored and reviewed at 6-yearly intervals.

The Directive does not define the 'coastal zone', and it is for the Member States to define this. For this study, the coastal zone incorporates all tidal waters up to the MHWM (therefore including estuaries) and tidal limits of the waterbody as outlined in the UK Marine Policy Statement (HM Government, 2011). Spatial plans for estuaries such as the Humber Estuary have existed for many years with statutory plans such as River Basin Management Plans, or non-statutory plans such as shoreline management plans, however the Directive now formalises this process.

The steps in creating a Marine Spatial Plan are similar to those identified in the MSFD (Figure 6). The steps involve characterising the baseline, developing a marine plan, monitoring and reviewing the plans to ensure the management plans and monitoring programmes are appropriate for the objectives. The concept model shown below (Figure 6) will be

incorporated into the EPSS. This is to firstly ensure the relevant directives are considered when developing a new project or policy, and secondly to ensure the decision-making process is iterative. An iterative process is important to ensure any management plans can be reviewed and to be confident that it will remain appropriate if any future developments occur.

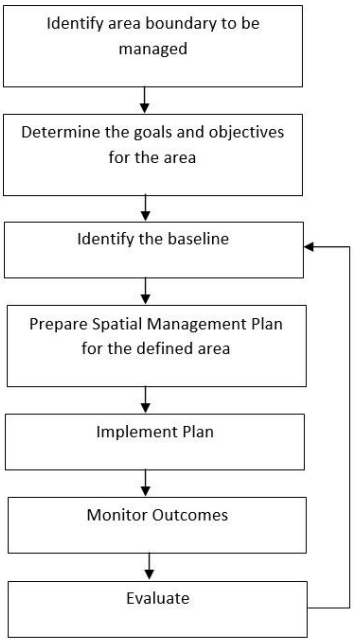



Figure 6 An overview of the Marine Spatial Plan process.

### 2.1.6 Conservation of Habitats and Species and the Wild Birds Directives

The Conservation of Habitats and Species Regulations (the Habitats Regulations) was created in response to the EU Habitats Directive to protect the features in designated Special Areas of Conservation (SAC) and habitats suitable for endangered and migratory species of birds under Special Protection Areas (SPA) under the EU Wild Birds Directive (Birds Directive)

The Directives aim is to conserve natural habitats and wild fauna and flora that are rare, vulnerable and endangered within the EU. The aim is that if the habitats can be conserved and maintain good environmental characteristics, then the species (as well as the habitats and ecosystem services and societal benefits) will be protected for future generations (Apitz *et al.*, 2006). Sites, such as the Humber, with designated SACs and SPAs are collectively referred to as Natura 2000 sites.

The process of determining if a project will have an adverse impact on a designated site is a Habitats Regulations Assessment. The Competent Authority must undertake this. Under

article 6(4) of the Habitats Directive a plan or project can only proceed provided three sequential tests are met (Figure 7):

- There must be no feasible alternative solutions to the plan or project which are less damaging to the affected European site(s)
- There must be "imperative reasons of overriding public interest" (IROPI) for the plan or project to proceed
- All necessary compensatory measures must be secured to ensure that the overall coherence of the network of European sites is protected.

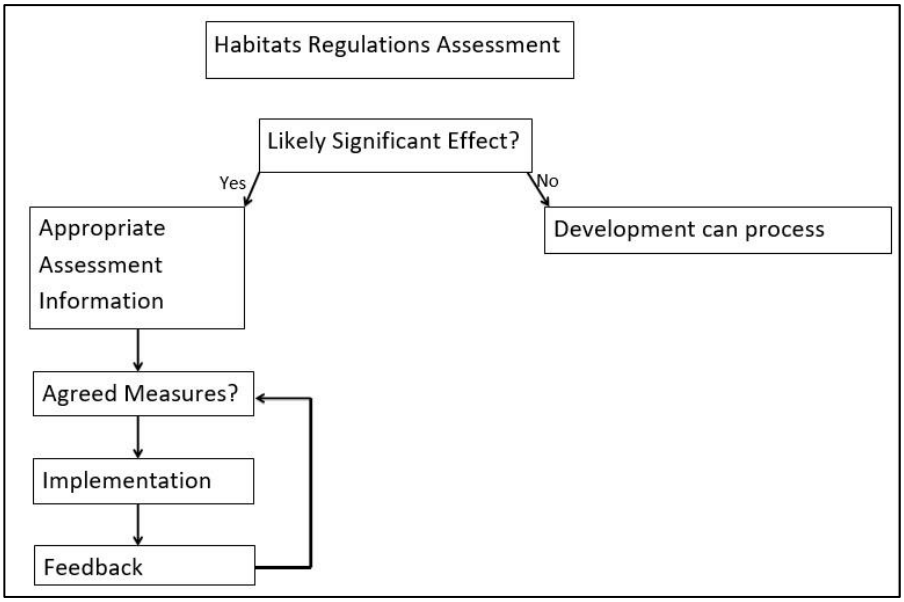



Figure 7 A simplified overview of the HRA process to be carried out when a project may have a likely significant effect on features of conservation interest and potentially affect the Natura 2000 network.

The process of the Habitats Regulations Assessment will be fed into the EPSS as it is a requirement under EC Directives, and therefore recommended that any requirements under the directives are identified early in the process to allow effective consultation and communication between the applicant and the Competent Authority to agree an approach and any mitigation packages.

### 2.1.7 Marine Policy Statement

The UK Marine Policy Statement sets out the UK Governments high-level policy for the marine environment (including estuaries (see HM Government, 2011)) and provides the context and policy reference point for the development of marine plans. It details high-level principles that the MMO should follow in exercising its functions including marine licensing below the MHWM.

The Marine Policy Statement is a framework for preparing marine plans and taking decisions affecting the marine environment. It was prepared and adopted for the purposes of section 44 of the Marine and Coastal Access Act 2009. Its high level marine objectives are:

- Achieving a sustainable marine economy;
- Ensuring a strong, healthy and just society;
- Living within environmental limits;
- Promoting good governance, and
- Using sound science responsibility.

These objectives need to be incorporated into the EPSS given that they are all working towards sustainable development and management, whilst ensuring robust science on which to base policy decisions.

#### 2.1.8 Marine Plans

Marine Plans are currently being developed by the MMO for England, on behalf of the Secretary of State for DEFRA. The English waters are split into 11 areas with the Humber Estuary falling into the East Marine Plan area. It is envisaged that marine plans will guide developers in terms of where they are likely to be able to carry out activities and where conditions or restrictions may apply (Defra, 2011).

The Marine Plans are being primarily developed to comply with the framework of the Marine Policy Statement, the Marine Coastal Access Act and the Directive for Maritime Spatial Planning, but they also must comply with other UK national policy and legislation such as the Energy Act 2013. Marine plans are designed to be forward looking to determine how the marine areas will change, but they should also be able to be iteratively developed in response to monitoring and subsequent review. The marine plans can therefore be updated to accommodate new developments, evidence, technologies, techniques and evolving demands.

A current limitation of Marine Plans for the management of marine areas is a lack of guidance and practical tools that integrate the complex array of drivers set out in plan policies to facilitate economic growth, social well-being and environmental protection.

#### 2.1.9 Marine and Coastal Access Act

The Marine and Coastal Access Act (MCAA) introduced a revised licensing system whereby the MMO (on behalf of the Secretary of State) considers and issues Marine Licences for construction, deposition or removal of any substance or object in English territorial waters

up to MHWM and for such activities where they are undertaken outside of UK Territorial Waters (except for exempted activities[4]). If a project has one or more of these aspects associated with it, a Marine Licence must be obtained for each aspect. One Marine Licence however can cover multiple activities. Applying for a Marine Licence follows a process whereby the applicant identifies if a Marine Licence is required and follows a set route through the process with the MMO (Figure 8).

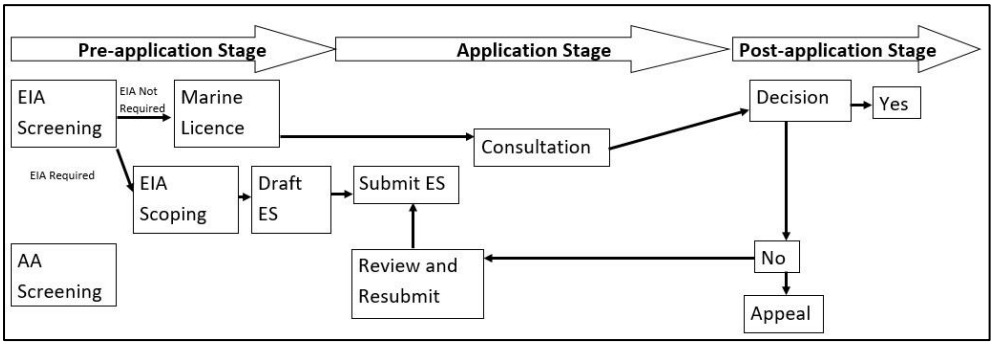



Figure 8 An overview of the Marine Licensing process of the MMO under the MCAA

The Marine and Coastal Access Act also provides the provision and legal requirements for the UK to develop marine plans (before the adoption of the EU Directive for Maritime Spatial Planning) under Part 3 (see section 3.8).

### 2.1.10 Planning Act (2008)

The Planning Act (2008) is a licensing system whereby the Planning Inspectorate, on behalf of the Secretary of State, considers projects that require consent (both terrestrial and marine) that are considered Nationally Significant Infrastructure Projects. The aim of the Planning Act (2008) was to streamline the licensing process for larger projects whereby the developer effectively 'front loads' the consultation with the regulators and consultees e.g. Natural England, to ensure all of the impacts of the development are considered prior to the submission of the application. The Planning Inspectorate then has six months, as set out by the Act, to grant consent for the project, or not. Following consent, the marine components, then fall under the responsibility of the MMO.

The process for applying for a consent under the Planning Act, is similar to the process under the Marine and Coastal Access Act and Environmental Impact Assessments (see below).

[4] The Marine Licensing (Exempted Activities) Order 2011 http://www.legislation.gov.uk/uksi/2011/409/contents/made [accessed 09/11/2017]

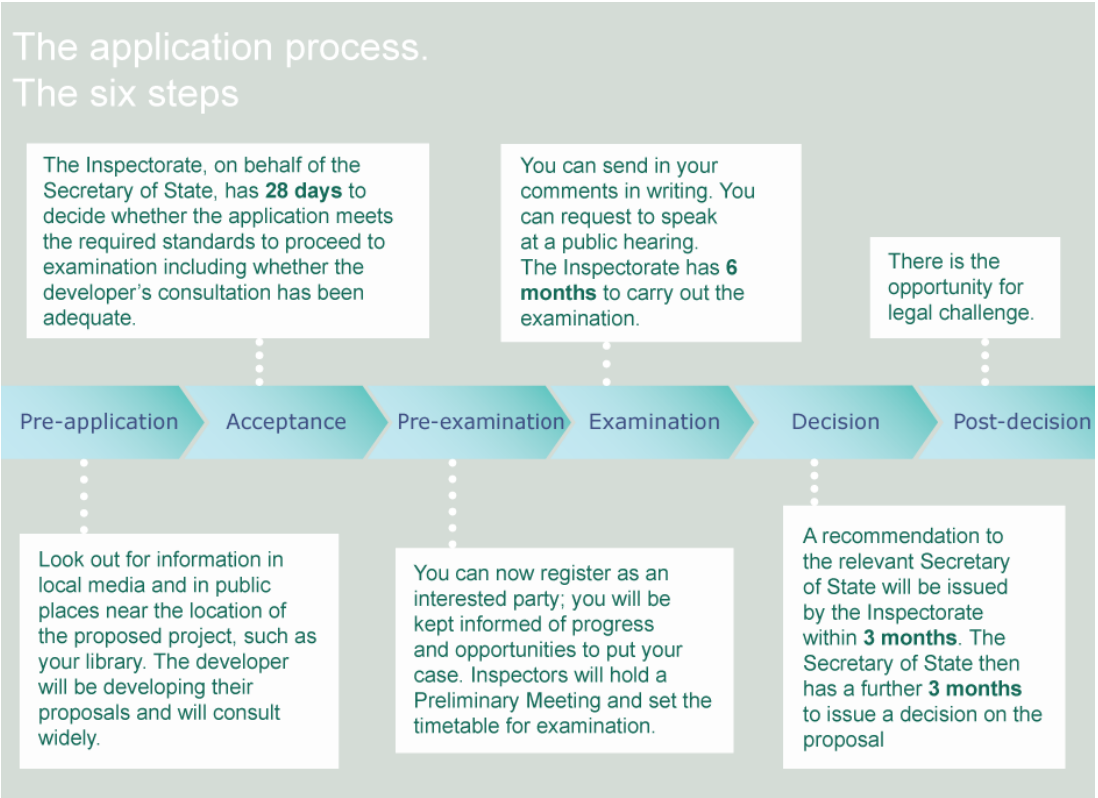



Figure 9 An overview of applying for consent under the Planning Act (2008) [from: https://infrastructure.planninginspectorate.gov.uk/wp-content/uploads/2013/03/Application-process-diagram2.png [viewed 09/11/2017]

### 2.1.11 Environmental Impact Assessment (2014/52/EC)

The Environmental Impact Assessment Directive states that an Environmental Impact Assessment must be carried out to assess the effects of a project on 1) humans, fauna and flora; 2) soil, water, air, climate and the landscape; and the interactions between these depending on the scale and nature of the project (Lonsdale *et al.*, 2017).

Currently an EIA assesses the project's impacts of the final ecosystem products and services rather that assessing the impacts the development could have on the ecosystem services that support the final products (section 3.5). The Directive is transposed into UK law by the Marine Works (Environmental Impact Assessment) Regulations (as amended) 2011 for marine projects (2.1.12 below) and the Town and Country Planning Act 1990 for terrestrial projects (not covered in this study).

### 2.1.12 The Marine Works (Environmental Impact Assessment) Regulations (as amended) 2011

The Marine Works (Environmental Impact Assessment) regulations (as amended) 2011 (referred to as Marine Works EIA Regulations) came into force on the 6th April 2011 and requires that should a marine proposal fall under either an Annex I or Annex II proposal and

has the potential to significantly affect the marine environment, an EIA is required to be undertaken.

The EIA process follows a similar process to the Marine Licensing process in which the applicant identifies if an EIA is required; the content of the EIA and required surveys are agreed through a consultation process and finally an Environmental Statement is produced to support the application (Figure 10). The process shows that it can be consultation dominated, with the applicant requesting guidance from the Licensing Body and being iterative with the EIA and final ES being reviewed and amended as required. The resulting product will be an ES with an integrated mitigation package, perhaps a Habitats Regulations Assessment, and if necessary, a compensation package.

Figure 10 will be integral to the EPSS, given that the requirement is from an EC Directive and early confirmation of an EIA is essential to the robust and effective planning of a project. By identifying the requirements for an EIA, the applicant can then work through the EPSS to determine what will be required in the final product, and in terms of costs, how much time and resource may be required.

Figure 10 Overview of EIA process

### 2.1.13 Flood Defence Schemes

The Environment Agency is responsible for most of the flood defences along the Humber Estuary and prioritises the maintenance of these defences based on the flood risk of an area with regards to climate change and sea level rise, and the impacts these may have on people, properties, industry, landscape, historical assets and wildlife (Environment Agency 2008a, b).

The Flood Risk Strategy is determined by the state of the flood defences and the risk of flooding from the climate change and sea level rise (Figure 11). The plan is reviewed every five years. The Flood Risk Strategy and the Humber Shoreline Management Plan complement each other with their objectives (these are discussed below).

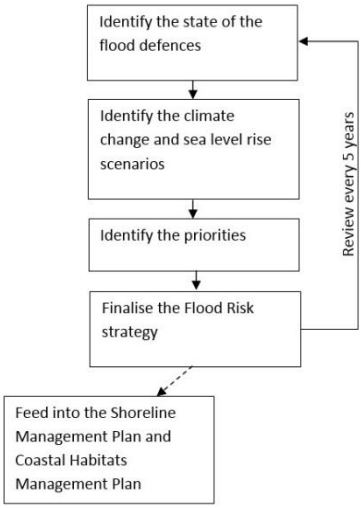



Figure 11 An overview of the process to determine the Flood Risk Strategy

### 2.1.14 Humber Shoreline Management Plan

The objectives of the Shoreline Management Plans (SMP) are to develop a coherent and realistic plan for the Humber Estuary's flood defences (Figure 12) and to ensure projects are sustainable e.g. the ten tenets of sustainability (see section 3.4 for a full explanation). Pontee and Cooper (2005) identified that the first round of SMPs within the UK were inconsistent regarding inclusion of estuaries. Various management issues arise since the low lying estuarine shores, as well as the water bodies themselves are subject to the often-disparate requirements of commerce, residences, recreation and conservation.

The diversity of estuaries i.e. infrastructure, transport, recreation, conservation, residential dwellings, together with the management pressures that they face, illustrates the need for estuaries to be incorporated within a strategic shoreline management framework to proactively plan flood risk management (Pontee and Cooper, 2005). Whilst it is reasonable to assume that the SMP should extend to tidal limits, there are two practical reasons it is not always possible as outlined by Pontee and Cooper (2005). In heavily modified estuaries or in long, narrow tidal rivers, the limit of tidal influence may be many tens of kilometres inland and may lie beyond conventionally accepted limits of the estuary system (Elliott and McLusky, 2002).

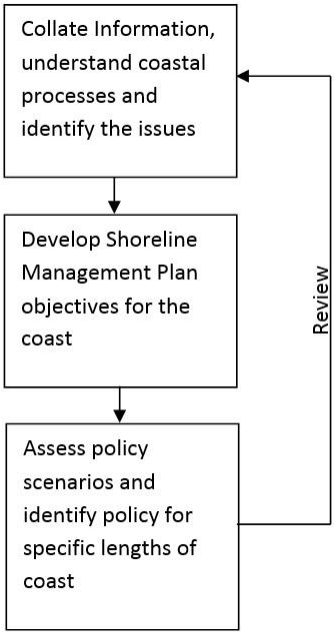



Figure 12 An overview of the process to develop the Shoreline Management Plan

## 2.2 Current Condition of the Humber Estuary

To develop an EPSS, the environmental baseline of the Humber Estuary first needs to be established. This section describes the physical characteristics, uses (land and estuarine) and population demographics of the Humber Estuary. Given the objectives of this thesis, it was prudent to use the existing condition of the Humber Estuary as the baseline. Where there are data gaps or limitations with the data, these are identified. The governance systems that are relevant to the Humber Estuary are discussed in section 2.1 above as they apply to the wider marine area.

The Humber Estuary is located on the East Coast of the United Kingdom and starts at the confluence of the River Ouse and River Trent. It flows easterly to Kingston-Upon-Hull (Hull) where it then flows south eastwards, and enters the North Sea between Spurn Point and Donna Nook (Jarvie *et al.*, 1997) (Figures A3 and A4). The geographical scope of this research included the tidal limits of the Humber Estuary (Cromwell Weir on the River Trent and Naburn on the River Ouse) to the mouth of the estuary between Donna Nook and Spurn Point (Law *et al.*, 1997)

### 2.2.1 Physical Characteristics of the Humber Estuary

The Humber Estuary has a large tidal range, with the mean being 5.7m at Spurn, increasing to 7.4m at Saltend decreasing to 6.4m at Hessle and 5.6m at Trent Falls (Hemingway *et al.*, 2008). Due to its spring-neap tidal range being over 4m, the Humber Estuary is considered a

macro-tidal estuary (Masselink and Anthony, 2000; Pontee *et al.*, 2004). The tidal waters extend from the outer estuary at Spurn Point to Cromwell Weir on the River Trent and Naburn on the River Ouse (Harris, 2003, Pontee *et al.*, 2004, Tappin *et al.*, 2003).

The Humber Estuary provides the largest UK contribution of freshwater from British Rivers to the North Sea approximately an average 250 $m^3s^{-1}$ (Jarvie *et al.*, 1997*)* with the freshwater from the River Ouse being approximately >400 $m^3s^{-1}$ in winter to <10 $m^3s^{-1}$ in summer (Uncles *et al.*, 1998). Maintaining the sediment budget (Figure 13) (the quantity of material entering and leaving the system) of the Humber Estuary is important to ensure that the hydrodynamics of the estuary are not adversely affected with activities such as dredging and the removal of flood storage areas (Townsend, 2004). An important consideration to maintaining the sediment budget is the sediment that is stored in suspension (Townsend and Whitehead, 2003). Edwards and Winn (2006) and Marshall and Elliott (1998) report suspended sediment concentrations of 5-20 $gl^{-1}$.

The Humber Estuary is thought to be near its theoretical equilibrium of the sediment budget, therefore it is important to ensure that the sediment budget is not altered and is taken into consideration when proposing new projects or dredging practices. It is because of this equilibrium that Natural England advise that the maintenance dredge arisings are kept within the sediment budget to avoid disturbing this equilibrium, thus disturbing the functionality of the estuary and therefore will be taken into consideration when investigating the potential uses (Pethick, 2002).

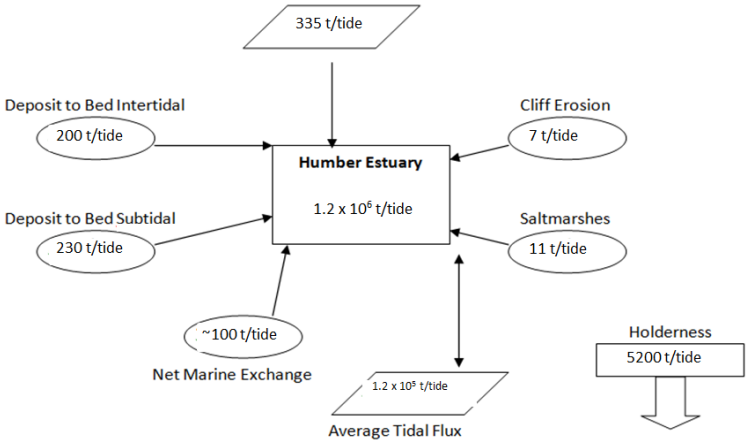



Figure 13 A schematic view of the sediment budget for the Humber Estuary (Townsend and Whitehead, 2003)

i. Nutrients

There are several dissolved nutrients that enter the Humber Estuary, but those that can cause eutrophication are dissolved inorganic nitrogen (nitrate, nitrite and ammonium); phosphate and silicate which in turn can affect the biological oxygen demand (Cave *et al.*, 2003; Uncles *et al.*, 1998).

In the Humber Estuary it is the high turbidity that is the limiting factor on the use of these nutrients, so the area does not become eutrophic (de Jonge *et al.*, 2002). It is estimated that the total dissolved inorganic nitrogen input (nitrate, nitrite, ammonium) for the Humber Estuary and tidal rivers is estimated to be 57.4 x $10^3$ t $yr^{-1}$ (Cave *et al.*, 2003). The peak of these was well defined during summer and early autumn when the turbidity maximum occurred. Coastal levels are less than 10µM in winter and less than 2µM in summer for nitrate (Uncles *et al.*, 1998). The dissolved inorganic phosphate is estimated to be 57.4 x $10^3$ t $yr^{-1}$, with approximately 15% entering from the North Sea (Cave *et al.*, 2003). Phosphate levels are dominated by freshwater inputs during the spring to late summer (Uncles *et al.*, 1998). The biological oxygen demand is important in the Humber Estuary as the oxygen levels can determine how stressed fish species are and can also play a part in determining when migratory species migrate through the estuary and begin spawning (Kramer, 1987).

### 2.2.2 Designations

Sites can be designated at the local, national and international scale to protect species and/or habitats that are considered rare or threatened. The Humber Estuary has several international and national designations for the protection of habitats, flora and fauna and physical features (Figure A 5). Only those designations that border the Humber Estuary's intertidal area, i.e. below MHWS, have been included, however others above this may require consideration for a development or proposal e.g. terrestrial Sites of Special Scientific Interest. The Humber Estuary is designated for the following:

- The Humber Estuary Special Protection Area (SPA) is designated under the EC Birds Directive (79/409/EEC) to support bird populations of European importance that are included in Annex I and Annex II;
- The Humber Estuary Ramsar Site is designated for its estuarine habitats for bird populations;
- The Humber Estuary Special Area of Conservation (SAC) qualifies under the EC Habitats Directive (92/43/EEC) for its Annex I habitats and Annex II species; and

- The Humber Estuary Site of Special Scientific Interest (SSSI) is designated under the Wildlife and Countryside Act 1981 for its nationally important habitat, geological interest, importance to breeding, wintering and passage birds, breeding grey seal.

As the Humber Estuary has several designations that cover most of the estuarine environment, the EPSS for the Humber Estuary must provide applicants and decision makers guidance on the required and recommended steps and processes.

Activities that have the potential to significantly adversely affect the features of conservation designations may be required to undertake a Habitats Regulations Assessment under the Habitats Directive. In response to this concern, in 2008 Defra, Marine Fisheries Agency (now Marine Management Organisation (MMO)), English Nature (now Natural England (NE)) and the ports industry collaborated[5] to establish the Maintenance Dredge Protocol to help those wishing to seek approval for dredging applications to maintain navigation channels that could potentially affect the features, and therefore the condition of the marine protected areas. This is currently a voluntary scheme, but by having a protocol it allows applicants to put their application for future dredging into the historic context allowing any potential impacts to be assessed and is included in the considerations of the EPSS (ABP HES, 2011).

### 2.2.3 Managed Realignment Sites

Managed realignment sites rebuild the sea defences landwards and breach (either actively or passively by allowing a breach to occur) the original flood defence so the land will then inundate with tidal estuarine water (Elliott *et al.*, 2016; Wolanski and Elliott, 2015). This is used as a compensatory measure for habitat loss either through coastal squeeze (which occurs when coastal habitats such as saltmarsh become 'caught' between fixed sea defences and rising sea levels resulting in the gradual loss of these habitats) or due to projects encroaching into the estuary and affecting the conservation designations (see section 2.1.6) (Lonsdale, 2013; Manson and Pinnington, 2012a-d). They can also be used as flood alleviation areas or as a natural sea defence, for example saltmarsh aids in attenuating the wave energy (Lonsdale, 2013). The location of such sites on the Humber is provided in Figure A6.

### 2.2.4 Tourism

The Humber Estuary, with its large area, various habitats and waterways, provides many tourism and leisure opportunities (no differentiation between the terms leisure, recreation

[5] http://webarchive.nationalarchives.gov.uk/20080907160245/http://www.defra.gov.uk/wildlife-countryside/ewd/mdp-invite.pdf [accessed 11/11/2017]

and tourism has been provided as these terms overlap and will be used interchangeably throughout this study) (Figures A7-A11). The tourism industry is based on sand beaches, estuarine habitats and species and the use of the waterways. Waterways also support activities such as walking, bird watching, and public education regarding the ecosystems and sustainability (Fearnley *et al.*, 2012; Freestone *et al.*, 1987).

The estuary has several wharves, jetties and marinas, which make the Humber estuary popular with recreation boaters (Figure A 12) and by the Royal Yachting Association (RYA) as it is used as a general sailing and racing area, as well as accommodating 6 RYA clubs, 2 training clubs, 1 RYA marina and a heavily used recreational route (Figure A 13) (RYA, 2008). Wildfowling is also carried out during the period 1st September and the 20th February (excluding Christmas Day) (Fearnley *et al.*, 2012) (Figure A 7). This is where game (being geese and ducks) can be shot, but only over water below mean high water and participants must be licenced.

### 2.2.5 Cultural Heritage

Spurn Point at the mouth of the Humber Estuary is defined as a Heritage Coast (Figure A 14) for its changing shape and the species that the area supports, particularly the migratory bird species (Lonsdale, 2013). It is designated given its undeveloped coastline and there are facilities in place to allow public access to the site (Lonsdale, 2013).

There are several protected and known wrecks (vessels, aircraft and historical landscapes) within the Humber Estuary (Figure A 15). These are designated as being likely to contain the remains of a vessel or its contents, which are of historical, artistic or archaeological importance. All protected wrecks are listed in the annual Admiralty Notices to Marinas and marked on the appropriate UK Hydrographic Office charts to avoid disturbance. Some of the wrecks are visible in the intertidal areas of the Humber Estuary, which also attracts visitors.

There are several listed buildings, which border the Humber Estuary, which are listed for either their architectural or historic interest features. To manage and conserve the Humber Estuary, the Humber Nature Partnership have released a 'Code of Conduct[6]' for the public. These are beyond the scope of this study for developing an EPSS but given that they attract tourism they need to be recognised as the wider holistic management, the EPSS will recognise their presence and importance.

[6] http://www.humbernature.co.uk/admin/resources/codes-of-conduct-pdf.pdf [accessed 11/11/2017]

### 2.2.6 Climate Change Considerations and isostatic rebound

In the UK, estuarine processes are directly affected by anthropogenic activities, which can be further affected by external factors such as effects from climate change (Panditharatne, 2016; Robins *et al.*, 2016). Robins *et al.* (2016) noted that the projected increased winter river flows throughout UK catchments will enhance the risks of coastal eutrophication, harmful algal blooms and hypoxia in some contexts, although there are spatial variabilities in river flow projections. The reproductive success of estuarine biota is also sensitive to saline intrusion and corresponding turbidity maxima (area where the suspended sediment concentrations are at their greatest) that are predicted to gradually shift landwards because of sea-level rise (Little *et al.*, 2017).

Antonson *et al.* (2016) highlighted the need to mitigate the impacts of climate change and discussed that there is a challenge of putting climate change policy into practice due to the institutional misfit (supported by Chang and Lin, 2016, Kettle and Dow, 2016 and Panditharatne, 2016). To address this, the UK Marine Policy Statement (HM Government, 2011) highlights the importance of understanding issues surrounding climate change and how it might be reflected in the future marine environment stating, *"climate change is likely to mean that the UK will experience hotter, drier summers and warmer, wetter winters . . . increased drought, heatwaves, changes in seasonal precipitation and the intensity of weather events such as rainfall leading to flooding*" (HM Government, 2011). Specifically, the potential impacts of climate change on the UKs marine environment, amongst others, include relative sea level rise, increased seawater temperatures, ocean acidification and changes in ocean circulation. The potential impacts and effects of climate change need to be assessed and evaluated holistically to ensure that all potential receptors and cumulative impacts are taken into consideration (Holman *et al.*, 2005).

### 2.2.7 Anthropogenic Uses and Drivers of the Humber Estuary

The Humber Estuary is bordered by several population centres (Figure A4). The Marine Management Organisation (MMO) (2011) has defined the coastal communities by classifying them based on grouping areas with similar characteristics; they are intended as an internal tool, not as a definitive list (Figure A 16).

The social typologies as defined by the MMO define most of the land that borders the Humber Estuary as being "Coastal Retreats: Working Countryside" and "Coastal Retreats: Rural Chic" (MMO, 2011). The areas surrounding the major towns and cities are classified as being "Coastal Challenges" including structural shifters, new towns and ports and striving

communities or "Cosmopolitan Coast" for re-inventing resorts and coastal professionals (MMO, 2011).

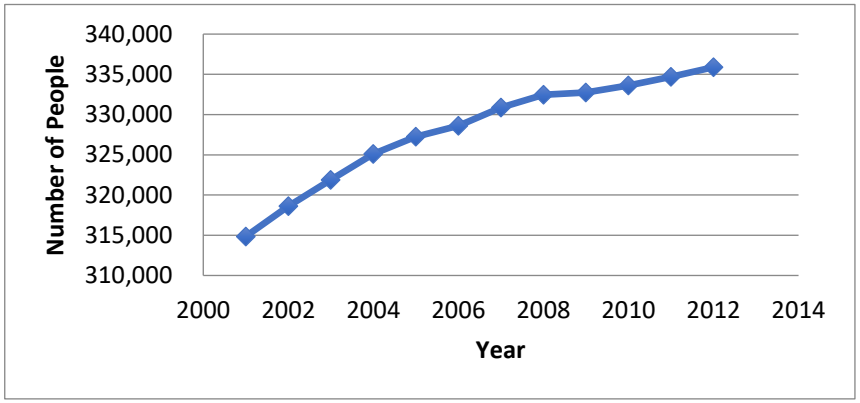
#### 2.2.7.1 Demographic Distribution and Changes

There are four unitary authorities surrounding the Humber Estuary: East Riding of Yorkshire, Kingston-Upon-Hull, North East Lincolnshire and North Lincolnshire (Figure A 5). All the local planning authorities are responsible for authorising or determining the projects and developments proposed for the boundaries of the Humber Estuary that are landward of the Humber Estuary. Where proposals fall below Mean High Water Springs (MHWS), the Marine Management Organisation (MMO) has jurisdiction for issuing consents for developments e.g. new marinas, offshore wind farms, and ensure any developments are in line with the English Marine Plans (see section 2.1.9).

The populations of these bordering authorities can be a major driver in the management of the Humber Estuary (Elliott *et al.*, 2017). As population increases, this can lead to increased demand, leading to more imports and exports of goods; potentially increasing the number of vessels in the estuary. This, in turn, requires more places to berth, leading to the expansion of the ports to accommodate these vessels (MEMG, 2003). This could also lead to a requirement to dredge the estuary to accommodate larger vessels with a deeper draught (MEMG, 2003). This increase in dredging in areas of the estuary and movement of sediment around the estuary could lead to hydrological changes in sediment transport regimes (MEMG, 2003). This, in turn, can affect ecological receptors as well as having impacts (although these can be beneficial or adverse) on tourism, recreation, employment and housing.

It is therefore important to understand the trends in populations of the counties, and to be able to determine future trends to inform any assessment (Figures 13-16) (Office for National Statistics, 2014[7]).

[7] https://www.ons.gov.uk/ [viewed 02/2017]



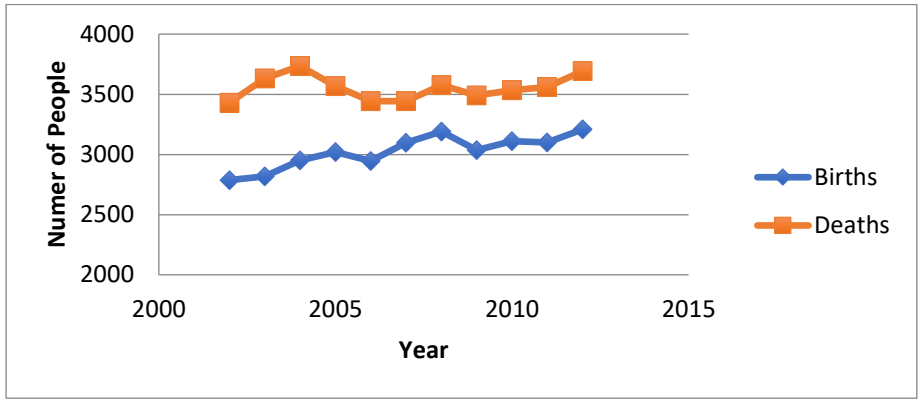
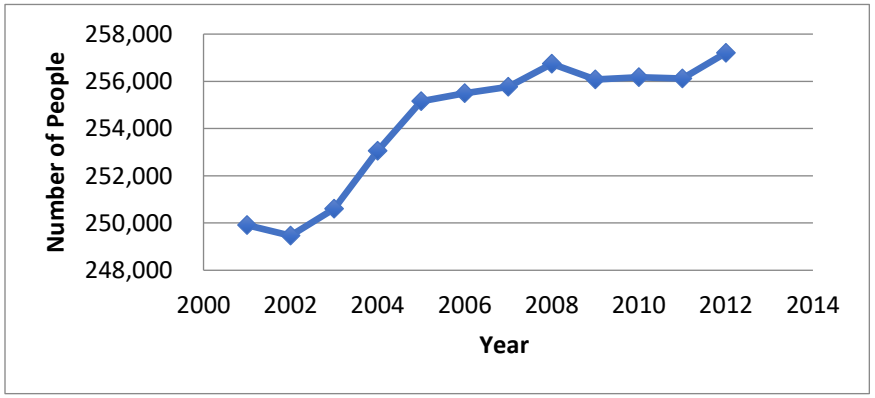




Figure 14 East Riding of Yorkshire population changes and the trends in births and deaths (above left and right figures respectively) (Office for National Statistics, 2014)



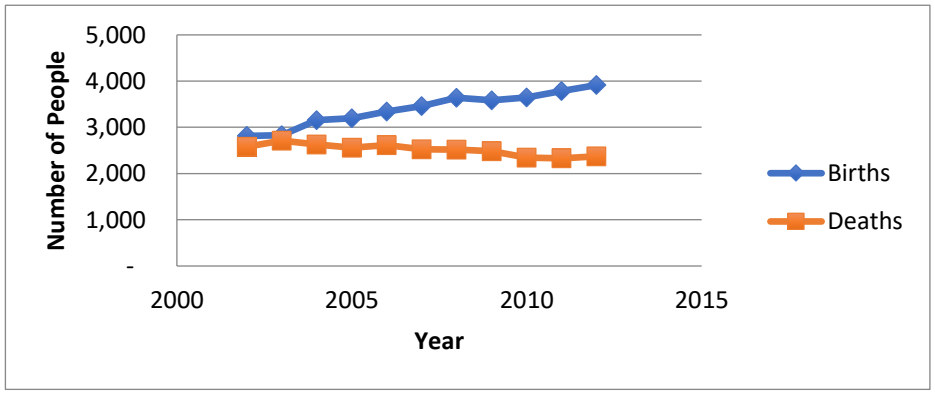
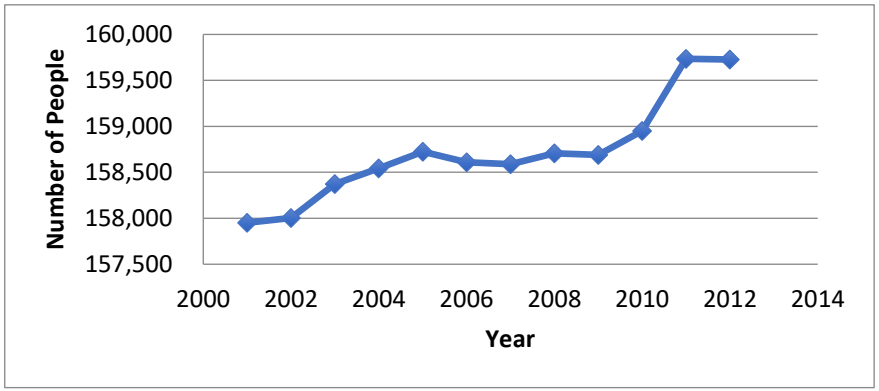




Figure 15 Kingston-upon-Hull population changes and the trends in births and deaths (above left and right figures respectively) (Office for National Statistics, 2014).



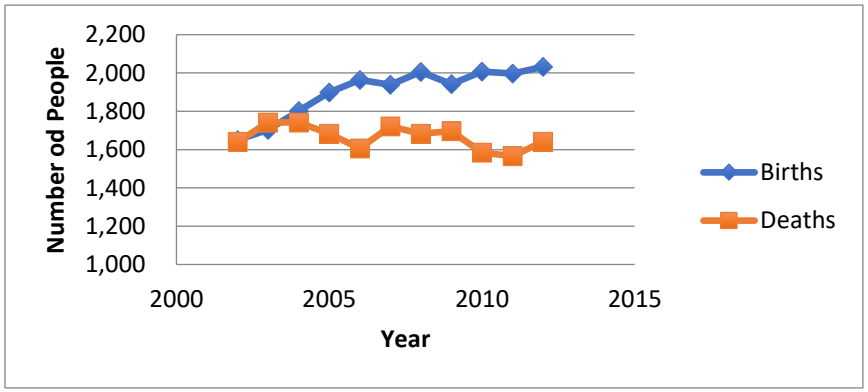
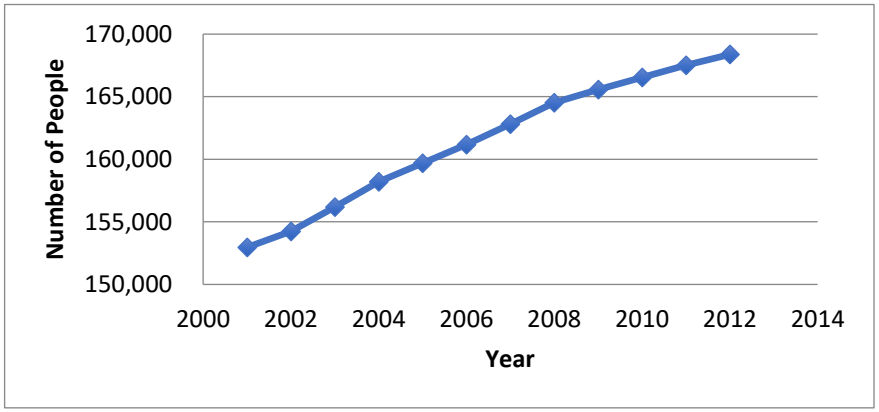




Figure 16 North East Lincolnshire population changes  and the trends in births and deaths (above left and right figures respectively) (Office for National Statistics, 2014).



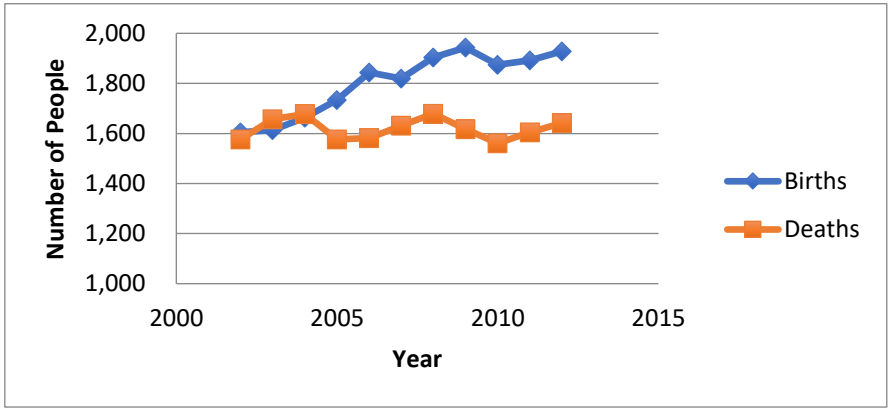




Figure 17 North Lincolnshire population changes and the trends in births and deaths (above left and right figures respectively) (Office for National Statistics, 2014).

#### 2.2.7.2 Ports and Shipping Density

The Humber Estuary supports four major ports: Goole, Hull, Immingham and Grimsby[8], as well as several smaller wharves linked to the major towns on the banks of the Humber Estuary (Cleethorpes, Grimsby, Immingham, South Killingholme, Barton-Upon-Humber and South Ferriby) (Figure A4). The Humber Estuary also has additional ports in the post-application and construction phase (e.g. Green Port Hull and Able Marine Energy Park).

The imports have remained relatively stable from 2010 in line with the UK import tonnages (DfT, 2015). The inwards tonnage show that the Humber Estuary is particularly important to the UK, representing an average of 19% per year and 20% in 2012 and 2013 (DfT, 2015) (Figures Figure 18 and Figure 19).

The outward tonnages for the Humber Estuary have also remained relatively stable, whilst the UK outward tonnages have decreased from 199 Mt in 2010 and 183 Mt in 2015 (DfT, 2015). The outward tonnages again show the importance of the Humber Estuary to the UK trade with the Humber Estuary exporting on average 10% of the UK trade per year with 2013 showing the Humber Estuary exporting 11% of the UK trade (DfT, 2015) (FiguresFigure 20 Figure 21). There are inter-annual variations on the import and export volumes that could be influenced by several factors such as the port owner organisation's business plans, local and national economy drivers.

[8] http://www.humber.com/Estuary_Information/ [viewed 16/08/2017]

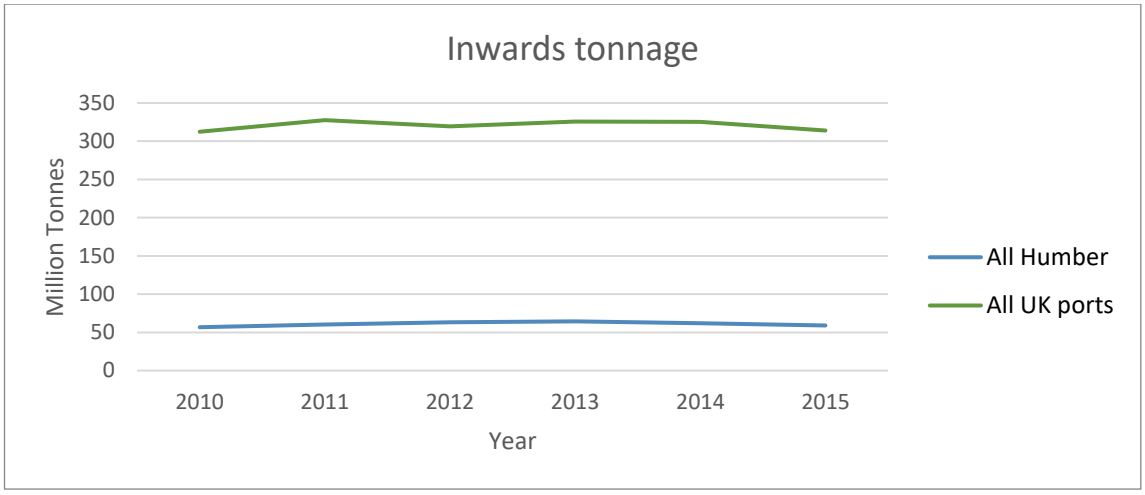



Figure 18 Inwards tonnages for the Humber Ports and UK from 2010 - 2015

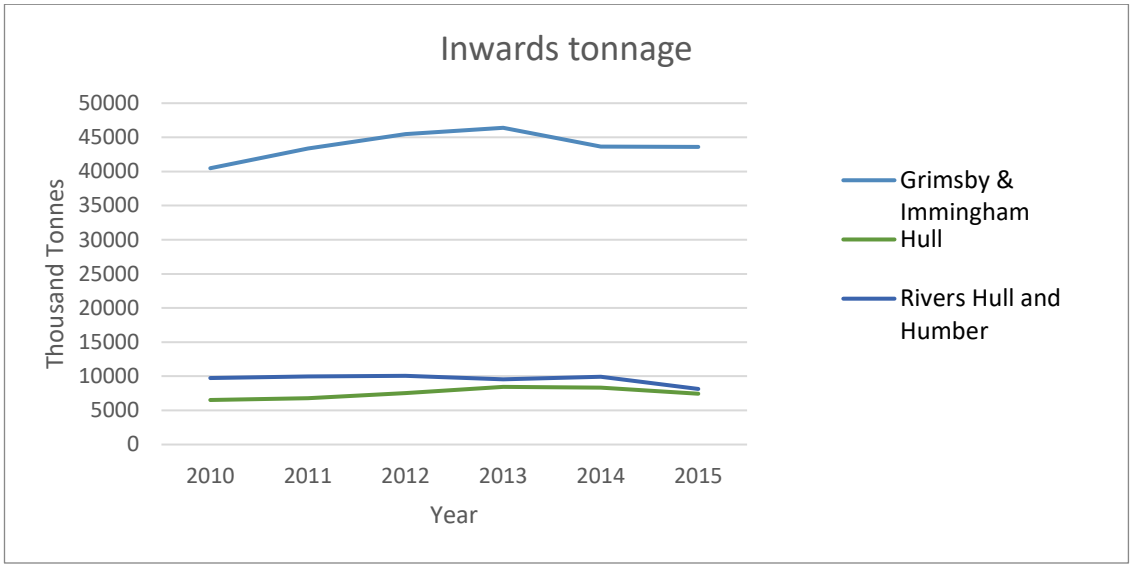



Figure 19 Inwards tonnages for the Humber ports from 2010 - 2015

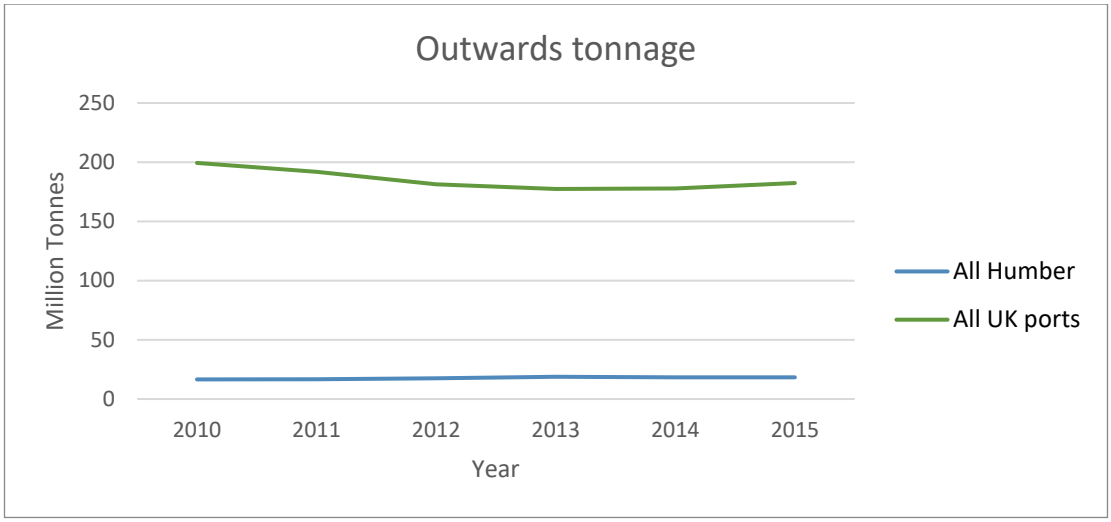



Figure 20 Outward tonnages for the Humber Ports and UK from 2010 - 2015.

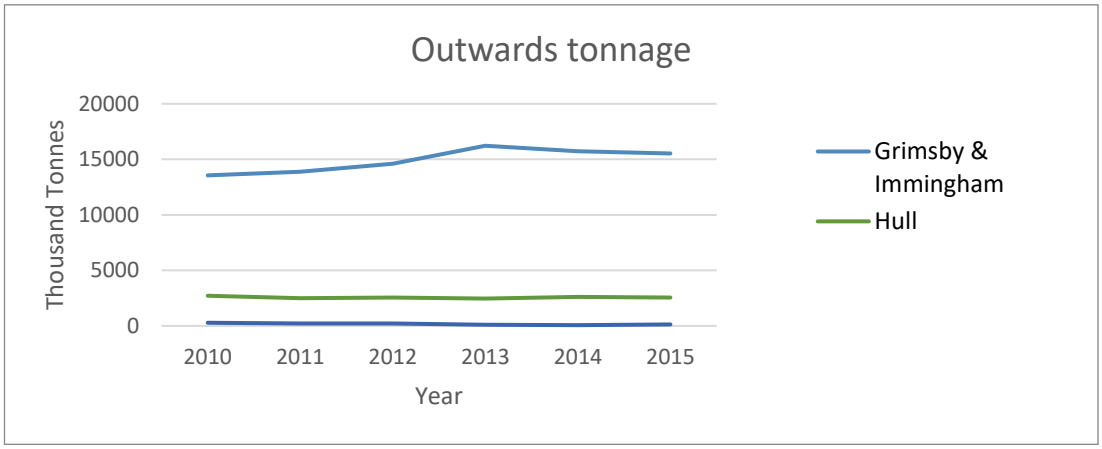



Figure 21 Outwards tonnages for the Humber Ports from 2000 to Q3 2013

#### 2.2.7.3 Dredge and Disposal Operations

Dredging is an important activity on the estuary (ABPHES, 2011) as it facilitates the movement of vessels for the import and export of goods, as well as allowing passenger vessels to berth. The effects on the hydrodynamics and hydromorphology can cause a number of negative impacts: (Johnston, 1981; Day *et al.*, 1989; Mitchell *et al.* 1998; McLusky and Elliott, 2004; Bolam *et al.*, 2006; Harbasins, 2008; Lonsdale, 2013):

- increased turbidity leading to
- reduced light penetration and
- altered behaviour in fish;
- altered tidal exchange, mixing and circulation;
- reduced nutrient outflow from marshes and swamps;
- increased saltwater intrusion;

- altered dissolved oxygen levels, and
- modifies the ratio of intertidal and subtidal, and therefore alters the area of exposed mud available for feeding birds

There are two types of dredging: maintenance and capital. Maintenance dredging is dredging that is carried out on a regular basis to maintain navigational channels to a set depth (MEMG, 2003). Capital dredging is defined as removing sediment that has not been disturbed in the last 10 years (Gupta *et al.*, 2005) or historically.

Due to the large amount of vessel traffic that uses the Humber Estuary both for commercial and recreational purposes (ABPHES, 2011), it is important that the channels are maintained to a sufficient depth to allow the vessels to navigate safely. The dredged material that is removed as part of maintenance dredge campaigns is usually disposed of to designated disposal sites within the Humber Estuary to maintain the estuary's sediment budget (see section 2.2.1). These are located throughout the Humber Estuary (Figure A 17 and Figure A 18) and generally receive material from certain ports to minimise sailing time and reduce costs (Lonsdale, 2013).

The dynamic nature of the Humber requires a large volume of material to be dredged under maintenance operations. From 1983 to 2012, an average of 1,280,317 tonnes of material was disposed of annually for all the disposal sites on the Humber Estuary (ABPHES, 2011). Disposal site HU080 received the most material in any one year: 8,945,818 tonnes in 1997 (ABPHES, 2011) (see Figure A 18). Given the maritime importance of the Humber Estuary, there have been several port developments and land claim extensions to accommodate larger and greater number of vessels (ABPHES, 2011). As part of the process for applying for a marine licence for dredging and disposal, the applicant must demonstrate that the material is not contaminated and can be disposed of to sea without having a significant adverse impact on the marine environment (OSPAR Commission, 2014).

The Humber Estuary has a legacy of mining and industrial activities, and even though these activities have decreased, the legacy of contamination remains (Luisetti *et al.*, 2014; Jarvie *et al.*, 1997) due to the tributaries (Trent, Ouse, Don, Aire, Ancholmes, Foulness and Holderness Drains) (ABPHES, 2011) having accommodated iron and steel production industries, mining, shipping, fishing, being a receiving point for oil and gas, refining capabilities, cooling water use for energy production, waste recreation, agricultural use and urbanisation (Cave *et al.*, 2005; 2003) (see Figure A 19).

To assess the potential of contaminants being released from the sediments during dredging, action levels are used (OSPAR Commission, 2014). For the UK, the Cefas Action Levels are used (Apitz and Black, 2010). There are two Cefas Action Levels: results below Action Level 1 are considered to be of no concern or within background levels. Results above Cefas Action Level 2 are generally considered to be unsuitable for sea disposal. Results that fall between Cefas Action Level 1 and Action Level 2 require further assessment such as regional differences and using the result in the context of the area to be dredged (OSPAR Commission, 2014).

Dredging applications are required to have representative samples analysed, including one or more of the following analyses: trace metals, organotins, polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs) and particle size analysis (PSA) to ensure that the material is suitable for disposal to sea (OSPAR Commission, 2014). The OSPAR Commission (2014) recognises that the requirements will change depending on the local conditions and that expert judgement and knowledge should be used. For instance, the Port of Goole has known contamination issues with PAHs and dichlorodiphenyltrichloroethane (DDT) (Dichlorodiphenyldichloroethylene (DDE) and 1,1-Dichloro-2,2-bis(p-chlorophenyl)ethane (TDE) (ABP HES, 2011) and therefore analyses for this area include PAHs and DDT/DDE.

For PCBs and PAHs there are no Cefas Action Level 2 values (Appendix 3) therefore an assessment is carried out based on previous results, of samples taken within the area to be dredged, within the vicinity of the dredge area to be dredged, dredging methods, proportion of contaminated material to be dredged and the disposal site (MEMG, 2003). Generally, in the Humber Estuary, the levels are slightly above Cefas Action Level 1. Given the large amount of data available from the Humber Estuary, there is greater certainty regarding what constitutes its suitability for disposal to sea.

#### 2.2.7.4 Agriculture

Much of the land bordering the estuary is agricultural land used for arable and dairy/sheep farming (Luisetti *et al.*, 2014; Freestone *et al.*, 1987). To provide a basis for assessing how development proposals may affect agricultural land, the agricultural land classification classifies farmland into 5 categories, with 1-3a being the best for flexibility i.e. variety of crops, productivity and efficiency (requires fewer inputs) (Natural England, 2012). The classification provides a method for assessing the quality of farmland to enable informed choices to be made about its future. The intensity of the agricultural land use does not currently affect the classification (Natural England, 2012).

The Humber Estuary supports a large area of agricultural land. Most of the land bordering the estuary is Grade 2 and Grade 3 agricultural land (with only the major towns and cities being excluded from the classification (Figure A20) (Natural England, 2012).

#### 2.2.7.5 Pipelines and cables

There are several pipelines and cables that go into, and across the Humber Estuary and are an important consideration for any future development (The Crown Estate, 2012). The construction or decommissioning will have an impact as they can temporarily alter the seabed and benthic ecology, and temporarily increase the suspended sediment load which may release contaminants into the water column (Meißner *et al.*, 2006). Even though during this operation pipelines and cables have little impact, they are at risk from damage caused by dredging or navigation of vessels, and especially during work on new projects and developments causing them to be exposed during their lifetime (The Crown Estate 2015).

#### 2.2.7.6 Barriers to Migration

Although the Humber Estuary does not have any structural barriers within the estuary, there are several barriers present within the rivers and tributaries that feed into the estuary (Figure A21) (Environment Agency, *unpub*.). These can have a negative impact on the fisheries and migratory fish species that inhabit or use the estuary as a migratory route to the spawning areas upriver (Nunn and Cowx, 2012).

The Environment Agency recognises this, and where possible they are encouraging or installing fish passes (Rickard *et al.*, 2003). These mitigation measures are beyond the scope of this study but need to be recognised as the wider holistic management, as such the EPSS will recognise their presence and importance if relevant to the study area.

#### 2.2.7.7 Water Abstractions

There are several water abstractions that are licensed within the Humber Estuary (Environment Agency, *pers. Comm*- see Appendix 4). The European Environment Agency[9] defines abstraction as "*the process of taking water from a ground source, either temporarily or permanently. Most water is used for irrigation or treatment to produce drinking water*". Most of the abstraction points (Figure A22) are within the rivers and tributaries feeding into the Humber Estuary. These abstraction points are beyond the geographical scope of this research but are noted for their importance in estuarine management.

[9] https://www.eea.europa.eu/themes/water/wise-help-centre/glossary-definitions/groundwater-abstraction [viewed 16/08/2017]

#### 2.2.7.8 Construction Licences

Any activity below MHWS requires a Marine Licence from the MMO (for England); given the Humber Estuary's importance for economic growth and sustainability, it is subject to numerous marine licence applications (section 2.1.9). Since 2010 the MMO has handled 64 Marine Licence applications for the Humber Estuary (excluding pre-application requests, dredge and disposal applications and those that were withdrawn or rejected) (correct as of 2nd July 2014) (Table 2).

Table 2 Summary of the types of construction licences issued for developments in the Humber estuary (correct as of 2nd July 2014).

| **Type of Application** | **Number Completed** | **Number Still to be Determined** |
|---|---|---|
| Construction | 35 | 4 |
| Emergency Work | 2 | 0 |
| Removals | 14 | 0 |
| Renewables | 8 | 1 |

## 3. Critique of other Tools and Concepts for Estuarine Management

Decision makers need relevant information to help inform solutions to marine problems, through formulating and implementing policy decisions (NcNie *et al.*, 2016). The next section provides an overview of the existing tools and management concepts with their advancements and shortcomings.

### 3.1 The DAPSI(W)R(M) Approach

A key problem in managing a large ecosystem such as the Humber Estuary is the defining of the hierarchy of decisions within the management framework given the numerous managers that are present (Lonsdale *et al.*, 2013; Apitz and White, 2003). The Driver-Activity- Pressure-State change- Impact (on Welfare)- Response (using Measures) (DAPSI(W)R(M)) model (Elliott *et al.,* 2017) is a tool for the integration of economic, social and natural system information into a framework in order to provide a basis for a more detailed analysis (Ness *et al.*, 2010; Maxim *et al.*, 2009). The aim of the DAPSI(W)R(M) framework is to help managers identify the ecological and human systems that may impact on, or interact with, the structure and function of the ecosystem. It is used to link the drivers of a development with the scientific evidence of what impacts these drivers can cause, and how the management options can also impact (whether beneficially or adversely) on the ecosystem (Wolanski and Elliott, 2015; Elliott, 2014; Atkins *et al.*, 2011) (Figure 22).

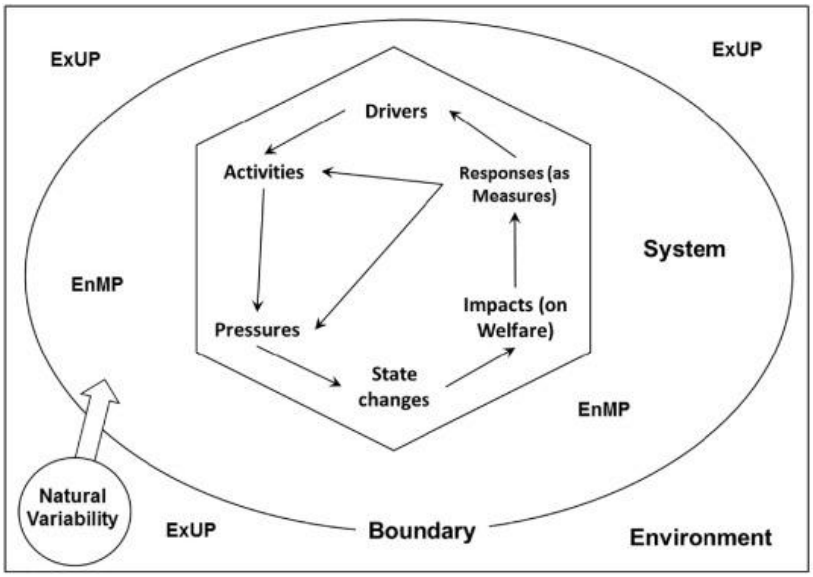



Figure 22 The DAPSI(W)R(M) framework ExUP = Exogenic Unmanaged Pressures; EnMP Endogenic Managed Pressures (from Elliott *et al.*, 2017).

The model is based on six components:

- **Drivers** of change are the economic and social forces that result from government policies, markets and activities of the private industry, e.g. the needs of society, determine the needs for the development of land.
- **Activities** are the human actions carried out to provide the Drivers;
- **Pressures** from the Drivers are created e.g. the effects of land reclamation on fish species;
- The **State Change** of the natural system needs to be determined by characterising the physical, chemical and biological conditions, against which the pressures can be assessed;
- The **Impacts (on human Welfare)** are the results of the pressures on the system, and ultimately their impacts on the human system;
- The Impacts, if adverse, will require a **Response (through Measures)** either by the system (to re-establish equilibrium) or by managers to reduce the magnitude of the changes. The response can be directed towards any other element of the model to achieve a balance between the benefits of economic and social development and ecosystem costs.

It should be noted that there are two different types of pressures: endogenic managed pressures (those causes and consequences arising from within the system that managers can control) and exogenic unmanaged pressures (those pressures arising from outside of the system and for which only the consequences within the system can be managed) (Brown *et al.*, 2014; Elliott, 2011). A response can be split into several types: *recovery* is carried out naturally by the system from change; *anthropogenic intervention* is in response to a degradation or anthropogenically changed environment; *anthropogenic response* to a single stressor, and *habitat enhancement or creation* (Elliott *et al.*, 2007).

The DAPSI(W)R(M) framework is not meant to capture the complex interdependences of a system but rather provide a framework to allow managers to prioritise and manage the system (Elliott *et al.*, 2017; Bremer and Glavovic, 2013; Diedrich *et al.*, 2010; Barnes and McFadden, 2008; Mateus and Campuzano, 2008; Berger and Hodge, 1998). A simplified cyclical demonstration of how the DAPSI(W)R(M) framework can be applied (Figure 23) and a simplified view of the framework for the Humber Estuary for increasing maritime transport is provided below in Table 3 but only shows one aspect of increasing the maritime transport (Grant and Elliott, 2016; Scharin *et al.*, 2016).

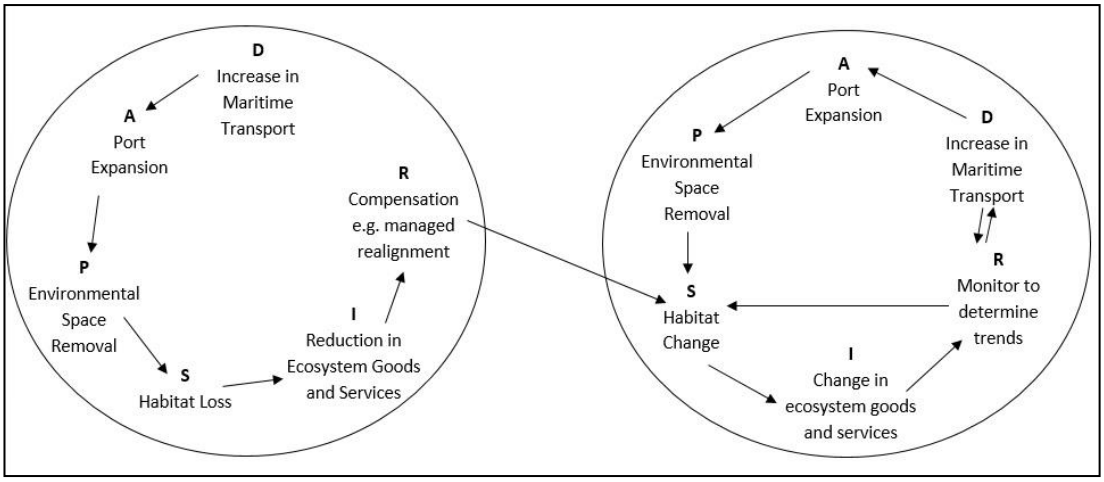



Figure 23 The application of the DAPSI(W)R(M) approach to demonstrate how it can be applied due to the increase in maritime transport on the pressure, state changes, impacts and responses and one consequence of such a response.

Table 3 A simplified view of the DAPSI(W)R(M) for the Humber Estuary for increasing maritime transport

| | Indirect Driver | Direct Driver | Activity | Pressure | State Change | Impact | Response |
|---|---|---|---|---|---|---|---|
| Endogenic Managed Pressures | Population increase | Demand for Food | Fishing | Capture Fisheries | Changes to populations, spawning sustainability, by catch and habitat damage | Stock viability, ecosystem services reduction | Economic and legal instruments such as legislation |
| | Demographic changes, science and technology advances, socio-political agendas. Economic changes | Maritime Transport | Building new ports, marinas and mooring facilities. Building associated facilities i.e. roads, waste management. Undertake dredging to enable more and larger vessels to navigate waterbody | Infrastructure demands, pollution, dredging | Community change, habitat alteration. Change in water quality, contaminant release. | Pest introduction, invasive and nuisance species, effects on ecosystem services. Contamination effects on species. Loss of conservation interest features. | Introduction of ballast water technologies and practices. Periodic analysis of dredged material. Requirement for EIA/Appropriate Assessment. |
| | | Energy Demands | Build power stations or input renewable energy devices into the waterbody. | Infrastructure Demands. Change in Land use and cover. Change in water quality. | Habitat/ biodiversity Loss and gain. Energy/ hydrodynamic change | Gains and losses of ecosystem services | Marine spatial planning, economic and legislative constraints |
| | Demographic changes. Economics. | Tourism and Recreation Demands | Building associated infrastructure such as roads and visitor centres. Tourists visiting the area and walking the landscape | | Loss of natural habitats/ biodiversity, reduction in resilience | | Planning controls, coastal spatial planning |
| | Demographic changes, science and technology advances, socio-political agendas. Economic changes | Total Societal Demands | Multiple users using the same areas and resources | Interactions between multiple users and sectors, often conflicting. | Cumulative effects on natural structure and functioning | Effects on ecosystem services | Changes in policy |
| | Demographic, climate change | Demand for flood protection | Increase in sea level rise and coastal erosion requires more flood protection to be built and maintained. | Sea level rise and coastal erosion | Physical modification and hydrodynamic changes. | Changes in accretion/ erosion patterns. Habitat modification. Altering ecosystem goods and services. | Implementation of CHaMPs to record and compensate any habitat loss. |
| Exogenic Unmanaged Pressures | Demographical Changes, science and technology advances, socio-political agendas | Increasing urbanisation, agriculture and industrialisation | Increasing the number of cars, vessels and buildings in an area affecting the micro and macro climate of the area. | Changes in temperature regimes and weather patterns | Climate Change and related impacts (natural and anthropogenic effects on structure and functioning and on ecosystem services) | | Local adaptation, compensation, policy, economic and legal mechanisms |
| | | | Increasing the number of vessels in an area. | Increased $CO_2$ and decreased pH | Ocean acidification | Reduced ecosystem services, ability for waste removal | Global agreements such as the Global Ocean Commission |
| | | | Building more waste management facilities, or cooling pipes for power stations. Increase in agriculture to meet growing demand. | Diffuse and point source land-derived pollution | Polluted components; | Environmental and food quality reduction; reduced ecosystem services | Diffuse and point source controls through permits from the Environment Agency and monitoring under WFD. |
| | | | Building facilities or changing land use for agriculture or recreation. | Habitat Removal | Loss of carrying capacity | Loss (and) gain of ecosystem service | Planning control such as requiring an EIA to be undertaken and planning permission required for land use change |

The DAPSI(W)R(M) framework (Figure 24) is a simplified version of the environmental impact assessment and management, and risk assessment and risk management processes. It identifies the relationships between the drivers and impacts (through the pressures and state changes) and the points at which managers can respond to negative pressures, state changes and impacts. It emphasises the requirement to have an iterative management process whereby response strategies can be monitored, assessed and modified to meet the requirements of the management strategies, regulations and directives.

The concept framework will be included in the EPSS as it provides a basis for a more detailed analysis with no strict layout for the outputs (as shown in Figure 23 and Table 3) (see Elliott *et al.*, 2017). As the process is iterative, re-assessing and adjusting management responses accordingly, it gives users the flexibility to modify the framework based on their needs and identifies that management options may need to be re-assessed along with new developments and drivers. This is important as ecosystems are not a static system, therefore management options need to be responsive to ecosystem changes.

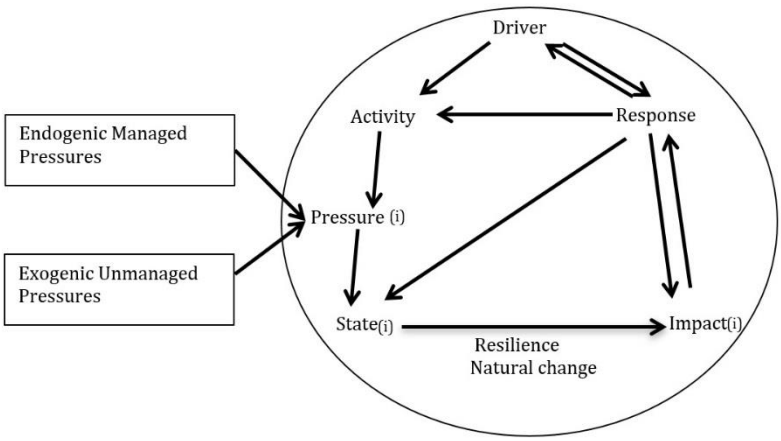



Figure 24 DAPSI(W)R(M) Framework

## 3.2 The Ecosystem Approach

The ecosystem approach is a holistic process for integrating and delivering the three objectives of the Convention on Biological Diversity (Hartje *et al.*, 2003; Maltby, 2000): conservation; sustainable use of biodiversity, and equitable sharing of benefits. Many factors must be taken into consideration when managing an ecosystem e.g. the carrying capacity, growth rate of populations over time, the extent to which an ecosystem is isolated or connected to adjacent ecosystems, and the impacts of ecological influences such as rainfall

to maintain the integrity of the system (Atkins *et al.*, 2010; Low *et al.*, 1999). The ecosystem approach has been widely adopted as an overarching principle of MSP. However, the concept is subjective and not necessarily translated into practice sufficiently (Jay *et al.*, 2016).

Areas are generally managed sectorally by concentrating on one area, activity or organisational remit (Galler *et al.*, 2016; Aubry and Elliott, 2006; Roesenberg and McLeod, 2005). Different environmental administration sectors are bound by their sectoral environmental objectives and evaluation systems (Lonsdale *et al.*, 2015). These are normally generated independently from each other, hence sectoral methodological requirements and established standards may work against a coordinated inventory and data management, and broader integration of objectives (Galler *et al.*, 2016).

Ensuring the integrity of the system requires a long-term integrated management of human activities taking into account the physical, chemical and biological interactions, explicitly (Atkins *et al.*, 2010; van Hoey *et al.*, 2010; Barnes and McFadden, 2008; Varghese *et al.*, 2008; Helsinki and OSPAR, 2003; Fabbri, 1998; Edwards *et al.*, 1997; Cicin-Sain, 1993):

- Managing human activities to respect the capacity of ecosystem to fulfil human needs sustainably;
- Recognising values of ecosystem, both in their continued unimpaired functioning and specifically in meeting those human needs, and
- Preserving or increasing their capacity to produce desired benefits in the future.

The ecosystem approach was designed to develop and promote a holistic and broad-scale approach to research, policy and management, that takes account of both people and their relationship to environment which can be understood by non-scientists, stakeholders and other interested parties (Arbo and Thuy, 2016; Haines-Young and Potschin, 2011; Carpenter *et al.*, 2009; Environment Agency, 2009; Elliott *et al.*, 2006; Holman *et al.*, 2005; Berger and Hodge, 1998; Edwards *et al.*, 1997). The ecosystem approach is designed to take into account the structure, function and processes of marine ecosystems bringing together natural, physical, chemical, physiographic, geographic and climatic factors, and integrates the activities in the area concerned to identify the relationships and interactions that may be present (Helsinki and OSPAR, 2003). By identifying these, the potential impacts that policy changes or developments may have on the ecosystem as a whole, rather than placing the emphasis on one particular area or receptor (van Hoey *et al.*, 2010). The ecosystem approach is now being incorporated into directives, legislation and policy (it is a core element of the marine spatial plans being developed in the UK) with managers being required to view the

system as a whole, and not as their component parts. An ecosystem approach allows for a better understanding of how marine socio-ecological systems operate, including how ecosystems are generated for human benefit, and how these benefits are captured and sustained. However, in bringing social systems and ecological systems together in an ecosystem approach, there will be challenges. One of which is that the spatial and temporal scales may not match (Zaucha *et al.*, 2016; Carpenter *et al.*, 2009). To address this, there is an overlap in policy to promote joined up thinking between the local actions arising from directives such as the WFD and larger geographical areas such as the MSFD. Concepts such as the DAPSI(W)R(M) framework make management of large areas within the different legislative sectors more understandable for the different stakeholders and decision makers. This includes ensuring the multiple spatial and temporal scales in any decision-making process to obtain a complete view of the consequences (Zaucha *et al.*, 2016; Atkins *et al.*, 2010; Mee *et al.*, 2008; Ranganathan *et al.*, 2008).

The United Nations Environmental Programme defines five core elements of ecosystem-based management (Cormier *et al.*, 2013). These will be incorporated into the EPSS and how they will be represented in the EPSS has been identified (in italics after the point):

1. Recognising connections between marine, coastal and terrestrial systems, as well as between ecosystems and human societies- (cf. 3.7);
2. Using an ecosystem service perspective, where ecosystem is valued for the basic goods they generate (cf 3.5);
3. Addressing cumulative impacts of various activities affecting an ecosystem (cf. section 3.10)
4. Manage and balancing multiple and sometimes conflicting objectives that are related to different benefits and ecosystem services (cf. section 3.5 and 3.7); and
5. Embracing change, learning from experience and adapting policies throughout management process- (cf. section 3.1).

The Ecosystem Approach is not a stand-alone tool but rather a facilitator to be used with other management techniques and tools to manage an ecosystem. It should be utilised to achieve sustainable management, and to do this the Convention for Biological Diversity states that the implementation should be based upon 12 guiding principles (Secretariat of the Convention on Biological Diversity, 2004). Shepherd (2004) has produced guidance on how to implement the 12 principles of ecosystem approach in five steps, which will be incorporated into the EPSS through the processes already identified i.e. the EIA process:

1. Is to determine the stakeholders, define the ecosystem area and identify the relationship between the two;
2. Is to characterise the structure and function of the ecosystem and develop a mechanism for management and monitoring;
3. To identify the economic issues that will affect the ecosystem and inhabitants and determine which economic issues will drive management choices;
4. Refers to adaptive management over space and is the likely impact of the management measures on the ecosystem on adjacent ecosystems; and
5. Refers to adaptive management over time and involves long term goals such as the MSFD (based on short term goals) and flexible ways to achieve them.

The ecosystem approach will be used to build up the EPSS as it requires the outputs to be understandable for the policy makers, non-scientists, stakeholders and scientists from different disciplines. It is important to ensure the EPSS applies an ecosystem approach as it focuses on managing an ecosystem as a whole, rather than by its component parts. By investigating the potential impacts of development or policy changes on the ecosystem it allows transboundary affects to be identified, as impacts will not cease to be an impact due to a new jurisdiction.

As identified, the United Nations Environmental Programme has defined 5 core elements of the ecosystem approach and these will be incorporated into the EPSS as the connections and relationships will be identified through the baseline characterisation, DAPSI(W)R(M) framework and through the identified and development of a conflicts matrix (discussed further in section 3.7).

The United Nations Environmental Programme has also identified that learning from experience and adapting policies and management options, is an important role for the ecosystem approach. As part of this, is the adaptive management process whereby the implementation is monitored to evaluate and review any management practices. The evaluation should include the changes to ecosystems, and other baseline conditions to determine the effectiveness of the management measures in relation to its goals. In order to make the process as comprehensive as possible, multiple stakeholders should be included in these discussions. The iterative process (which is embedded in many of the directives and frameworks) will be incorporated into the EPSS and also in other management steps, as any policy or management tool/ option should be monitored on a regular basis to ensure it firstly has the desired effect, and secondly is still the most appropriate form of management.

### 3.3 Resistance and Resilience

There are multiple scales within an estuarine ecosystem such as the Humber, and this is also true for the recovery, where different receptors will recover from different pressures at different speeds (Borja *et al.*, 2010a). If the physio-chemical system is restored then the re-colonisation should follow, leading to the recovery of the ecosystem structure and processes, although the temporal scale and extent of the recovery is dependent on many factors such as impact type, magnitude and species etc (Wolanski and Elliott 2015; Borja *et al.,* 2010a; Elliott *et al.*, 2007).

Recovery however does not always follow removal or reduction of the stressor (Figure 25), and many systems will respond to change in a non-linear manner to degradation and recovery (Duarte *et al.*, 2015; Borja *et al.*, 2010a; Mee *et al.*, 2008). Changes due to pressures to a new state (regime shifts) may occur as emergent properties, those that cannot be localised to any particular component of the ecosystem and are therefore a property of the whole system (Tett *et al.*, 2013). In an assessment of an ecosystem and its health, its resilience and recoverability should also be considered (Tett *et al.*, 2013).

An ecosystem may return to its pre-existing state i.e. before the impact occurred, depending on the time, scale and intensity of the stressor that caused the change (Borja *et al.*, 2010a). The return to a pre-existing state can be reached either naturally or by anthropogenic intervention, (management through the implementation of mitigation, compensation and remediation) but any anthropogenic intervention must have clear and defined objectives.

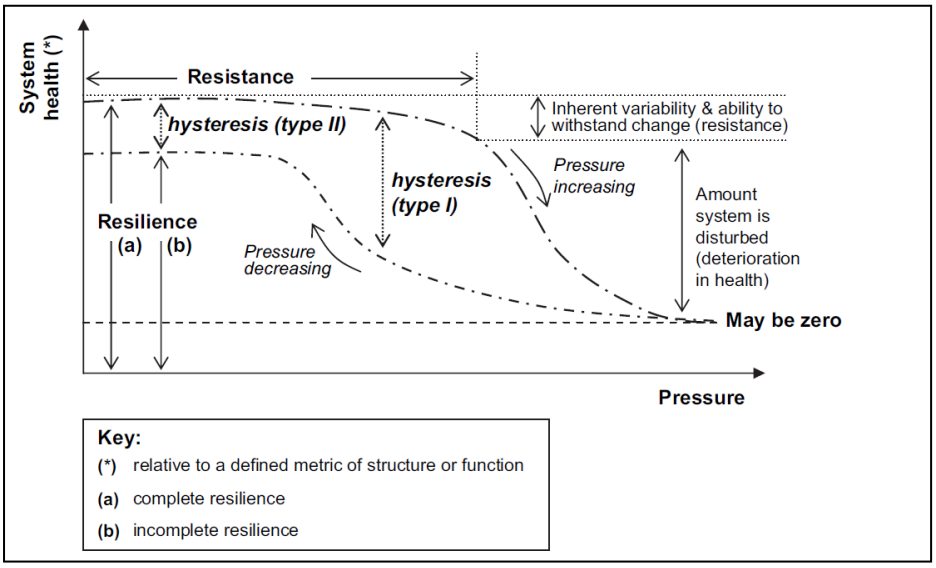



Figure 25 A conceptual of changes to the state of a system with increasing pressure (Elliott *et al.*, 2007).

Another feature to consider in the resistance and resilience is ecosystem robustness, which Elliott and Quintino (2007) define as "*the ability of the estuary to achieve a stable state by compensating for changes in the environment. The high [natural] variability [of the environment] may confer an ability to withstand stress, thus showing a resilience created by its robustness*". An issue which has been termed the "Estuarine Quality Paradox" (Elliott and Quintino, 2007) is that a naturally stressed and variable system, which is non-linear, complex and adaptive, may already be subject to high levels of anthropogenic stress. This leads to a resultant problem of trying to distinguish the natural stress from the anthropogenically-induced stress (Carpenter *et al.*, 2009; Elliott and Quintino, 2007; Arrow *et al.*, 2000) taking into consideration natural cycles making management problematic. To distinguish these changes, it is important to determine the baseline characteristics of the ecosystem to determine the consequences (environmental, social and economic) and the possible magnitude of these changes (Borja *et al.*, 2013b; Bingham *et al.*, 1995).

The discussion of sustainability is again present in the determination of a system's resilience as it can be argued that sustainability is the system's ability to maintain its structure and function over time with stressors applied (Costanza and Mageau, 1999; Chapin *et al.*, 1996). It is important to consider the length of time it takes for a system to recover and the magnitude of stress from which a system can recover i.e. does the system have thresholds for absorbing the stressors or is there a tipping point to a regime shift? Are these individual or do they change when the stressors are applied cumulatively? This should be integrated into the monitoring cycle of the EPSS. The time it takes for a threshold to be exceeded or for a system to recover will aid in determining the frequency of any monitoring and subsequent remedial actions.

Determining the resilience and resistance of an ecosystem against a proposed project is a challenging task given that an ecosystem can tolerate different levels of pressures and that different ecosystems, even if apparently similar in nature such as an estuary, all respond differently. Therefore, whilst it is useful to investigate previous studies, surveys and cycles of the ecosystem during the baseline characterisation and during the EIA, monitoring is also required to substantiate any predictions made during the EIA.

Therefore, to ensure that the EPSS emphasises ensuring the resilience of a system, it requires monitoring and feedback mechanisms. Feedback mechanisms for this purpose are an essential tool because if the monitoring shows that the project has not had a significant impact, then monitoring can cease. However, if monitoring shows that the system has

responded differently to that predicted then it allows alternative management options to be explored and the monitoring regime modified.

### 3.4 Ten Tenets of Sustainable Management

It has already been established that sustainable development not only refers to the environment, but also to the society and economy (Barnes and McFadden, 2008). This is now established in international policies, such as the United Nations which have developed 17 sustainable development goals which signatories have committed to reaching by 2030 (United Nations, 2015). Developments, applications and responses should be in line with sustainable development, and to achieve this, ten tenets have been proposed as explained below (Elliott, 2013; Barnard and Elliott, 2015).

These 10 tenets of sustainable management re-emphasise the need for a multidisciplinary approach to marine management by ensuring all stakeholders are considered and the proposals are sustainable to the different stakeholders. This requires the natural, socio-economic and political scientists to have agreed definitions and terminology to allow the effective communication to decision makers and society. To ensure the management measures are informed, the future scenarios and the management of moving baselines should be linked to monitoring and modelling.

It is important to recognise that ultimately, although these tenets are working towards a sustainable marine environment, the tenets themselves are to manage human behaviour and actions towards to the marine environment, not the marine environment itself. These include definitions that relate to the society (including recreational and working patterns), economy and environment of the area under investigation/ assessment. Whilst the balance of weighting is unclear (do society, economy and the environment have equal weighting?) the responses to potential impacts identified in assessments should be in line with the ten tenets of sustainable development outlined below. Rogers *et al.* (2007) argue that each should have equal weighting however their importance differs according to the current economic and political climate (Elliott, 2013; Marine Management Organisation, 2014a). Elliott (2013) states that the setting of social, economic and ecological objectives is ultimately a process of social choice, informed by the best available science and therefore the weights may differ depending on the political and economic climate at that time. Dowe and Ryan (2003) however view the weighting differently, and identify that the 3 pillars of sustainable development are interconnected where the economic pillar is nested in society, and the

society leg is nested in environment, which emphasises that the environment is the single limiting factor that governs what is possible.

This study reviews responses to pressures, impacts or state changes and they will be reviewed against the ten tenets of sustainable management with a confidence rating to determine how effective a management measure will be. As part of the EPSS, each step will identify which tenets the step is referring to or is addressing. This will focus the attention to one area, such as if public acceptance is proving problematic during the planning process.

Table 4 A summary of the ten tenets of sustainable development with examples to the Humber Estuary.

| **Tenet** | **Explanation** | **Humber Example** |
|---|---|---|
| Ecologically Sustainable | Any management measure should be ecologically sustainable in terms of maintaining the natural system and ecological carrying capacity as well as protecting ecosystem services and structure (what is present i.e. number of species) and the functioning (rate processes) of the estuary, not only for the present but also for future generations. | The Chowderness Managed Realignment Site, which was constructed as part of the Immingham Outer Harbour application. The site was constructed as part of the mitigation package to compensate for the direct habitat loss (22ha) and indirect habitat losses (5ha) of the designated habitat. The site would ensure the function of the designated sites and overall the Natura 2000 network would continue and was monitored against its objectives (Hemingway *et al.*, 2008; Mason and Pinnington, 2012a) |
| Economically Viable | Any management measures require funding to maintain it. It would be unjust to have an obligation to carry out the most environmentally sustainable option if the costs are so onerous it would make the scheme unviable, a cost benefit analysis of any management option should be undertaken (Elliott, 2013). | The management of dredging and disposal activities on the Humber Estuary whereby the applicant has to consider alternative, beneficial uses for the dredged material. Maintenance dredge material is generally fine, more mobile material that has recently been deposited There are limited uses for this material without first de-watering and treating it, therefore it would be economically unviable to require the applicant to wait until an alternative use for the material had been investigated and confirmed before dredging can commence |
| Technologically Feasible | To ensure that the management measures are feasible and sustainable, it is important to consider whether we currently have the methods and technology to carry out and maintain the measures | As technology such as modelling tools has advanced, applicants can use realistic scenarios in calibrated and validated models to inform the EIA. Where a significant impact has been identified on designated habitats, the Competent Authority may require the applicant to create compensation land such as Chowderness Managed Realignment Site (discussed above). Given these sophisticated models, scenarios could be used to ensure that the site will develop as required by the Habitats Regulations. |
| Socially Desirable or Tolerable | This refers to the public's perception of the impact and or response to an impact (whether it is a set of mitigation or compensation measures, policy or | To ensure that a scheme is socially desirable or tolerable, the most effective method is to consult with the different stakeholder including the public, non-government organisations, local planning authorities and |

| | | |
|---|---|---|
| | other management techniques such as restrictions) and if the public in general agree with the scheme. | businesses. It is important to communicate across the benefits to society of a healthy and managed marine environment to benefit from the ecosystem goods and services it provides (Elliott, 2013; Mee *et al.*, 2008). |
| Legally Permissible | Any management measure must abide by the various laws, regulations, directives and international agreements and treaties. As discussed above, it is important to consult with the relevant governance bodies to ensure that the objectives are not conflicting, and the measures adhere to the legal constraints. | Developers generally identify the different regulations and management strategies that the development must abide by, and gain permission from in the Environmental Statements, e.g. the Green Port Hull Environmental Statement produced a "Planning Policy" Section, which identified these requirements (URS Scott-Wilson, 2011). |
| Administratively Achievable | This tenet refers to the organisations that are responsible to the consenting, implementation and regulation of the activities and whether these already exist to regulate the scheme. | The Green Port Hull project, which due to the extent of the works involved, need permission from the Marine Management Organisation, Environment Agency, Hull City Council and required input from Natural England. It is therefore important that the developer receives clear advice from the different organisations and licensing bodies whilst ensuring that all the legal instruments are abided by. |
| Politically expedient | As Elliott (2013) states, "*if political leaders are not committed to sustainable development and management it will not happen*", even if all the other aspects are in place. It is therefore important that political leaders understand the scientific and socio-economic arguments for marine management measures as well as the political landscape. | There are no specific examples for the Humber Estuary, but any new developments must strike a balance between economic growth and environmental protection from degradation. |
| Ethically defensible (or morally correct) | This tenet refers to the understanding that any sustainable solution for the resolution of identified issues must be considered in terms of their ethics and morals (Elliott, 2013). | The Environment Agency prioritises the maintenance of flood defences and to ensure this prioritisation is ethically defensible they consult with stakeholders and the public to ensure that all possible aspects and impacts had been considered and that the Flood Risk Management Strategy fully explained the rationale (Environment Agency, 2008a, 2008b). |

| | | |
|---|---|---|
| Culturally inclusive | This ensures there is an increased stakeholder consultation allowing public and stakeholders to be involved in the decision-making process and to ensure any decisions are accepted (or at least tolerated) by society | If indigenous peoples still inhabited the same or neighbouring area as the development, then their culture should be taken into account. There is not a specific example of this on the Humber Estuary, but this tenet should still be considered when determining a new project, policy or response |
| Effectively communicated | A common theme running through these tenets is the need to communicate effectively between scientists, decision makers, stakeholders and the public (Mee *et al.*, 2008). | The Green Port Hull ES provided a Statement of Community Involvement evidencing the public and regulator consultations and an analysis of the responses as well as an analysis of the website produced for the project (URS Scott-Wilson, 2011). |

### 3.5 Ecosystem services and societal benefits

The UK Government recognises that "*maintaining and enhancing ecosystem services and restoring them where they have been lost or degraded, is increasingly recognised as essential for sustainable economic growth, prosperous communities and promoting [peoples] wellbeing*" (Defra, 2013a). It should be noted that in this context the term ecosystem services refer to the services the environment provides to people, however for the service to become a societal good and benefit, then additional capital is required to obtain the benefit (Turner and Schaafsma, 2015). Ecosystem services and societal goods and benefits are those goods and services that the ecosystem provides to the environment and that benefit humans either directly or indirectly. Eftec (2005) defines them as "*… the range of conditions and processes through which natural ecosystems and the species that they contain, sustain and fulfil human life*". Without human beneficiaries, the ecological functions and processes are not classed as ecosystem goods and services (Martin de Agar *et al.*, 2016; Fisher *et al.*, 2009; Fisher and Turner, 2008; Brauman *et al.*, 2007).

To ensure that environmental decision-making is sustainable, efficient and equitable, it is essential that all social, economic and environmental impacts of a development, both short and long term, are identified and where possible measured (Figure 41). By describing and assessing the baseline based on ecosystem services and societal goods and benefits, it enables a more thorough understanding of what is being gained and lost (for ecology, economy and human wellbeing) when a development, change in land use or exploitation takes place (Zaucha and Breedveld, 2013).

Ecosystems are experiencing serious degradation in regard to their capability of providing services, yet at the same time the demand for ecosystem goods and benefits is rapidly increasing as populations and standards of living increase (Liu *et al.*, 2010; Turner *et al.*, 2010). There are at least three broad goals that have been identified as important to managing economic systems within the context of the global ecological life support system (Liu *et al.*, 2010):

1. Assessing and ensuring that scale or magnitude of human acts within the biosphere are ecologically sustainable;
2. Distributing resources and property rights fairly both within current generation of humans and between this and future generations and between humans and other species; and

3. Efficiently allocating the resources constrained and defined in 1 and 2 above for the purpose of maximum utility or human welfare.

Benefits brought by ecosystem services are poorly quantified and it is difficult to fully comprehend the impacts of human activities. Changes in sea temperature are already affecting species populations and habitat distribution, which in turn drives alterations to community structure and function. However, it is envisaged that the valuation of ecosystem services can improve the understanding of the problems and trade-offs, and be used directly to make decisions (Chee, 2004).

Often EIAs give ecosystem goods priority over other benefits and services. This is because the goods are the end product and are directly beneficial to humans, however, to conserve these goods, the underlying services must also be maintained (Beaumont *et al.*, 2007). Once degraded, the ecosystem services may recover slowly (see section 3.3), if at all, meaning that this could lead to a long-term loss of that ecosystem service or good, and ultimately wellbeing (Carpenter *et al.*, 2009).

This study will include final ecosystem services and, where necessary, the intermediate services will be incorporated (de Groot *et al*., 2002) as although they are not easily recognised, once lost their absence usually is recognised i.e. through the loss of the final service or benefit which the intermediate service supports. This study will also include benefits such as recreation as an ecosystem service, given that these activities can boost economy, conservation etc. (Brander *et al.*, 2006).

Ecosystem services and societal benefits are integrally linked and therefore changing or preserving one aspect can lead to the changes in others. For example, by wanting to protect properties, local authorities build sea walls and groynes to combat coastal erosion. However, these structures can inadvertently accelerate the degradation of the coastal environment, either where they are installed or further up or downstream. These can affect the recreational and aesthetic value of the area and can also disturb wildlife.

It is important to identify the links between the ecosystem functions and human support systems. To understand how the relationships are connected and how even small changes could negatively influence ecosystem function, goods and services. Figure 26 demonstrates a simplified process, which needs to be followed to determine these links.

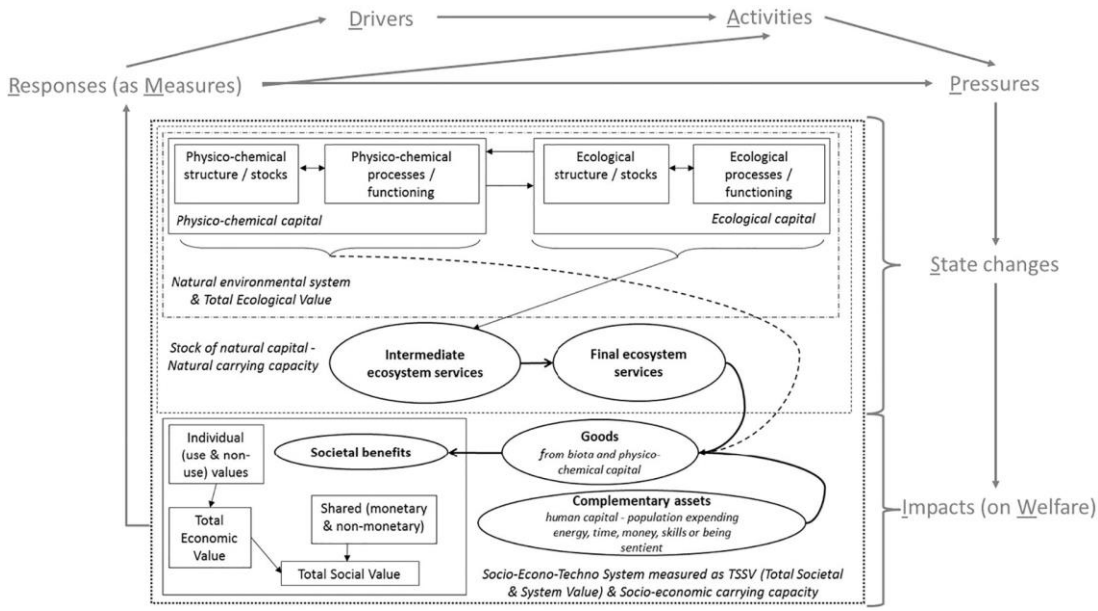



Figure 26 A conceptual model showing how ecosystem functions link to human support systems (from Elliott *et al.*, 2017).

### 3.6 Valuation of Ecosystem goods and services

The application of economic valuation techniques to ecosystem services and societal benefits, can provide valuable information for conceptualizing decision choices and evaluating management options. The concept of ecosystem services encompasses the delivery, provision, production, protection or maintenance of a set of goods and services that people perceive to be important (Chee, 2004). Many studies have put an economic value to the ecosystem goods and societal benefits (Luisetti *et al.*, 2013; Barbier *et al.*, 2011; Bullock *et al.*, 2011; Barbier 2009; Boyd and Banzhaf, 2007; Brauman *et al.*, 2007; Brander *et al.*, 2006; EFTEC, 2005; de Groot *et al.*, 2002; Loomis *et al.*, 2000; Costanza *et al.*, 1997).

However, due to the large area of the Humber Estuary, determining the total ecosystem services and societal goods and benefits for the entire area would not be feasible (Barbier *et al.*, 2011; Swift *et al.*, 2004; Townsend *et al.*, 2011). This study will use the ecosystem services and societal benefits, as well as environmental indicators (these are developed in section 4.14), to determine the state of the ecosystem and determine how plans and projects could affect the system (environmental indicators are discussed in more detail in section 4.7). The EPSS tool will instead broadly identify the ecosystem services and societal benefits provided by the Humber Estuary and advise the most appropriate valuation methods with the references for the users to determine the best way to incorporate ecosystem services and

societal benefits into an impact assessment. The ecosystem services and societal benefits and their uses will be categorised as such for this study by their function and usage (Table 5).

Table 5 The classifications of the ecosystem goods and services (Fothergill *et al.*, 2012; Eftec, 2005)

| **Value** | **Service Group** | **Examples** |
|---|---|---|
| Direct | Provisioning | Production of food<br>Production of timber<br>Production of water<br>Navigation |
| | Cultural | Recreation<br>Tourism<br>Landscape Use |
| Indirect | Cultural | Education<br>Research |
| | Regulating | Water/ Soil/ Air purification<br>Climate regulation<br>Carbon sequestration |

### 3.7 Conflicts

Since the Humber Estuary acts as an interface between the coast, land and various water bodies and watercourses, it produces cumulative ecosystem services and societal goods and benefits. However, due to the limited space, the different uses and users of these ecosystem services and societal benefits can come into conflict, and need to be managed to diminish any negative impacts and optimise benefits (Chang and Lin, 2016; Barbanti *et al.*, 2015; Toonen and Tatenhove, 2013; Fearnley *et al.*, 2012; Barbier *et al.* 2011; Varghese *et al.*, 2008).

To determine the conflicts, the ecosystem services and societal benefits have been put into a conflict matrix against the different land uses (Table 6) (using Jacobs *et al.*, 2012 as a base). This can be adapted to other conflicts matrices for stakeholder conflict identification. These matrices can help identify where conflicts exist and identify unsustainable activities. Conversely, it can also identify beneficial or 'neutral' impacts, which can occur between the different activities, users and ecosystem services.

On the Humber Estuary there are several conflicting activities that occur, but also there are several ecosystem services and societal benefits that can benefit from certain activities (Table 6). It should be noted the "education/ research" service has been included as it is a resultant beneficiary of all activities. This is because regardless of the activities that may be carried out, there are always opportunities to research and learn from the potential changes that may occur following the implementation of any activity.

As such there are several land uses that have been categorised as “dependent”. These have been assigned as such, and are dependent on the location and details of the activity; the resulting change could be a conflict, benefit or neutral. For example, many of the ‘impacts’ on ecosystem services have been classed as “dependent” for “Flood Bank” construction. Taking ‘carbon sequestration’, if the flood bank is a grass bund, then the change could be beneficial by increasing the surface area of vegetation available for carbon dioxide uptake. Whereas if the flood bank is of a hard structure such as rock armour or concrete, then the surface area of vegetation will be reduced (developed using Jacobs *et al.*, 2012).

Table 6 Conflicts Matrix. Green Cells- beneficial interation, orange- conflict, blue- interaction depends on situation, grey- no know interation

| Function | Land Use | Conservation | | Archeaology | | Recreation | | | Flood Defence/ Coastal Protection | | Ports | | | | | | | | Infrastructure | | | | Industry | | | Agriculture | | Extraction | | | residential | | | Tourism |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ecosystem | Sub Land Use / Ecosystem Good/ Service | protected subtidal areas | protected intertidal areas | heritage on land | heritage in estuary | Footpath | sailing/ boating | Bird Watching | Flood bank | Managed realignment | Navigation | Capital dredging | Maintenance dredging | Vessels | Land reclamation | disturbance adjacent to the system | disturbance in the system | import pipelines | bridges | piers/ jetty | seawall | cables | Water Abstraction | Discharge | Activity adjacent to system | run-off | Water Abstraction | commercial | recreational | wildfowling | Discharge | disturbance adjacent to the system | drinking water abstraction | beaches |
| Estuary Water body | Fish | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Vegetation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | water supply | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | navigation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | climate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | carbon sequestration | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | maintain biodiversity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | nutrient cycling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | recreation future uses | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | visual amenity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | tourism | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | education/ research | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | landscape use | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Estuary - Mudflats | Fish | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | carbon sequestration | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | water purification | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | air purification | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | maintain biodiversity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | nutrient cycling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | sediment formation and stability | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | shoreline protection | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | recreation future uses | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | visual amenity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | tourism | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | education/ research | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | landscape use | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Estuary - Sand Dunes | Vegetation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | water supply | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | climate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | carbon sequestration | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | water purification | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | air purification | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | maintain biodiversity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | nutrient cycling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | sediment formation and stability | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | shoreline protection | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | recreation future uses | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | visual amenity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | tourism | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | education/ research | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | landscape use | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Managed realignment Sites | Fish | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Vegetation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | water supply | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | climate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | carbon sequestration | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | water purification | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | air purification | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | maintain biodiversity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | nutrient cycling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | sediment formation and stability | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | shoreline protection | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | recreation future uses | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | visual amenity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | tourism | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | education/ research | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | landscape use | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Conservation Designations | Fish | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Vegetation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | water supply | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | climate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | carbon sequestration | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | water purification | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | air purification | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | maintain biodiversity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | nutrient cycling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | sediment formation and stability | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | shoreline protection | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | recreation future uses | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | visual amenity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | tourism | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | education/ research | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | landscape use | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Agriculture | Crops | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | livestock | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Carbon sequestration | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Disease and Pest Control | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Pollination | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Water Purification | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Nutrient Cycling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Future Uses | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Visual amenity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Education/ research | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

The EPSS cannot identify all the stakeholders of a system as it depends on the data provided for input in the GIS system, and this requires maintenance. It can however provide the guidance of when to start consulting the stakeholders, such as identifying their requirements and any conflicts e.g. of space or resource. To ensure decision- making results in sustainable outcomes (both in terms of use and development), it is essential that all potential social, economic and environmental impacts of a development, both short term and long term, are identified and, where possible, measured.

Ecosystem services and societal benefits are increasingly being referred to in policy, and therefore the EPSS should identify the method of identifying and assessing/quantifying those goods and services a system provides. The EPSS framework developed here accommodates the need for identifying and assessing the ecosystem goods and services by incorporating the steps into the characterisation of the baseline for an EIA. These steps have been incorporated into the EPSS framework as by describing and assessing the baseline, based on the ecosystem goods and services, it enables a more thorough understanding of what could be gained and lost in terms of ecology, economy and human wellbeing.

The EPSS will be based on identifying the structure and function on an ecosystem to identify the ecosystem goods and services and categorising for inclusion into the assessment.

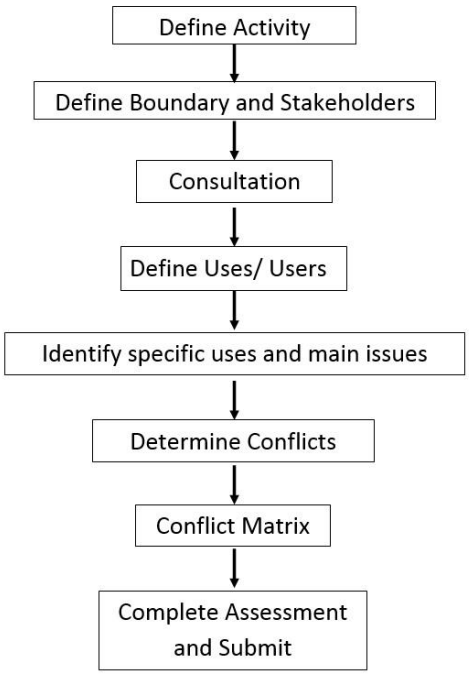



Figure 27 Determining a conflicts matrix

### 3.8 Critique of the Application of Marine Spatial Planning in Decision Making

Spatial planning has historically been used for managing land use, whilst this concept has been applied in various forms in the marine environment, it has predominantly been for individual sectors such as shipping lanes, mineral extraction (managed by the MMO in England), protected areas (managed by Natural England and JNCC in England) etc. rather than as a holistic approach (Kelly *et al.*, 2014; Douvere, 2008).

With an increasing population, advances in technology and shifting consumer demands, these have all considerably increased the need for more food, energy and trade from the marine environment and therefore a form of marine planning is required to influence where and when human activities can occur to reduce user-user and user-ecosystem conflicts (Arkema *et al.*, 2015; Baldwin *et al.*, 2014; Jay *et al.,* 2016; Prestrelo and Vianna, 2016; Douvere and Ehler, 2009; Douvere, 2008). Marine spatial planning is steered by, amongst others, the EU Integrated Maritime Policy, Marine Strategy Framework Directive, Water Framework Directive and in UK the Marine and Coastal Access Act (Kelly *et al.*, 2014). It is an ecosystem-based approach that must consider the entire ecosystem including human beings, with the objective to maintain an ecosystem in a healthy, productive and resilient condition, continuing to provide ecosystem services and societal goods and benefits (Baldwin *et al.*, 2014; Kelly *et al.*, 2014).

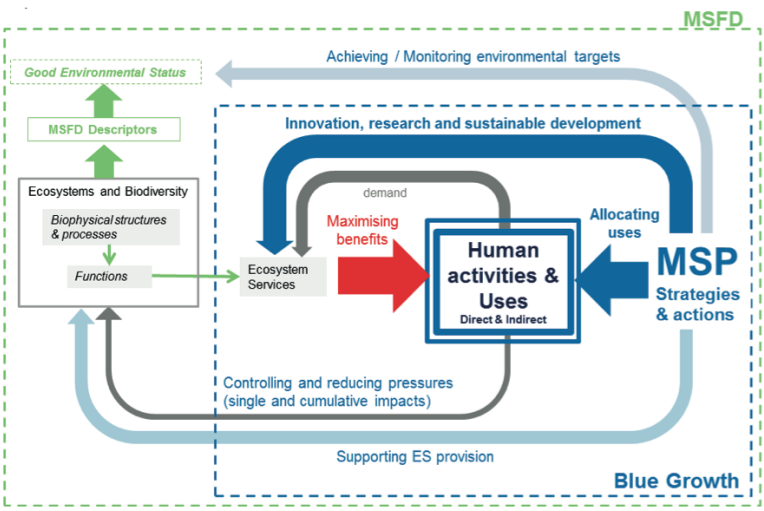



Figure 28 Conceptual model of the role of Marine Spatial Planning within the concept of European Directives and human activities. From Trosin *et al.* (2016)

Trosin *et al.* (2016) undertook a review of the MSP process of the State of Washington's coast. The scope of which was to ensure a resilient and healthy marine ecosystem on the State of Washington's coast that supports sustainable economic, recreational and cultural opportunities for coastal communities, visitors and future generations. The authors provide

an example of a developer wanting to develop a renewable energy facility and interviewed participants as to how worried they were about the impacts on existing uses and users. They found that MSP was a method, if implemented robustly, to strategically plan for new uses and protect existing uses.

The multiple uses, as well as new emerging uses such as renewable ocean energy, constitute a management challenge for sustaining resources and coordinating state decision-making to improve coordination and reduce duplication between agencies (Trosin *et al.*, 2016). This is demonstrated by Boyes *et al.* (2007) who showed that it is feasible to create a multiple-use *a posteriori* zoning scheme for the Irish Sea through summarising and mapping the existing area, based legislation and regulations.

A MSP should be a framework to facilitate an integrated strategic and comprehensive planning process to take into account spatial and temporal overlap of human activities and to identify potential conflicts; allow a connection between the various authorities; provide a connection between the offshore activities and resource use and onshore communities; identify areas of conservation for sensitive marine areas; and identify areas of investment certainty (Baldwin *et al.*, 2014; Ehler, 2003; Douvere, 2008; Gilliland and Laffoley, 2008). Douvere (2008) states that MSPs should ensure there is consistency between the land and a marine system as one is not wholly independent of the other, especially at the land-sea interface. The success of MSP is challenged by the need to manage many human activities that vary in spatial and temporal footprint, the pressures from which impact the marine environment and overlap in many areas (Goodsir *et al.*, 2015).

In order to accomplish this, MSPs should draw together the relevant objectives and information about pressures, use and state of the marine environment to assess spatial interactions and cumulative impacts among different sectors, activities and uses. The spatial planning process should then analyse a range of alternative measures for managing interactions, reducing impacts, restoring ecosystem function and delivering sustainable use (Gilliland and Laffoley, 2008). Sea use management is a continuous, iterative, adaptive and participatory process which includes research, analysis, planning, financing, implementation, monitoring and evaluation (Barbanti *et al.* 2015; Ehler, 2008); but no one approach exists for all of these to be undertaken, and the comparability is often not accomplished to allow lessons learnt to be directly applicable to other areas or projects. Jay *et al.* (2016) identified that historically the ecosystem approach and MSP had not achieved its potential in that single uses were regulated independently, whilst conflicts were overlooked and the opportunity to resolve them was missed.

To support the implementation of the English marine plans, there are several tools and documents that the MMO have developed including the Marine Information System Tool (which displays where policies and activities (such as aggregate extraction) take place although not on one map); a Planning Advisory Service Soundness Toolkit (provides advice on how to prepare local plans); the Marine Planning Portal (where developers, decision makers and stakeholders can view and appraise the evidence base) and the documents on the development.

The tools provide useful information, however given the potential for overlap in activities, potential conflicts and policy objectives, by having these as separate tools it can still leave gaps in knowledge for developers and decision makers. There is currently no universal tool that can guide a developer/decision maker through the process and highlight where receptors, activities, legislative requirements etc. are, in relation to a development.

Even though MSP is still in its infancy and therefore still being developed, there appear to be several omissions, for example one objective of the marine plans was to allow connection between the various authorities to allow a more holistic approach to the decision-making process, however the marine plans do not appear to address this. Trosin *et al.* (2016) identified that as a minimum, MSP will identify areas that 1) new uses should avoid, and 2) may be suitable for new uses. The MMOs Marine Planning Portal does contain a layer with the administrative boundaries, however without exact coordinates this can sometimes be misleading, and a developer may identify the incorrect authority. Whilst this would be identified in the planning process, an objective of the marine plans is to reduce regulatory burden and improve efficiency which may not be met in this instance. The tool developed as part of this study will allow developers and decision makers to input the coordinates and identify the relevant authorities, directly and indirectly affected, and ensure the process is streamlined.

### 3.9 Existing Decision Support Systems/Tools

Oinonen *et al.* (2016) put forward a framework for probabilistic and holistic cost-effectiveness analysis, to provide support in selecting the least-cost set of measures to reach multiple environmental objectives for achieving GES under the MSFD. This was accomplished by analysing complex ecological-economic trade-offs and accounting for uncertainty. Dunstan *et al.* (2016) however developed a hierarchical approach for ecosystem based management and marine spatial planning which highlights the importance of, and encourages using available scientific knowledge and governance whilst supporting the

gradual process to more complex and information rich structures for adaptive management as required, which will be fed into the EPSS tool.

i. Marine Scotland's Impact Assessment Tool

Marine Scotland (the Regulator for Scottish Waters) has developed an impact assessment tool (http://www.gov.scot/Topics/marine/Licensing/marine/tool), which 'predicts' potential impacts of wave and tidal renewable energy development on Scotland's marine environment. The impact assessment tool was mainly driven by the Climate Change (Scotland) Act 2009 which specifies that Scotland has an obligation to cut its emissions by 100% by 2020 to protect the environment. The aim of the tool was to identify what is known about the impacts of wave and tidal energy devices in the marine environment and use present knowledge to provide information to decision makers.

The tool interprets ecological data and information to address potential vulnerability of species and habitats. It has the potential to absorb technical information to identify stresses placed on the environment from certain types of developments. It identifies potential effects and allows interactions to be scored using a set of criteria to identify priority issues associated with any type of marine energy development. It also has the potential to absorb new information and data.

This portal was developed for the sole use of assessing the marine renewable energy devices. However, it can be adapted to incorporate other activities and pressures as potential effects and impacts can be similar across the sectors e.g. piling for a harbour development and offshore wind farms. The information used in the impact assessment tool will be used in this study to develop activities/pressure and impacts matrices to sit behind the database to indicate the potential impacts associated with the activities.

ii. OSPAR Ecological Quality Objectives

Ecological Quality Objectives (EcoQOs) are tools that have been developed to assist OSPAR and the North Sea Conference process to apply the ecosystem approach to the management of human activities (OSPAR Commission, 2010). EcoQOs define clear environmental indicators that promote a healthy North Sea ecosystem as part of the ecosystem approach. However, none of the EcoQOs are either applicable to the case study area or appropriate in the context of this study and will therefore not be considered further. Decision makers and planners should however take these EcoQOs into consideration for future applications.

iii. Options for Delivering Ecosystem-Based Marine Management

The Options for Delivering Ecosystem-Based Marine Management (ODEMM) Project Pressures Assessment (PA) User Guide (Robinson and Knights, 2011) provides a tool to identify the key pressures on marine ecosystem characteristics to prioritise management. It identifies that pressures can be physical (e.g. abrasion), chemical (e.g. introduction of synthetic components) or biological (e.g. introduction of microbial pathogens) and the same pressure can be caused by several different activities.

Expert judgement was used to complete the pressure activity matrix by categorising the following factors using the best available information on the spatial and temporal distribution of the sectors and ecological characteristics within a region:

(i) The total extent of pressure from sector where there is overlap with ecological characteristic;

(ii) The frequency of occurrence of the pressure from sector where there is overlap with ecological characteristic in an average year;

(iii) The generic degree of impact of pressure from sector on ecological characteristic;

(iv) The generic resilience of ecological characteristic within the region being assessed based on its current status;

(v) The persistence of the pressure i.e., the length of time that the pressure continues to occur after cessation of the activity causing it in ecological characteristic.

The ODEMM PA involves expert judgement to carry out the assessment. Such expert judgement requires information on spatial and temporal extent of sectors and ecological characteristics and knowledge of the generic sensitivity of the different habitats to the pressures. Four steps are needed:

1. Actual footprint of sector/pressure;
2. Generic sensitivity to a sector/pressure;
3. Management potential, and
4. Confidence assessment.

The steps identified by the ODEMM PA (above) will be used to ensure that the EPSS tool encompasses all the relevant considerations for impact assessment including cumulative impact assessment. The activities, pressures and receptors will be used alongside the other studies identified (Eassom and Church, 2013; Elliott *et al.*, 2013; Marine Scotland, 2012; Koss *et al.*, 2011; Robinson and Knights, 2011; Tillin *et al.*, 2010; JNCC, 2013) to ensure a comprehensive list is provided (see Chapter 4).

Similar work was carried out by ABPmer on behalf of Defra as part of the MB0102 project, which sought to develop a pressures-sensitivity matrix to describe the sensitivities of MPA features to a variety of pressures (Tillin *et al.*, 2010). The pressure assessment weights the interactions shown by the linkage tables according to the generic sensitivity of an ecological characteristic to any sector/pressure, the actual footprint of the overlap with the pressure and the ecological characteristic and the likely persistence of the pressure on the environment.

iv. Integrated Valuation of Ecosystem Services and Tradeoffs

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) is a suite of modelling tools developed in the US that map, measure and value the services and societal benefits that sustain human life developed by the Natural Capital Project (Nelson *et al.*, 2009). The tool is designed for use with ArcGIS software and a marine-specific version enables the mapping and trade-off analysis potential ecosystem services to assist academics and decision makers in the planning process.

InVEST informs and assesses baseline conditions, and tests the condition of the ecosystem under different scenarios to develop a spatial plan for management. It can be used to assess how ecosystems interact with each other and with marine users, although it is limited in how it models human interactions and indirect effects of activities.

Decision makers develop future scenarios to show, for example, alternative areas where marine protected areas might be established, where agricultural land might be converted to residential development, or where climate change is expected to affect precipitation and temperature patterns.

v. Artificial Intelligence for Ecosystem Services

The Artificial Intelligence for Ecosystem Services (ARIES) methodology "*adopts a uniform conceptualisation of ecosystem services that gives equal emphasis to their production, flow and use by society while keeping the model complexity low enough to enable rapid and inexpensive assessment in many contexts and for multiple services*" (Villa *et al.*, 2014). It is a web-accessible tool for use in ecosystem services assessment and provides scenario testing. ARIES uses valuation data from the University of Vermont Ecosystem Services Database and obtained spatial data from open sources. It is acknowledged that data for the UK are limited, although users may upload their own GIS data for analysis.

ARIES uses probabilistic Bayesian Network models to map ecological and socio-economic factors that contribute to the provision and use of ecosystem services (Villa *et al.*, 2014). Outputs therefore come with an uncertainty rating, and allow models to be run with incomplete data sets, with caveats regarding uncertainty. Improved maps of provision, use and benefit flows can help guide policy decisions. ARIES can identify those areas critical to the supply of services to beneficiaries and therefore enable conservation and restoration activities to be focused in relevant places to increase or maintain benefit flows. Currently, the ARIES models for marine ecosystem services are limited.

As above, this tool has not been incorporated as this study will not put an economic value to ecosystem services and societal benefits, because the aim of the tool is to provide the information to navigate the legislative requirements required for a project or development, and to provide the information for an impact assessment to be carried out.

vi. Baltic Sea Management-Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning

The BALANCE Project (Baltic Sea Management-Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning) aimed to take a holistic approach to MSP taking both human and environmental interests into account, operating within the multinational context of the Baltic Sea region (Marine Management Organisation, 2014a; b; c; Leth, 2008; Nyberg *et al.*, 2007). The approach was built around three key elements: a combination of ecological information and information on multiple human uses, pressures and impacts; a spatial planning template describing the steps towards marine spatial planning; and a simple, zoned approach allowing space for all human uses while minimising environmental impacts

In addition, for a consistent future approach to mapping programmes and facilitation, the uses of internationally agreed Protocols and Standards are crucial for different survey methodologies and sectors (Nyberg *et al*, 2007). The aim was to show that it is possible to agree to a joint approach to the development of ecological relevant models and maps at the regional sea level even though 10 independent States share the area. Whilst useful, it has been developed for an area and cannot easily be transferred to another area, (or at least this has not been demonstrated) and does not address the information required in the early stages of assessment e.g. screening and scoping which the EPSS tool will deliver.

vii. EIA Calculator

The EIA Calculator is a free software package available for windows operating systems (available from http://www.5oes.com/eia-calculator/10). Its aim is to provide "*a consistent and transparent methodology for determining the significance of environmental impacts*"( Quilliam, 2015). Its developers also view it as a way to validate conclusions of submitted impact assessments and for use in Strategic Environmental Assessments.

The developers highlight that the tool does not replace the guidelines for EIA approaches and any conclusion should be supported by evidence. The EIA Calculator was used by Quilliam (2015) to assess the impacts of large infrastructure on the marine environment. The concept behind the calculator is derived from Leopold *et al.* (1971) whereby a matrix sits behind the assessment tool, and against which environmental impacts are scored based on the receptors' sensitivity. The calculator applies an equal weighting across significance and should be used for each potential impact in turn, in both pre-mitigation and post-mitigation scenarios.

The tool itself is a simplified view of the process of carrying out an impact assessment; however, the inputs are still subjective and can provide inconsistent results as it is the user who decides what weight to provide to an impact/receptor combination. Therefore, if one user values a receptor more than another, the two results will show differing results of the same impact assessment.

viii. Bowtie Analysis and Bayesian Network

The management of the marine (including estuarine and coastal) environment is a version of risk assessment and risk management whereby the decision maker considers the potential risks, and the uncertainties associated with these risks to decide (Cormier *et al.*, 2013). It is generally considered that high risks will occur if there is a high likelihood that a hazard will be realised, and the receptors are vulnerable to the risk, but the risk can be limited if there is a low likelihood of this happening, hence the inclusion of mitigation measures within the final decisions (Judd *et al.*, 2013). Table 7 shows the steps taken to undertake a risk assessment, which may lead to risk management, and Figure 29 shows the matrix for the associated risk based on the consequence and likelihood of the hazard occurring.

[10] Accessed 16/08/2015

Table 7 Stages in risk assessment leading to the need for risk management

| Stage | Detail |
|---|---|
| Problem formulation | What needs to be assessed? |
| Hazard identification | What can go wrong? (What are the hazards) |
| Cause identification | What can lead to the hazard occurring. (what causes the hazard)<br>Quantitative- how often or how likely if it that these causes will occur? |
| Exposure assessment | Quantitative: how does the hazard reach the receptor? At what intensity? How long for? And how frequently does it reach/affect the receptor?<br>How likely is it that the receptors will be exposed to the hazard? |
| Consequence or effect identification | What are the consequences of the hazard if it occurs? |
| Risk characterisation and estimation for consequences | What are the risks? What is the probability of the consequence happening? Estimated both before and after preventative and mitigation measures are put in place. |

| Consequences | | | |
|---|---|---|---|
| | Medium | High | High |
| | Medium | Medium | High |
| | Low | Medium | Medium |
| Likelihood | | | |

Figure 29 Matrix demonstrating the associated risk based on the consequence and likelihood of the hazard occurring

In decision-making, low consequences or low likelihood risks are typically perceived as acceptable and therefore only require monitoring, whereas high consequences or high likelihood risks are perceived as unacceptable and a strategy is required to manage the risk, if consent is to be granted. Medium risks may require a structured risk assessment depending on the hazard posed, the pathways available, and the receptors' vulnerability (Judd *et al.*, 2013).

In undertaking an environmental risk assessment, Bowtie analysis can be used. Bowtie analysis provides a visual tool, generally as part of risk assessment and risk management (like the DAPSI(W)R(M) model) (Figure 30). It can be used to examine the potential causes of an impact and source and how it could be prevented and/or mitigated against. Whilst Bowtie

diagrams are useful to demonstrate the potential causes of an impact, they are restricted to a geographical representation and may not represent the complex interactions of the natural world (Smith *et al*, 2014; Badreddine and Amor, 2013).

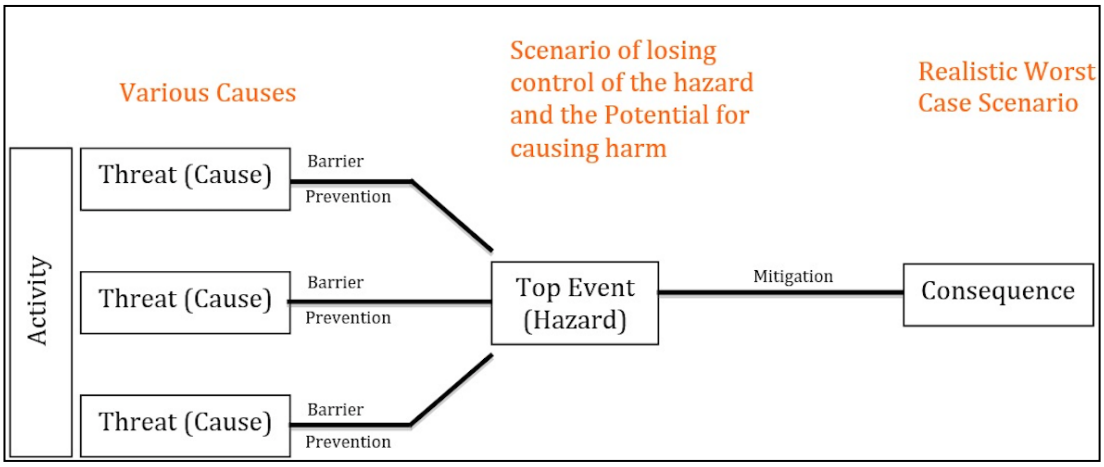



Figure 30 General layout of the Bowtie Analysis.

This can be overcome by incorporating Bowtie analysis with a Bayesian approach which is also a graphical technique used in risk analysis based on probabilistic and uncertain knowledge (Badreddine and Amor, 2013; Khakzad *et al.*, 2013). By using a Bayesian approach, it means relative data can be incorporated and enables implementation of appropriate preventative or mitigation measures (Smith *et al.,* 2014; Badreddine and Amor, 2013).

A decision tool such as the EPSS can benefit from incorporating the Bayesian approach as it requires spatially explicit environmental risk assessment frameworks with quantitative or probabilistic measure of risk, enabling an evaluation of spatial management scenarios (Stelzenmüller *et al.*, 2014). However, neither Bowtie analysis nor Bayesian networks were used in the development of this EPSS tool. Bowtie analysis was not used, as whilst it provides a useful visual aid in managing an environment, it is already demonstrated in the model by identifying the activities (cause), pressures (problem) and impacts (consequence) as well as the mitigation measures (barriers).

Bayesian belief network was not used in the development of the EPSS tool as there is currently not sufficient data to be able to run the entire model and the scenarios accurately. In the absence of such data, Bayesian belief networks would instead use a high, medium, low and negligible risk rating which is already incorporated into the tool.

ix. Life Cycle Assessment

Woods *et al.* (2016) identified that life cycle assessments have been applied to terrestrial and freshwater, but are lacking in the marine environment, given that many see the marine environment "*as the next frontier for economic development, new marine activities, such as renewable energy harvesting, carbon sequestration and gas hydrate mining, are rapidly emerging*", this could be short sighted. While some drivers, such as climate change and eutrophication-induced hypoxia, can be traced back to both land-based and sea-based activities; other drivers, such as habitat change, invasive species, and overexploitation, are predominantly linked to sea-based activities. A quantitative understanding of the environmental impact of these industrial activities on the marine environment would greatly improve the robustness and completeness of a life cycle assessment or a decision support system such as an EPSS.

x. Marine Ecosystems Research Programme

A Defra and NERC co-funded project MB0130 Marine Ecosystems Research Programme aims to advance the understanding of the processes that drive the dynamics of marine ecosystems and food webs. It aims to do this by integrating into existing ecosystem models to predict impacts of environmental change on the structure and function of marine food webs, the services they provide and the development of effective indicators to measure environmental status.

Sheaves *et al.* (2016) identified that whilst these tools have been developed to facilitate stakeholder access to information, these tools are often not "*perceived by stakeholders to be usable, useful, and salient to their concerns*" therefore the importance of stakeholder engagement and testing is invaluable in ensuring that these tools are continued to be used by those for whom if was designed for.

xi. Decision support SYstem for COastal climate change impact assessment

DESYCO (Decision support SYstem for COastal climate change impact assessment) is a GIS based decision support system specifically designed to better understand risks that climate change poses at the regional scale (Torresan *et al.*, 2016). It has been applied to low-lying coastal plains and islands (the North Adriatic Sea, the Gulf of Gabes and the Republic of Maritus), river basins and groundwater systems (Upper Plain of Veneto and Friuli-Venezia Giulia, Marche Region) but it has not been applied to the UK (Torresan *et al.*, 2016).

It is known that global climate change is likely to pose increasing threats in nearly all sectors and across all sub-regions worldwide (Robins *et al*., 2016). The impacts envisaged for coastal systems will have severe implications for population and economic activities and are rising the attention of decision makers and coastal managers at different levels. Particularly, the need to develop national and regional adaptation strategies and cross sectorial risk management plans, to better prepare and adapt to climate related disasters. Accordingly, decision makers are increasingly calling for information on what impacts are expected under projected climate change.

Most of the tools are focussed at a specific sectoral level (e.g. ODEMM on cumulative impact assessment, InVEST and ARIES for ecosystem goods and services) or on physical or environmental issues e.g. morphological shoreline processes by DELFT 3-D or ecological functions by BTELSS (Barataria-Terrebonne Ecosystem Landscape Spatial Simulation). Many are developed for research purposes, and are not readily available to the public as they require a certain level of expertise. Finally, they also do not readily integrate the needs and questions from the policy debate by engaging stakeholders and decision makers through the participatory process.

The final aim of the DESYCO tool is to support a preliminary phase of risk assessment (first-pass or screening analysis), providing an integrated view of all the potential threats caused by climate change in the analysed region, and fostering decision-makers (and long-term investors) in the identification of a portfolio of adaptation policies and measures. More specifically, DESYCO fills a gap among existing decision support tools, since it allows, amongst other things, the integration of multi-disciplinary and heterogeneous information and scenarios (climate, environmental and socio-economic) into a structured Multi-Criteria Decision Analysis (MCDA) process based on a trade-off between expert judgement and stakeholder perspectives in an open source software.

### 3.10 Current Models for Cumulative Impact Assessment

Cabral *et al.* (2016) highlighted that throughout geological history, the environment has always changed, and has always been subjected to natural internal and external influences, but there are now additional anthropogenic stressors causing change at unprecedented rates and scales. The cumulative and synergistic effects between these human–induced pressures with other environmental factors may compromise the status and functioning of some of these areas (Clarke-Murray *et al.*, 2014). Furthermore, knowledge of how climate

and anthropogenic impacts interact, and affect hydrodynamic, geographical, geochemical biological and ecological processes in marine areas is still limited.

Many different sectors and their associated activities overlap in time and space, potentially changing the severity of their impact as pressures combine, and undermine the efforts of environmental managers to mitigate the harmful effects of those activities. Managing the complex interactions of overlapping multiple activities that compete for space remains a challenging task, but one which has been recognized as essential if the sustainable provision of ecosystem services and societal goods and benefits from our oceans is to be achieved (Goodsir *et al.*, 2015; Brown *et al.*, 2014). Comparing the impact of human activities on the marine ecosystem requires a method of linking human activities to specific pressures and a measure of sensitivity of the ecosystem and its components to those pressures. However, linkages have tended to be viewed independently of each other, such that the full range of pressures affecting a characteristic may not be identified or managed effectively.

Assessing the distribution and intensity of human threats to biodiversity is a prerequisite for effective MSP and harmonizing conservation purposes with sustainable development (Guarnieri *et al.*, 2016). Emerging legislation from the EU has aims of assessing impacts on whole ecosystems over long periods of time to ascertain a good environmental state of the ecosystem such as the MSFD and Common Fisheries Policy (CFP) (Hyder *et al.*, 2015). Cumulative impact assessment involves the establishment and evaluation of lineages between multiple activities with multiple ecological components, which includes complex interactions of the direct and indirect effects in assessment. However cumulative impact assessment is still a complex assessment in which one standard and agreed approach is not yet utilised given the complexity that arises from the multitude of potential linkages and the lack of agreed terminology (Uusitalo *et al.*, 2016; Judd *et al.,* 2015; OSPAR Commission 2008; Therivel and Ross, 2007; Vries *et al.*, 2012; MMO 2014d). It is therefore to the mutual benefit of all to collaborate in identifying cumulative impacts, data collection and modelling, and agreeing on strategic level mitigation and monitoring (Renewable UK, 2013) such as that currently undertaken by the aggregate industry in identifying changes in benthic ecology over time because of aggregate extraction (Cooper, 2012; 2013). This allows for a more consistent and more cost-effective approach to monitoring which will also provide greater certainty in the interpretation of the results.

The increasing awareness of cumulative impacts from industrial and recreational activities, as well as effects from climate change has meant that the subject has been given more

emphasis in recent years (Elliott *et al.*, 2015; Eassom and Church, 2013; Elliott *et al.*, 2013; JNCC, 2013; Marine Scotland, 2012; Koss *et al.*, 2011; Robinson and Knights, 2011; Tillin *et al.*, 2010; O'Boyle and Jamieson, 2006). Legislation at national or regional levels aims to control the potential adverse impacts of marine management from studying and managing individual pressures separately towards managing the cumulative and in combination activities and their pressures in a holistic, ecosystem based management approach (ABPmer and Cefas, 2015).

Given the complexities of cumulative impact assessment, it is still an integral part of environmental assessment at both the project and strategic level as it helps link the different scales as it focuses on how a receptor is affected by the totality of plans, projects and activities (Therivel and Ross, 2007). Karman and Jongbloed (2008) and the OSPAR Commission (2008) provides the methods and tools that can be used in assessments including cumulative impact assessments together with their advantages and disadvantages. If cumulative impacts are not managed as early as possible i.e. through the identification of mitigation and/or compensation through the application process, then the impacts can accumulate not only in the potential receptors in each location, but also across administrative boundaries. The severity of the impact from any activity is dependent on the affected ecosystems sensitivity and the pathways in which an impact causes an effect as well as the intensity, duration and scale of the impact (OSPAR Commission, 2008).

There has been debate on whether cumulative impact assessment should emphasise the assessment on the potential significant impacts, or to assess every conceivable impact to ensure that those impacts that were on their own determined insignificant, then become significant when considered cumulatively (Lonsdale *et al*., 2017). For example, a development on the north side of an estuary may not lead to a significant impact on fisheries (from underwater noise) on its own, but in combination with another development on the south bank which may be under construction at the same time, may lead to a cumulatively significant impact on fisheries.

To address some of the deficiencies of cumulative impact assessments, several cumulative impact assessment models have been developed, however each of these have their limitations. Existing approaches to cumulative impact assessment to varying degrees produce outputs related to the state of the environment in the form of GIS pressure maps. What is often missing is a direct account of how the outputs of the cumulative pressure

mapping exercise may be applied in practical management measures to maintain or improve the state.

The cumulative impact assessment models, Harmony, CUMULEO and ODEMM, are all reliant on expert judgement. Harmony and CUMULEO use cumulative impact scores using formulae based on Halpern (2008) where anthropogenic activity is weighted by ecological importance. They use the activity footprint, however this can over or underestimate the impacts (OSPAR Commission, 2013). The CUMULEO model groups data on spatial distribution and intensity of human activities by generic pressures. The impacts are mapped by accounting for sensitivities to pressures, but for marine planning, the use of weighting with more constrained values should be used in conjunction with a sensitivity analysis (Stelzenmüller *et al.*, 2010).

The framework developed by Stelzenmüller *et al.* (2010) also grouped human activities by their generic pressures and in GIS merged activities exerting the same pressure into a single layer. As there was a difference in the units, measures and levels of generalisation in the data, they all possess a level of uncertainty and therefore standardisation of multi-raster layers is required to maintain validation of outputs. There is a need to establish knowledge of the source-pathway-receptor framework, as where there is no conceivable pathway there can be no tangible affect (Judd *et al.*, 2015; OSPAR, 2013).

A fundamental part of the cumulative impact assessment process is using risk assessment criteria to filter and prioritise the complex interaction of source, pressures, pathways and receptors. With the requirement to have a simple tool for usability and comprehension of outputs, but have a robust enough model to evaluate the effects of fishing, eutrophication, wind farms, spatial reserves and sand extraction, amongst others, on important ecological indicators. A key question is: “Is one model possible?” One generic methodological framework that is agreed amongst the different industries, governments and practitioners is required to simplify the processes and that keeps population dynamics separate (Vries *et al.*, 2012).

Barnard and Elliott (2015) applied a quantitative scoring system for the standard implementation of each of the ten tenets of sustainable development on a common scale from minimal to full compliance, however further work is needed to develop a single (composite indicator) score for both the intensity of the development and likely management measures. The method also has to be extended to accommodate the fact that

most environments have many competing and conflicting developments across which cumulative impacts occur/ need to be addressed.

The previous sections have demonstrated that an EPSS is needed to bring together the different users, uses, data and approaches that are used to assess the potential impacts and implications of new developments or policies. The current tools, concepts and frameworks available have been reviewed and broken down to their component parts. Alongside the earlier component diagrams for legislative requirements, these will be brought together into one conceptual framework on which to base the final EPSS tool (see below).

### 3.11 Estuarine Planning Support System Framework

Earlier management concepts and tools have been developed, but have either focussed on one aspect or have been a simplified guide and have not gone into the detail of the requirements of the legislative tools. An initial EPSS framework has been constructed (Figure 31 below) by taking all of the directives, legislations and planning tools available in relation to the Humber Estuary and taking their component parts (Chapters 2 and 3), and then combining them into one overarching conceptual model. The framework however does not allow an applicant or decision maker to easily work through from one starting point to determine the relevant steps and decisions for them, and is focussed on the EIA process.

The EPSS framework was further developed to address both policies and responses, and plans or projects (Figure 32). In either case, the EPSS framework demonstrates that the primary step in any project development or decision-making process is to define the problem or aims and objectives, and to be able to focus the assessment and where necessary the surveys. By defining the aims and objectives of the plan, it allows the developer/ manager to start identifying the legislation that may be applicable.

The EPSS framework as already identified, conforms to the DAPSI(W)R(M) approach, as it requires the identification of drivers and activities (users and uses) and then to assess any potential impacts on these as well as their impact on the natural and human system. This includes identifying both the benefits and conflicts to determine any mitigation, and/or compensation measures by identifying the best available option. To accomplish this, consultation and communication should start early to agree terminology and process. Feedback loops identified within the EPSS framework allows any mitigation and/or compensation that has been agreed, to be monitored to ensure it is appropriate or whether further modification is required. The feedback loops also allow the management to be

adaptive to achieve long-term goals and to ensure transboundary effects are as predicted (Zaucha and Breedveld, 2013).

The EPSS framework identifies which steps accommodate the different stages in the DAPSI(W)R(M) framework, and the ten tenets of sustainable management, to demonstrate that the EPSS framework is compliant with these specific management tools. With regards to the ecosystem goods and services, these should be identified when characterising the baseline and be assessed in the impact assessment given their importance in sustaining and improving human wellbeing. Guidance on how to do this is provided in Figure 41.

The EPSS framework developed here relates to the legislation and management tools that are specific to the Humber Estuary, but the approach is considered to be generic. As the EPSS framework has been developed based on specific European legislation, the steps within the processes are common across several of the legislative and management tools and the approach can be applied to other European estuaries. In addition, given that many other countries have similar legislation, (such as the Nonindigenous Aquatic Nuisance Prevention and Control, National Environmental Policy, Clean Water and Oceans Acts in the US) the principles and philosophies described here will apply elsewhere. It does not apply weighting to those aspects with perceived greater importance i.e. economic or environment; rather it provides the basis on which the decision makers can develop their assessment.

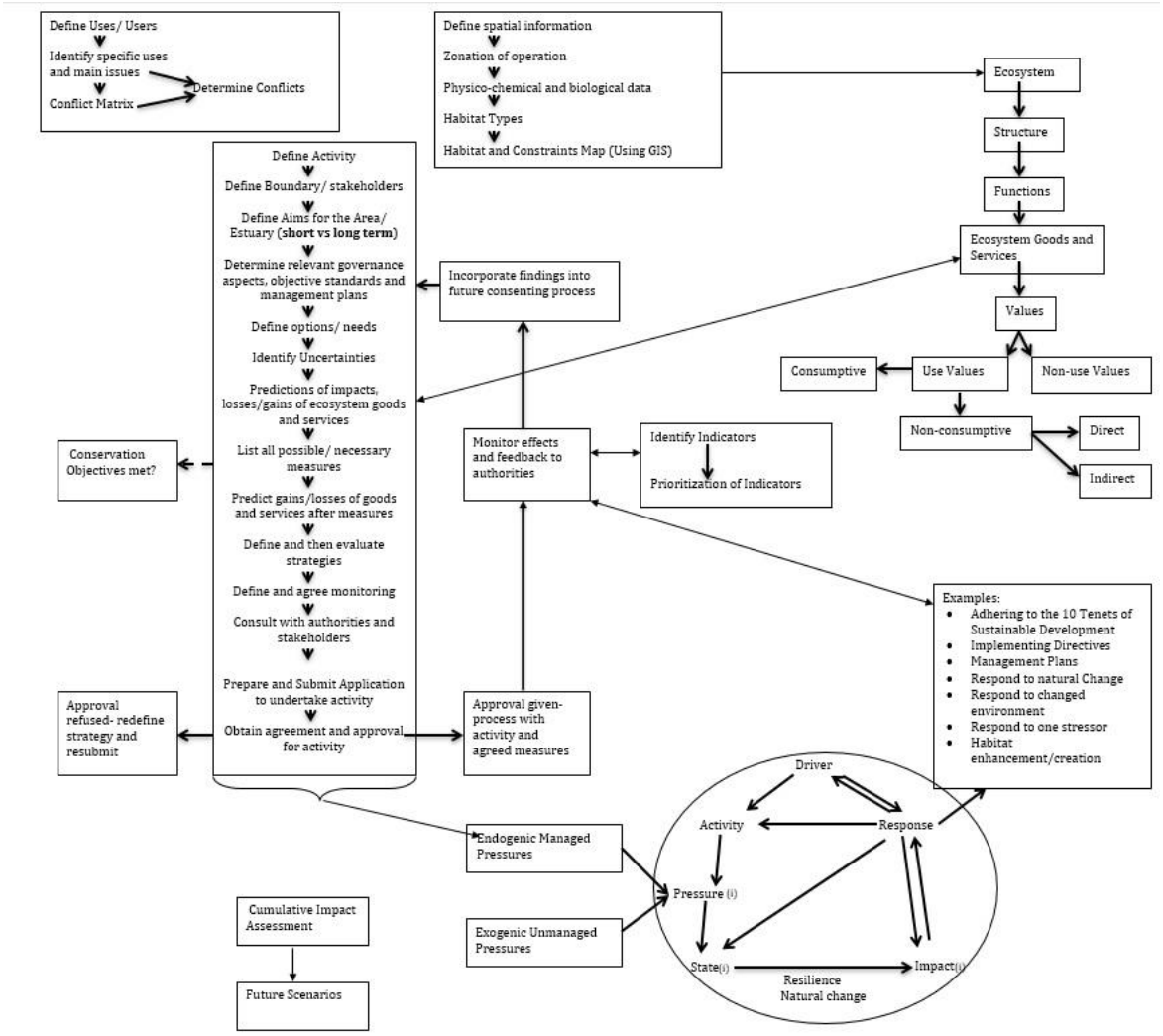



Figure 31 Generic Conceptual Model of Estuarine Planning Support System.

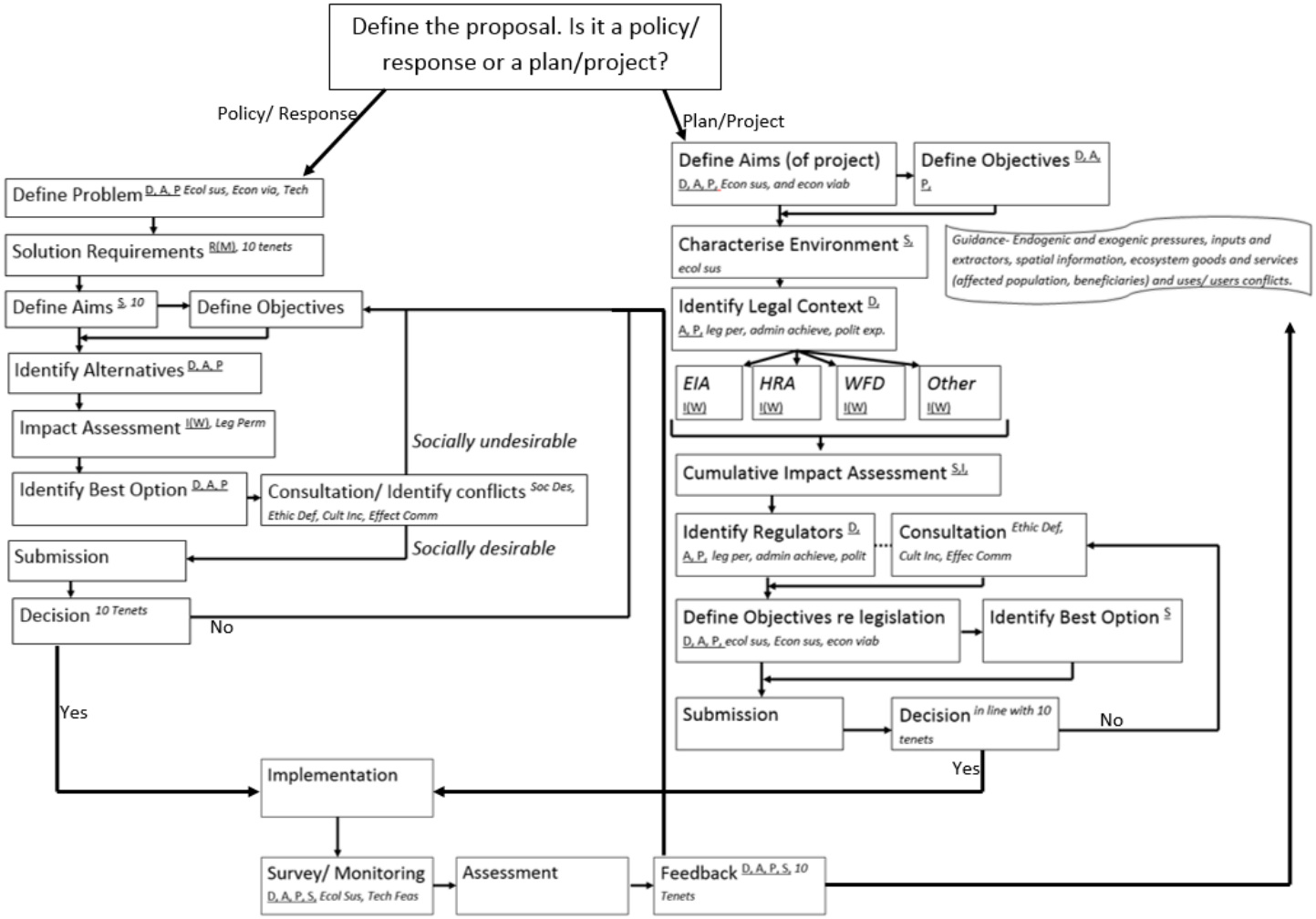



Figure 32 EPSS framework for a plan/project or policy response

This study has identified the need for a 'toolkit' of management approaches, and where possible to incorporate monitoring results in the future to aid and inform the decision-making process. It reaffirms the conclusions by Lucrezi *et al.* (2016), that there is virtually no aspect of the environment that does not require some degree of management and due to the state of any considered aspect being likely to be dependent upon the state of another, that it would be non-beneficial and difficult to manage single attributes of the ecosystem. The EPSS framework has been developed to be flexible in its approach, to allow it to be used elsewhere internationally but also to allow for it to be adaptable for future changes and as science develops.

This study has used the Humber Estuary as a case study as it is a data rich area but the EPSS framework, or the approach to developing an EPSS framework does not require a data rich site for it to be effective. The EPSS informs the user of the steps to take, to identify what data are required, when they should be obtained and how to progress through to submission and/or the decision.

Given the changing future, adaptable and easy to use management tools are needed to manage our pressured coastlines. The EPSS framework in its current form allows this by giving a structured process with sufficient flexibility to allow for regional priorities and project specific information.

## 4. Development of the Estuarine Planning Support System

To aid in effective marine management, user- friendly tools are required to analyse and visualise the effect that measures may have. Runhaar (2015) identified that an abundance of approaches, strategies and instruments (tools) have been developed that intend to simulate or facilitate the integration of a variety of environmental objectives into development planning, national or regional sectoral policies, international agreements, business strategies etc.

In Chapter 2, the current condition of the Humber Estuary was identified to give a baseline to enable any impact assessment on the Humber Estuary to consider the receptors that are currently present within the system. In Chapter 3 a conceptual framework for an EPSS was developed that took the existing management tools and concepts, as well as legislative requirements, and combined them into one overarching framework (Figure 32) (Lonsdale *et al.*, 2015). In this Chapter, an EPSS Tool will be developed following the baseline developed in Chapter 2 and the critiques of management tools in Chapter 3.

The EPSS tool will provide a platform to provide access for concerned individuals, groups and organisations to relevant information, and opportunities for consultation and participation in planning and decision-making. The development was informed by consulting with Cefas experts in GIS, EIA and regulatory frameworks, alongside other organisations such as Environment Agency, Natural England, Joint Nature Conservation Committee, Marine Management Organisation and Natural Resources Wales.

The GIS will use the user's development shapefile and responses to questions in the user interface about the location and size of the project, and by using proformas and look up tables it will provide the outputs including an overall risk of the project as well as regulatory requirements. The GIS is a standalone tool, which can be used by stakeholders to interrogate the potential impacts of a development or to inform the regulatory process for developers. The tool can be maintained, as the data can be updated without the need to update the code behind. It also uses a risk-based assessment developed by Judd *et al.*, (2013) and develops further on Judd (2011) to highlight where high, medium, low and negligible environmental risks are expected and how these should be handled.

The overall outline of the tool is shown in Figure 33 and the more detailed processes are shown in Figure 34 and are detailed in the below sections.

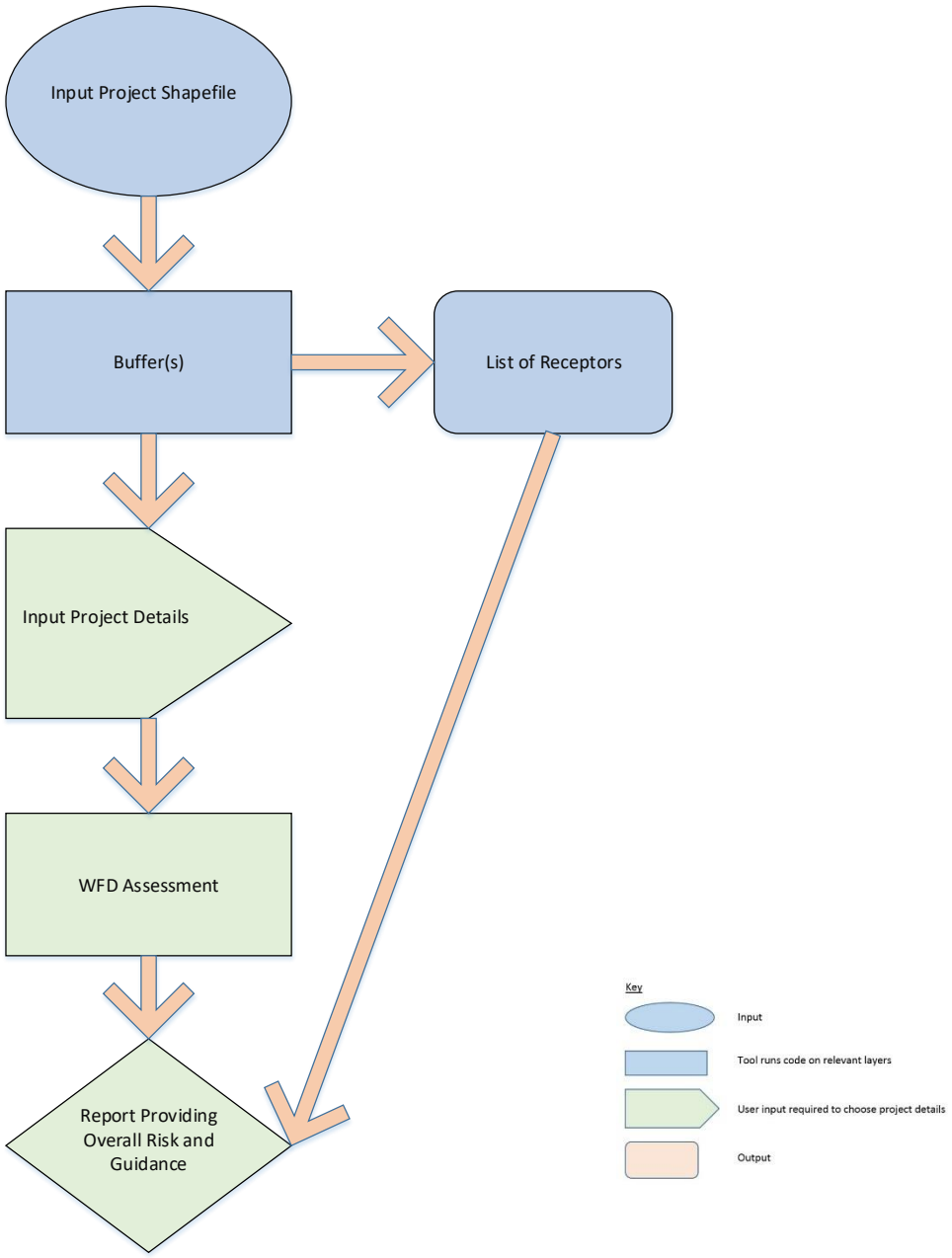



Figure 33 The overall outline of the tool.

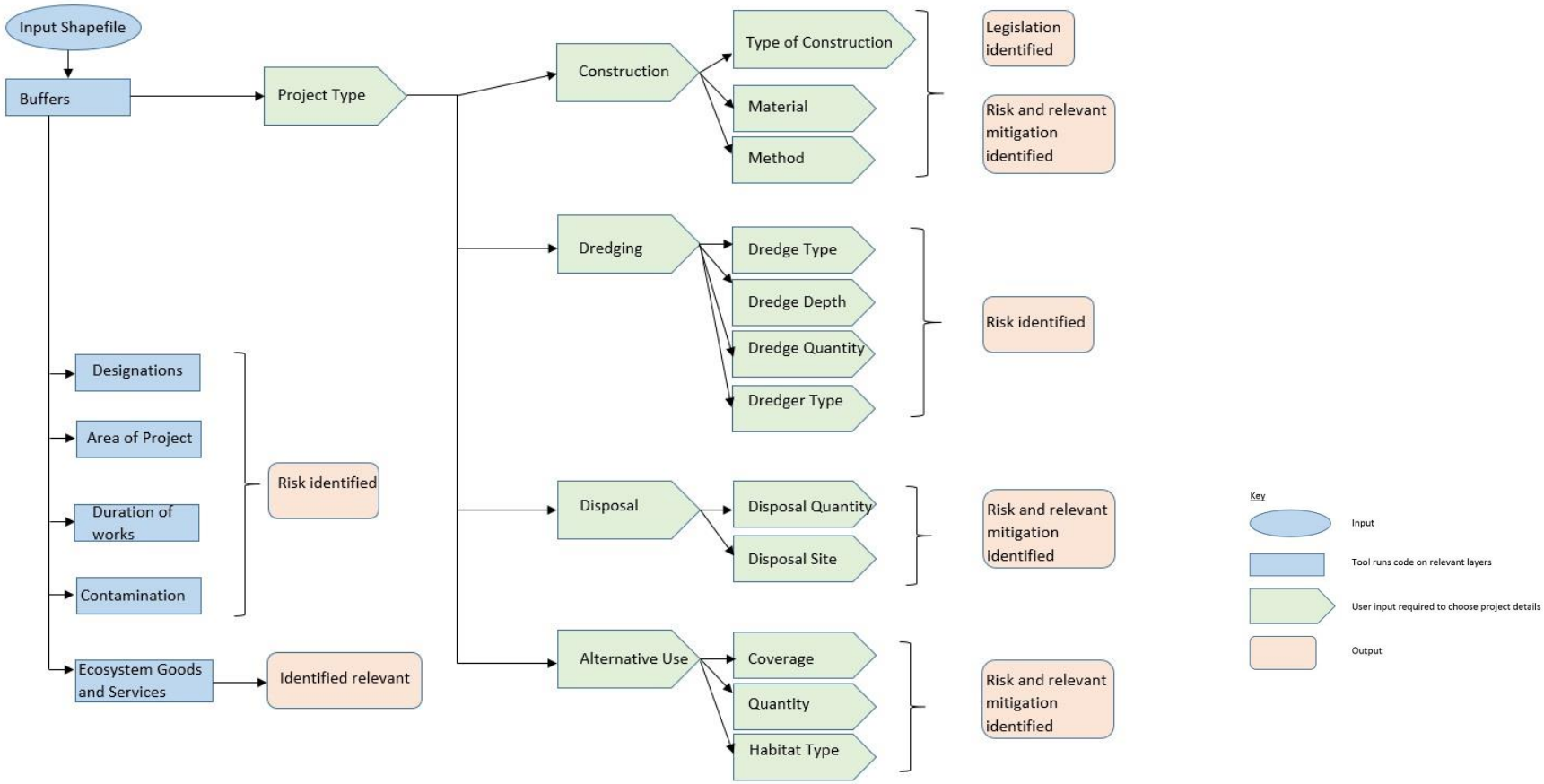



Figure 34 A detailed flow diagram of the GIS tool.

## 4.1 GIS Development

The GIS tool was developed using ArcGIS 10.1 and Python Win 2.7. ArcGIS online was considered, however this required access to a server where the tool could be stored and run, which was not available for the study. ArcGIS is widely used by several stakeholders and is an effective way of producing the tool. A method was also developed of ensuring those stakeholders who do not have access to ArcGIS can still test the tool based on the output (section 6.1).

The data that was used for the GIS tool is provided in Appendix 2. The GIS layers have been linked to the indicators identified in Appendix 5 to enable assessments to be carried out as well as the ecosystem services and conflicts.

The shapefiles were transformed into the British National Grid coordinate system to allow certain functions to be able to be carried out such as defining the area of the project (it is noted that this is suitable for coastal zones out to 12nm but after 12nm this coordinate system can distort the shapefiles). Once these layers were transformed into British National Grid, they were clipped to the area of interest (Figure 35). This allows spatial analyses to be undertaken more quickly when determining the viability and testing of the software. It is important to note that the layers have been clipped to only cover the area of interest, and other infrastructure or receptors may lie outside the area of interest and therefore if used, early consultation with the relevant authorities is recommended to ensure all potential receptors are identified.

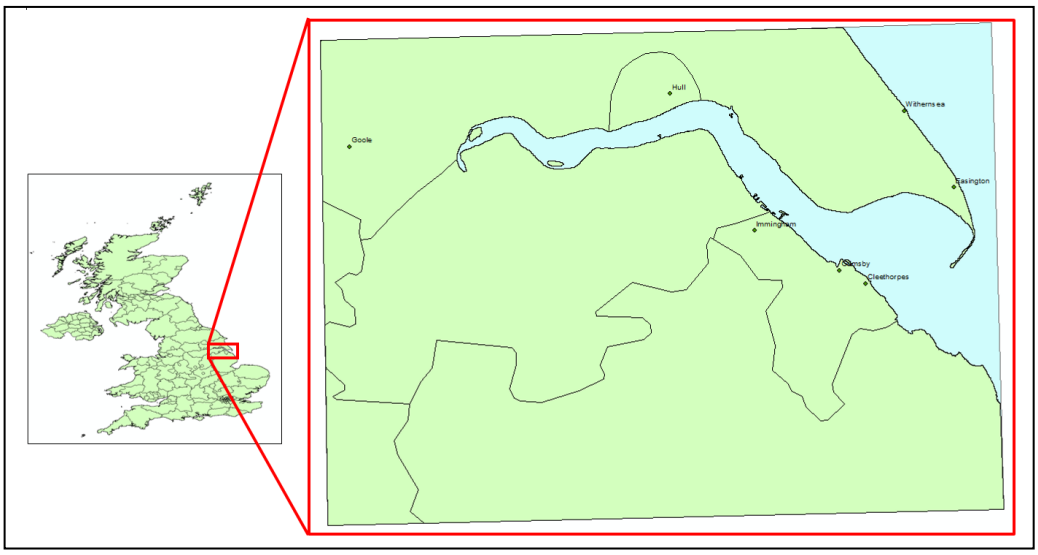



Figure 35 Area of Interest

To ensure that the software did not slow during the geoprocessing tool being run, where possible, layers were combined into as few as possible based on the shapefile type and buffers to be applied, and the relevant attributes in the data. A summary of the layers combined is provided in Table 8. The buffers applied are based on the conservative buffers used by the Regulators for England (and their scientific advisors) when assessing applications for marine developments and marine protected areas on receptors (Cefas, *pers. Comm.*). The buffers are considered conservative for the purposes of this study, as the buffers applied by JNCC (2015) and Batista *et al.* (2014) to pressures based on generic hydromorpholgical conditions are much less that those provided in this study.

Table 8 Summary of layers and their combinations

| Buffers to be Applied | Shapefile Type | Layers | Final Layer Name |
|---|---|---|---|
| 1km | Polygon | UK Seabed<br>Bathing Waters Sensitive Areas<br>Country Parks<br>Agricultural Land Classification | ReceptorsWithin1kmPG |
| | Polygon | Parks and Gardens<br>Scheduled Monuments | ReceptorsWithin1kmPG_EHCon |
| | Point | pH<br>Salinity<br>Turbidity<br>Water Depth<br>Water Temperature | EAParametersWithin1kmPT |
| | Point | Slipways<br>Marinas<br>Bait Digging<br>Beaches<br>Horse Riding<br>Kite Surfing<br>Managed Realignment Sites<br>Wildfowling<br>Wharves<br>Bathing Waters | ReceptorsWithin1kmPN |
| 5km | Polygon | WFD River WBS Cycle 2 Draft<br>WFD Coast WBS Cycle 2 Draft<br>WFD Management Catchments Cycle 2 Draft<br>WFD RBD Cycle 2 Draft<br>WFD River WB Catchments Cycle Draft 2 | WFDCycle2DraftWithin5kmPG |
| | Polygon | WFD Coastal Waterbodies | WFDCurrentWihtin5kmPG |

| | | | |
|---|---|---|---|
| | | WFD Transitional Waterbodies | |
| | Polygon | Reasons for Failure under the WFD | WFDReasonForFailureHumber- Within5kmPG |
| | Polygon | Flood Alert Areas<br>Flood Risk Areas<br>Flood Warning Areas | FloodAlertWithin5kmPG |
| | Polygon | SPA<br>Ramsar<br>SSSI | DesignationsWithin5kmPG |
| | Polygon | Nursery Grounds<br>Spawning Grounds | FisheriesWithin5kmPG |
| | Polygon | Construction<br>Dredge | DevelopmentsWithin5kmPG |
| | Polygon | ABP<br>ABP Goole Harbour Authority<br>ABP Humber Estuary Services Harbour Authority<br>Administrative County<br>Defra<br>Eastern IFCA<br>Environment Agency<br>Humber Nature Partnership<br>Lincolnshire Wildlife Trust<br>Marine Management Organisation<br>Metropolitan County<br>Natural England<br>North Eastern IFCA<br>RSPB<br>Unitary Authority<br>Unitary Authority (City)<br>Yorkshire Naturalists Union<br>Yorkshire Wildlife Trust | ManagementBoundariesWithin5kmPG |

| | | | |
|---|---|---|---|
| | Polygon | FishLandingsbyICES2007<br>FishLandingsbyICES2008<br>FishLandingsbyICES2009<br>FishLandingsbyICES2010<br>FishLandingsbyICES2011 | FishLandingsWithin5km |
| | Polyline | PhysicalStructures<br>Defences | PhysicalStructureandDefenceWithin5kmPL |
| | Polyline | WFD Transitional WBS Cycle 2 DRAFT | WFDCycleDraftWithin5kmPL |

Table 9 Summary of Layers that could not be combined

| Layer | Shapefile Type | Final Layer Name |
|---|---|---|
| Barriers | Point | BarriersWithin1kmPT |
| Flow Gauges | Point | FlowGuagesWithin1kmPT |
| Water Abstraction | Point | WaterAbstractionsWithin1kmPT |
| Water Pollution Incidents | Point | WaterIncidentsWithin1kmPT |
| PSA Data | Point | PSADataWithin1kmPT |
| CMS All Data | Point | CMS_AllDataWithin1kmPT |
| Listed Buildings | Point | ListedBuildingsWithin1kmPT |
| Humber Wrecks | Point | HumberWrecksWithin1kmPT |
| Woodlands | Polygon | WoodlandsWithin1kmPT |
| Construction | Points and Polylines | ConstructionWithin5kmPT<br>ConstructionWithin1kmPL |
| Towns | Point | TownsWithin5kmPT |
| Shoreline Management Plans | Polyline | ShorelineManagementPlan-Within5kmPL |
| SAC Master | Polygon | SACSensitivitiesWithin5kmPG |
| Saltmarsh Extents | Polygon | SaltmarshExtentsWithin5kmPG |
| Heritage Coast | Polygon | HeritageCoastsWithin5kmPG |
| Disposal Site | Polygon | DisposalSitesWithin5kmPG |
| High Water | Polyline | High_water_polyline |
| Risk of Flooding from Rivers and seas | Polygon | RiskofFloodingfromRiversandSea-Within5kmPG |
| MMO Typologies | Polygon | MMOTypologiesWithin5kmPG |
| Gas Pipes | Polyline | GasPipesWithin1kmPL |
| Cables | Polyline | CablesWithin1kmPL |
| Wind Farm Export Cable Areas | Polygon | WFExportCablesWithin1kmPG |
| Tidal Export Cable Areas | Polygon | TidalExportCablesWithin1kmPG |

Certain layers required additional work to be undertaken:

- The SAC layer from Natural England to incorporate the sensitivities of the features of conservation interest (see section 4.2);
- WFD layer to incorporate reasons for failure and measures to improve the state (see section 4.11).

The tool has a user interface where the user inputs their shapefile of the development and answers questions regarding the development i.e. is it construction or dredge? What are the thresholds? etc. Once the user has input all the required information, the tool runs the Tool Validation Code and the python code. The code firstly identifies which receptors are within 1km or 5km of the development depending on the receptors (Table 10).

The code uses look up tables and user inputs to determine the risks associated with the project types, as developed by Judd (2011) and Judd *et al.* (2013), MEMG (2003) as well as

by experts who review and assess such marine licence applications (Sustainable Environment and Advice for Licensing Team (formerly known as the Regulatory Assessment Team) (Cefas), *pers. Comm*)). Each aspect is in turn discussed below.

Table 10 The buffers applied to the GIS layers to identify the users/uses and receptors that may be affected or may need to be included in an assessment.

| **Buffer** | **GIS Layer** |
|---|---|
| 1km | ReceptorsWithin1kmPG |
| | ReceptorsWithin1kmPG_EHCon |
| | EAParametersWithin1kmPT |
| | ReceptorsWithin1kmPN |
| | BarriersWithin1kmPT |
| | FlowGuagesWithin1kmPT |
| | WaterAbstractionsWithin1kmPT |
| | WaterIncidentsWithin1kmPT |
| | PSADataWithin1kmPT |
| | CMS_AllDataWithin1kmPT |
| | ListedBuildingsWithin1kmPT |
| | HumberWrecksWithin1kmPT |
| | WoodlandsWithin1kmPT |
| 5km | ConstructionWithin5kmPT<br>ConstructionWithin5kmPL |
| | TownsWithin5kmPT |
| | ShorelineManagementPlan- Within5kmPL |
| | SACSensitivitiesWithin5kmPG |
| | SaltmarshExtentsWithin5kmPG |
| | HeritageCoastsWithin5kmPG |
| | DisposalSitesWithin5kmPG |
| | HighWaterPolyline |
| | RiskofFloodingfromRiversandSea-Within5kmPG |
| | MMOTypologiesWithin5kmPG |
| | WFDCycle2DraftWithin5kmPG |
| | WFDCurrentWihtin5kmPG |
| | WFDReasonForFailureHumber-Within5kmPG |
| | FloodAlertWithin5kmPG |
| | DesignationsWithin5kmPG |
| | FisheriesWithin5kmPG |
| | DevelopmentsWithin5kmPG |
| | ManagementBoundariesWithin5kmPG |
| | FishLandingsWithin5km |
| | PhysicalStructureandDefenceWithin5kmPL |

| | |
|---|---|
| | WFDCycleDraftWithin5kmPL |
| | ShorelineManagementPlanWithin5kmPL |

## 4.2 Tool Development- Scripts Vs Look Up Tables

To ensure that the tool ran effectively the options are stored in look up tables, and the script refers to the tables and shapefiles rather than hard coding. To ensure that only those options relevant to the project (i.e. not being able to select the use of 'concrete mattresses' for a project just for 'dredging'), the tool validation in Arc GIS was used to 'grey out' the options that are not relevant, and to group the options together i.e. all construction options fall under a 'construction' subgroup etc. in the tool interface to avoid confusion (Figure 36).

The sections that would require updating in the script are only the 'Project Type' options, being: construction, dredging, disposal and alternative use. Any additional changes would only require the tables and shapefiles to be updated. This 'future proofs' the tool in that managers do not have to go into the complex and long script to update options, assessments and data, making management of the tool easier.

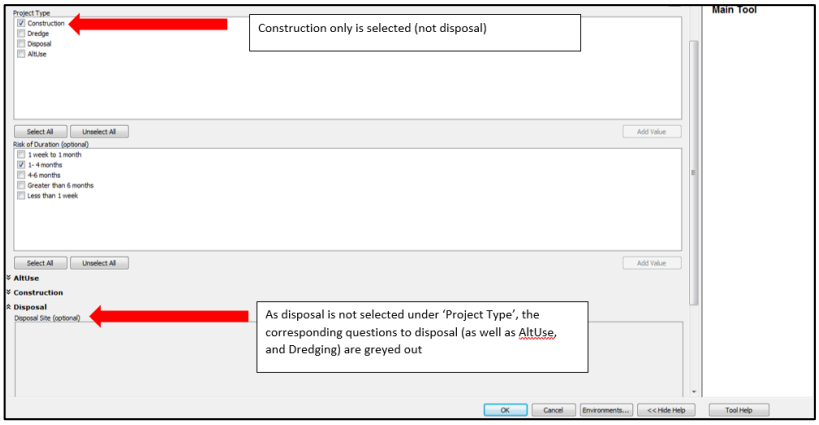



Figure 36 EPSS tool interface showing that when the project type is not selected, then the relevant options are greyed out to avoid answering irrelevant questions to the development

## 4.3 Look-up Table Development

As discussed above, look-up tables have been used to determine the risk associated with a project to make the EPSS tool as integrated as possible. These relate to main 'Project Type' classification, and with regards to the location of relevant shapefiles (these are demonstrated as the 'user input required to choose project details' as well as 'designations', 'area of project', duration of works', 'contamination' and 'ecosystem services and societal goods and benefits' in Figure 34). Most were developed and modified from (Judd, 2011; Judd *et al.*, 2013; MGEM, 2003; Cefas, *unpubl.*), however some required more development and are described below.

## 4.4 Thresholds for Determining Legislation a Project Falls Under

Look-up tables are used to access the 'thresholds' to determine if the project requires an application through the Planning Act, an EIA under the EIA Directive, (either mandatory under Annex I and subjective under 'Annex II') or if a marine licence is required. This is important because if the project is consented under the incorrect legislation then the project could be judicially reviewed which is time and cost intensive. However, before this, if the developer is not aware of stipulations of a legislation, and does not consult the regulators then the developer may end up doing more than is required, or the incorrect level of work leading to potential delays and costing money to rectify. To address this, the legislative requirements were included as part of the tool to help developers and decision makers alike, ensuring consistent application.

For ease of use and updating, and for projects that will always require a certain legislative requirement i.e. EIA, a threshold value of '0' was applied; for those where it would never be required i.e. only a marine licence is required, an exceptionally high threshold was inserted (10,000,000,000,000). This appears in the tool once the 'construction' project has been selected, and the detailed construction type is selected. A message will then appear asking for a value of the project in certain units i.e. for a windfarm, the value will be for the output in MW. This message and units are stored in the look up table to ensure the tool can be updated in the future if legislative requirements are changed/updated without having to update the code behind the tool.

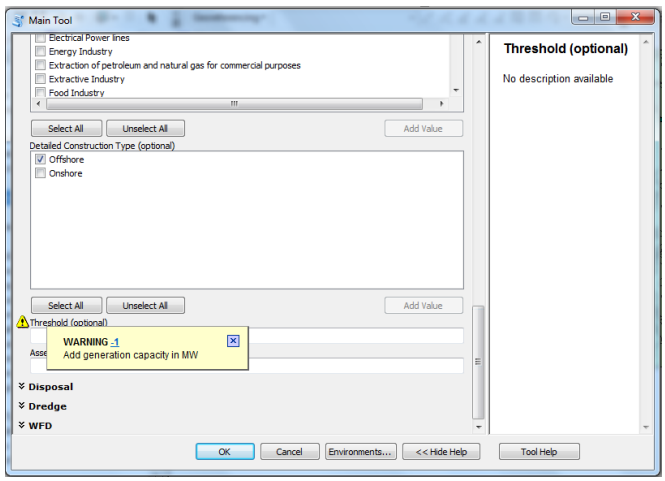



Figure 37 Screenshot of the EPSS tool whereby the threshold is required to determine the legislative scope of a development

### 4.5 Determining Impact and the Extent of Impact

One of the challenges of impact assessment, including cumulative impact assessment, is the determination of the extent and magnitude of impacts arising from the development both within the footprint of the activity, and the far-field impacts. As discussed, there are many activities occurring in the marine environment, and these uses are likely to increase with new technologies, however, whilst many studies have attempted to define the area of near and far field effects, these are still based on proxies or conservative efforts. There is also the complication that activities not only overlap in space, (footprints of the near and far field effects) but also in time e.g. shipping can occur at the same time as construction, recreational activities and discharges. The potential impacts of construction, dredging and disposal operations within the marine environment are summarised in Figure 57-Figure 59 but are summarised in Table 17.

### 4.6 Risk of Projects

To determine the level of potential impact a development or proposal may have on the environment, society or economy, a risk assessment needs to be undertaken to evaluate the development and alternatives. Judd *et al.* (2013) summarised the approach the MMO use in risk assessments for marine projects (Figure 38) which has been incorporated into the EPSS tool by identifying the pressures, receptors and potential vulnerabilities.

In the tool, whilst projects are assessed against their activity and threshold to determine which legislation the project falls under i.e. Planning Act, EIA or Marine and Coastal Access Act (see next section), the sub-activities within the project also apply a risk rating using the risk-based assessment developed by Judd *et al.*, (2013) and develops further on Judd (2011) to highlight where high, medium, low and negligible environmental risks are expected and how these should be handled. An example is provided in Figure 38 and Table 11.

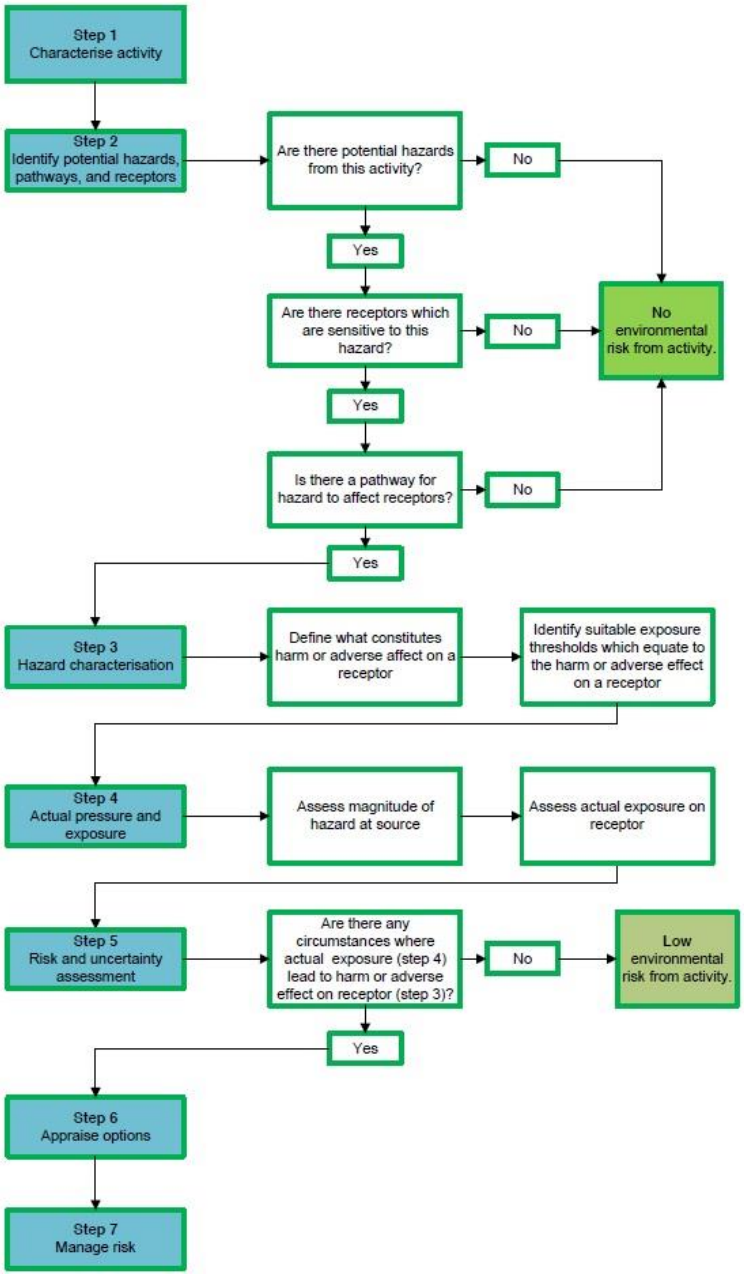



Figure 38 MMO approach for risk assessment of marine projects (taken from Judd *et al.* (2013))

Table 11 Risk Assessment of Dredge activity based on area

| **Dredge Activity** | **Dredge Area** | **Risk** |
|---|---|---|
| Large | >500,00m3 | High |
| Medium | 100,000-499,999m3 | Medium |
| Small | 1,000-99,999m3 | Low |
| Negligible | <1,000m3 | Negligible |

## 4.7 Developing Indicators for the Uses of the Humber Estuary for use in the EPSS

Indicators are used to provide and help communicate information, or an evaluation of an aspect or multiple aspects of a system, or the entire system over time, (Carapuco *et al.*, 2016; Runhaar, 2016; Diedrich *et al.*, 2010; Mateus and Campuzano, 2008; Aubry and Elliott, 2006;

Boyd, 2004; Bowen and Riley, 2003) and are defined as "*a qualitative or quantitative parameter characterising the current condition of an element of the environment or its change over time*" (Mateus and Campuzano, 2008). In the management of a system it is not only important to identity the objectives of the management schemes, but also the indicators that will be used to ensure the objectives are being met. It is important that indicator development is a coordinated approach, since if multiple schemes are developed there is a risk of duplicated effort and increased monitoring costs. Indicators should be selected to give a "snapshot" of the given ecosystems structural properties but also to inform ecological functioning.

The ecosystem as a whole will behave differently to the sum of its parts (Borja and Dauer, 2008; Mateus and Compuzano, 2008; Costanza and Mageau, 1999). It is therefore important to identify sufficient indicators not only in number, but in their purpose to evaluate the success of the different objectives of the different monitoring strategies and directives (Palmer and Filoso, 2009). To select the appropriate elements and individuals based on their sensitivity, robustness and confidence, the need for inter-calibration is also necessary (van Hoey *et al.*, 2010; Borja and Dauer, 2008). An ideal combination of indicators should be used in a conceptual model that efficiently identifies what, where, how and why change is occurring. It should be noted that multiple indicators may be useful for one objective or if management response is not clearly defined, (Rogers *et al.*, 2007).

Many studies have considered the identification and use of environmental indicators for change and management purposes (Borja *et al*, 2008; HM Government, 2012a; Ware *et al.*, 2010; Borja and Dauer, 2008; Borja *et al.*, 2006; Bidone and Lacerda, 2004; Aubry and Elliott, 2006; Bowen and Riley, 2003). This study will identify the relevant indicators based on the criteria below (adapted from van Hoey, 2010; Ware *et al*, 2010; Aubry and Elliott, 2006; Delbaere, 2003; Ehler, 2003; Gabrielsen and Bosch, 2003), the directives and ecosystem services and societal benefits identified above:

- Be legally robust and relative to the regulatory or policy objectives;
- Be scientifically and statistically valid;
- Be responsive to change in time/space;
- Be technically feasible and cost efficient to use within acceptable limits;
- Be useable for scenarios of future projections;
- Allow comparison between member states;
- Be developed with managers and be user led;

- Be able to communicate the factual, quantitative information to non-scientists and decision makers with ease;
- Demonstrate a clear link to the environmental outcome being monitored; and
- Be practical to measure over the spatial scale to which it is applied.

The indicators themselves should be a way of identifying problems and helping to identify solutions, whether it be a response on the driver or mitigation (or compensation). Even though the "polluter pays" principle[11] is easy to focus on, it is not necessarily the most effective method of managing an environmental issue, as the damage will have already been done and any work is then remedial. The indicators (socio-economic, biological and physical) used in this study are provided in Table 12.

[11] The polluter pays principle is set out in the Treaty on the Functioning of the European Union (Article 191(2) and it is the principle that those who produce pollution should bear the costs of remediating the damage to prevent further damage to the environment or human welfare. (http://ec.europa.eu/environment/legal/liability/ Accessed 12/04/2015)

Table 12 Indicators for the Humber Estuary

| Socio Economic Indicator | Data Layer | Relevance to Directives | Limitations | Applicable to the Humber Estuary |
|---|---|---|---|---|
| Density of resident population | Population | Relevant to all directives and legislation as the governance has to take into consideration the impacts of implementation on the population and wider socio-economics | Not incorporated into GIS so is additional data. Only goes up to 2012. The data does not take into consideration other factors such as affluence etc. | To determine the trends in population changes surrounding the Humber Estuary, this will enable scenarios to be run with census data. |
| Number of Moorings | Marinas and Slipways | EIA/SEA/CIA directives for new developments and WFD for determining water quality and impacts from associated activities. | Does not include the Royal Yachting Association data, this is provided by a pdf atlas. There may be other private moorings not represented by the data or maps. | The Humber Estuary is used as a recreational boating area and for training and races. The number of moorings give an indication of the estuary's popularity |
| Quality of Beaches | Bathing Waters and Bathing Waters Sensitive Areas | 2006 Bathing Water Directive to designate and maintain such beaches | Data provided in excel file format and only certain information was plotted on GIS. Raw available If required. | The Humber Estuary has two bathing beaches and therefore these beaches must be able to maintain their standard for public health. |
| Water Abstractions | Water Abstractions | Achieving GES (or in the case of the Humber GEP) under the WFD | Abstraction licences provided in in a text file and only certain information was plotted on GIS. Raw available If required. | The Humber Estuary is classified as a Heavily Modified Water Body under the WFD. The overall aim of the WFD is to promote sustainable use of water and to attain GEP of which flow regime is a supporting element. |
| Population Growth | Population | Relevant to all directives and legislation as the governance has to take into consideration the impacts of implementation on the population and wider socio-economics | Not incorporated into GIS so is additional data. Only goes up to 2012. The data does not take into consideration other factors such as affluence etc. | To determine the trends in population changes surrounding the Humber Estuary, this will enable scenarios to be run with census data. |
| Number of pressures per $km^2$ | All data showing land uses | WFD for water quality, biological components and hydromorphology.<br>MCAA as any new development/activity requires a Marine Licence or notification to the MMO<br>Habitats Regulations directive to determine if the developments/activities will have a significant impact on features of conservation interest. | Averages the pressures therefore some areas will have higher pressures and some lower. Not all pressures are represented due to difficulty in obtaining data. | The Humber Estuary has a variety of uses and users, which can have a variety of impacts on the estuary. This indicator gives a representation of the magnitude of the pressure intensity on the estuary. |
| Vessels | Shipping Density | MCAA as any new development/activity requires a Marine Licence or notification to the MMO<br>EIA/CIA directives to determine the potential impacts of any new development/activity | Not incorporated into GIS. The data only goes to 2013. The data does not provide vessel or cargo type. | The Humber Estuary is an important area for maritime transport with relatively large quantities of cargo being imported and exported annually (see Figure 18 and Figure 20). |
| Tourism | Location and number of tourist areas and activities. | Relevant to all directives and legislation as the governance has to take into consideration the impacts of implementation on the population and wider socio-economics | Data on tourist recreational activities is collected sporadically and not with consistent methodologies. When data is collected there is the possibility of all recreational activities not being represented. | The Humber Estuary is used for several recreational activities which may have an impact on the ecosystem goods and services and therefore where possible, these should be taken into account |

| | | | | |
|---|---|---|---|---|
| Maintenance Dredging | Disposal site returns | OPSAR Convention to ensure that the material is not contaminated, this would have an adverse impact on the marine environment | 2013 data not available and 2012 data not complete | This is important for the navigation of the estuary by ensuring the channels have sufficient draught for the importation and exportation of goods for economy |
| Capital Dredging | Disposal site returns | OPSAR Convention to ensure that the material is not contaminated this would have an adverse impact on the marine environment | 2013 data not available and 2012 data not complete | Capital dredging projects are important to allow infrastructure to develop to accommodate larger or a greater number of vessels to allow economic development. |
| Construction Licences | Developments | MCAA as any new development/activity requires a Marine Licence or notification to the MMO | Data correct as of 2nd July 2014. Does not include FEPA or CPA licences prior to the MMO being established under MCAA. | Any works below MLWS for the Humber Estuary requires a Marine Licence from the MMO under the MCAA |

| Ecological Indicator | Data Layer | Relevance to Directives | Limitations | Application to the Humber Estuary |
|---|---|---|---|---|
| Area of land and sea protected by statutory designations | Conservation Designations | Habitats Regulations directive to show the boundaries of the designations. | The layer does not show the location of the features of conservation interest or the reasons for designation. | The Humber Estuary is designated as an SAC, SPA, Ramsar and SSSI as well as supporting several other designations landward of the MHWM. This requires that any new marine development will be required to demonstrate that the works will not have an adverse impact on the features of conservation interest. |
| Fishing | Fearnley *et al.*, 2012 | EIA/CIA as any new development will need to be assessed against their potential impacts on current activities and users of the estuary. | Data on tourist recreational activities is collected sporadically and not with consistent methodologies. When data is collected there is the possibility of all recreational activities not being represented. | The Humber Estuary is used for several recreational activities which may have an impact on the ecosystem goods and services and therefore where possible, these should be taken into account |
| Managed Realignment Sites | Managed Realignment Sites | Habitats Regulations directive to maintain the habitats of interest. | Only locations are given, not shapefiles for the areas covered. | In the Humber Estuary the Environment Agency have to be aware of the potential requirement to develop managed realignment sites to compensate for those lost due to coastal squeeze such as for Donna Nook. Managed realignment sites have also been developed by private industries to compensate for loss of designated habitat when developing for example a port such as Chowder Ness. |
| Water Pollution | Water Incidents | Water quality under WFD potentially affecting achieving GEP. | It is not clear what incidents have occurred and what the extent or remediation was. There is no indication as to the chronic or acute impacts. | The Humber Estuary is classified as failing GEP under the WFD for morphological conditions. As part of the WFD one of the criteria is the water chemical status which is affected by pollution incidents and should be taken into consideration for WFD assessment and management. |
| Polluted Sediments | CMDS | OSPAR.<br>Marine and Coastal Access Act.<br>WFD | Data up to 2013. Only provides data for those determinands required under the OSPAR convention. Only provides contamination levels for sediment not water. | To allow dredged material to be disposed of to sea, the applicant must prove that the material is suitable in terms of contaminant levels. If the material is found to be contaminated, it may jeopardise a project/ economic development. |
| Species richness | Saltmarsh Species. | Habitats Regulations directive to determine if the developments/ activities will have a significant impact on the designated habitats. | Not a GIS layer as the location of the species was not provided. | The Humber Estuary is designated under national and international legislation for its saltmarsh species. |
| Species richness | Macrobenthic species | Habitats Regulations directive to determine if the developments/ activities will have a significant impact on features of conservation interest. | Not a GIS layer as the location of the species was not provided. | The Humber Estuary is classified as failing GEP under the WFD for morphological conditions. As part of the WFD one of the criteria is biological components including benthic communities. |
| Interference with fish migration routes: physical barriers | Barriers | Salmon and Freshwater Fisheries Act is aimed at activities that could lead to fish mortality, act as barriers to migration and degradation of habitats.<br><br>Eel regulations enable the Environment Agency to implement measures for the recovery of European eel stocks and have important implications for operators of abstractions, discharges and barriers. | It is assumed that all the water discharge points, abstraction points etc. are barriers and that no mitigation has been installed. There could be other barriers that are unrecorded such as large litter deposits. There are also barriers that may be present which are not physical such as chemical barriers which are not represented. | The Humber Estuary is used by several species including salmon, eel, river and sea lamprey as a migratory route therefore any obstructions/ barriers may reduce the viability for the species to spawn. |

| | | | | |
|---|---|---|---|---|
| | | The ability for species to migrate and spawn are part of the GES/GEP status under the Water Framework Directive. | | |

| Physical Indicator | Data Layer | Relevance to Directives | Limitations | Application to the Humber Estuary |
|---|---|---|---|---|
| Area of artificial coast | Flood Defences | CHaMPs to ensure the designated features are maintained.<br>WFD as hydromorphology contributes to the achievement of GEP or otherwise. | Flood defences were not provided as a shapefile but rather as pdf maps. | The Humber Estuary is a generally low lying and flat coastline, which is susceptible to flooding under certain conditions. The flood defences protect homes and businesses from the risk of flooding. |
| Relative Sea Level Rise | Data taken from documented records and projections. | EIA/SEA/CIA directives for new developments as the amended directive now requires EIA's to take into account the impacts of climate change. | Sea level rise is not a shapefile, but the data has been recorded. | The Humber Estuary has been subject to land reclamation, which can cause coastal squeeze, and with sea level rise, it increases the risk of flooding to the adjacent land, residences and businesses. |
| Land Claim | Flood Defences<br>Ports | CHaMPs to ensure the designated features are maintained.<br>WFD as hydromorphology contributes to the achievement of GEP or otherwise. | Flood defences and ports not provided as shapefiles but as maps and estimated shapefiles respectively. Not based on a baseline as historic records not reviewed. | The Humber Estuary has been subject to land claim for port developments and flood defence works. This causes coastal squeeze and requires managed realignment sites to be created. It also must take into account sea level rise and isostatic change. |
| Number and location of berths, jetties etc | Marinas and Slipways | EIA/SEA/CIA directives for new developments and WFD for determining water quality and impacts from associated activities. | Does not include the RYA data, this is provided by a pdf atlas. | The Humber Estuary is used as recreational boating area and for training and races. The number of moorings give an indication of the estuary's popularity. |
| Topography and bathymetry of sea bed | Bathymetry | Potentially the bathymetry (and changes) could be relevant to all legislation as the impacts of and on bathymetry changes need to be assessed. | The Humber Estuary is a dynamic estuary and therefore the levels are a snapshot in time and can vary. | The Humber Estuary is a dynamic estuary where the material is moved around rapidly and the levels can be changed due to erosion and accretion patterns. These can impact the maritime transport for both commercial/ industrial and recreational vessels. |
| Current Velocity | Average velocities taken from published charts and documented records. | Potentially the bathymetry (and changes) could be relevant to all legislation as the impacts of and on bathymetry changes need to be assessed. | No shapefile but data recorded. Velocity variable. | The Humber Estuary is used for recreational purposes and therefore the public need to be made aware of velocities. The velocities can affect the accretion and erosion rates of the estuary. |
| Turbidity | Data taken from documented records | Potentially the turbidity (and changes) could be relevant to all legislation as the impacts of and on turbidity changes need to be assessed. | No shapefile but data recorded. Turbidity variable. | The Humber Estuary is a turbid environment and therefore influences the species that can inhabit it and affects the accretion rates within the estuary. |
| Volume | No public data available at the time of this study | Potentially all, as the volume (and changes) could be relevant to all legislation as the impacts of and on volume changes need to be assessed. | No public data available at the time of this study | The volume of water can influence the tidal prism, wave height, flow, velocity and can affect the physical processes of the Humber Estuary. |

| | | | | |
|---|---|---|---|---|
| Depth | EA Parameters | Potentially all, as the water depth (and changes) could be relevant to all legislation as the impacts of and on water depth changes need to be assessed. | Point layer and therefore only the water depth at certain locations are known. | The water depth can influence the tidal prism, wave height, flow, velocity and can affect the physical processes of the Humber Estuary. |
| pH | EA Parameters | Potentially all, as the pH (and changes) could be relevant to all legislation as the impacts of and on pH changes need to be assessed. | Point layer and therefore only the pH at certain locations are known. | The pH of a water body can affect the achievement of GEP under the WFD but it also has adverse impacts on the biological communities of the Humber Estuary. The change in pH can ultimately change the functions undertaken, and if left, the ecosystem goods and societal benefits provided by the system. |
| Salinity | EA Parameters | Potentially all, as the salinity (and changes) could be relevant to all legislation as the impacts of and on salinity changes need to be assessed. | Point layer and therefore only the salinity at certain locations are known. | A change in salinity can have an adverse impact on the biological communities which can lead to ultimately a change in the functions undertaken and if left, the ecosystem goods and societal benefits provided by the system. |
| Substratum | UK Seabed SeaMap | Potentially all, as the seabed (and changes) could be relevant to all legislation as the impacts of and on seabed changes need to be assessed. | The layer is produced from several surveys for European waters and is built on from the EUNIS and MESH projects. Survey specific information and date of data unknown. | The seabed consistency is important as the Humber Estuary is important for navigation of commercial and recreational activities, dredging and disposal activities, further developments and tourism. The seabed can influence these developments and activities to determine the method used (is the least damaging method to the environment the most appropriate one?), the most appropriate site for the works to be undertaken, the disposal of any dredged material etc. |

### 4.8 Determination of Risk for Dredge Material Disposal

To determine if the quantity of material to be disposed of to a disposal site is considered a high, medium, low or negligible risk with regards to the potential impacts on the marine environment, the method used by Birchenough and Pacitto (2013) and Lonsdale and Birchenough (2014) was applied. This can be summarised as the amount of material to be disposed of above the average the site has received in the previous last years[12]. As the calculation is in the code, and data are in a table, it allows the table to be updated and the code to remain the same for future use. The thresholds for high, medium, low and negligible effect are as follows:

- High risk- the disposal amount exceeds the 75% threshold (i.e. the amount to be disposed is 75% higher than the average for the previous five years' worth of data) at least once in the period;
- Medium risk- the disposal amount exceeds the Upper 50% threshold at least once in the period but does not exceed the 75% threshold;
- Low risk- the disposal amount does not exceed the Upper 75% or 50% thresholds in the five-year period but is above the average; and
- Negligible risk- the disposal amount is below the average in the period.

The output provides a risk assessment based on the above to inform any impact assessment and application for dredge/disposal activities.

### 4.9 SAC, SPA, Ramsar Conservation and Sensitivity

To determine the sensitivity of the habitats and species likely to be present within the study area, the sensitivity used by Tillin *et al.* (2010) and the approach used by Lonsdale and Birchenough (2014) was used to create a feature and sensitivity layer. The SAC layer was expanded to list the features of the SAC's for the Humber Estuary, using JNCC's list of SAC's, (http://jncc.defra.gov.uk/page-1458) and then by using the approach set out by Lonsdale and Birchenough (2014) (for detail see Appendix 6). The features of the SAC's were aligned with the features assessed as part of the Tillin *et al.* (2010) project. Where features of the SAC's could not be directly linked to features undertaken in the sensitivity analysis, the most suitable feature was chosen as a proxy (as set out by Lonsdale and Birchenough, 2014). The

[12] The last five years' worth of data is defined as the last year the disposal returns were reported to OSPAR and the preceding fours year. In this study it was 2009-2014.

SPA and Ramsar features were also assessed for their sensitivity (and the SAC features updated from the Tillin approach) using the Regulation 33 advice (English Nature, 2003).

To standardise the sensitivities, where several habitats could be attributed to one feature e.g. mudflats, sandflats and coastal lagoons the scores are averaged. The overall ranking was used, and these were translated into a numerical format for the analysis, this being a lower number for a lower sensitivity risk, and a high number for high sensitivity risk (it should be noted that this is a high-level assessment and a more detailed, site specific assessment should be undertaken prior to any application being made to the regulators). The numerical values were then aggregated and averaged: the average values were rounded to integers and assigned sensitivities as per Tillin *et al.* (2010) (the calculations are provided in Appendix 6) (Table 13).

Table 13 Values based on sensitivity

| Value | Sensitivity |
|---|---|
| 0 | Not sensitive/ not enough information |
| 1 | Low sensitivity |
| 2 | Medium sensitivity |
| 3 | High Sensitivity |

Features of the SPA and RAMSAR sites were not included, as the sensitivity analysis undertaken by Tillin *et al.* (2010) did not include ornithological features and this study is to determine the appropriateness of an EPSS tool that incorporates the current management practices and tools. Should a sensitivity analysis be undertaken for ornithological features, this could be included in future developments of the tool.

Features of SSSI's were not included, as the sensitivity analysis of the features were either of terrestrial, ornithological or geological, and those features in the marine environment are covered under the SAC's for the Humber Estuary and surrounding area. The layers do however contain links to the relevant websites should the developer or decision-maker wish to investigate the features in more detail. Specific species are also not included, as they were not included in the English Nature (now Natural England) guidance or Tillin *et al.* (2010) study.

### 4.10 Water Framework Directive Assessment

The purpose of the WFD Assessment is to determine whether an individual dredging or disposal activity needs further assessment to establish if it complies with the WFD. There

may be some activities that can be exempted from the WFD Assessment, however it is recommended that all projects are screened, and a record/audit should be kept and provided to the Licensing Authority to aid the decision-making process (Environment Agency 2012a; b; c; d; e).

The guidance provided by the English Environment Agency (2012a; b; c; d; e) is used by applicants to establish if the project complies with the WFD, however currently the way in which it is applied is not consistent and during a workshop to train scientific advisors, it was highlighted that when using the same data, different answers can be produced (Regulatory Assessment Team, Cefas, *pers. comm.*). This is an issue because it demonstrates that there is no standardised approach for undertaking the assessment, potentially preventing England from meeting its WFD objectives and requirements.

To overcome this inconsistency and to provide a more consistent way forward, this study has integrated the WFD Assessment into the tool (Figure 39). This allows for a transparent and consistent method of carrying out the WFD assessment (to be tested by the Environment Agency). The Further Assessment Stage is not included in the tool as it requires a full assessment, including expert judgment, to be undertaken by the applicant. As the Further Assessment stage requires additional stages such as cost benefit analysis, socio-economic and political assessments and consideration of expert judgement, the development of this tool could not further streamline this part of the process and therefore was not considered further.

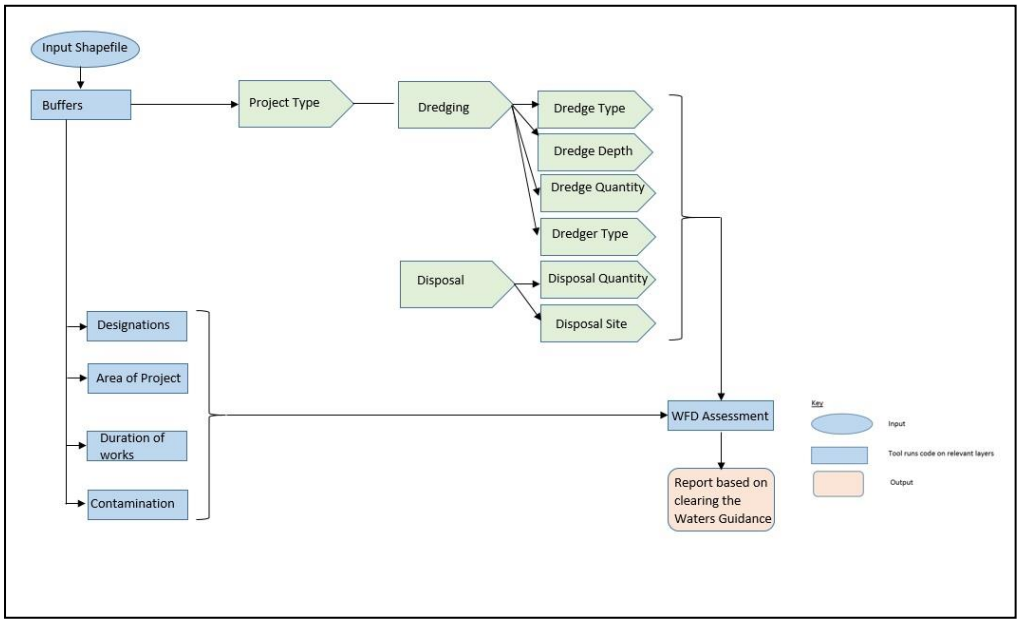



Figure 39 Flow diagram of how the tool undertakes the WFD Assessment.

In determining if an assessment is required, the developer needs to determine if the works are to occur within 2km of a designated area, including shellfish areas, however in this instance the shellfisheries layer has not been included for this part of the tool as the layer is not applicable to the study area.

Once the user has input the required details, the code takes the information and calculations and completes the WFD screening as per the 'Cleaning the Waters Guidance' (Environment Agency, 2012a; b; c; d; e) and the outputs are specifically designed to align with the tables provided in the guidance for consistency.

The Environment Agency have recently updated their guidance on WFD assessments to encompass all marine activities, not just dredging and disposal, however this was released during the final stages of this study so have not been incorporated.

It should be noted that the assessment requires contaminant testing. The data accessible for this study is from tests obtained by Cefas as part of past dredge and disposal applications under the Marine and Coastal Access Act. As such these do not include the results for hexachlorobutadiene (HBCD) as this is not required for marine licensing applications (and so is not in the GIS shapefile) and is therefore not included in the code and the WFD assessment.

### 4.11 Creating WFD Layer Describing Reasons for Failure under the WFD

To determine why a section of the Humber Estuary is failing the requirements of the WFD, the Environment Agency has divided the Humber Estuary into three (Figure 40). The reasons for failure, and the measures to address the failures, were received via email (Appendix 4) and then attributed to the relevant sections in a GIS layer for reference. The layers were then created and amalgamated into one overall layer: 'ReasonsForFailureHumber', for use in the EPSS tool. This was created as it is often difficult to determine the reasons for a water body failing, due to the information being in a different place to the assessment guidance and EQS's. By creating a single shapefile with the relevant WFD required information, it enables the tool to run more quickly, and also holds the data in one place for users to interrogate and update where necessary.

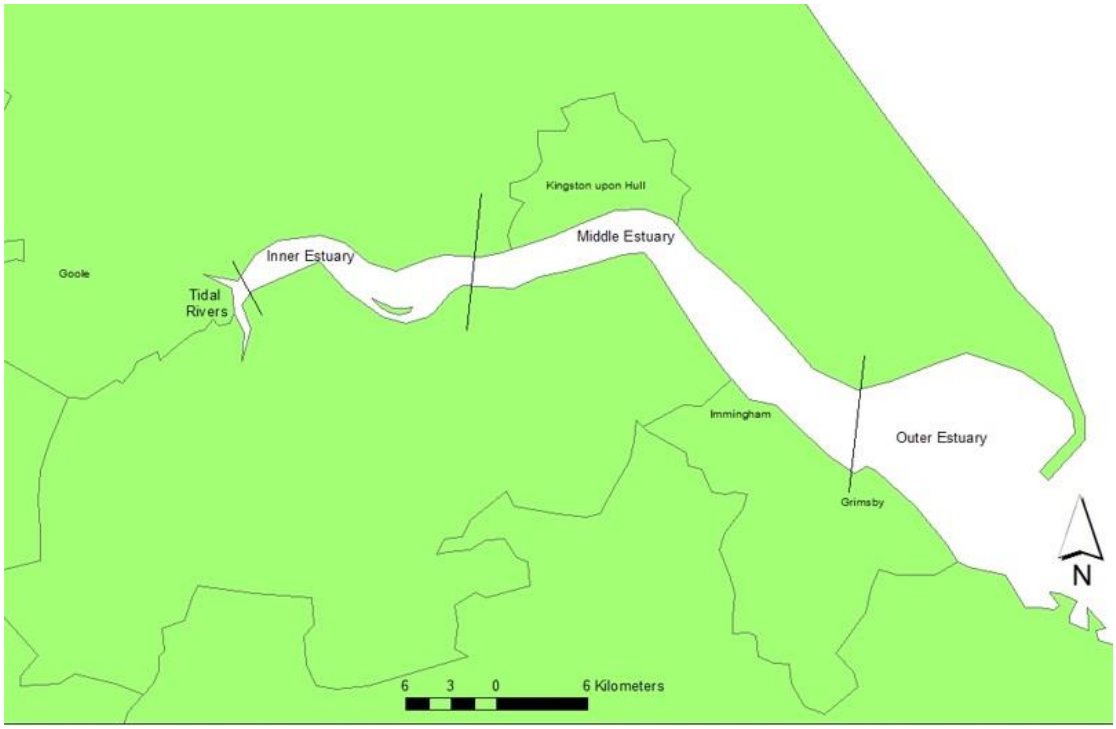



Figure 40 The Humber Estuary and the divisions as used by the Environment Agency for determining compliance with the WFD.

### 4.12 Conflicts Matrix

Arbo and Thuy (2016) identified that the weakest element of the ecosystem approach is the regulation of multi-use conflicts i.e. where many activities occur in one area, and at one time, which can degrade the environment and cause tensions amongst the different social groups. They further concluded that resolving this issue of conflict is a central problem, and to ensure ecosystem based management is truly integrative. Therefore, to incorporate the conflicts matrix into the EPSS tool, the matrix was reconciled with the GIS layers to determine which feature classes are associated with the land uses, and ecosystem goods and services as demonstrated in section 3.7. The tool then identifies which of the layers (and therefore conflict elements) are within 1 or 5km of the input shapefile (development) dependant on the conflict element (see Table 10). By using the 1 and 5km buffers, it is assumed that the conflict elements are sufficiently close to have an influence on each other. This is a simplification and precautionary approach to the assessment of existing and potential conflicts in the study area.

### 4.13 Ecosystem goods and services in the Humber Estuary

The ecosystem goods and societal benefits that the Humber Estuary provides have been summarised in Table 14. As ports are a man-made use of the estuary rather than being

provided by the estuary itself, these have not been included in this assessment of ecosystem services and societal goods and benefits (Section 3.7). Navigation of the estuary has been included as this is a use of the estuary i.e. the natural deep-water channel which provide the means for vessels to access a port.

Many of the land uses provide the same ecosystem services to human wellbeing, although through different processes (Table 14). These ecosystem services and societal goods and benefits arising from the Humber Estuary are interlinked, and have complex interactions (see Figure 41 and 42 for a simplified conceptual model of these interactions and links).

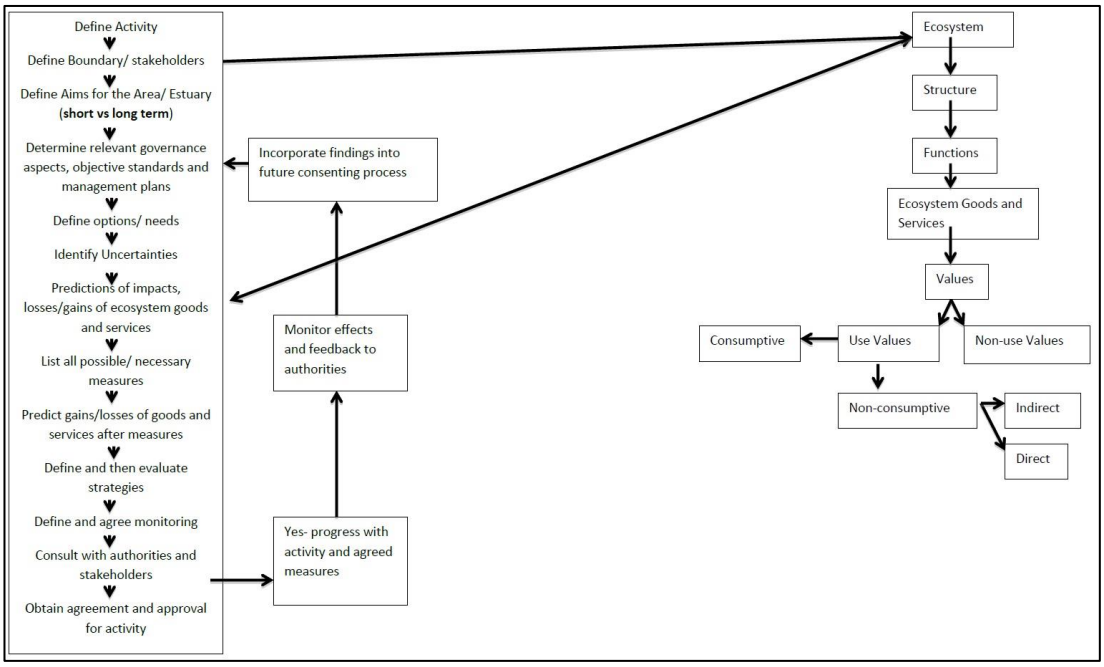



Figure 41 Determining the ecosystem goods and services of an area

With more developments such as port expansions to accommodate larger vessels, impacts from coastal squeeze and an increase in the need for infrastructure either in, or adjacent to the system, the demand on these services increases. It is important that these services are considered in assessments, as well as identifying the conflicts that are placed on these services to help inform the assessment (discussed in section 3.7).

Table 14 The ecosystem goods and services provided by the Humber Estuary (below mean high water).

| Service Group | Final ecosystem service | Estuary- water body | Estuary- mudflats | Estuary- sand dunes | Managed Realignment Sites* | Conservation Designations*[2] | Agriculture*[3] |
|---|---|---|---|---|---|---|---|
| Provisioning | Crops | N/A | N/A | N/A | N/A | N/A | Food |
| | Livestock | N/A | N/A | N/A | N/A | N/A | Food |
| | Fish | Food and for recreation | For recreation | N/A | Food and for recreation | For recreation | N/A |
| | Trees/ vegetation | N/A | N/A | Prevention of erosion, for recreation and healthy climate | Prevention of erosion, for recreation and healthy climate | Prevention of erosion, for recreation and healthy climate | N/A |
| | Water supply | Drinking water | N/A | N/A | N/A | N/A | Irrigation |
| | Navigation | Import/Export of goods | N/A | N/A | N/A | N/A | N/A |
| | | | | | | | |
| Regulating | Climate regulation | Healthy climate | Healthy climate | Healthy climate | Healthy climate | Healthy climate | N/A |
| | Carbon sequestration | Healthy climate | Healthy climate | Healthy climate | Healthy climate | Healthy climate | Healthy climate |
| | Disease and pests | N/A | N/A | N/A | N/A | N/A | N/A*[4] |
| | Pollination | N/A | N/A | N/A | N/A | N/A | Food |
| | Noise | N/A | N/A | N/A | N/A | N/A | N/A |
| | Water purification | Drinking water | Drinking water | Drinking water | Drinking water, fish for food and recreation | Drinking water | Irrigation |
| | Soil purification | N/A | N/A | N/A | N/A | N/A | N/A |
| | Air purification | Healthy climate | Healthy climate | Healthy climate | Healthy climate | Healthy climate | Healthy climate |
| | Maintain biodiversity | For recreation, visual amenity, education, research | For recreation, visual amenity, education, research | For recreation, visual amenity, education, research | For recreation, visual amenity, education, research | For recreation, visual amenity, education, research | N/A |
| | Nutrient cycling | Healthy climate | Healthy climate | Healthy climate | Healthy climate | Healthy climate | Healthy climate |
| | Sediment formation and stability | N/A | Prevention of coastal erosion/ sea defence | Prevention of coastal erosion/ sea defence | Prevention of coastal erosion/ sea defence | Prevention of coastal erosion/ sea defence | Prevention of coastal erosion/ sea defence |
| | Shoreline protection | N/A | Prevention of coastal erosion/ sea defence | Prevention of coastal erosion/ sea defence | Prevention of coastal erosion/ sea defence | Prevention of coastal erosion/ sea defence | N/A |
| | | | | | | | |
| Cultural | Places and Seascapes | Recreation, future uses, visual amenity, tourism, education, research and landscape use | | | | | Future uses, education, research and landscape use |

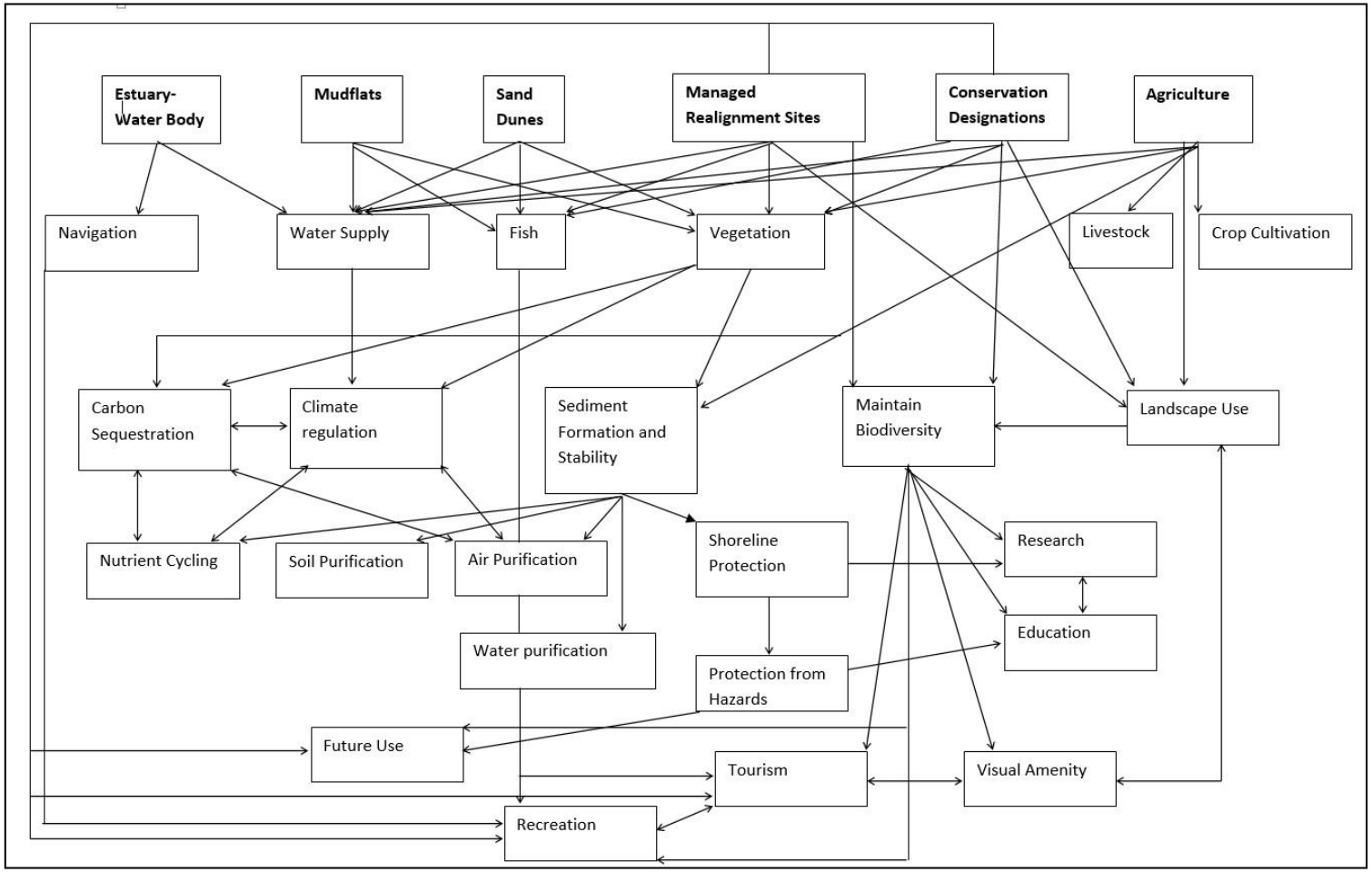



Figure 42 A simplified concept model showing the interactions and links between ecosystem goods and services (below mean high water).

### 4.14 Ecosystem services and societal goods and benefits- Valuation

Ecosystem service valuation is the process of assessing the values of such benefits to humans; this is a rapidly emerging science as it not only has the potential to highlight hidden ecosystem benefits and costs that may be otherwise overlooked, but also allows a view that can easily be shared across stakeholders (Borger *et al.*, 2014). For non-market services such as research, it can be difficult to apply a monetary value given there is no market on which to base the assessment; the HM Treasury (2003) Green Book however, states that non-market impacts may not be measured in monetary terms but might "*sometimes still sensibly be given money values*": this is discussed below.

The current MSPs for England do not currently incorporate the ecosystem costs and benefit, and even though work has been carried out there is still a lack of primary evidence. The challenges of incorporating environmental costs include lack of valuation data; methodological challenges; assessment of non-use values; inability to link scenarios to ecological outcomes, and values and high mobility of certain marine resources (Borger *et al.*, 2014).

Borger *et al.* (2014) recommend that to assign monetary costs there is a requirement to improve our understanding of ecosystem service provisions, and the associated and underlying functions and processes. There is also a need to consider the baselines, and standardisation and development of valuation approaches. It is important to highlight however that evidence from a small number of cases does not provide a robust evidence base, because although sites can be similar geographically and geomorphically, there are impacts that are unique to the areas, such as legacy of industrial activities and contamination (Luisetti *et al.*, 2014).

The EPSS tool does not assess the ecosystem services and societal goods and benefits, nor does it assign monetary values, it will however identify those ecosystem services and societal benefits provided by the Humber Estuary using the GIS layers, (see Appendix 5 to see how the layers tie into the indicators) and recommend the most appropriate valuation methods as described by Turner *et al.* (2014), Bhatia (2012) and Turner *et al.* (2010) (Table 15). It is then for the user to assess the economic benefits or impacts of the development on the ecosystem services and societal goods and benefits for the regulator. The subsequent look up table was quality checked by experts within Cefas (Dr T Luisetti and L Paltriguera, *pers. Comm*). It is important to consider the overall aim of the tool: to provide the information to

navigate the legislative requirements required for a project or development, and to provide the information for an impact assessment to be carried out.

Table 15 The Reconciliation of shapefiles and ecosystem goods and services

| GIS Layer | Fundamental services | Final services | Societal Benefit | Valuation Techniques | References |
|---|---|---|---|---|---|
| None identified | Production | Gas and Climate regulation | Healthy climate | Production Function, Replacement Cost, Damage Avoidance Costs, Defensive Expenditure Costs | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Water abstraction; | Physical habitat | Clean water and sediments | Water Supply inc. irrigation | Contingent Valuation Methods, Choice Experiment Method | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Water abstraction; | Hydrological Processes | Nutrient Cycling | Water Supply inc. irrigation | Replacement Cost, Cost of Illness | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Water abstraction; Outfall discharge points | Ecological interactions/waste breakdown and detoxification | Clean water and sediments | Waste burial, removal and neutralisation | Replacement Cost, Cost of Illness, Damage Avoidance Costs | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Beaches; MR Sites; Bathing waters; Agricultural land classification; World Heritage Site; SAC, SSSI, SPA, Ramsar; Saltmarsh Extents; nursey grounds; spawning grounds | Habitats and species/ sea space/ seawater/ substratum/ ecological interactions/ hydrological processes/ geological processes | Biological control/ natural hazard regulation/ water and nutrient cycling | Resilience and resistance | Production Function,Replacement Cost, Damage Avoidance Costs | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Agricultural land classification; nursey grounds; spawning grounds; Fish landings 2007-2011. | Species present/ food web dynamics | Fish and shellfish | Food provision | Market analysis | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Agricultural land classification; Woodlands; UK Seabed Map | Substratum | Sediment type/composition | Raw materials | Market analysis | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Marinas; slipways; wharves; disposal sites; docks; dredge areas; ports&docks; shipping density; import/export values | Seawater/ sea space/ hydrological processes | Climate regulation/ natural hazard protection | Transport and navigation (import/export of goods) | Market analysis | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Water abstraction; | Hydrological Processes | Nutrient Cycling | Water Supply inc. irrigation | Market analysis, Production Function, Deliberative Monetary Valuation | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Coastal Design Sea Level; Flood Alert Areas; Flood Risk Areas; Flood Warning Areas; Risk of Flooding from Rivers and Sea; Saltmarsh Extents | Hydrological Processes | Natural hazard protection | Flood/sea defence | Production Function, Replacement Cost, Market Analysis, Damage Avoidance Costs, Defensive Expenditure Costs | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Saltmarsh Extents | Hydrological Processes | Natural hazard protection | Prevention of erosion | Production Function, Replacement Cost, Market Analysis, Damage Avoidance Costs, Defensive Expenditure Costs | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Bait Digging; Bathing waters; beaches; horse riding; kitesurfing; MR sites; wildfowling; country park; woodlands; Listed buildings; Battlefields; heritage coast; Park and Gardens; Protected Wrecks; Scheduled monuments; World Heritage Site; SAC, SSSI, SPA, Ramsar; Saltmarsh Extents; MMO Typologies | Habitats and species/ sea space/ seawater/ substratum/ ecological interactions/ hydrological processes/ geological processes | Places and seascapes | Recreation and Tourism | Travel Cost Method, Hedoic Pricing, Contingent Valuation Methods, Choice Experiment Method | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Beaches, MR sites; country parks; woodlands; Listed buildings; Battlefields; heritage coast; Park and Gardens; Protected Wrecks; Scheduled monuments; World Heritage Site; SAC, SSSI, SPA, Ramsar; Saltmarsh Extents | Habitats and species/ sea space/ seawater/ substratum/ ecological interactions/ hydrological processes/ geological processes | Places and seascapes | Visual amenity | Travel Cost Method, Hedoic Pricing, Contingent Valuation Methods, Choice Experiment Method | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| MR Sites; woodlands; Listed buildings; Battlefields; heritage coast; Park and Gardens; Protected Wrecks; Scheduled monuments; World Heritage Site; SAC, SSSI, SPA, Ramsar; Saltmarsh Extents | Habitats and species/ sea space/ seawater/ substratum/ ecological interactions/ hydrological processes/ geological processes | Places and seascapes | Education | Contingent Valuation Methods, Choice Experiment Method | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| MR Sites; woodlands; Listed buildings; Battlefields; heritage coast; Park and Gardens; Protected Wrecks; Scheduled monuments; World Heritage Site; SAC, SSSI, SPA, Ramsar; Saltmarsh Extents | Habitats and species/ sea space/ seawater/ substratum/ ecological interactions/ hydrological processes/ geological processes | Places and seascapes | Research | Contingent Valuation Methods, Choice Experiment Method | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Beaches, MR sites; country parks; woodlands; Listed buildings; Battlefields; heritage coast; Park and Gardens; Protected Wrecks; Scheduled monuments; World Heritage Site; SAC, SSSI, SPA, Ramsar; Saltmarsh Extents; MMO Typologies | Habitats and species/ sea space/ seawater/ substratum/ ecological interactions/ hydrological processes/ geological processes | Places and seascapes | Landscape use | Contingent Valuation Methods, Choice Experiment Method | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |
| Beaches, MR sites; country parks; woodlands; Listed buildings; Battlefields; heritage coast; Park and Gardens; Protected Wrecks; Scheduled monuments; World Heritage Site; SAC, SSSI, SPA, Ramsar; Saltmarsh Extents | Habitats and species/ sea space/ seawater/ substratum/ ecological interactions/ hydrological processes/ geological processes | Places and seascapes | Future use | Contingent Valuation Methods, Choice Experiment Method | Turner et al, 2014; Bhatia, 2012; Turner et al, 2010 |

| |
|---|
| Supporting services |
| Provisioning services |
| Cultural services |
| Regulating services |

### 4.15 Contaminated Sediment Layer

The Contaminated Marine Dredging Sediments (CMDS (see Appendix 2)) tool is a freely available tool from Cefas that holds all the data, from any analyses undertaken on marine sediments for the purposes of disposal to sea in England and Wales. This holds the results, and can give an indication of whether the samples are above Cefas Action Level 1 or 2, but this is not within the attribute table itself. There were two options to include this in the tool; firstly, to leave the table as is (following clipping the layer to the area of interest) and code the action levels which could slow down the running of the model; or secondly amend the attribute table to contain additional columns, which states if the results are above or below the action levels as these are unlikely to change. This allows the filter to be applied relatively quickly to speed up the operation of the tool, and means that the table will only need amending should the action levels be changed in the future, rather than the coding behind.

### 4.16 Climate Change Data and Scenarios

Kettle and Dow (2016) identified that coastal communities will face different risks to climate change because of differences in the rate, magnitude, and timing of exposure to changing climate conditions. The impacts of climate change will also vary within, and between communities, given that individuals and communities experiencing these changes have different sensitivities, and structural and institutional challenges.

There are often differences in the level of perceived risk, which are mediated by socio economic and demographic attributes, political affiliation, environmental beliefs, and physical vulnerability, values and worldview, experiential factors and trust. It was envisaged that the tool would incorporate climate change effects to inform any assessments, the developers, regulators and users, however the climate Change Projections were over land apart from sea level rise, which only covered a small portion of the Humber estuary at low resolution, therefore the climate change projection data have not been included (Figure 43). In addition, the DESYCO tool (section 3.9, xi) could not be integrated with the GIS tool developed as part of this study due to the use of the statistical analysis package ‘r’ in the DESYCO tool.

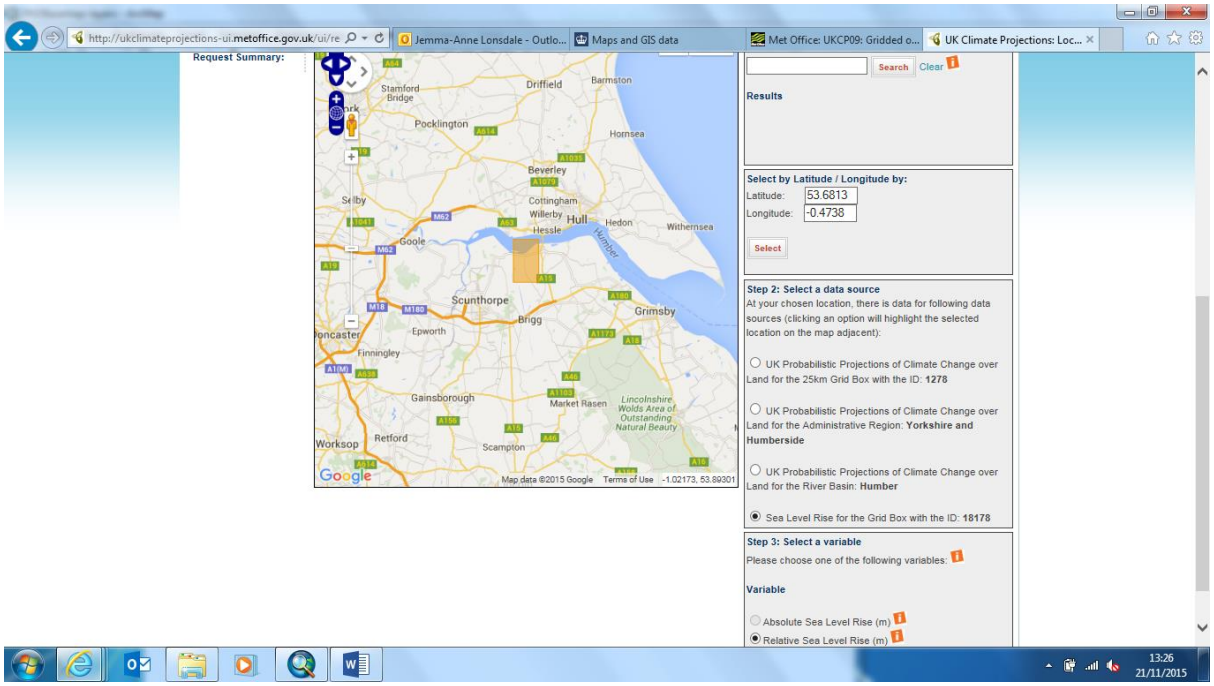



Figure 43 Screenshot of the UKCP09 website and search tool showing the data available for the Humber Estuary.

## 4.17 The Incorporation of the Cumulative Impact Assessment in the EPSS Tool.

To incorporate the potential impacts from pressures on the potential receptors into the tool for cumulative impact assessments, the pressure matrices constructed in section 4.2 were reconciled with those of the other references, and allowed all the tables to be incorporated into the CIA. Impacts were defined using the JNCC pressures-activities Database (JNCC, 2013). The features of the SSSI are not subject to a sensitivity analysis as are the SAC, SPA and Ramsar site features, because Natural England have not yet produced advice to this effect, however, once this is provided, the look up tables, and some code, would need to be updated to reflect this addition. The tool will output the cumulative impact assessment in the form of maps (Figure 44).

The extents of the impacts have been determined in the absence of accurate data being available regarding the physical properties of the estuary. By identifying the receptors/users within 1 or 5km (based on Table 10) of the input shapefile, it allowed the conflicts matrix to be incorporated into the tool, and into the cumulative impact assessment. This assumes that they are sufficiently close to have an influence. It is acknowledged that this is an oversimplification and a precautionary approach, but is a reasonable compromise on which to test the EPSS.

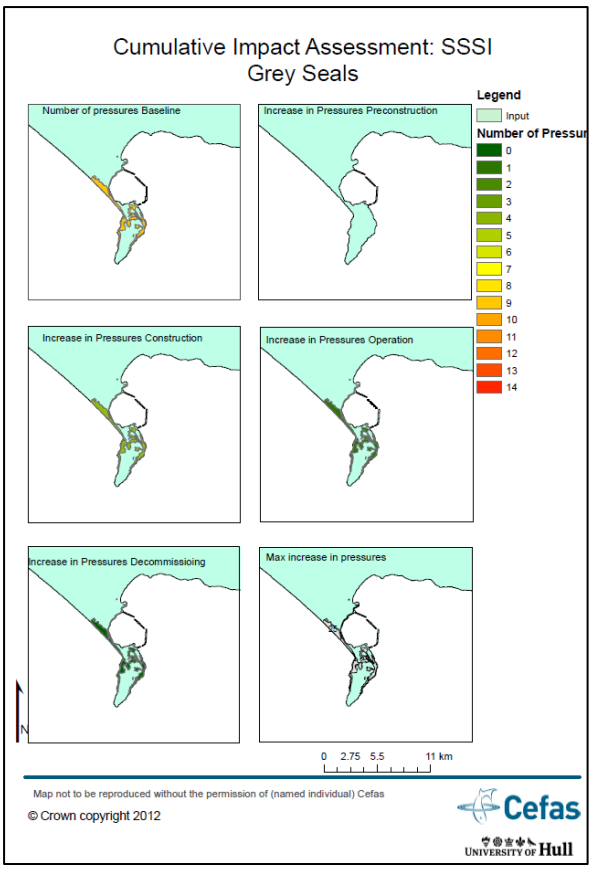



Figure 44 Example of CIA Output

To address the 3D nature of the ecosystem in a 2D tool (ArcGIS), the receptors, activities and pressures were defined as being in the seabed, benthic, or in the water column. Additive impacts are included in the cumulative impact assessment as it is known that increasing pressures, (and impacts) increases the stress on receptors, although the degree of such cumulative impacts cannot still be quantified. Other relationships (e.g. synergistic or antagonistic) are not considered on the basis that it is often unclear, in part due to a paucity of direct manipulative evidence of multiple stressor effects, how the severity of interacting pressures can change beyond a simple additive process of the same pressure type

Furthermore, at this stage, only additions of the same pressure type (e.g. abrasion from fishing, combined with abrasion from aggregate dredging) were considered, rather than combinations of different pressure types (e.g. abrasion from fishing with changes in siltation from aggregates), although the potential for such interactions to occur is recognised.

Temporal overlap is perhaps a more challenging concept. Here, “time” refers to not only the persistence of the pressure but also its intensity. This interaction determines how frequently a pressure type needs to be introduced to cause a combined effect. However, the persistence

and intensity thresholds required for combined effects to occur are unknown and remain unquantified. The EPSS tool takes a precautionary approach; the activities / sub-activities can occur in one of four phases: pre-construction, construction, operation and decommissioning. It is possible that all phases can occur at the same time due to multiple activities, but 2 developments within 5km could be in different phases at any one time, therefore 4 assessments, 1 for each phase and one for the baseline, will be carried out. The tool assumes anything in the buffer may be in any or all phases, except those only in operation e.g. fishing. The existing pressures in the baseline associated with the pressures to the layers, are all assumed to be in the operational phase, as the phases are not included in the layers, (given that these can change and create uncertainty) and for the purposes of testing this demonstrates the applicability.

To address the issue of double counting, a hierarchal approach to pressures/impacts is proposed, by only taking the most relevant pressure/impact into the assessment etc. For example, dredging does not require abrasion as the pressure of physical loss covers this. The next step is the consideration of the 'effects' and whether there are any acute effects, and if so, are there any effects which mean other effects cannot occur (i.e. once an organism is killed it cannot be killed again) or are there a series of chronic effects that may cumulate into a more serious outcome (A Judd *pers. Comm*, August 2015). Those activities considered relevant to the North East Atlantic as identified by the OSPAR commission, is provided in Table 16. The overall method is provided in Figure 45.

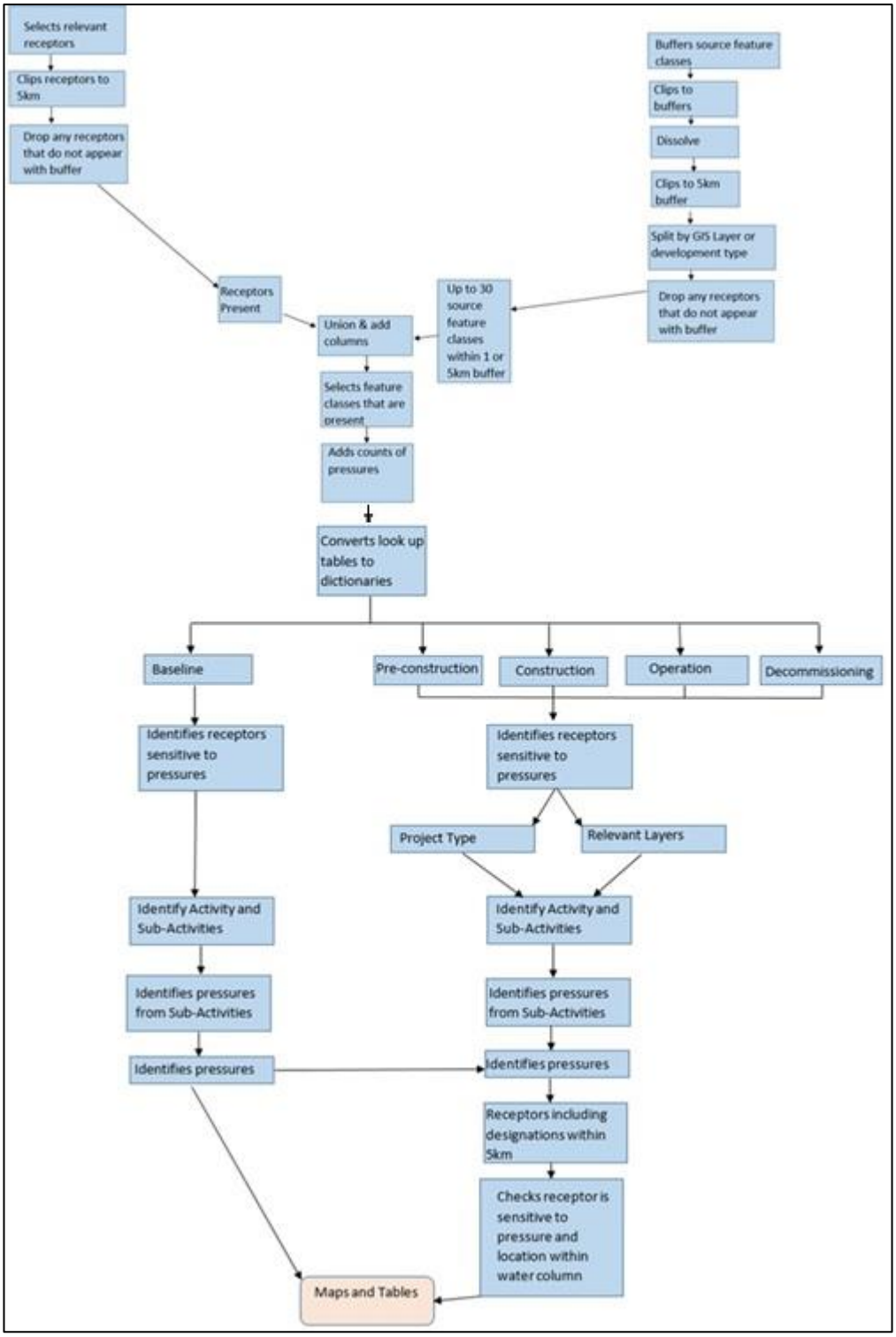



Figure 45 Overall approach and method to the cumulative impact assessment incorporated in the EPSS tool.

Table 16 The activities in relation to the pressures of the North East Atlantic as identified by OSPAR Commission (A. Judd pers. Comm.) and the layers these relate to as part of this study (where these are not relevant to the study area, this is specified).

| **Human Activity** | **OSPAR Comment** | **Comment in relation to EPSS Tool Developed** |
|---|---|---|
| CCS | None provided | Not relevant to study area |
| Coastal defence | Very difficult to map/quantify | Demonstrated by flood defences and MR Sites |
| Artificial Reefs | None provided | Not relevant to study area as far as I am aware |
| Dredging for navigational purposes | Limited spatial data on dredge areas | Demonstrated by maintenance and capital dredge applications. |
| Disposed past chemical and conventional munitions | Source- Environmental Impacts of Human Activities (EIHA) committee munitions database | Not relevant to study area as far as I am aware |
| Disposal of wastes or other matter | EIHA dumping returns | Demonstrated by disposal returns |
| Exploration and exploitation of deep sea mineral resources, including deep sea mining | None provided | Not relevant to study area |
| Exploration and exploitation of oil and gas and placement and decommissioning of structures for the exploitation of oil and gas | Source- Offshore Industry Committee (OIC) | Not relevant to study area |
| Extraction of living resources | None provided | Demonstrated by fish landings data |
| Fisheries | None provided | Demonstrated by fish landings data and spawning and nursery areas |
| Installations and structures- offshore wind farms and other marine energy developments | None provided | No wind farms in study area but tool includes MCAA applications including renewable energy |
| Installations and structures other than for oil and gas and offshore wind farms but including artificial reefs | None provided | Tool includes MCAA applications |
| Land reclamation | None provided | No readily available data to quantify but can be interpreted from MCAA applications. |
| Mariculture | None provided | Not relevant to study area as far as I am aware |
| Marine scientific research | Difficult to quantify as often not subject to licences | Agreed. Any exemption must be notified to the MMO so limited data may be available. |

| Human Activity | OSPAR Comment | Comment in relation to EPSS Tool Developed |
|---|---|---|
| Maritime transport | None provided | Tool includes shipping density |
| Placement of cables and pipelines | None provided | Tool includes cables and pipelines data. |
| Sand and gravel extraction | Source- ICES Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem (WGEXT) | Not relevant to study area. |
| Tourism and recreational activities | Very difficult to map/quantify | Agreed. Tool has some data for recreational activities but unsure of extent or certainty of data. |
| Barrier to species movement | Human activities will fit into two types:<br>1) Physical obstructions e.g. bridges, barrages etc.<br>2) chemical, noise or electromagnetic changes with activities. | Physical obstructions demonstrated by MCAA applications and known structures. Other obstructions based on sediment contamination issues and where pipelines/cables are located. Barriers by noise have not been mapped in this study. |
| Changes in pH | It is unlikely that direct maps of pH changes for specific human activities can be generated. A whole range of factors will contribute to ocean acidification. | Agreed- pH changes not mapped other than those that can be obtained from the Climate Change data. Climate change was not included in this study. |
| Changes in suspended solids (water clarity) | Human activities include dredging, disposal, aggregate extraction, cable lying. Pressure will be concurrent with the activity and will cease once the activity stops (with a short time lag). | This has been demonstrated by applying buffers to the activities for both the EPSS tool and CIA tool. Temporal considerations need to be incorporated. |
| Death or injury by collision | Difficult to map. Whilst there is potential for biota to collide with subsea infrastructure or vessels, evidence suggests that this is relatively rare. | Included in the pressures matrix behind the CIA tool. Not mapped directly given the difficulties in mapping such impacts. |

| Human Activity | OSPAR Comment | Comment in relation to EPSS Tool Developed |
|---|---|---|
| | May be best to consider this pressure in terms of trends in populations. | |
| Deoxygenation | Difficult to map from a human activities context. May be best to base on regional eutrophication data sets. | Eutrophication data provided in EPSS tool. |
| Electromagnetic changes | The only human activity for this pressure is subsea cables. However, it is important to consider scaling as a typical cable is approx. 20cm in diameter and is often made bigger to be mapped therefore any impact is often overestimated. | Tool includes cables and pipelines data. |
| Emergence regime changes- local including tidal level change considerations | Probably best not to map this in terms of human activities but to map where coasts have changes or at risk of change. If human activities are adjacent to these vulnerable areas, they can be identified as potential pressures. | The Tools have the Flood alert and warning area data which show the Humber Estuary is a large vulnerable area and therefore all activities have been considered in relation to their potential impact on the emergence regime changes in the pressure matrices behind the CIA |
| Generic modification and translocation of indigenous species | Not straightforward to map from a human activities perspective. Causal activities could be aquaculture facilities, ballast water discharges or radionuclide contamination. However, all are well managed/regulated so likelihood is low. May be best to consider where incidents have occurred and map as high-risk areas. | Not relevant to study area as far as I am aware |
| Habitat structure changes- removal of substratum | Aggregate extraction and navigational dredging will be the main activities. | Demonstrated by maintenance and capital dredge applications. |
| Hydrocarbon and PAH contamination | Given the wide range of human activities that have the potential to release chemical | This is demonstrated in the EPSS and CIA tools by having the sediment contamination data to show |

| Human Activity | OSPAR Comment | Comment in relation to EPSS Tool Developed |
|---|---|---|
| | contaminants it will be very difficult to generate a sensible map based on human activity data. May be best to consider this pressure in terms of data on contaminants from Hazardous Substances & Eutrophication Committee (HASEC). | where the areas of high risk/ high contamination are. |
| Introduction of Light | This could be any marine or coastal infrastructure/development including towns, harbours, platforms, navigation aids, lighthouses, coastal roads etc. Effects will only be manifested at night therefore will need to consider temporal aspects. Best to only consider this pressure at locations identified for sensitive species and habitats. | As this cannot be mapped without specific data from all industries and users both within and adjacent to the estuary, this pressure has not been mapped. It has however been included in the pressures matrices behind the CIA to provide for conservative assessments. |
| Introduction of microbial pathogens | Possibly difficult to map- focus will be discharge points for untreated effluent and run-off. | Not aware of any untreated effluent discharge points. Run-off can be demonstrated by the eutrophic data from the Environment Agency. |
| Introduction or spread of non-indigenous species | Infrastructure provides habitat on which non-indigenous species may colonise or use as stepping stones. | Without knowledge of known locations and pathways difficult to map. |
| Litter | Generally, at best the only data will be on sinks not sources or pathways. Any marine industry has the potential to introduce litter, but bulk will be from non-marine resources. Appending litter pressures to all potential marine human activities would be a gross overestimate of the pressure. | As this cannot be mapped without specific data from all industries and users both within and adjacent to the estuary, this pressure has not been mapped. It has however been included in the pressures matrices behind the CIA to provide for conservative assessments. |
| Noise disturbance- above water | Little information of airborne propagation and likely sensitivity/effects on biota. | As data is limited on this aspect, this has not been included in this study. As more data |

| Human Activity | OSPAR Comment | Comment in relation to EPSS Tool Developed |
|---|---|---|
| | | become available, the tool can be adapted to include this in the assessment. |
| Nutrient enrichment | Difficult to map from a human activities context. May be best to base this on regional eutrophication data sets from Eutrophication Committee (EUC). | Demonstrated by the eutrophic data from the Environment Agency. |
| Organic enrichment | Difficult to map from a human activities context. May be best to base this on regional eutrophication data sets from EUC. | Demonstrated by the eutrophic data from the Environment Agency. |
| Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion | Should only consider human activities that do not extract seabed. Human activities include shipping anchoring points, cable laying operations, demersal fishing. | Demonstrated by maintenance and capital dredge areas (through applications), cables and pipelines and anchorage areas. |
| Physical loss (to another sea bed type) | Could be from introduction of steel, concrete or rock from marine infrastructure and/or scour protection. Aggregate extraction/dredging only to be considered where the seabed type changes. | Demonstrated by maintenance and capital dredge areas (through applications). |
| Physical loss (to land or freshwater habitat) | Land reclamation is the only human activity that will exert this pressure | Not relevant to study area as far as aware. |
| Radionuclide contamination | Best to base on data from Royal Society of Chemistry rather than mapping locations of nuclear powers stations and cooling water intakes/outfalls. | Whilst there are levels of radionuclides around the coast from fallout and movement from power stations, these are relatively low levels and there are no nuclear power stations or nuclear-powered submarines in the vicinity of the Humber Estuary therefore it was considered out of scope for this study. |

| Human Activity | OSPAR Comment | Comment in relation to EPSS Tool Developed |
|---|---|---|
| Removal of non-target species | Only relates to by-catch data from the fisheries sector. ICES may be the best source | Not aware of any fishing activities taking place in the study area and therefore this has not been considered further although fish landings data can be used as a proxy. |
| Removal of target species | Only relates to by-catch data from the fisheries sector. ICES may be the best source | Not aware of any fishing activities taking place in the study area and therefore this has not been considered further although fish landings data can be used as a proxy. |
| Salinity changes-local | Data may be sparse- freshwater discharges from outfalls that reduce salinity or brine discharges from salt caverns that may increase salinity. | As this cannot be mapped without specific data this pressure has not been mapped. It has however been included in the pressures matrices behind the CIA to provide for conservative assessments. |
| Siltation rate changes, including smothering | Human activities need to be considered in context of prevailing sedimentary conditions. Where background suspended sediments are high, biota is adapted to change to pressure and is of limited consequence. Substrate is also important e.g. if in a rocky/gravelly area the likelihood of suspension and redisposition of sediments is low. Another consideration is the longevity of the activity e.g. the majority of the disposal sites for dredged material has been used for decades so biota adapt to changes. As such it may be best to only consider new activities that cause changes in siltation rate. | The Humber Estuary is a turbid and dynamic environment and therefore the likelihood of increase in suspended sediment having a significant adverse impact on biota is unlikely but has been included in the pressures matrices behind the CIA to provide for conservative assessments. |
| Synthetic compound contamination (pesticides, anti-foulant, pharmaceuticals) | Given the wide range of human activities that have the potential to release chemical | This is demonstrated in the EPSS and CIA tools by having the sediment contamination data to show |

| Human Activity | OSPAR Comment | Comment in relation to EPSS Tool Developed |
|---|---|---|
| | contaminants it will be very difficult to generate a sensible map based on human activity data. May be best to consider this pressure in terms of data on contaminants from HASEC. | where the areas of high risk/ high contamination are. |
| Temperature changes- local | Only relates to cooling water outfalls- may need to consider dispersion of thermal plumes based on local hydrodynamics. | This has been included in the pressures matrices behind the CIA to provide for conservative assessments, but no actual data is available to incorporate into the tool. Hydrodynamic modelling would be better suited for this assessment type. |
| Transition elements and organometals | Given the wide range of human activities that have the potential to release chemical contaminants it will be very difficult to generate a sensible map based on human activity data. May be best to consider this pressure in terms of data on contaminants from HASEC. | This is demonstrated in the EPSS and CIA tools by having the sediment contamination data to show where the areas of high risk/ high contamination are. |
| Underwater noise changes | Generally- may be best to base this on context of the impulsive noise registry and ambient noise monitoring programme rather than extrapolating from location of human activities. | As noise propagation models have not been incorporated, as specific models would be better placed to carry out such assessments, the pressure has been included in the pressures matrices behind the CIA to provide for conservative assessments. |
| Visual disturbance | Potentially difficult to map/quantify- presence of vessels, infrastructure etc. does not directly equate to disturbance. | Due to the difficulty in mapping this has not been included in the tools. Any future developments should consult the public on potential aesthetic impacts prior to the application being submitted. |
| Water flow changes- local, including sediment transport considerations | Human activities include tidal energy converters; capital dredges, and managed realignments. | As this cannot be mapped without specific data from all industries and users both within and |

| Human Activity | OSPAR Comment | Comment in relation to EPSS Tool Developed |
|---|---|---|
| | | adjacent to the estuary, this pressure has not been mapped. It has however been included in the pressures matrices behind the CIA to provide for conservative assessments. |
| Wave exposure changes- local | Probably best not to map this in terms of human activities but to map where coasts have changes or are at risk of change. If human activities are adjacent to these vulnerable areas, they can be identified as potential pressures e.g. wave exposure changes can be associated with aggregate extraction, however if the adjacent coastline consists of bedrock this pressure will not be manifested. | As this cannot be mapped without specific data from all industries and users both within and adjacent to the estuary, this pressure has not been mapped. It has however been included in the pressures matrices behind the CIA to provide for conservative assessments. |

The cumulative impact assessment does not discriminate the seabed habitat type, rather the tool identifies the 'seabed' as one receptor. As knowledge advances to discriminate the seabed types and map the seabed sediment (and associated habitat), then the tool can be updated. Similarly, as knowledge regarding impacts of the pressures on different sediment and habitat type advances, then the look up tables that identify these pressures-impact relationships can be updated.

To comprehensively undertake a cumulative impact assessment, certain layers had different buffers applied to assess their baseline pressure (and impact) on the receptors of the Humber Estuary (see Table 17) (Stelzenmuller *et al.*, 2010a).

Table 17 Buffers applied to data layers for the cumulative impact assessment

| **Data Layer** | **Buffer Applied** |
|---|---|
| Cables | 750m |
| Wrecks | 1000m |
| Receptors | 1000m |
| Water Abstraction | 500m |
| Developments | 5000m |
| Fishing* | 0m |
| Physical structures | 1000m |

*It should be noted that with regards to the activity 'fishing', this has not been further defined into the type of fishing gear, as with the data it is not possible to determine the type of fishing occurring. Additionally, as the nursery and spawning ground data (from Coull *et al.*, 1998) have been used, the assessments show that if there is a pressure to which the species is sensitive, the receptor will always be shown as being affected, so this should be used with caution, and alongside other empirical evidence of the locations of spawning and nursery grounds.

There are two types of cumulative impact assessments to be undertaken in the tool, one for the estuarine environment whereby the impacts are general and there is less knowledge of feature and effects and the relationship, and the other which is more specific for the designations. However, the assessment for designations assumes all features are present in the Humber estuary, as there are no habitat maps available yet for the Humber Estuary.

The general impacts/pressures from an activity uses a presence/absence scoring of 0 for absence and 1 for presence, and by taking the number of pressures and receptors present will provide a measure of intensity but not frequency. As such, everything has equal weighting within the tool. A weighting scale of 1-10 of the pressures/impacts/receptors, used

for conservation features has not been used for general impacts, as knowledge on the effects is limited and there are many variables that would increase the uncertainty. Work is currently being undertaken to increase knowledge in this area, but given the uncertainty this has been left as a presence or absence (0-1). Although it is recognised that impulsive noise sources can have more of an effect (even though the pressure is short lived and sporadic) and it is also different to ambient noise such as noise from vessels in a shipping lane due to different frequencies, so these have been separated out in the pressures matrix. It is acknowledged that the pressures and impacts from the development in question may get 'lost in the noise' when looking at cumulative impacts. To overcome the uncertainty of different pressures having varying impacts during different stages, the tool assumes the influence is the same from the development and other activities, but these have been separated out into the development phases to allow an overall assessment to be undertaken.

The tool has limitations in that as yet seasonal constraints, temporal constraints and future projections cannot be incorporated.

## 5. Use of the Estuarine Planning Support System

As outlined in Chapter 4 the tool delivers:

- A user friendly, interactive interface where the user is guided through the process;
- Information on the legislative regime the project will fall under (screening);
- Information regarding the risk of the assessment based on scale, location etc of the project including standardised conditions;
- Identification of the receptors and impacts which should be considered (Scoping);
- Information on whether a WFD Assessment is required (WFD Screening), and
- Information on the impacts of the development i.e. may interact with other impacts or developments cumulatively.

Each of these are taken in turn below to describe what is required, the processes of the EPSS tool and the outputs.

### 5.1 User Interface

All of the data, scripts and look-up tables are stored in one directory so that the tool can be shared between machines (depending on the user) (Figure 46).

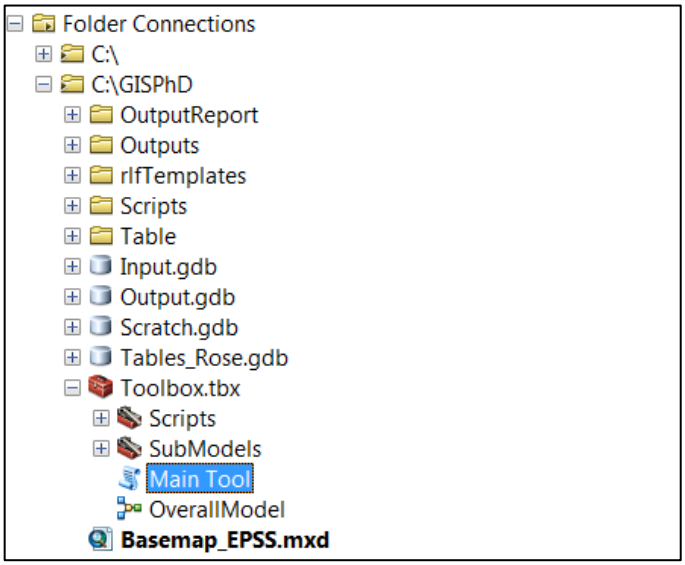



Figure 46 File Directory of the EPSS tool.

On opening the tool, the blank user interface is opened (Figure 47) A brief introduction to the user interface was provided in section 4.2. The interface is a series of questions, the first of which are:

1) The location of the files (this ensures the tool can run if the users store the tool in different locations);

2) The shapefile of the development so the spatial analyses can be carried out, and
3) The type of project the development falls under (construction, dredge, disposal or alternative use of dredged material).

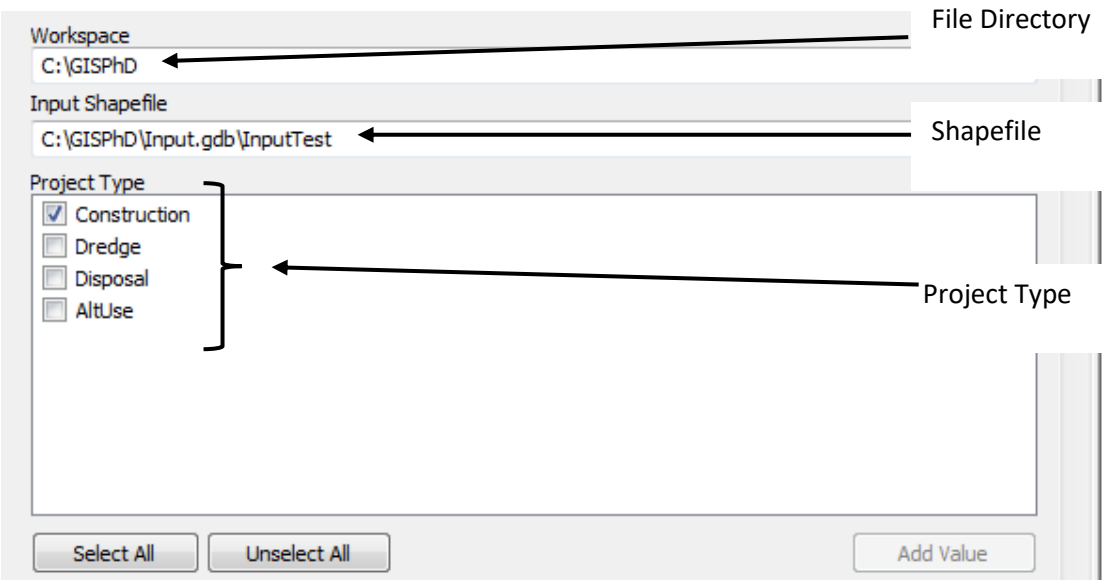



Figure 47 Interface of the EPSS Tool.

The type of project is important, as when one or more of these options are selected the additional and associated questions become available (Figure 36). The user interface has been designed to be easy to use, although it is noted that users with little or no knowledge of GIS may not find the interface intuitive, as the project details (the boxes that will be 'un-greyed' out following the 'Project Type' selection) will need to be expanded. This section on its own will be of little help to developers, managers or regulators without the following sections, it does however start the process off, thinking about the development and what may be required should an application be submitted.

### 5.2 Legislative Regime (Screening)

For 'Construction' projects, the series of questions requires information regarding the specific type of construction and then asks follow up questions based on the previous responses. For example, for an offshore wind farm the 'Threshold' required is in 'MW'. If the generating capacity was '150,000 MW', the tool would indicate that the project falls under the Planning Act (2008) and therefore requires an application to be made to the Planning Inspectorate (rather than the MMO) (Figure 48).

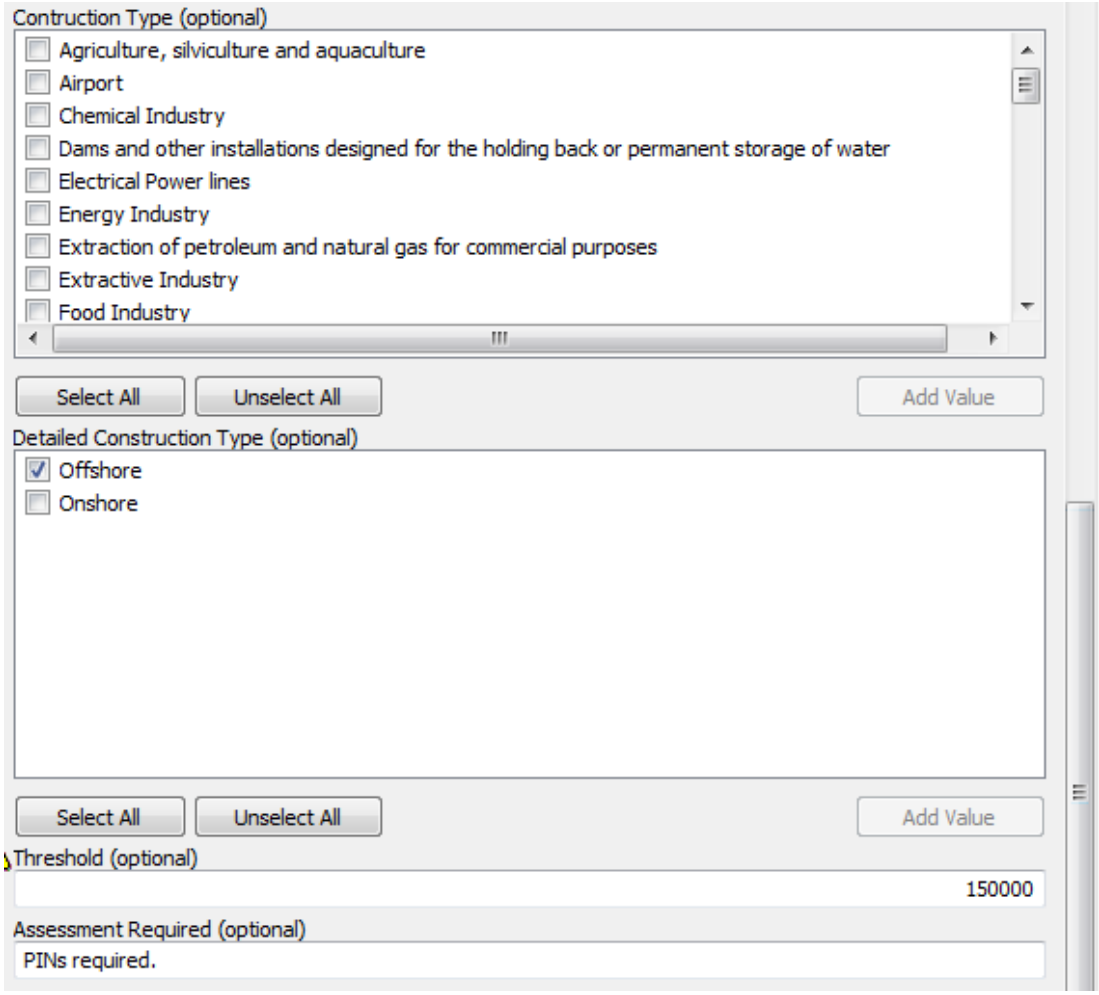



Figure 48 Example of the tool screening a project under the Planning Act, 2008.

A port development for container ships would require a threshold in TEUs (Twenty Equivalent Units). If the threshold was 10,000 TEUs, the tool would indicate that the project falls under the Marine (Environmental Impact Assessment) Regulations (Figure 49).

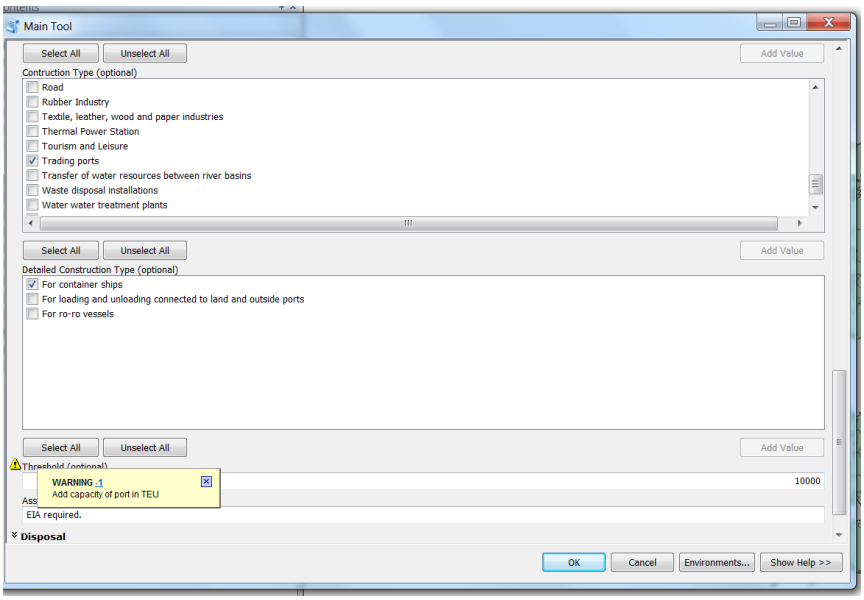



Figure 49 EPSS Tool interface for an EIA project

For a small marina development, the tool would advise that the developer needs a Marine Licence, but as the development falls within Annex 2 of the EIA Directive the developer would need to consult with MMO and/or Local Planning Authority, as an EIA requirement would depend on the scale of the project and its potential to impact the environment (Figure 50).

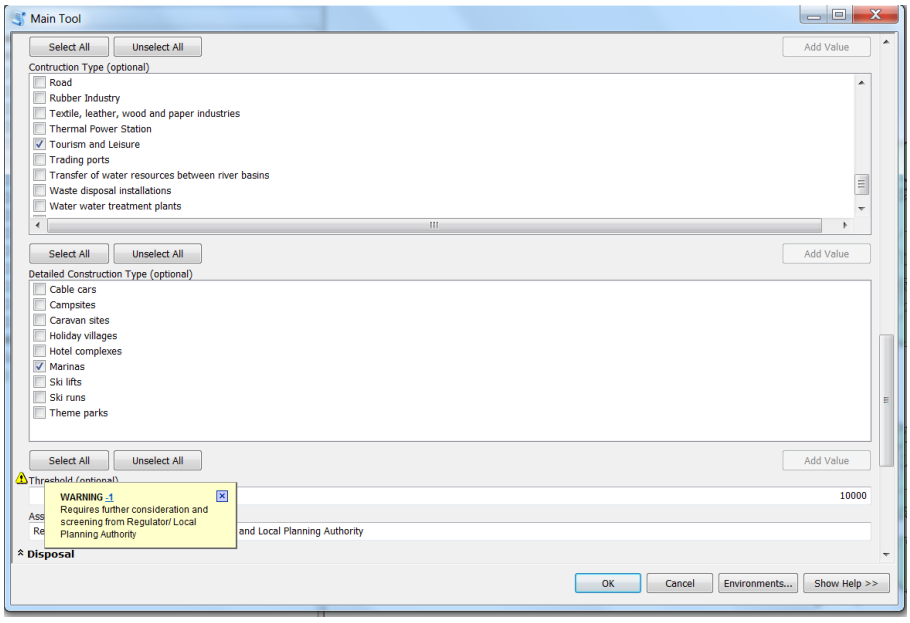



Figure 50 EPSS Tool interface for a non-EIA project

This part of the tool carries out the 'Screening' of the development, taking into consideration the three main legislative drivers for the marine environment (Planning Act, Marine and Coastal Access Act and Marine (EIA) Regulations). This is useful for both the developers and managers/regulators, for the marine environment as for the development as it reduces the

economic burden of having to pay for a screening opinion from the regulator, ensuring the application is made under the correct legislation. It also reduces the time investment, as the tool provides this information within a few minutes (the legislative driver is provided in the tool interface and therefore the full tool does not have to be run). It further reduces the burden on regulators/managers as they will receive fewer screening requests.

### 5.3 Risks, Receptors and Impacts (Scoping)

Under the European EIA Directive (2014/52/EU), the developer may request a scoping opinion from the regulator to determine the receptors, and potential impacts that should be included in the EIA and presented in the final ES. This includes the potential stakeholders that are likely to be positively or negatively affected by the developer.

As discussed above, the EPSS tool, based on the inputs from the user, data within the geodatabase and look-up tables, and formulae within the scripts, provides an indication of the receptors (including stakeholders), impacts and levels of risk the component parts of the overall development are likely to have. These are provided in the tool output reports (Figure 51 - Figure 55). To determine which receptors are considered in the assessment, buffers were applied between the development and the spatial data depending on the receptor type (see Table 10).

**Risk of Construction Method**

| Project Type | Construction Method | Risk | Potential Condition |
|---|---|---|---|
| Construction | Precussive Piling | Medium | Should adopt a soft start piling procedure (See JNCC Guidance). Use of a cofferdam |

Figure 51 Risk of Percussive Piling- an output of the EPSS tool

## Risk of Dredge Quantity

| Project Type | Dredge Quantity | Risk |
|---|---|---|
| Dredging | 500,000m3 and above | High |

Figure 52 Risk of disposal volume- an output of the EPSS tool, which is calculated from the input from the user formulae in the script.

## Conflicts Matrix

| EGS | Abstractions | Beaches | Bird Watching | Bridges | Cables | Capital dredging | Commercial | Discharge | Disturbance next to system |
|---|---|---|---|---|---|---|---|---|---|
| Conservation Designations Fish | Not Applicable | Not Applicable | Not Applicable | Conflict | Not Applicable | Not Applicable | Conflict | Not Applicable | Conflict |
| Conservation Designations Vegetation | Not Applicable | Not Applicable | Not Applicable | Dependant on location | Not Applicable | Not Applicable | No known conflict | Not Applicable | No known conflict |
| Conservation Designations air purification | Not Applicable | Not Applicable | Not Applicable | No known conflict | Not Applicable | Not Applicable | No known conflict | Not Applicable | No known conflict |
| Conservation Designations carbon sequestration | Not Applicable | Not Applicable | Not Applicable | No known conflict | Not Applicable | Not Applicable | No known conflict | Not Applicable | No known conflict |
| Conservation Designations climate | Not Applicable | Not Applicable | Not Applicable | No known conflict | Not Applicable | Not Applicable | No known conflict | Not Applicable | No known conflict |
| Conservation Designations education and research | Not Applicable | Not Applicable | Not Applicable | Beneficial | Not Applicable | Not Applicable | Beneficial | Not Applicable | Beneficial |

Figure 53 An example of the Conflicts Table- an output of the EPSS tool- e.g. there is a potential conflict between fish species and disturbances that occur next to the system.

## CIA Summary

| Pressure | Receptor | Baseline | Construction |
|---|---|---|---|
| ABRASION | BENTHIC_FAUNA | 0 | 41.770209 |
| ABRASION | BENTHIC_FLORA | 0 | 41.770209 |
| ABRASION | FISH | 501.826961 | 0 |
| ABRASION | PHYTOZOOPLANKTON | 0 | 41.770209 |

Figure 54 Receptors and Impacts- an output of the EPSS tool showing that at the baseline (without development) only fish have existing abrasion pressures, whereas benthic flora and fauna and phytoplankton will have abrasion pressures from the construction of the development.

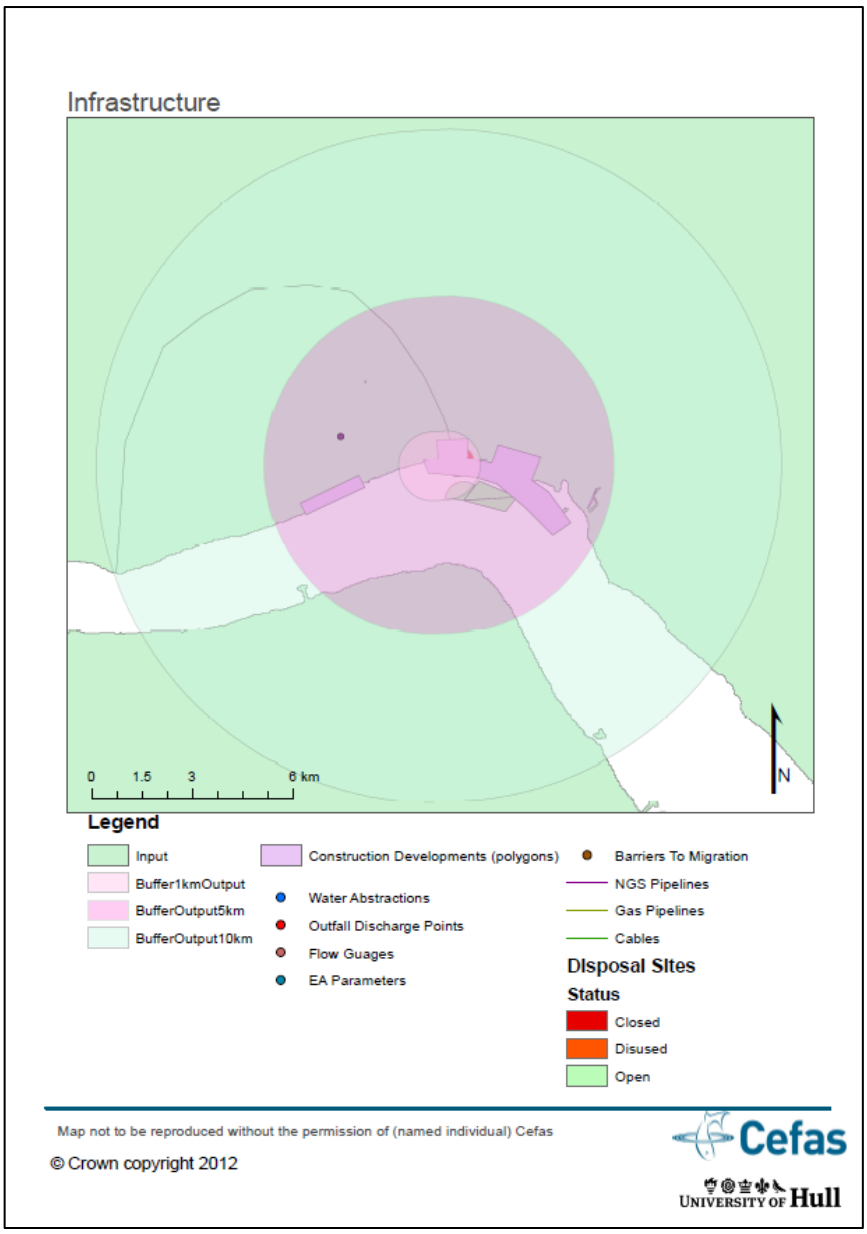



Figure 55 Map of infrastructure receptors- an output of the EPSS tool showing the infrastructure within 1, 5 and 10km of the development which may be subject to impacts from the development.

The EPSS tool provides an indication of the receptors and impacts to be considered in the EIA process, however it does not replace the need to consult with the regulators as there are potential receptors such as socio-economic, which may not be captured in the spatial data or look up tables. For example, some tourist activities are not mapped, but are known by the local managers as being undertaken, and can advise who to contact to inform the EIA. The tool reduces the burden on the developer as it provides an indication of the potential receptors and impacts prior to the consultation with the regulators. It further reduces the burden on the regulators as they will only need to provide advice on those receptors and impacts considered to have been omitted from the scoping report.

## 5.4 Water Framework Directive Screening

For dredge and disposal projects, the questions under the WFD Assessment are required to ensure the project is considered under the Water Framework Directive. The tool does not carry out the full WFD Assessment, only the screening part to advise if a full assessment is required. The screening assessment the tool undertakes is based on standard questions, and a standardised method as outlined by the Environment Agency (2012a-e). The tool therefore provides a transparent and consistent approach to the screening activity, and reduces the burden on developers, as the tool undertakes this part of the assessment and runs the screening assessment within approximately 10 minutes, as opposed to days of a consultant's time working through the development details and assessment guidance. The tool also reduces the burden on regulators and managers as the tool has been validated.

The EPSS tool does not undertake the 'Further Assessment' part of the WFD Assessment, as this requires expert input regarding a cost benefit analysis which is outside the remit of the tool.

## 5.5 Cumulative Impact Assessment

The outputs will be a series of maps showing the 'counts of pressures'. The maps will show the increase in pressures from the baseline (Figure 56, based on Figures 57-59), e.g. the baseline may have four pressures already present on a receptor, and following the development this may increase to six pressures (an increase of two). The maps also provide the increase in pressures from the 'baseline' (i.e. before the new development), to demonstrate the increase from the new development, and to avoid attributing pressures to the new development which may already exist. This method does not state whether the increase in pressures is significant or not, as this requires a site and receptor specific assessment to be undertaken. Rather it provides the information for the assessors to consider the magnitude of an impact from a pressure on a receptor. In addition, the output of the tool includes the maximum number of pressures including the baseline, and the largest number of pressures from any phase to inform such an impact assessment.

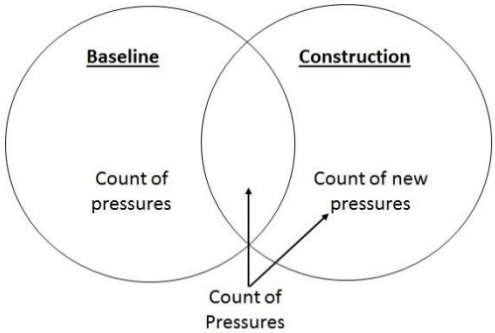



Figure 56 Concept model showing how the pressures are presented in the EPSS tool output.

The outputs will be maps that take into consideration the:

- spatial extent of pressure using GIS shapefiles and look up tables;
- mode of action of the pressure (Inc. 3D characteristics) to avoid over estimation;
- temporal characteristics of the activity (and pressure) by considering the different phases of a development;
- the sensitivity of receptors to pressures using advice from English Nature (now Natural England), and
- a conceptual knowledge of the source- pathway- receptor relationships.

To provide an indication of the extent of the impacts, these have been determined by Barnard *et al.* (2015). These are shown in the GIS tool by basing the impacts firstly on the footprint of the activity ('input' shapefile provided by the user of the tool), then the project type, construction type and construction method selections made by the user in (Figure 34). Based on these selections, the extent of the impact is then indicated using the 1km and 5km buffer depending on the sub-activity and receptor (summarised in Table 18). Given that these buffers are greater than those provided by Barnard *et al.* (2015) (as well as Anderson *et al.*, 2015; Batista *et al.*, 2014) this approach is considered precautionary

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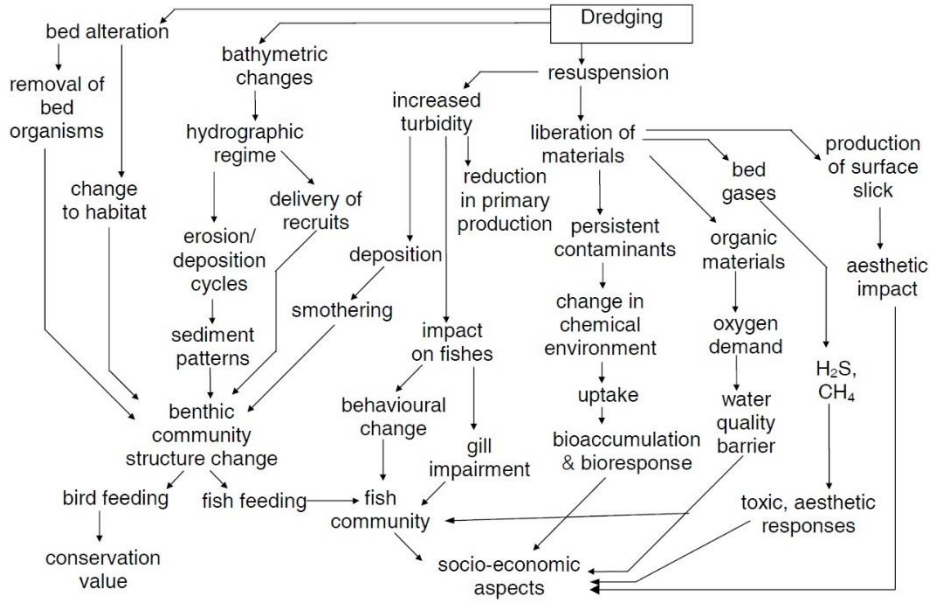


Figure 57 Potential impacts from dredging (taken from McLusky and Elliott, 2004)

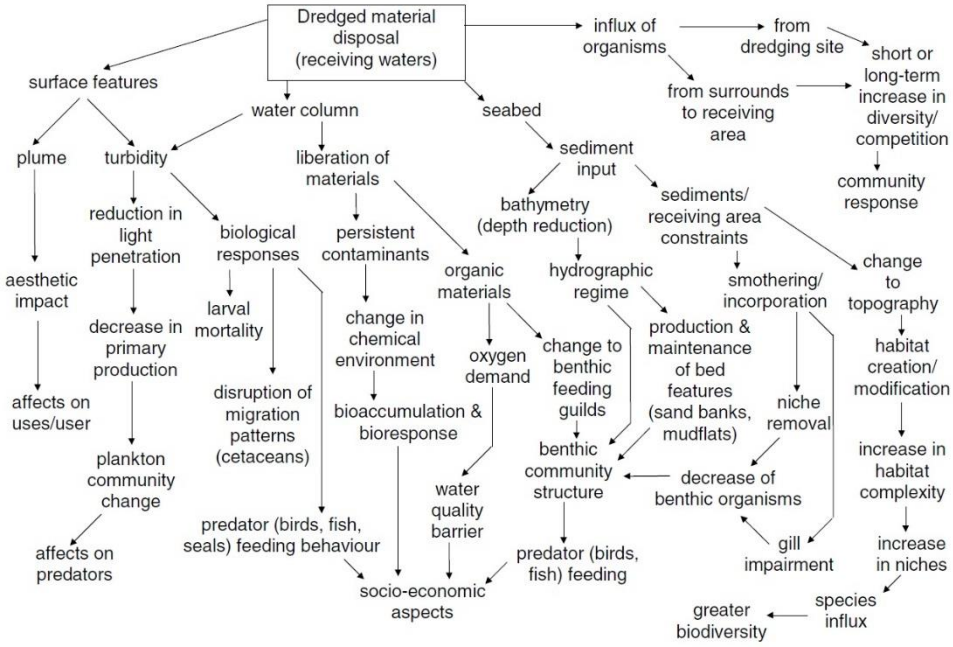


Figure 58 Potential impacts from disposal operations of dredged material (taken from McLusky and Elliott, 2004)

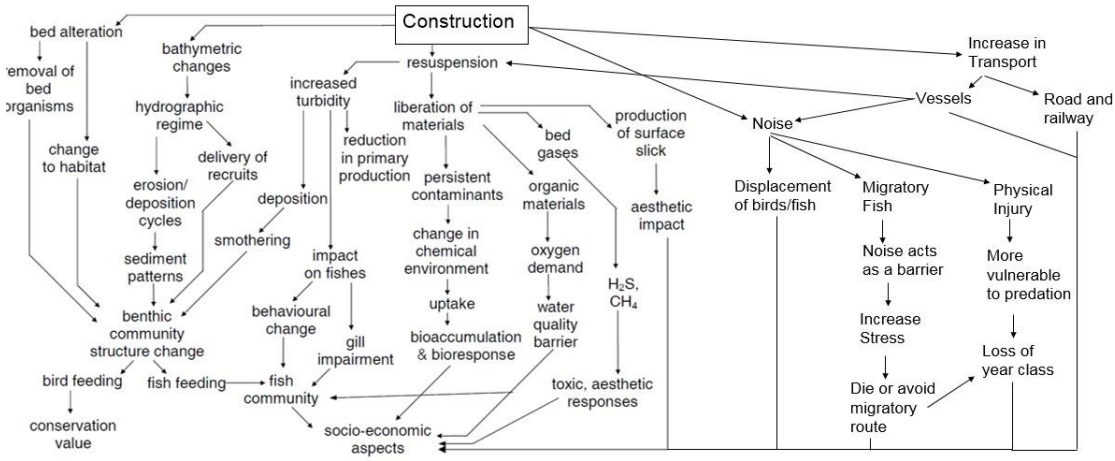


Figure 59 Potential impacts of construction works (modified from McLusky and Elliott, 2004; MEMG, 2003; Lonsdale, 2013; Judd 2011; Judd *et al.*, 2013).

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Table 18 The potential impacts of construction and dredging operations in an estuarine environment, the 'footprint' of the impact (from Anderson *et al.*, 2015; Batista *et al.*, 2014; JNCC, 2015 (Where both had buffers but differed, the most conservative buffer was applied)) and the layers these impacts relate to.

| **Activity** | **Sub-activity** | **Range of influence (m)** | **Layer this relates to** |
|---|---|---|---|
| Commercial Fisheries | Habitat destruction (Trawling) | 500 | Nursery grounds; spawning grounds |
| Commercial Fisheries | Non-habitat destruction- purse seine | 100 | Nursery grounds; spawning grounds |
| Commercial Fisheries | Multi gear (lines, nets, traps) Local vessels (<9m length) | 100 | Nursery grounds; spawning grounds |
| Commercial Fisheries | Multi gear (lines, nets, traps) Coastal vessels (>9m length) | 100 | Nursery grounds; spawning grounds |
| Subtidal artificial reefs | Artificial Reefs | 1000 | Not applicable |
| Dredging Activities | Dredging deposition | 1500 | Dredge Areas |
| Commercial Port Activities | Ship Traffic | 1000 | Estuary shapefile |
| Recreational Activities | SCUBA diving | 100 | Not applicable |
| Recreational Activities | Recreational motor boating | 1000 | Marinas; slipways |
| Recreational Activities | Marinas | 1000 | Marinas; slipways |
| Pressures from transitional waters | Larger estuaries | 30000 | Not applicable |
| Pressures from transitional waters | Small estuaries and coastal lagoons | 2000 | Coastline shapefile; designations If the lagoons are protected |
| Direct human impact/population | Benthic structures (pipelines, communication structures) | 750 | Cables and pipelines |
| Direct human impact/population | Beaches (leisure activities e.g. swimming, kayaking, kitesurfing) | 500 | Beaches; bathing waters; kite surfing |
| Direct human impact/population | Artificial coast line (piers, docks, harbours and other constructions) | 1000 | Flood defences |
| Direct human impact/population | Sewage (urban nature) | 5000 | Outfalls |
| Industry | Industrial infrastructures and thermal plants | 7500 | Outfalls |
| Extraction | Aggregate extraction | 500 | Not applicable |
| Water extraction | Water extraction | 500 | Water abstraction |

# 6. Validation and Testing of the Estuarine Planning Support System Tool

## 6.1 Internal Validation

To ensure the tool is performing as intended, it was validated using four existing, past applications for construction and/or dredging/disposal within the Humber Estuary under both the MCAA and Planning Act 2008 legislation. The applications made under the MCAA[13] are (for locations see Figure 60):

- MLA/2011/00332 Green Port Hull development (URS Scott-Wilson, 2011);
- MLA/2012/00373 Hedon Haven and Stone Creek Dredge and disposal, and
- MLA/2014/00183 Keadby Power Station Dredge and disposal

The application made under the Planning Act 2008 used as validation, is the Able Marine Energy Park development[14] (AMEP, 2011). To test the tool, each application will be taken in turn.

These four applications have been selected to validate the tool as they range in their location, project requirements and legislative requirements to ensure the tool is tested against a wide range of options.

[13] Details are freely available from: https://marinelicensing.marinemanagement.org.uk/mmofox5/fox/live/MMO_PUBLIC_REGISTER/ [viewed 04/09/2016]

[14] Details are freely available from: https://infrastructure.planninginspectorate.gov.uk/projects/yorkshire-and-the-humber/able-marine-energy-park/ [viewed 04/09/2016]

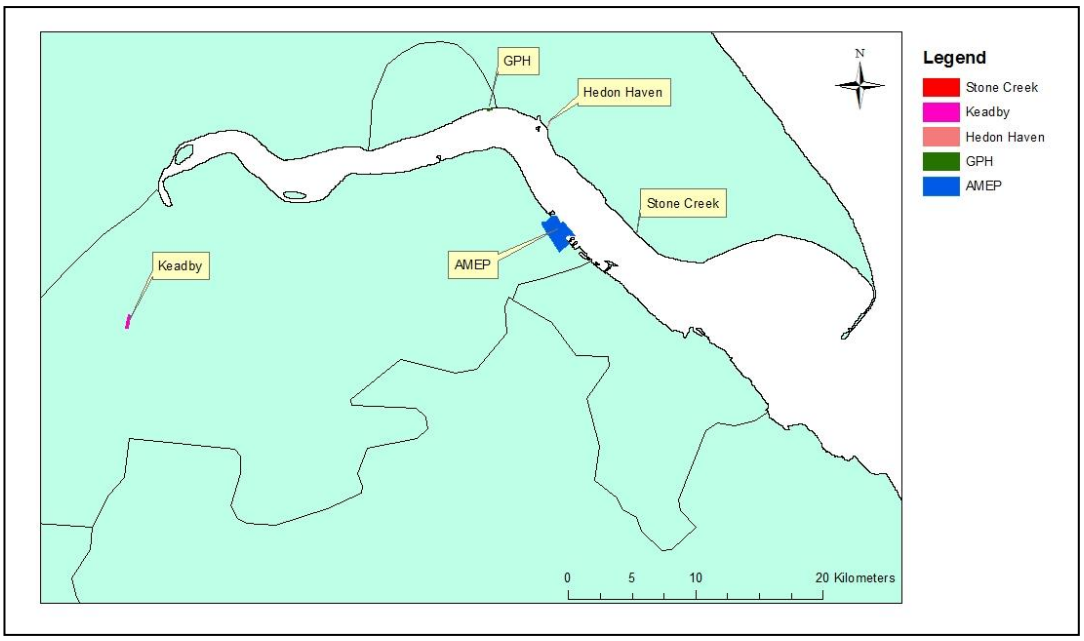



Figure 60 Location of applications used for tool validation

7.2.1 Validation using MLA/2011/00332 Green Port Hull

Application Details for input into user interface of the tool

Table 19 provides the details taken from the Environmental Statement for the Green Port Hull development (URS Scott-Wilson, 2011). As the project will be using multiple disposal sites, the tool was run for each disposal site, with all other construction details remaining the same.

Table 19 Details for input into the tool:

**Project Details**

| | |
|---|---|
| Location of Project | North side of Humber Estuary at Port of Hull (shapefile provided) |

| **Does the project include:** | |
|---|---|
| Construction | Yes |
| Dredge | Yes |
| Disposal | Yes |
| Alternative use of dredged material | N/A |
| How long will the project last? | 9 years |

| **Alternative use of dredged material** | |
|---|---|
| Alternative Use Habitat Type | N/A |
| Alternative Use Quantity (m3) | N/A |
| Area cover by the alternative use aspect ($m^2$) | N/A |

| **Construction** | |
|---|---|
| What materials will be used? | Steel, concrete, aggregate |
| What methods will be employed? | All |
| Construction Type | Ports |
| Detailed Construction Type | Ro-ro |
| Threshold | <250,000 TEU[15] |

| **Disposal** | | | |
|---|---|---|---|
| Disposal Site | HU021 | HU081 | HU082 |
| Disposal quantity m3 | 16600 | 169100 | 169100 |

| **Dredge** | |
|---|---|
| Dredge Type | Capital |
| Dredger Type | Unknown/ all |
| Dredge depth | >2m |
| Dredge quantity | 354,800 tonnes |

[15] TEU (Twenty Equivalent Units) is a measure of cargo capacity and is the threshold provided in the Planning Act 2008.

| **WFD** | |
|---|---|
| Timing | All year |
| Is the project removing intertidal habitat or within 10m of intertidal habitat? | Yes |
| Has the dredge been assessed as part of an Appropriate Assessment or Maintenance Dredge Protocol? | No |
| Is there a Marine Licence in place? | Yes- Fepa[16] |

[16] FEPA refers to a consent under the Food and Environment Protection Act 1985 which was the former UK marine licensing mechanism that has now been superseded by the Marine and Coastal Access Act

7.2.2 Validation using MLA/2012/00373 Hedon Haven Dredge

Application Details for input into user interface of the tool

Table 20 provides the details taken from the application for MLA/2012/00373 for input into the tool.

Table 20 Details of the application for MLA/2012/00373 for input into the tool

**Project Details**

| | | |
|---|---|---|
| Location of Project | Stone Creek (shapefile provided) | Hedon Haven (shapefile provided) |

| **Does the project include:** | | |
|---|---|---|
| Construction | N/A | |
| Dredge | Yes | |
| Disposal | Yes | |
| Alternative use of dredged material | C | |
| How long will the project last? | 1 month (March to April 2013) | |

| **Alternative use of dredged material** | |
|---|---|
| Alternative Use Habitat Type | N/A |
| Alternative Use Quantity (m3) | N/A |
| Area covered? by the alternative use aspect ($m^2$) | N/A |

| **Construction** | |
|---|---|
| What materials will be used? | N/A |
| What methods will be employed? | N/A |
| Construction Type | N/A |
| Detailed Construction Type | N/A |
| Threshold | N/A |

| **Disposal** | | |
|---|---|---|
| Disposal Site | HU023 | HU022 |
| Disposal quantity m3 | 19000 | 17000 |

| **Dredge** | | |
|---|---|---|
| Dredge Type | Capital | Capital |
| Dredger Type | Cutter suction dredger | Cutter suction dredger |
| Dredge depth | 1m | 1m |
| Dredge quantity | 19000 | 17000 |

| **WFD** | | |
|---|---|---|
| Timing | 1 month (March to April) | 1 month (March to April) |

| | | |
|---|---|---|
| is the project removing intertidal habitat or within 10m of intertidal habitat? | Yes | Yes |
| Has the dredge been assessed as part of an Appropriate Assessment or Maintenance Dredge Protocol? | No | No |
| Is there a Marine Licence in place? | No | No |

### 7.2.3 Validation using MLA/2014/00183 Keadby Power Station Dredge

Application Details for input into user interface of the tool

Table 21 provides the details taken from the application for MLA/2014/00183 for input into the tool.

Table 21 Details of the application for MLA/2014/00183 for input into the tool

**Project Details**

| | |
|---|---|
| Location of Project | River Trent (shapefile provided) |

| **Does the project include:** | |
|---|---|
| Construction | N/A |
| Dredge | Yes |
| Disposal | Yes |
| Alternative use of dredged material | N/A |
| How long will the project last? | 1 year |

| **Alternative use of dredged material** | |
|---|---|
| Alternative Use Habitat Type | N/A |
| Alternative Use Quantity (m3) | N/A |
| Area cover by the alternative use aspect ($m^2$) | N/A |

| **Construction** | |
|---|---|
| What materials will be used? | N/A |
| What methods will be employed? | N/A |
| Construction Type | N/A |
| Detailed Construction Type | N/A |
| Threshold | N/A |

| **Disposal** | |
|---|---|
| Disposal Site | None/ HU043 |
| Disposal quantity m3 | 3600 |

| **Dredge** | |
|---|---|
| Dredge Type | Maintenance |
| Dredger Type | Cutter suction dredger |
| Dredge depth | 3m |
| Dredge quantity | 3600 |

| **WFD** | |
|---|---|
| Timing | 5 months (June – October) |
| is the project removing intertidal habitat or within 10m of intertidal habitat? | No |

| | |
|---|---|
| Has the dredge been assessed as part of an Appropriate Assessment or Maintenance Dredge Protocol? | No |
| Is there a Marine Licence in place? | No |

7.2.4 Validation using Able Marine Energy Park

Application Details for input into user interface of the tool

Table 22 provides the details taken from the Environmental Statement for the Green Port Hull development (URS Scott-Wilson, 2011). As the project will be using multiple disposal sites, the tool was run for each disposal site with all other construction details remaining the same.

Table 22 Details of the AMEP development for input into the tool

| **Project Details** | | |
|---|---|---|
| Location of Project | South Bank adjacent to Immingham (coordinates provided) | |
| | | |
| **Does the project include:** | Yes | |
| Construction | Yes | |
| Dredge | Yes | |
| Disposal | Yes | |
| Alternative use of dredged material | Yes | |
| How long will the project last? | 10 years | |
| | | |
| **Alternative use of dredged material** | | |
| Alternative Use Habitat Type | Silt/ saltmarsh | |
| Alternative Use Quantity (m3) | 1961409 tonnes | |
| Area cover by the alternative use aspect ($m^2$) | >500 | |
| | | |
| **Construction** | | |
| What materials will be used? | All | |
| What methods will be employed? | Unknown/ all | |
| Construction Type | Port | |
| Detailed Construction Type | Ro-ro | |
| Threshold | >250,000 TEU[17] | |
| | | |
| **Disposal** | | |
| Disposal Site | HU080 | HU082 |
| Disposal quantity m3 | 1428140 | 555556 |
| | | |
| **Dredge** | | |
| Dredge Type | Capital | |
| Dredger Type | Unknown/ all | |
| Dredge depth | >2m | |
| Dredge quantity | 4478000 | |

[17] TEU (Twenty Equivalent Units) is a measure of cargo capacity and is the threshold provided in the Planning Act 2008.

| | |
|---|---|
| **WFD** | |
| Timing | All year |
| Is the project removing intertidal habitat or within 10m of intertidal habitat? | Yes |
| Has the dredge been assessed as part of an Appropriate Assessment or Maintenance Dredge Protocol? | No |
| Is there a Marine Licence in place? | No |

The tool has been validated at every decision-making stage of the process. Where some of the outputs were initially incorrect, these have been updated so that all the case studies provide outputs as expected. The tool however does not take into consideration mitigation or compensation regimes to avoid or reduce the potential impacts from the project.

Once finalised the tool provided the same results as those marine licence applications shown above, however the process has been streamlined and carried out using a significantly quicker process (less than 20 minutes from opening the tool to the output being produced). The tool provides a centralised point of contact for developers or managers for the initial assessments, this can take months when consulting with different agencies, also identifying the potential receptors and impacts that can be affected by the new development.

## 6.2 Testing of EPSS by External Stakeholders

### 6.2.1 Identification of Stakeholders

Science and scientists are just one source of expertise concerning environmental management, and increasing involvement will not necessarily lead to better policy (Wolters *et al.*, 2016). Environmental problems are becoming increasingly more complex requiring scientific knowledge however, what should be stressed is that they are part of a collaborative and malleable process that will require adaptation and communication to form, shift and deploy policy goals.

ABPmer and Cefas (2015) state that "*Ultimately, for any ecosystem assessment to be effective it needs to be transparent, repeatable and easy to communicate to wide audiences*". To ensure that the EPSS tool is effective, it was sent to several stakeholders from the Humber estuary (from the marine perspective) for testing. The stakeholders were identified as being those who would potentially use the tool or could verify data and/or methods. It is generally considered that any development should be 'co-designed' between developers, policy and

decision makers and the public, for a holistic and adaptive environmental management, and therefore this is an important step (Newton and Elliott, 2016).

Whilst developing the list of stakeholders to contact to test the tool, it was important to ensure that there was no stakeholder bias which may give the impression that certain institutions are the most important or providing a 'bigger voice'. As defined by (Newton and Elliott, 2016) 6 types of stakeholders can be identified:

1. Inputters- those who discharge or place material (including infrastructure) into the marine environment e.g. power plants discharging water into the marine environment.
2. Extractors- those who use the space or take resources (both biotic e.g. fish and abiotic e.g. aggregate) from the marine environment e.g. fishermen.
3. Beneficiaries- those who benefit from the ecosystem goods and services the marine environment provides e.g. tourists benefitting from the bird populations that utilise the intertidal habitat.
4. Affectees- those who are positively or negatively affected by the uses, users or decisions taken by decision makers such as politicians e.g. a reduction in catch quotas will affect the income for fishermen.
5. Regulators- those who give permission for users to use the marine environment either through the use of space, or extraction of resources e.g. the Marine Management Organisation for English territorial waters.
6. Influencers- those who influence users, uses or policy makers e.g. expert groups, NGOs etc.

To ensure that the consultation minimised the stakeholder bias, the list of stakeholders (Table 23) was categorised into the type of stakeholders identified above and checked to ensure a balance was met. As noted from Chapter 2, stakeholders may have multiple roles.

As this is a consultation for a tool and not a project/development, there are no 'affectees' identified however this is a type of stakeholder that would be important to have in any project/development consultation.

Table 23 The list of consultees who were contacted to test the EPSS tool and their categorisation. "-" denotes that the group/organisation does not fall under the "type" category

| Area of Responsibility/ Interest | Group/Organisation | Inputters | Extractors | Beneficiaries | Affectees | Regulators | Influencers |
|---|---|---|---|---|---|---|---|
| Water Quality | Defra | - | - | - | - | X | - |
| | Environment Agency | - | - | - | - | X | - |
| | Severn Trent Water | X | X | X | - | - | - |
| | Yorkshire Water | X | X | X | - | - | - |
| Nature Conservation | JNCC | - | - | - | - | - | X |
| | Natural England | - | - | - | - | - | X |
| | RSPB | - | - | - | - | - | X |
| | Lincolnshire Wildlife Trust | - | - | - | - | - | X |
| | Yorkshire Wildlife Trust | - | - | - | - | - | X |
| | Yorkshire Naturalists Union | - | - | - | - | - | X |
| | Humber Nature Partnership | - | - | - | - | - | X |
| | Spurn Heritage Point | - | - | - | - | - | X |
| Shipping and Ports | MMO | - | - | - | - | X | - |
| | ABP Humber Estuary Services | - | - | - | - | X | - |
| | Humber Sea Terminals, | X | X | X | - | - | - |
| | APT, | X | X | X | - | - | - |
| | Conoco Philips | X | X | X | - | - | - |
| | Canal and Rivers Trust | - | - | - | - | X | X |
| Development | Associated British Ports | X | X | X | - | X | - |
| | Hull City Council | - | - | - | - | X | - |
| | Lincolnshire County Council | - | - | - | - | X | - |
| | North East Lincolnshire Council | - | - | - | - | X | - |
| | Hull & Humber Bondholders | - | - | X | - | - | X |
| | North Lincolnshire Council | - | - | - | - | X | - |
| | National Grid | X | X | X | - | - | X |
| | East Riding of Yorkshire Council | - | - | - | - | X | - |
| Flood Protection | Humber Estuary Coastal Authority Group | X | X | X | - | X | X |
| | Ouse and Humber Drainage Board | X | X | X | - | X | X |
| | Ancholme Drainage Board | X | X | X | - | X | X |
| | Scunthorpe and Gainsborough Drainage Board | X | X | X | - | X | X |
| | South Holdernss Drainage Board | X | X | X | - | X | X |
| | North East Lindsey Drainage Board | X | X | X | - | X | X |
| | Local Landowners | - | - | X | - | - | X |
| Tourism | Visit Hull and East Yorkshire | - | - | X | - | - | X |
| | Visit Lincolnshire | - | - | X | - | - | X |
| Recreation | RYA | - | - | X | - | - | X |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fishery | North Eastern Inshore Fisheries and Conservation Authority | - | - | - | - | X | - |
| | Fishing/ Sea Angling Clubs | - | X | X | - | - | X |
| | National Federation of Fisherman's Organisations | - | X | X | - | - | X |
| Wildfowling/ Hunting | Local wildfowling clubs, | - | X | X | - | - | X |
| | Upper Humber wildfowling committee, | - | X | X | - | - | X |
| | Humber wildfowl refuge committee Lincolnshire | - | X | X | - | - | X |
| | Humber wildfowl refuge committee East Midlands | - | X | X | - | - | X |
| | Humber wildfowl refuge committee | - | X | X | - | - | X |
| Agriculture | National Farmers Union (North East Region ), | X | X | X | - | - | X |
| | Country Landowners Association (East Lincolnshire) | X | X | X | - | - | X |
| | Country Landowners Association (Yorkshire) | X | X | X | - | - | X |
| Archaeology | English Heritage | - | - | - | - | X | X |
| | National Trust | - | - | - | - | X | X |
| | WAERC at Hull Uni | - | - | X | - | - | X |

### 6.2.2 Method of Testing the Tool

Stakeholders were sent an initial screening letter (Appendix 7) to explain the rationale of the project and how they could get involved. As it is known that not everyone will have access to the software (ArcGIS) the letter proposed two options: 1) to be supplied with the tool and they run the tool themselves if they have access to ArcGIS; or 2) if they do not have access to GIS, they can fill in a questionnaire and have the output report sent to them (either electronic or paper copy) and discuss the results with the author. The instructions and questionnaire used are provided in Appendix 7 and Appendix 8 respectively. A talk was also provided at the university of Hull on the 25th January 2017 with potential users.

### 6.2.3 Responses to the Tool

Overall the feedback to the tool was positive with respondents expressing the use of such a tool as a whole, or as its component parts e.g. use as a screening tool. Most of the responses were verbally provided following a demonstration of the tool, and explanation of the background, use and development. The responses to the tool were logged (see Appendix 9) and the way in which these responses were addressed are shown in Table 24.

Table 24 Collated responses and how these have been addressed

| Response | How Addressed? |
|---|---|
| Can ecosystem goods and services valuations be incorporated for sites where an assessment has been carried out with reference into the tool. | In response, yes. The relevant shapefiles have been updated to include the valuations of specific ecosystem goods and services and have been updated to include on maps. These are not exhaustive but provide the concept within the tool. In the future, the tool could be integrated with other tools specific to this area of science such as InVEST. |
| Can certain parts of the tool be taken in isolation e.g. the legislation part? | In response, yes. Certain parts of the tool can be taken in isolation but would require additional modification of the code. The scope of this project is to develop an integrated tool and therefore will not be undertaken as part of this study. |
| Can the tool weight sensitivity be based on density such as bird or marine mammal data? | In response, yes. The tool can apply weights to the assessments, however the application of weights is subjective and therefore will not be considered in this study. |
| Can the tool incorporate data where high resolution data is available for some parameters but not others? | The tool can incorporate different resolution data. If the data falls within the buffers, the data will be used. |

| | |
|---|---|
| Can confidence be incorporated such as age of data, date inferred from expert opinion and qualify data source rather than apply a confidence score. | Source has been provided rather than applying a confidence, as the use of the data may change the confidence/certainty, so the user can interpret their own confidence for their own purposes. |
| The tool can be commercialised with additional features to support the free version therefore only one tool needs maintaining and updating. | The commercialisation of the tool is outside of this study but the suggestion to have one tool with locked features for paid users only has been noted for future development. |
| Data gaps need to be flagged i.e. identify the information that needs to be available before the tool can be used. | See below. |
| Following on, can a checklist be provided to address the above. | The code has been developed to handle 'null' values or the absence of data. |
| The tool needs to be able to function based on expert opinion only in the scenario where there is no data. | Provided the data/information is available in the form of look up tables or GIS data, the data can be utilised in the tool and assessments.<br>The data will still require interpretation, so whilst the tool can be used (and further developed) to assist / inform decision-making it is not intended (nor beneficial) for any tool to replace the human element of decision-making. The EPSS is not designed to be a black box. |
| Needs to consider the wider marine spatial plan area and wider developments such as offshore wind farms i.e. impact over much larger scale for a large area. | In order to consider the wider aspects, the raw data for the full extents will be used and then the tool will clip according to the use of the tool. The tool will in the first stage set the extent to 10km around the input shapefile to incorporate all the potential receptors. This means that a polygon that partially intersects the 10km buffer will have all the attributes included in the assessment. |
| A specific response from a Local Authority was that they expected the tool to do more with regards to HRA and therefore was not a usable tool for their role. | Whilst the tool highlights if a HRA is needed it is not intended to do the assessment (as per other legislations) therefore this comment cannot be addressed. However, it will be partly addressed by the integration of impact risk zones developed by Natural England (see below).<br>The data will still require interpretation, so whilst the tool can be used (and further developed) to assist / inform decision-making it is not intended (nor beneficial) for any tool to replace the human element of decision-making. The EPSS is not designed to be a black box. |

| | |
|---|---|
| A meeting with Natural England highlighted a recent tool of theirs: Impact Risk Zones which provide buffers to SSSI features depending on the development type. | This has been included in the tool by the development of a look up table between the Impact Risk Zones and the legislation reconciliation table, so is now also included in the tool assessment. |
| Natural England asked if terrestrial legislation was, or would be included in the tool. | Terrestrial legislation is currently not included in the tool. It is noted that many coastal and estuarine developments would also require consent under legislation applicable to the area above Mean High Water e.g. the Town and Country Planning Act, however, this is beyond the scope of the study. This study has identified Local Authorities should be consulted. The terrestrial requirements could be included in future iterations of the tool. |

#### 6.2.4 Changes Made to the Tool

To reflect the comment regarding implementing the tool for the wider marine environment, the tool was updated by taking the raw data (see Appendix 2) and applying to English territorial waters: the data were not extended to UK territorial waters, as most of the data were for England. To get the data for the UK, update the tables such as legislation tables, and changes in code to reflect differences in applying the Water Framework Directive, would have been time intensive. The aim of this study was to provide proof of concept by applying to a national context (English territorial waters), and testing against local and large-scale developments which is demonstrated.

All data except the following were applied to the wider marine environment

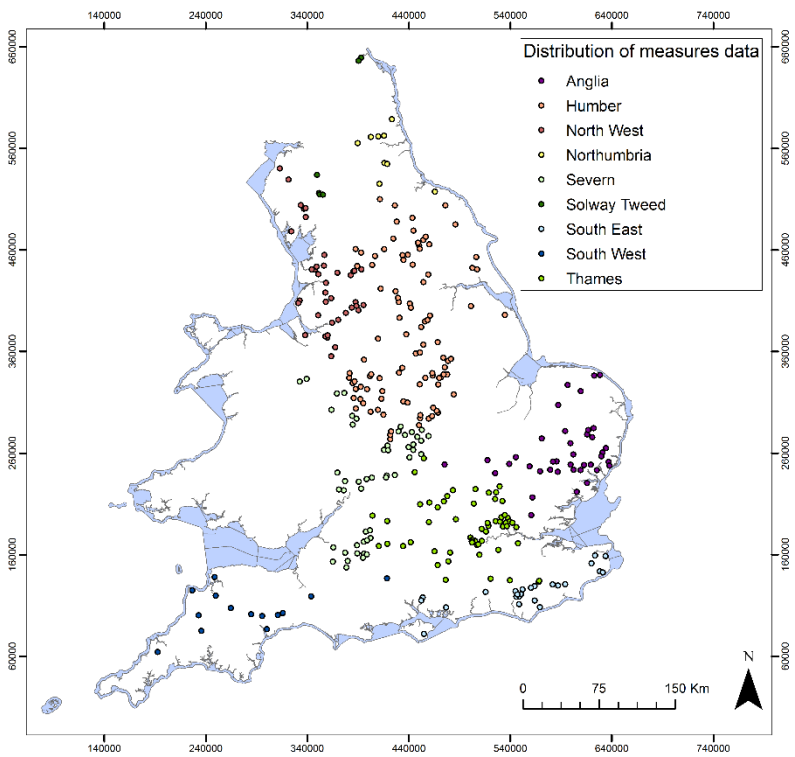
- Barriers;
- Environmental Agency Parameters;
- Flow Gauges;
- Humber wrecks;
- Outfall discharge points;
- PSA data;
- Water Abstractions;
- Water Incidents, and
- Physical structures and defences.

In addition, the import and export tables as well as the shipping density data were not transposed to England. It has however been demonstrated that the data can be included in

the tool in the future by reconciling the location of the project to the import/export data and shipping density data, and including in the report. This is because these data were either locally collected or provided, or were provided through a query through the regulators, which would be time consuming to incorporate due to the format of the raw data. If the tool is applied by regulators to inform assessments, these locally acquired data could be collected and stored in either a GIS shapefile or geodatabase table to allow the data to be interrogated within the tool and reduce the resource for querying and providing such data.

*Water Framework Directive*

The data layers that support the assessment under the WFD were created based on the Environment Agency's shapefiles of waterbodies, and supporting data files from their Catchment Data Explorer[18]. It should be noted that the national datafiles had data missing or corrupted files, e.g. the (English) Dee district, the data files for the measures and reasons for failure were blank and therefore the tool cannot be run for the WFD Assessment in the Dee district with accurate results. For the other river basin districts, the data for the measures datafile appear to only include data in the upstream waterbodies, not the coastal or transitional waterbodies (Figure 61).




[18] http://environment.data.gov.uk/catchment-planning/ [viewed 30/05/2017]

Figure 61 The Environment Agency's data for the 'Measures' dataset demonstrating the lack of data in transitional and coastal waterbodies.

However, the code used to create these integrated shapefiles (waterbodies and datafiles) has been created to future proof the process, so that should the shapefiles or datafiles be updated, the code can be run to automatically update the data required for the EPSS tool. The steps taken to create and to run the tool are summarised below:

1. Manually moved Waterbody ID column as index 0, and checked whether the column name was the same across the WBD districts as data was inconsistent. Replaced commas with nothing (this would create a confusion later when joining data has a comma as a delimiter.
2. Set up working folders/directories.
3. Split waterbody IDs in measures that contained multiple values per cell into rows. Each row had only one 'waterbodyID'. This ensured that no data was lost.
4. Copied easting and northing from classification to measures and reasons based on the matching waterbody IDs.
5. Creating empty point feature classes for classification, measures and reasons and copying all the fields from the csv files in the feature classes.
6. 2km buffer around the waterbody shapefile.
7. `Select by location' tool to find points that intersect with the buffered waterbody layer. The selected points were exported as csvs.
8. Concatenating all the exported csvs in relevant dataframes and saving them as csv Look up tables. The index from the dataframes was saved in the csv as well.

### 6.2.5 Conclusions of the Testing by External Stakeholders

The overall feedback from the stakeholders was that the tool, or parts of the tool, would be useful for developments and regulators alike, as either an informative tool, for scoping or for ensuring all legal requirements have been met. The use of stakeholders to test the tool has allowed for some specific improvements to be made to the method, tool and outputs. One major development is the expansion of the tool to English waters (estuaries, coastal and open sea). It does not include the terrestrial legislation, policies or assessments, however with consultation with such experts it can be expanded to include such assessments. All feedback from stakeholders considered that the tool has been useful, and is needed in an age of increasing technology and data advancements. It is a way to centralise data management and assessment methods whilst ensuring a consistent and transparent method, but still requiring expert input to undertake the full impact assessments.

## 7. Limits of Acceptable Change

In the preceding chapters, the approaches for impact assessments have been reviewed and considered. Current approaches for determining the significance of an impact i.e. will it have a lasting detrimental effect on the marine environment, uses limits of acceptable change (also referred to as thresholds or benchmarks). These are often applied to receptors across a large region, (national or European) however the appropriateness of one threshold for one receptor across a large region has never been tested to determine if this is the most appropriate approach.

Marine areas are subject to many activities and areas, leading to an intensification in the pressures, often with adverse effects on the environment and society (Lonsdale *et al.*, 2017; 2015; Borja *et al.*, 2010a; Lotze, 2010; Halpern *et al.*, 2008; Berger and Hodge, 1998) therefore monitoring is required to determine whether the environment has significantly changed from a baseline state. Among the various tools to assess potential impacts, numerical models can be applied to assess the potential impacts of a development (e.g. a port development) on the physical components of the marine environment such as changes to water velocity, accretion and erosion patterns, noise intensity or tidal prisms (URS Scott Wilson, 2011; Kyozuka, 2004) and the magnitude of changes induced by a new structure is quantified by the model. In such cases, a model is calibrated to replicate the ocean dynamics to model the changes induced by a development. These modelled impacts are assessed alongside environmental quality legislation, such as the EIA Directive and European Water Framework Directive (WFD). Potential impacts are assessed and evaluated regarding its effects on society; impacts can range from the depletion of resources, to the change of natural system dynamics for example.

To assess adverse change from the reference state, an emerging area of science and management is the development of 'Limits of Acceptable Change' (or LOAC). Examples of such management measures, where thresholds are applied to determine the status of the environment are the European Directives: Water Framework Directive (2000/60/EC) and Marine Strategy Framework Directive (2008/56/EC). These directives use thresholds such as Environmental Quality Standards to classify whether the environment is 'healthy' (definition dependent on the criteria and therefore the directive).

LOAC can be defined as the variation in an ecological component or process that is considered acceptable, as it does not indicate a change in ecology that may lead to a

reduction or loss of function or biodiversity (adapted from Australian Government, 2012). The thresholds that are set in any LOAC should define the compromise society (society here is defined as being all encompassing of the public, scientists and politicians) is willing to accept, rather than the conditions of the environment that is desired, and allow environmental deterioration down to the threshold without further management being required (a threshold can change as societies priorities change) (Figure 62) (Cole and Stankey, 1997, Stankey *et al.*, 1985)

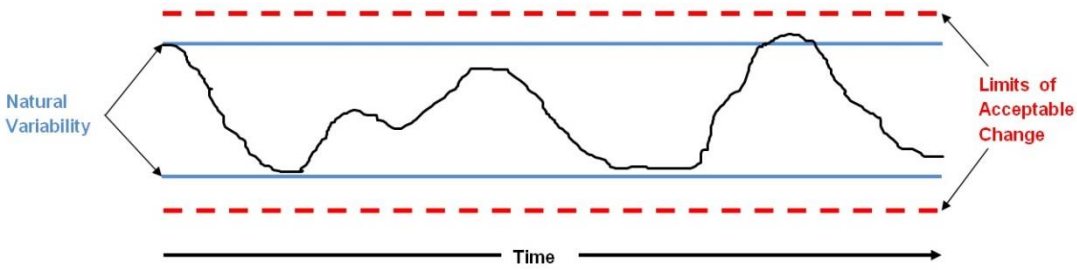



Figure 62 A conceptual model showing the concept of limits of acceptable change in relation to natural variability (adapted from Australian Government, 2012 and Phillips, 2006).

The concept of LOAC has gained momentum and is therefore gaining acceptance as it has been recognised through monitoring programmes, that an impact and change in ecology may occur either due to a development/activity or natural processes, but determining whether that impact or change is significant can hinder further management. As Elliott and Quintino (2007) identified, "*the main problem is that these methods detect naturally as well as anthropogenically stressed areas thus decreasing the ability of detecting and maximising the signal (anthropogenic change) to noise (natural change) ratio*". If LOAC can be determined, it can help managers to monitor an ecosystem, identify appropriate management actions and determine limitations to activities to maintain ecological character (Australian Government, 2012; Oliver, 1995). Hence, LOAC provides an adaptive management framework to prevent significant adverse environmental effects during resource use, addressing novel pressures and new research etc. (Zeldis *et al.*, 2006). The difficulty with using LOAC is that for some parameters monitoring will not show a change towards, or outside of the thresholds until the status is considered too late i.e. a regime shift is inevitable (Biggs *et al.*, 2009). With highly variable ecosystems such as estuaries, these thresholds will be wide and have to be considered with regards to the parameters being monitored (Dauvin and Ruellet, 2009; Elliott and Quintino, 2007).

As assessment through monitoring would not prevent the impact from occurring, but rather determine the system deterioration, numerical models have been increasingly used for the understanding and prediction of a process (Le Dimet, 1993). Their large applicability enables the assessment of various environmental variables. For example, hydrodynamic models have been used to assess the effect of turbine arrays in the far-field ocean system and estimate the induced energy removal by looking at effects on velocity and turbulence (Nash and Phoenix, 2017). The potential effect of river regulation and changing climate were evaluated with the hydrological modelling platform BIGMOD, and LOAC were derived from it.

Despite advances, the assessment and prediction of present and future impact on the hydrodynamics of estuaries are still challenging tasks for both managers and scientists. One such example of applying LOAC on hydrodynamics is the process of designating heavily modified water bodies (HMWB) under the WFD. The classification of a waterbody as HMWB is where an area cannot reach good ecological status because of physical modifications, but it will have a good ecological potential if the obstruction could be removed; there is an economic reason for not removing the obstruction (see Borja and Elliott, 2007). A criterion for HMWB is to assess if a development (e.g. building a harbour) affects 15% of the surface area of the water body (unless 15 % of the surface area of the water body is 1.5 $km^2$ or less) has been used (UK Technical Advisory Group on the Water Framework Directive, 2003). The 15% threshold is applied to many criteria, such as 15% of either bank being affected, 15% of the river or channel length, or a greater than 15% change in modifications to the sediment regime (UK Technical Advisory Group on the Water Framework Directive, 2003). These thresholds (15%) have been used to derive indicators by Aubry and Elliott (2006) but do not appear to have been tested rigorously for their ecological or hydrodynamic validity.

The UK Technical Advisory Group on the Water Framework Directive (2008) provided advice on the designation of HMWB, whereby the water body would not reach good status unless making substantial changes to the hydro-morphological features, or there would be a disproportionate cost in reaching the good status. The 15% threshold however can also be applied to a new development; for example, development on the scale of the Swansea Bay tidal lagoon in the Severn Estuary might cause a deterioration in the classification, as the development could potentially affect greater than 15% of the WFD waterbody (Natural Resources Wales, pers. comm.). To date, there have not been any developments that meet this 15% criteria.

The WFD requires managers to determine the ecological status of an area and classify it as High, Good, Moderate, Poor or Bad (Hering *et al.*, 2011). If an area is deemed to be in Good or High status then no further action (termed measures) are required, whereas if an area is deemed to be bad, poor or moderate then measures are required to bring it across the moderate-good boundary, unless an economic case can be made for derogation. Determining in which category a water body lies has methodological challenges (Alvarez *et al* 2013) including: defining the limits of the categories, the performance of any metric, the difficulty of combining metrics, etc. As with other examples of applying limits of acceptable change, the difficulty for the regulators is to determine how to adapt between good and moderate status.

The aims of this study are to test the 15% thresholds on the Humber Estuary by using a hydrographical model for the Humber, also by using a series of scenarios of a development, and by determining whether the application of the threshold(s) are acceptable. This will allow a comparative analysis to determine if the 15% threshold can be universally applied both within the area, and between areas national and internationally.

The changes in hydrodynamics was chosen, as a change in hydrodynamics can trigger change in sediment transport and accretion/erosion patterns that can affect benthic species and the higher trophic levels, and can therefore be used to infer potential changes to species populations through changes to physical properties (Day *et al.*, 1989, Mitchell *et al.*, 1998, McLusky and Elliott, 2004, Bolam *et al.*, 2006; Harbasins, 2008; Leon *et al*, 2003; Hu *et al.*, 2009; Walstra *et al.,* 2009; Hu and Ding, 2009; Leorri *et al*, 2011)

## 7.1 Method of Testing

The aim of this study is to quantify the impact of a newly built structure on a system which will trigger a hydrogeomorphology adaptation over the construction-time of the structure, and possibly after. Ultimately, the modified system can reach a new equilibrium. The purpose here is not to analyse the system adaptation to the new conditions, nor the ultimate hydro-geomorphologic equilibrium, but to quantify in a static way the impact of a given structure on the hydro-dynamics using a numerical model dedicated to the Humber Estuary.

The baseline Humber model has been built using the Delft-model suite (DELTARES, 2011). The Humber Estuary being well-mixed over the water-column, the depth-averaged (2D) model has been chosen to simulate the hydrodynamics. The model has been calibrated against observed estuarine and off-shore water-level time-series, optimising model

parameters to match measurements. After the calibration, the model was validated at new offshore and estuarine sites against both water-level time-series and one-off current velocity. Ideally, those new observations need to cover different locations and a different time-period from the calibration. For sake of replicability of the method, and representability of the model, model forcing was set as a standard condition calculated as an average value over the span of available data. Forcing can be seen as a most-frequent condition in the system. Sensitivity tests on discharges and waves were also carried out to quantify environmental forcing sensitivity.

The same model configuration has then been used to test the scenarios of developing a structure, that would affect 5, 10 and 15% of the waterbody area, at three locations across the Humber Estuary (Broomfleet, Hull and Grimsby (Figure 63)) for a comparative analysis. By testing the thresholds across several sites within the same waterbody it will give an indication of whether one threshold can be universally applied across different ecosystems, which have varying dynamics. The sites were chosen to represent a riverine system (Broomfield), an estuarine system (Hull) and the open coast/sea (Grimsby). Their locations and extents over the channel width have been chosen to disrupt as little as possible the flow course: riverine development overlaps several islands, as does estuarine development to a lesser extent, and ocean development is located where the channel is shallower. Depending on the site morphology, increase of the development area happens mainly cross-shore-wise (open coast/sea system) or alongshore-wise (estuarine and riverine systems); a 15% development is un-suitable by its extent over the riverine system. For each system, a cross-section overlapping the development extents has been selected (Figure 63).

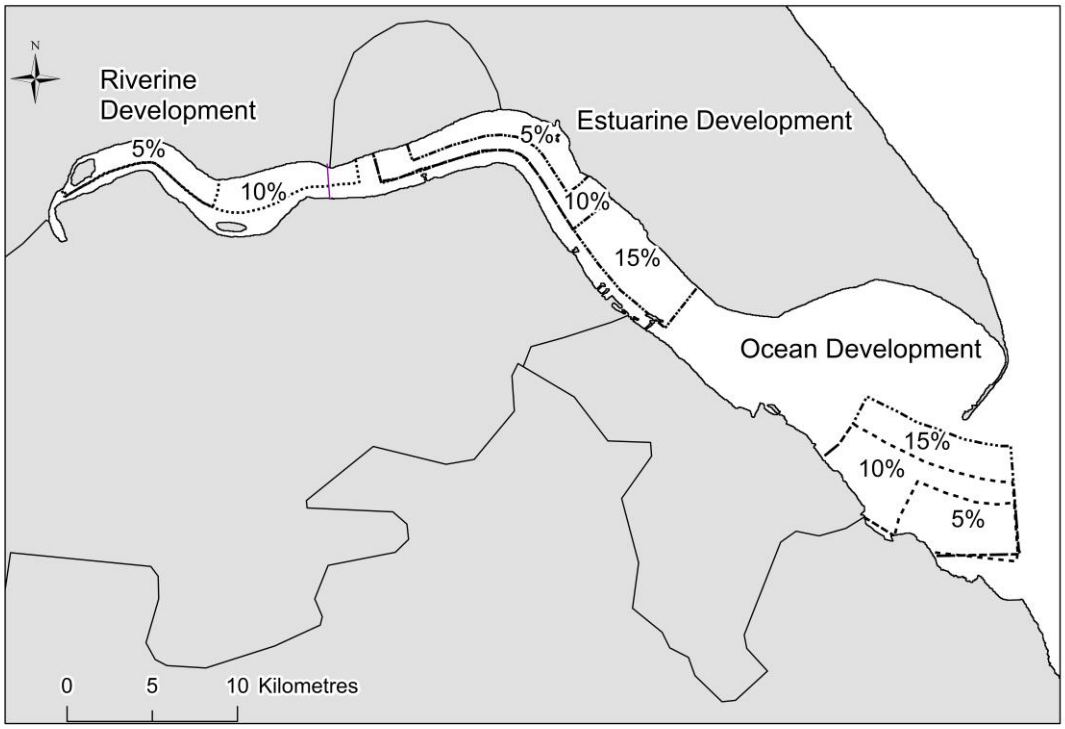



Figure 63- Sites used for hypothetical developments as part of this study (dashed areas, with associated percentage of the waterbody). Cross-sections, selected as a proxy to assess development impact on the system hydrodynamics, are represented with red lines.

Overall development impact is assessed through a plan-view of the percentage of change in maximum velocity for each system, and through the distribution of maximum and mean velocity ($V_{mean}(X)$ and $V_{max}(X)$ in Figure 64) along the selected cross-section displayed in Figure 63.

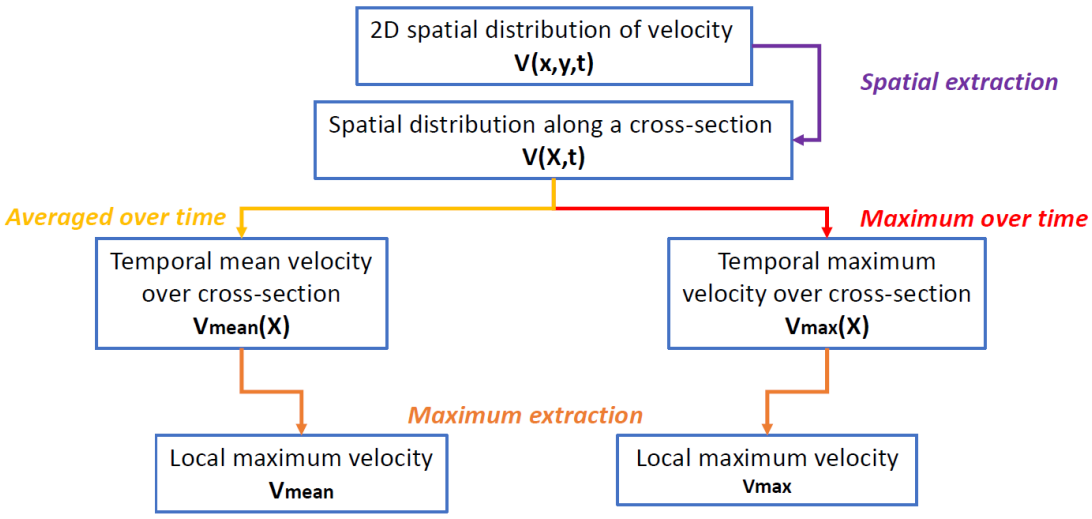



Figure 64 Post processes applied on the predicted velocity results for the development scenarios and the baseline model. The successive processes are indicated in italic. V stands for velocity, x and y are cartesian dimensions, t time and X is the axis along a cross-section.

To compare the effect of development extents (5, 10 and 15%) among the three systems, the maximum $V_{mean}$ and $V_{max}$ along the selected cross-sections are extracted following the steps in Figure 64, and impact of the development is estimated as a ratio.

$$R_{max} = \frac{V_{max}^{develop.}}{V_{max}^{baseline}} \quad \text{(eq.1)}$$

And:

$$R_{mean} = \frac{V_{mean}^{develop.}}{V_{mean}^{baseline}} \quad \text{(eq. 2)}$$

With $V_{develop}$ the predicted velocity considering a development of 5, 10 or 15% of the water body and $V_{baseline}$ without any development.

It was assumed that a ratio larger than 1.2 shows a significant impact of the structure. If the two ratios are close to each other, it means that the development is globally impacting the flow velocity, both in time and along the cross-section. An inequality $R_{max}>R_{mean}$ would depict a stronger local flow compared to the overall flow field, and therefore a more inhomogeneous flow. If $R_{max}<R_{mean}$, the development would tend to make the flow globally stronger, resulting in a more homogenized distribution of flow.

A plan view of the velocity vector change between a development of 10% and no development is also detailed, showing both the variation of current strength (arrow length) and direction (vector direction).

## 7.2 2D hydrodynamic model set-up

The model includes the whole Humber estuary, from Trent Falls to Spurn Point, and extends from the estuary mouth up to ~50 km eastward and southward, and ~35km northward. The domain excludes the Ouse and Trent rivers. The boundaries are located sufficiently far from the estuary and the calibration and validation locations, to have a fully developed tidal flow and prevent any boundary related effect.

### 7.2.1 Mesh structure/refinement

Three different mesh grids have been built, each having an overall resolution of 100m (fine), 300m (medium) and 700m (coarse), respectively. A preliminary study demonstrated that in the coarser mesh, cells were too large to properly reproduce the actual estuary-bed resolution with multiple channels. Comparable hydrodynamic results were found with the medium- and fine-mesh, but as the fine-mesh induced long computer-processing times, the

medium mesh was adopted. Its structure is as follows: it has been refined over the estuary down to ~200m-long (edge align with the main flow direction to ease numerical calculation) and ~100m-wide cells, as secondary currents and back water are most likely to occur. The mesh is coarser along the boundaries offshore (cell size ~5km*4km). As the mesh is structured and formed of quadrilaterals, the vertical refined section encompassing the estuary spreads up to offshore eastern boundaries; toward the North and South boundary, cells become gradually larger. This smooth coarsening of cells improved the model stability, and prevent any spurious computation.

### 7.2.2 Dry points and Thin dam

Dry points and Thin dam features in the Delft-model represent dry cell(s) in the mesh, to prevent water passage through a cell edge. The Spurn Point Peninsula acts as a breakwater and its width is about the size of the cell. It has been reproduced with 'dry points' feature. A "dry points" feature has also been used in the section opposite to the peninsula, to better reproduce the actual bed morphology by drying out specific areas. The development area (Figure 63) has been delimited with a "Thin dams" feature, preventing the simulated current from flowing through it.

### 7.2.3. Bathymetry

The model bathymetry is a combination of a Digital Elevation Model (DEM) created by Astrium (2011) with a resolution of six arc-second, and a local DEM measured in the estuary with an echo-sounder over 2013-2014 and provided by ABPport (pers. comm., April 2016). As both DEM were supplied relative to Chart Datum, they have been converted to mean sea level as the reference elevation. The height below Ordnance Datum Newlyn ODN, considered here as mean sea level, has been indicated at various gauging stations: height is equal to 3.9 m between Spurn and Albert dock and reduces to 3.3 m at Humber Bridge, 2.7 m at Ferriby and 2.5 m at Brough. Bathymetry conversion follows a linear interpolation given the different information at gauging stations. Overall, the Astrium DEM has been mainly used for offshore locations, while the refined DEM provided by ABPport was used along the estuary, where a finer resolution is required. Both DEMS fully overlapped the numerical mesh.

### 7.2.4 Forcing

Tidal water level has been extracted from the OTPS global model (OTPS7.2, 2005) with the following principal tidal constituents: M2, S2, N2, K2, K1, O1, and were imposed at the offshore boundary of the model to reproduce the tidal information at any moment in time. The Humber flow has been reproduced with a mean discharge of 250 $m^3/s$ in the model.

The averaged 1.2 m wave height coming from North and North-East directions have been simulated.

### 7.2.5 Model calibration and validation

Model calibration consists of optimising model parameters to match measurements. The present model has been calibrated against measured environmental time-series following successive steps. After calibration, the model was validated (without further adjustment) against new observations. Plots of the calibration and validation are presented as Appendix 10, while the maximum mismatch with observations are collated in this section.

### 7.2.6 Measured environmental parameters.

Water-levels time-series and local flow velocity statistics have been gathered through:

1) Offshore, two distinct water-level observations from the British Oceanographic Data Centre have been used to i) calibrate and ii) validate the tidal signal.

2) Along the estuary, Associated British Ports Humber Estuary Services (ABPHES) provided the water level measured over one month, and at seven gauging stations. The first tidal-cycle of the water level time-series (includes both a spring and a neap tide) has been used to calibrate the model at four of the seven stations, and the validation was then processed on the three remaining gauging stations and over the second tidal-cycle.

3) Velocity ranges from Hardisty (1999) (from Vermeulen, 2004) and Vandenbruwaene *et al.* (2013) have been compared with the simulated current within the validation process.

### 7.2.7 Model calibration

Different parameters have been adjusted in the calibration process, their impact on the calibration is explained and the final “best fit” parameters used in the final model are stated (Table 25).

Secondary currents, accounting for the spiral motion included in the momentum equations in horizontal direction, are included to reproduce the effect of estuary bends and islands/bars. To close the momentum equations, the vertical flow profile is assumed to follow a logarithmic velocity profile (WL¦Delft Hydraulics, 2011), which is a valid assumption in the absence of stratification within the Humber.

Table 25 Calibrated parameters

| **Parameter** | **tested** | **calibration** | **Value at the end-of the calibration** |
|---|---|---|---|
| Roughness (Chezy) | Too little information to calibrate roughness against grain size.<br>Constant spatial roughness tested from 50 to 70$m^{1/2}/s$ | Fit of a constant parameter improved the calibration. | 65 $m^{1/2}/s$ (U and V direction).<br>This roughness is representative of the sandy/muddy bed. |
| Horizontal eddy viscosity | It depends on the flow and the grid size.<br>Tested for 0.1 to 100 $m^2/s$. | Averaged grid resolution ~100m.<br>Fit of the parameter that would improve the calibration | 1 $m^2/s$.<br>Value coherent with the grid size (WL¦Delft Hydraulics, 2011) |
| Salinity | Influencing water density and other processes.<br>Tested linear gradient from 35 to 0 salinity | Did not improve the calibration and induced longer calculation | Not used |
| Secondary current | Inclusion of secondary currents.<br>Sensitivity test on associated parameters 'Initial velocity' and 'Beta' | Improved the calibration when included. | Secondary current included with the following parameters:<br>Initial velocity =0.2m/s<br>Beta=0.5 |

A good agreement with the observations has been found by applying the calibrated parameters, as specified in Table 25, throughout the estuary, tidal range is well reproduced with the maximum absolute error over the neap tide found at the Ferriby station with an over-estimation of ~35 cm, while over spring tide the maximum absolute error is found at Immingham gauging station with an under-prediction of ~36cm. A slight shift of the simulated tidal phase compared to measurement can be observed. At the offshore calibration point, no phase shift is found between observation and model results. The modelled tidal range are in good agreement with observed range, except when wind and/or waves affect the water surface, as observed from the 28th of December until the 4th of January (see Appendix 10).

### 7.2.8 Model validation

The model was validated by comparison of observed water elevations, with simulated time-series from the calibrated model. The water elevation validation shows good agreement between measured and simulated water levels, with a maximum absolute error of 35cm at Grimsby station, but this may be due to wind effects or larger field pressure effects, as the same behaviour is found at all three stations at the same time. Diurnal inequality is reproduced for all stations. Similarly, for the calibration, a slight shift in the modelled tidal signal is found.

The model accurately reproduced velocity magnitude, as observed near Spurn station in Hardisty (1999) (from Vermeulen, 2004). For current velocities observed near Immingham (Hardisty, 1999; from Vermeulen, 2004), the predicted ebbing strength is underestimated by 0.4 m/s over spring tide; this difference may be explained by a mismatch in the discharge value in the riverine boundary forcing and/or in the measurement location. Reported maximum flood current from the Admiralty Chart 109 agrees with model velocity, as does the reported range of velocities (DELTARES, 2011). Moreover, it can also be assumed that if high and low tide water level are reproduced by the model, the velocity magnitude should be adequately simulated.

### 7.2.9 Model sensitivity to forcing

As the riverine flow varies seasonally (Begum, 1999), a sensitivity test has been carried out with a discharge ranging from 62 to 500 $m^3/s$. Impacts of flow rate on water elevation were found in the section up-estuary to Ferriby over ebb flow, with a difference of about 400 m3/s, inducing a change in water elevation and flow strength of about 10 cm, and less than 0.1 m/s at Ferriby station, and a few cm and cm/s at other stations. As the impact of a discharge variation on modelled water elevation was local and small, and in the absence of other data for the year modelled, the Humber flow has been reproduced with a constant averaged discharge in the model.

An averaged 1.2 m wave height, and a 95th percentile 2.52m wave height have been calculated from the 15-year-long time-series. The wave forcing induced much weaker maximal orbital velocities compared to the maximal flow velocities with Vorb~10%*Vflow. The baseline model, based on averaged conditions, will hence not include any wave.

### 7.2.10 Model uncertainty and predicted pattern of flow.

To evaluate the adequacy and reliability of the model, the input data of the model such as the forcing (riverine and tidal constituents), the model resolution and the calibration/validation process are summarized, and their uncertainty is graded 1-5 in Table 26. This evaluation method enlightens the weakness and strength of the models' main constituents, while giving an overall evaluation of the model uncertainty. Pattern of flow characteristic of the Humber, and reproduced by the model are listed.

Table 26 Certainty in each model component, and in the model overall, with 5 ranked as unsuitable, 4 as uncertain, 3 as suitable, 2 as good, and 1 as high.

| Rank | Resolution | Bathymetry | Calibration /validation | Tidal forcing | Riverine forcing | Overall |
|---|---|---|---|---|---|---|
| 5 | | | | | | |
| 4 | | | | | Absence of measurements | |
| 3 | | -recent -Overlaps with mesh -finer over estuary | | | | |
| 2 | -reproduce bathymetry - Similar results to finer mesh | | -Covers the extent of the model -good fit | | | -Reliable prediction |
| 1 | | | | -Six constituents | | |

At Grimsby station, flood current strength is about 85% of ebb current, revealing a current asymmetry with an ebb dominance. The predominance of ebb current declines up-estuary, with a flood current being about 98% of the ebb current at Immingham. Further up-estuary, the inequality is reversed, with flood dominance in agreement with JBA Consulting (2011).

Slack water on the lee side of the Peninsula

At the estuary mouth, the Spurn Point Peninsula (acting as a breakwater) creates a zone of slack water on its lee-side. Closer to the Peninsula, velocities are stronger and highly variable (turbulence), with highest velocity at the Peninsula head where the channel is the deepest. While the slack water zone is of similar extent over the ebb and flood current, the velocity next to the Peninsula head is locally stronger over the ebb. Strong velocities are better distributed along the cross-section aligned with the Peninsula over flood. On the bank opposite the Peninsula, the current is weaker than in the middle of the channel.

Main channel close to South Ferriby station

North of the South Ferriby gauging station, water mainly flows through three sub-channels delimited by estuarine banks and a mid-river island, with the two most-northerly channels experiencing the strongest velocities. At the southern-most channel, where the Ferry box gauging station is, it can be inferred from the measurement of water level that velocities are stronger over flood than ebb.

Channels close to Trent Falls

Due to the presence of a muddy-sand island down-estuary of Trent Falls, the river flow is divided into two sub-channels, with the wider being the southern one. Flow travels more through the northern sub-channel during the flood due to upstream bed bathymetry forcing current direction.

Interaction with bathymetry

In estuarine meanders, the distribution of velocities along the cross-channel near King George or Brough gauging stations is typical of the flow pattern in a bend, with larger velocities in the outer bank than in the inner bank, inducing potential sediment deposition on the inner bank. The bend morphology also induces a secondary current, with the strongest current found near King George station, where the bend angle is large and induces a strong flow. Secondary currents are also predicted within the deepest channels, with most of them being located in the downstream part of the estuary, seawards of Hull.

### 7.3 Overall impact

The ebb velocity on the 15th of July 2018, 09:30, is displayed in Figure 65 without any development (blue arrow), and with a 10% development (red arrow) over each of the systems, with the development preventing flow through it. Over each system, upstream of the development, flow is diverted away from it and downstream of the development, the flow re-joins the main channel creating a zone of slack-water and re-circulation next to the development.

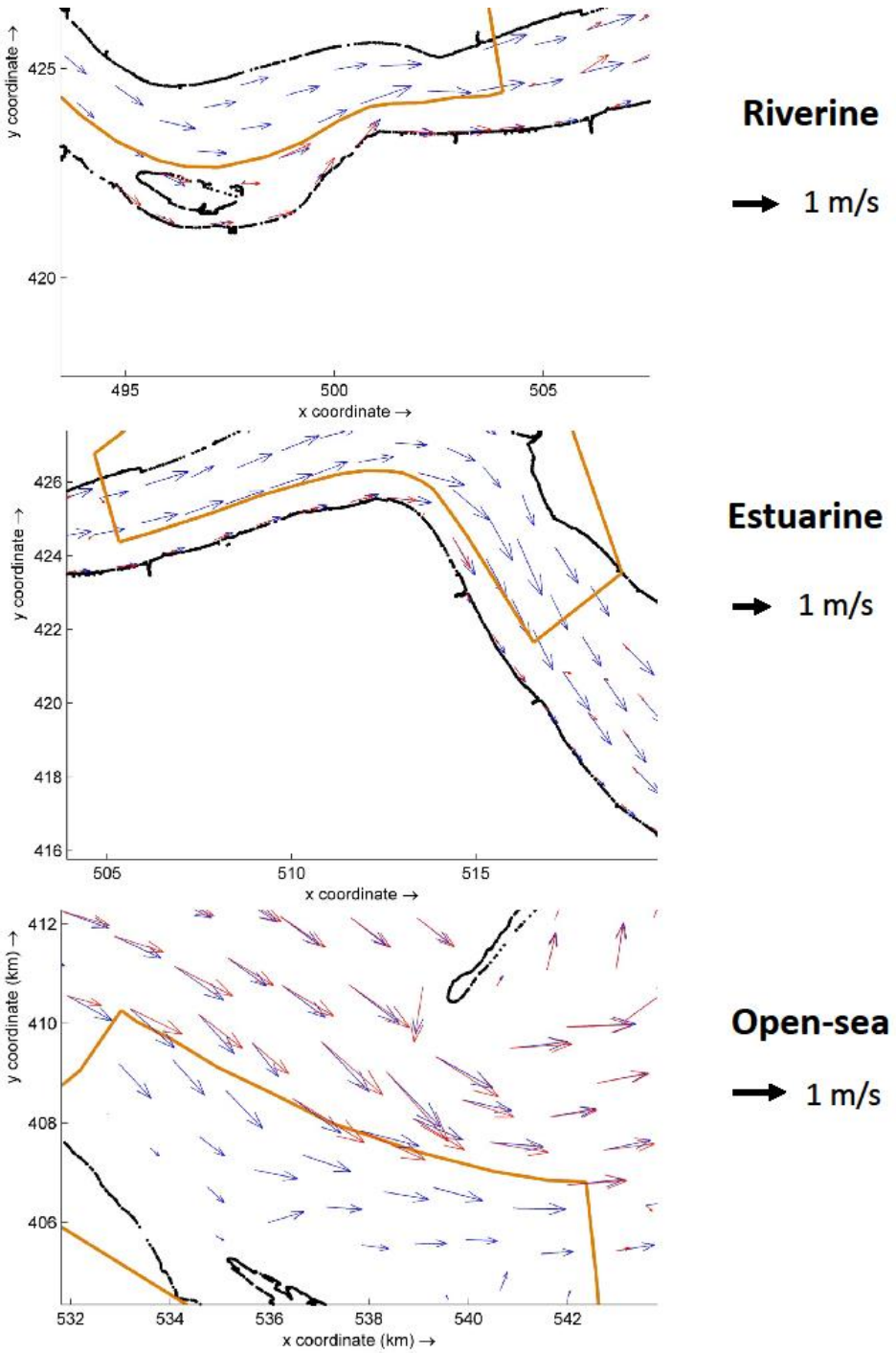



Figure 65 Predicted velocity fields on the 15th of July 2018, 09:30 with a 10% area development (red rooted arrows) and without any development (blue rooted arrows). The brown boxes are the developments

Averaged over the simulation time, the riverine system would be the most impacted, as a development of either 5 or 10% could induce a current up to ~2.7 times stronger relative to normal flow (Table 27), while velocity with a development of 5 and 10% over the two other systems would be bounded by about 1.05 and 1.3 times stronger flow relative to normal flow. The maximum development of 15% lead to a current acceleration up to 1.7, and 1.2 stronger for the ocean and estuarine systems, respectively. For a 5% development, increase

in the strongest velocity over time, compared to a maximum baseline velocity, is comparable over riverine and estuarine systems (~1.3), while over the ocean system, the same variable is only slightly increased (less than 0.05). Increase in development extent from 5 to 10% for the riverine, and from 10 to 15% for the estuarine, is associated with a small reduction in the maximum velocity, while an increase in development extent is quasi proportional with velocity increase over the offshore system (Table 27). A 5 or 10% development in the coastal system, and a 5% development in the estuarine system would result in a more homogeneous flow field. For all other scenarios, more disparity in the flow field were predicted.

Table 27 Ratios Rmean and Rmax (see equations 1 and 2) along the selected cross-sections for different percentage of change and over three different systems

| | **$R_{mean}$ [$R_{max}$]** | | |
|---|---|---|---|
| **% impacted** | **5** | **10** | **15** |
| **Coast/Sea** | 1.03 [1.02] | 1.21 [1.15] | 1.74 [1.32] |
| **Estuarine** | 1.04 [1.21] | 1.32 [1.44] | 1.29 [1.35] |
| **Riverine** | 2.67 [1.31] | 2.66 [1.29] | Non-applicable |

### 7.4 Open coast/sea development Scenario

The results for the scenario which models a development in an open sea environment and covering 10% of the waterbody, show that overall the development has minimal impact on the maximal velocities, with most of the case study area being affected by less than 25% of water velocity changes (Figure 66). Immediately up and down stream of the development, there are up to 75% water velocity changes, but with most changes falling within the 25-50% change. There are two locations upstream of the development whereby there is a modelled change of over 100% in water velocities. There is a modelled area north of the development, on the lee of the Peninsula, which shows a potential change of water velocity of 75-100%, likely to be caused by the narrowing of the channel between the Peninsula and development. Over the cross-section, the ocean development showed a gradual increase from the $V_{max}$ of under 2.6m/s to over 2.6m/s from the baseline to the 5% development. The $V_{max}$ change then increases 0.4m/s to 3 m/s for the 10% development. For the 15% development, it then increases 0.5m/s to 3.5m/s. From the mean current distribution along the cross-section, the

current is forced by the structure, inducing a shift and strengthen of the flow toward the northern channel. The extent of the slack water on the lee side of the Peninsula is the same, and spring tide ebb velocity on the edge of the slack-water is increased by about 0.1 m/s for a 15% development. With the presence of any development, strong velocities distribution along the cross-section aligned with the Peninsula is similar to the previous baseline velocity distribution, with a more localised velocity with ebb current than flood current.

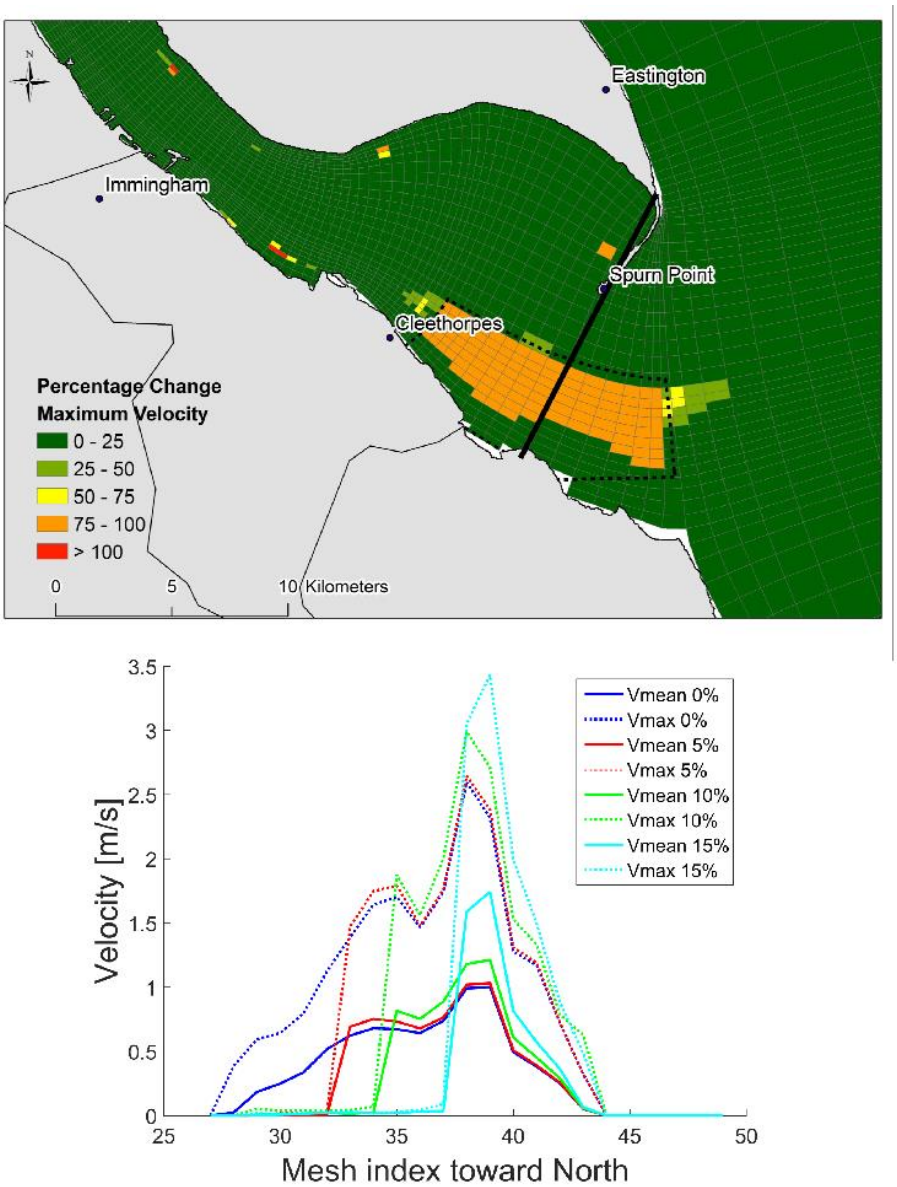



Figure 66 Percentage change in $V_{max}$ from a coastal development covering 10% of the waterbody (top), and maximum and mean velocity distribution along the ocean cross-section for 5, 10 and 15% development extents (bottom).

### 7.5 Estuarine development

With an estuarine development covering 10% of the waterbody, the water maximal velocities change upstream by mostly 50-75%, with some areas showing modelled changes of up to 100% (Figure 67). There are large changes modelled to the south of the development, the end closest to the open sea, where there are greater than 100% changes in water velocities. Downstream of the development there is a modelled change in water velocity of up to 100% immediately adjacent to the development, and decreasing to 50-75%, and <50% changes in water velocity after 4km. Along the cross-section, the estuarine developments also showed a gradual increase in $V_{max}$ from 1.5m/s at the baseline to ~1.75m/s for the 5% development. For the 10% development, the $V_{max}$ sharply increases to ~2.2m/s, but the $V_{max}$ decreases to ~2m/s for the 15% development showing an overall increase of 0.5m/s between the baseline and 15% development, but a maximum change of 0.7m/s. As the estuarine development is in the outer bank of a meander (north), the high velocities induced by the bed geometry are shifted toward the southern bank, with the highest velocity over time adjacent to the development. Similar velocities are found with a development of 10 and 15%, as development extent over the cross-section is the same (Figure 67).

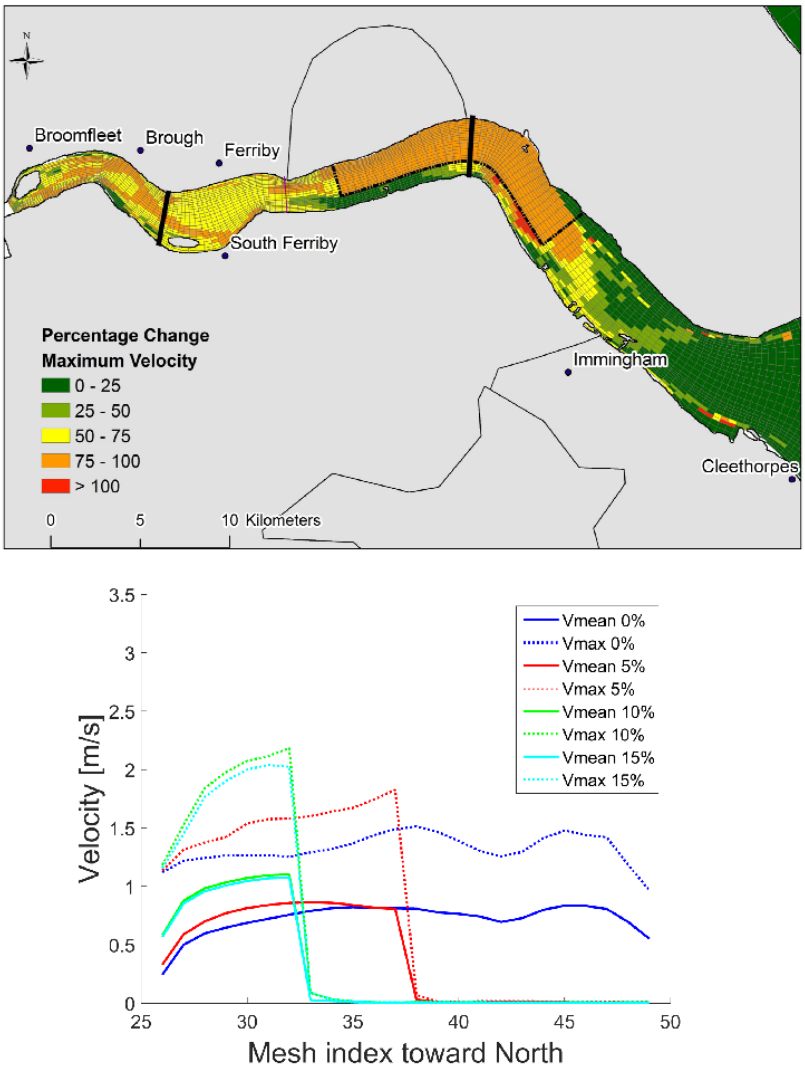



Figure 67 Percentage change in $V_{max}$ from an estuarine development covering 10% of the waterbody (top), and maximum and mean velocity distribution along the estuarine cross-section for 5, 10 and 15% development extents (bottom).

## 7.6 Riverine development

With a riverine development covering 10% of the waterbody, water velocities downstream of the development show changes of up to 75% for 2km (Figure 68). After which, the changes decrease to 25-50% for 5km. South of the development, there are changes in water velocities up to and greater than 100%. The changes to water velocities that exceed 100% are where the channel narrows near a mid-river island. Over the riverine cross-section, the flow is divided in three sub-sections, with the two northerly sub-sections connected. As 5 and 10% development extents over the cross-section are the same, a sharp $V_{max}$ increase from 1.88m/s to 2.5m/s is found between the baseline and both developments (Figure 68), with a shift of the maximum velocity from the north- and central-channels to the central- and southern-channels, as the development partly obstructs the central and northern channels.

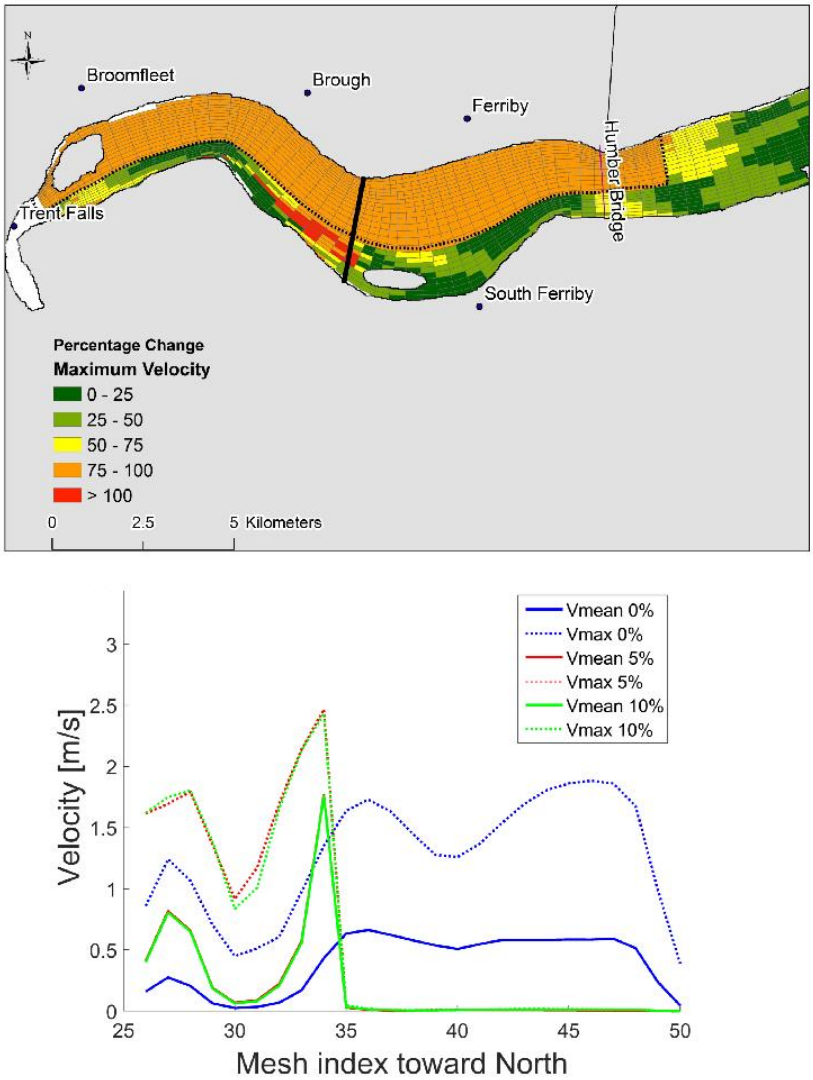



Figure 68 Percentage change in $V_{max}$ from a riverine development covering 10% of the waterbody (top), and maximum and mean velocity distribution along the riverine cross-section for 5, 10 and 15% development extents (bottom).

## 7.7 Discussion

In this study, the use and application of one threshold to be used nationally or wider, has been evaluated using three environments on the Humber Estuary representing riverine, estuarine and open sea systems, using hydrodynamics as an example. Hydrodynamic model uncertainties and scenario simulations are discussed; considering the results, a different and novel threshold linked with the system considered is proposed below.

Overall, averaging the score found for all the constituents, the model is considered as GOOD (Table 28). Predicted depth averaged velocity can be used as a proxy to assess development impact

Table 28 Certainty in each model component, and in the model overall

| Certainty in model set up | Resolution | Bathymetry | Calibration /validation | Tidal forcing | Riverine forcing | Overall |
|---|---|---|---|---|---|---|
| 5 (unsuitable) | | | | | | |
| 4 (uncertain) | | | | | X | |
| 3 (suitable) | | X | | | | |
| 2 (good) | X | | X | | | X |
| 1 (high) | | | | X | | |

This study has taken a novel approach to test whether a threshold for representing LOAC is appropriate for its intended use, using nine scenarios across three sites (to be representative of the different marine environments: open sea; estuarine; and riverine). Previous studies have been undertaken to propose such LOACs (Foley *et al.*, 2015; Ruckelshaus *et al*, 2008; Australian Government, 2012; Zeldis *et al.*, 2006; Cole and Stankey, 1997, Oliver, 1995; Stankey *et al.*, 1985) or provide monitoring data in relation to these LOAC (such as under the WFD e.g. Rowland *et al.*, 2011). Aubry and Elliott (2006) provided an initial review and critique of environmental indicators, but this study has taken their work further.

In this study, developments are reproduced in the model as "simple straight impermeable walls", leading to a huge diversion of the flow, even if the location and extent have been chosen to disrupt the flow as little as possible. Depending on the location along the whole estuary, increase of development surface happens mostly in a direction perpendicular to the main current direction (ocean), or along the flow direction (river and estuary) and the most impact has been found for the former direction. A development extending smoothly perpendicularly to the flow course would gradually divert the flow, and induce smoother change. Present study results suggest that extending a development in the direction of the main current would not inevitably increase local velocity strength. The impact of different elongated development shapes could be compared through modelling studies.

From the results, it appears that even within one ecosystem (Humber Estuary), the three environments (ocean, estuarine and riverine) have different responses to the developments of the same threshold (in this study based on area of the waterbody). It is therefore suggested that the application of one threshold to cover all environments across a national, European or international scale for physical processes is not suitable, as the response of the

environment will depend on multiple factors such as environmental (bathymetry, rainfall influencing fluvial run off etc.) and anthropogenic (design of the development for example).

We have demonstrated that for a system like the Humber Estuary, there are multiple scales within an estuarine ecosystem, and this is also true for the recovery where different receptors will recover from different pressures at different speeds (Borja *et al.*, 2010b). Borja *et al.* (2010b) have noted that analyses have indicated that if the physio-chemical system is restored, then re-colonisation should follow, leading to the recovery of the ecosystem structure and processes, although the temporal scale and extent of the recovery is dependent on many factors such as impact type, magnitude and species etc. Recovery doesn't always follow removal or reduction in stressor, and many systems will respond to change in a non-linear manner to degradation and recovery (Borja *et al.*, 2010b; Mee *et al.*, 2008). Changes due to pressures to a new state (regime shifts) may occur as emergent properties. Emergent properties are those that cannot be localised to any particular component of the ecosystem, and are therefore a property of the whole system (Tett *et al.*, 2013).

All three developments, at all three locations showed changes, although to varying degrees and with all showing an increase in $V_{max}$ and $V_{mean}$ above the baseline. With thresholds and benchmarks being used more (e.g. Natural England, 2017; OSPAR Commission, 2013; UK Technical Advisory Group on the Water Framework Directive, 2008; 2003) to determine 'when society should worry' it is important to ensure these are tested and are appropriate for the receptor, site and in relation to the level of impact that is acceptable to society. It is noted that the use of indicators and thresholds are a useful tool to manage, monitor and prioritise pressures, but as demonstrated in this study, thresholds may not be appropriate for all scenarios and all environments, even within a relatively small area such as an estuary.

Whilst the model itself is not new, the approach in which it has been used in testing a threshold is novel. We have shown that this approach does work for testing thresholds when looking at changes to flows from coastal or marine developments. This approach would be informative primarily for regulators or policy makers, who may set these thresholds for managing marine developments and their potential impacts on the marine environment.

It would be useful if other national, European and International standards could also be tested to determine if the application of thresholds for other receptors, whether they be

biological, chemical or physical can be applied, and if so whether at these larger scales, or whether regional or more local thresholds is more appropriate.

The EPSS tool can inform future limits of acceptable change as it contains the data, indicators and legislative requirements for an area. The current cumulative impact assessment in the EPSS tool can be adapted to demonstrate that receptors are already susceptible to impacts to assess any further pressures can be accommodated.

## 7.8 Conclusions

The approach used in this study has shown that models can be used to aid in the management of complex estuarine environments, by applying more site and development specific thresholds to reduce the adverse impacts of developments on the marine environment. The approach used here can be used in other areas, and other types of thresholds such as changes in sediment transport. It is a useful approach for ecosystem management in understanding how systems will change relative to baselines, and natural variability are key for ecosystem management.

# 8. Discussion

Many factors must be taken into consideration when managing an area such as an estuary, and managers need to understand what an area is currently like, as well as defining what it should be like (Aubry and Elliott, 2006; Roesenberg and McLeod, 2005; Atkins *et al.*, 2010; Low *et al.*, 1999). To ensure the integrity of the system, it requires a long-term integrated management of human activities considering the physical, chemical and biological interactions (Atkins *et al.*, 2010; van Hoey *et al.*, 2010; Barnes and McFadden, 2008; Varghese *et al.*, 2008; Helsinki and OSPAR, 2003; Fabbri, 1998; Edwards *et al.*, 1997; Cicin-Sain, 1993).

## 8.1 Aims, Objectives and Research Questions

The focus of this study is on the current and anticipated future use of space, and the development and testing of a planning tool to aid decision-making for sustainable use and development. This study provided a toolbox for aiding decision makers in taking a holistic approach to the management of an area; namely the EPSS framework and its comparison with similar, complementary or conflicting tools, the EPSS GIS tool and the investigation of limits of acceptable change. The overall aim was to develop a proof of concept that the different legislative requirements, tools and assessments could be integrated into one framework/ tool for simplifying the process for developers and decision makers. The objectives of this study are summarised in Table 29, with a commentary of how these have been addressed within the study:

Table 29 Summary of the Objectives of the study and how these have been addressed.

| **Objective** | **How addressed** |
|---|---|
| 1. To summarise the knowledge and understanding of the baseline(s) of the estuary with regards to the current environmental condition | This has been addressed by the tool using the data to produce maps and provide a baseline (Appendix 2). The ecosystem goods and services are identified by the look up tables, and associated with the relevant data layers to determine if the ecosystem goods and services are present within the vicinity of the development. |
| 2. To investigate the different management schemes and frameworks and integrate these into a novel framework | The different management schemes, frameworks and tools have been investigated, and whilst each scheme/framework/tool is useful for a particular sector, there has not been any attempt to collate these into one support system. In order to ensure these could be integrated, they were broken down into their component parts, and a framework developed prior to the development of the tool. |
| 3. To develop an EPSS framework for managers to assess the current baseline and future projects | A framework based on the current baseline, legislative instruments and management tools and concepts was developed to provide guidance to managers, planners, developers, stakeholders and the public on what needs to be considered when developing new infrastructure and/or policies. |
| 4. To develop a tool that provides a practical application of the EPSS framework | The EPSS tool was tested against five marine licence applications to ensure the results were accurate and correct. This was accomplished by the outputs for the ecosystem services by validating against literature (Luisetti *et al.*, 2014; Jacobs *et al.*, 2012). |
| 5. To further develop the tool to include a cumulative impact assessment technique | Cumulative impact assessment tools and approaches have been developed, however these have sat outside other impact assessment tools and have not included information on 3D elements of the water column, the temporal scale (phases of operation), nor have they provided an indication on the increase in potential impacts from a new development. The EPSS tool developed here combines these advancements alongside regulatory requirements and scoping criteria. |

| | |
|---|---|
| 6. To identify the current level and extent of ecosystem services and societal goods and benefits provided by the Humber Estuary, including a review of appropriate indicators ( | Based on current ecosystem service and societal benefit knowledge, the ecosystem services and benefits provided by the Humber Estuary were identified and linked to GIS layers and data to extrapolate this information to England wide habitats. To aid in the valuation of these services and benefits, a look up table was developed for the tool to advise the user on the appropriate valuation techniques, given more than one method can be applied to certain types of the services and benefits. |
| 7. To test the tool with several stakeholders and decision makers, on a consented project within the Humber Estuary and update the tool based on the received feedback | The tool was presented to, and tested by a number of stakeholders whose overall feedback was positive in that all reported that the tool was useful for the outlined purposes and would be good if it could include certain additions (most were outside of the scope of this study). The stakeholders responses were that the collation of information into one database and tool was useful and informative. The tool was then extended to English territorial waters in response to the feedback, although not all data could be extended. |
| 8. To determine if the application of standard indicators or thresholds for change are appropriate in estuarine management | A comparison of the indicators has been tested against those used in this study and EPSS tool in Appendix 5. The use of limits of acceptable change has been tested in Chapter 7, and demonstrates that limits of acceptable change to hydrodynamic changes are unsuitable as a national (and international) standard due to the site specific and development specific variabilities, but that the EPSS tool can aid in determining such thresholds. |
| 9. To provide an integrated toolbox to assess the current state and the way in which a new development impacts the estuary | This thesis has provided a toolbox for the management of an estuarine system using the Humber Estuary as a case study, by developing an ArcGIS based tool which provides a cumulative impact assessment (including the baseline of cumulative impacts and for each phase of the development) and a critique of the application of limits of acceptable change which are used for the management of a system. Together, these tools can aid managers and regulators to sustainably manage the marine environment. |

## 8.2 EPSS Framework Development

The EPSS framework has been developed to be flexible in its approach so that it can be used elsewhere internationally, but also to allow it to be adaptable for future changes and as science, technology, legislation and policy develops. The EPSS framework identifies some of the legislation that would be applicable to the Humber Estuary, but these can be updated with legislation that is relevant to other sites, and where steps are not applicable can be modified or, if redundant, removed.

The EPSS framework does not require a data rich site for it to be effective. The EPSS framework informs the user of the steps to take to identify what data are required, when they should be obtained and how to progress through to submission and/or the decision. It can be used by various specialists, e.g. planning officers, hydroecologists, socio-economists, as it has been developed to incorporate these fields, and rather than specifying steps specific to any one area of expertise, it provides guidance on the process which can be adapted to any of the disciplines. The focus of a plan or project i.e. policy, scientific or economic, will vary depending on its aims and objectives and it is important that the EPSS framework can accommodate these without prejudice.

This kind of adaptable approach to developing an EPSS framework is useful in the context of the marine and estuarine environment given its susceptibility to changes such as climate change (Elliott *et al.*, 2015), sea level rise (Harley *et al.*, 2006), as well as areas of high population density and development issues (Small and Nicholls, 2003). A flexible and adaptive EPSS framework will be needed to manage these changing coastlines to ensure all legislative requirements and management tools are adhered to before a decision on the plan, project or policy has been made.

The EPSS framework will be modified as it is used at new sites and with different legislative tools, and is structured to allow this to happen. It can be modified to allow site-specific requirements and legislation to be incorporated into the process. Given the changing future, adaptable and easy to use management plans are needed to manage our pressured coastlines. The EPSS framework in its current form allows this by giving a structured process, but sufficient flexibility to allow for regional priorities and project specific information.

## 8.3 The EPSS Tool Development

The EPSS framework was further developed into an integrated GIS tool. Three specific pillars are used when developing the operational framework for a relative new area: integration of

existing capacities into an operational framework, identification and filling key knowledge gaps, and transferring the new knowledge into operational instruments (She *et al.*, 2016). The EPSS tool has integrated the current knowledge and assessment capacities into one tool.

There is broad agreement that MSP should incorporate transboundary considerations, resources and activities, however the differences between institutional systems, priorities and practices may inhibit such initiatives as they are not easily overcome (Jay *et al.*, 2016). Currently, the most common approach for assessing the status of the marine environment across large areas, are the use of indices e.g. OSPAR and MSFD, however most are for point source problems or individual receptors (as proxies). However, to date, there are no indices for Strategic Environmental Assessments for example, but these are still needed to assess the individual pressures or activities at a system level. There has already been an emerging steer towards wider regional or sea basin assessments, focussing more on the ecosystem dynamics rather than administrative boundaries, however different policy and planning practices along with different priorities and perspectives mean there are still boundaries to be overcome. Similarly, there may be procedural obstacles for authorities seeking to work together in a transboundary manner, including unevenly matched administrative structures and processes, technical difficulties of sharing information, language barriers and other impediments to good communication (Jay *et al.*, 2016).

### 8.4 How the Tool ties in with the Framework

The tool has been developed to ensure that the legislations, policies, tools and management concepts identified in Chapters 2 and 3 have been incorporated to ensure the tool incorporates all the legislative requirements and is useful for the developers, decision makers and any other users of the tool. To demonstrate how these have been incorporated, this has been summarised in Table 30. Where, during validation, the tool was not giving the accurate output; the tool was updated to ensure the tool was accurate.

Table 30 How the EPSS framework and model ties in to the tools and management options identified in Chapter 2

| **Management Legislation/Tool/Option** | **In EPSS Framework** | **In Tool** |
|---|---|---|
| MSFD | The requirements of the MSFD were broken down to its component parts and incorporated into the overall framework (see section 2.1.4) | The tool is using the Humber Estuary as a case study and therefore the MSFD does not apply to this geographic area. |
| EU Directive for Maritime Spatial Planning | The requirements of the directive were broken down to its component parts and incorporated into the overall framework (see section 2.1.5). It is noted that Part 4 of the Marine and Coastal Access Act 2009 predates the directive. | The tool identifies which of the marine spatial plans the development falls within, so the developer and decision maker can provide a more strategic assessment on the marine environment. |
| Conservation of Habitats and Species | The requirements of the directive were broken down to its component parts and incorporated into the overall framework (see section 2.1.6) | The tool has used the GIS layers provided by Natural England and JNCC to show the areas designated under the Directive. The tool then applies buffers to determine those designations and features that are within 5km of the project to be further considered in an environmental assessment. |
| Birds Directive | The requirements of the directive were broken down to its component parts and incorporated into the overall framework (see section 2.1.6) | The tool has used the GIS layers provided by Natural England and JNCC to show the areas designated under the Directive. The tool then applies buffers to determine those designations and features that are within 5km of the project to be further considered in an environmental assessment. |
| The Marine Works (EIA) Regulations | The requirements of the legislation were broken down to its component parts and incorporated into the overall framework (see section 2.1.12 and 2.1.5) | The tool identifies if the works occur below MHWS based on the High-water polyline from the OS. Where the works do occur below this point, it is recommended that consultation with the MMO be sought to determine if an EIA is required. The tool provides a risk based approach to whether an EIA is required but consultation should still be sought. |
| WFD | The requirements of the directive were broken down to its component parts and incorporated into the overall framework (see section 2.1.2) | The tool identifies the waterbody the project will occur in and if the project is a dredge/disposal or dredge/disposal is an aspect of the overall project then the tool will carry out a WFD assessment up to the point of scoping and them the report will provide the tables the applicant will need to fill in to complete the assessment. |
| Flood Defence Schemes | The requirements of the schemes were broken down to its component parts and incorporated into the overall framework (see section 2.1.13) | The tool identifies the flood defences that are within 1km of the project, so these can be incorporated into the environmental assessment (if required), and if they are to be disturbed then consultation with the Environment Agency will be necessary. |
| DAPSI(W)R(M) Approach | The requirements of the management tool were broken down to its component parts and incorporated into the overall framework (see section 3.1 and 2.1.5) | The tool identified the pressures, impacts and sensitivities of the receptors to these pressures and impacts which can be fed into a DAPSI(W)R(M) assessment. |
| The Ecosystem Approach | The requirements of the approach were broken down to its component parts and incorporated into the overall framework (see section 3.2 and 2.1.5) | The ecosystem approach was designed to develop and promote a holistic and broad-scale approach to research, policy and management that takes account of both people and their relationship to environment which can be understood by non-scientists, stakeholders and other interested parties to explore solutions and agree priorities. The tool accomplishes this by identifying all potential receptors (where data was available) within the vicinity of the works including relevant legislation, policies, administrative authorities, businesses, tourism and recreation activities as well as biological and ecological receptors on which to base an environmental assessment. Consultation should also be carried out. |
| Ten Tenets of Sustainable Development | The requirements of the directive were broken down to its component parts and incorporated into the overall framework (see section 3.4 and 2.1.5) | Not explicitly defined in the tool, however the tool identifies the socio-economic (users and uses) receptors, the policies, decision makers and socio-indicators to be able to apply the ten tenets of sustainable development to an impact assessment and decision-making process. |
| Indicators | The requirements of the approach were broken down to its component parts and incorporated into the overall framework (see section 4.7) | The indicators identified in section 4.7 were used to determine the most appropriate GIS layers that could be used to identify receptors etc. These were incorporated into the tool to ensure that all possible socio-economic, ecological and physical indicators were taken into consideration. |
| Conflicts | The requirements of the directive were broken down to its component parts and incorporated into the overall framework (see section 3.7) | The tool also includes a conflicts assessment which identifies the ecosystem goods and services and land uses from the GIS data layers and then determine if there are known conflicts or benefits between the two. This is provided in the output from running the tool as part of the pdf report. |
| Risk Assessment and Risk Management | Whilst risk assessment and risk management were not explicit in the framework, the purpose of the framework (and underlying legislative requirements and management tools) are to undertake a risk assessment of the potential change, whether a development or policy change, to allow the managers to manage the risk either by mitigation or compensation of some sort. | The tool, following the identification of the impacts and receptors, provides a risk rating associated with the development. It also provides an overall risk score for the entire development. |

## 8.5 Cumulative Impact Assessment

The cumulative impact assessment approach undertaken as part of this study is a novel approach, it has taken temporal impacts into account by the inclusion of phases of a development, although it has not included temporal impacts such as the migration or spawning periods of fish receptors. It has also included the 3D impacts through the identification of the impacts and receptors being categorised as occurring below the seabed, on the seabed or throughout the water column. However, there is uncertainty regarding the relationships of impacts in space and time and with regards to the source-pathway-receptor chain which are difficult to address.

The approach taken in this study has used the approach developed by OSPAR (A Judd, pers. Comm., August 2015) to avoid double counting any impacts, with the conservative buffers applied with regards to the extent of impacts from activities. The assessment shows the areas of most concern being those where there are higher numbers of potential impacts, although not the significance of the impacts. It does not however address how to manage the source of the pressures, and therefore impacts that can occur from activities and developments. In addition, many approaches based the impacts on being 'source' points i.e. the impacts do not extend beyond the footprint of the development, which can underestimate the levels impacts, however this study has assumed the impacts are dispersive. Whilst this will give rise to an overestimation of impacts in each area, it is a more conservative approach to take. The use of monitoring data and modelling can inform more accurate assessments to be undertaken, and therefore more appropriate management measures being implemented. The tool can provide information on monitoring such as which receptors are at risk of increasing pressures from the development. However, the tool at present cannot inform more hypothesis based monitoring regimes, as monitoring is not currently collected and submitted in a standardised way.

The cumulative impact assessment approach used in this study, applied a sensitivity analysis to the features of the international designations to demonstrate the vulnerability of certain features to the pressures (and therefore impacts), however features of the SPA and RAMSAR sites were not included as the sensitivity analysis on which this study was based (Tillin *et al.* 2010) did not include ornithological features. Should a sensitivity analysis be undertaken for ornithological features, this could be included in future developments of the software.

This study did not analyse causality between the pressure-impact-biodiversity status, and therefore the results need to be interpreted in light of the wider understanding pressure-source interactions. This is also true for the Water Framework Directive, whilst the tool provides information on whether a development is likely to affect the status of a water body under the Directive, its aim is not to influence the implementation of the Directive, rather to direct the user to either consider the assessment further (in consultation with the Environment Agency) or that the development is unlikely to affect the water body status. It provides a consistency and a transparent way of undertaking the screening assessment for Water Framework Directive Assessment as set out by the Environment Agency. What is often missing is a direct account of how the outputs of the cumulative pressure mapping exercise may be applied in practical management measures to maintain or improve the state. As outlined in Table 16, not all pressures (and therefore impacts) can or indeed should be mapped given the nature of them. As such, there will never be one approach to cumulative impact assessment that can be applied to all pressures, impacts and receptors but by having a tool such as the EPSS tool, multiple approaches can be combined to inform one assessment thereby increasing the consistency of assessments and decisions taken by regulators across jurisdictions, both nationally and internationally.

### 8.6 Limitations of CIA

Whilst the cumulative impact assessment as part of this study has improved on previous approaches, it still has its limitations in that it does not differentiate between types of cumulative impacts (additive, synergistic or antagonistic), rather it assumes all are additive (i.e. 1+1=2). This can only improve as our understanding of the impacts and their interactions improve. Providing these impacts and interactions can be presented in a matrix or spatial database, which could be incorporated in to the tool.

In addition, the approach in this study does not consider the frequency or intensity of activities. For example, a ship transiting within the estuary may cause underwater noise impacts on species, however this will be affected by the intensity and frequency of the vessels using these shipping routes. A shipping route with 1 vessel movement a day will have a lesser impact that a shipping route that has one vessel movement per hour. The location of the impacts will also vary, as the former example will have an impact where, and in the vicinity of, the vessel movement whereas the latter example, whilst the same method is still applied, due to the increase in traffic, the impact will occur along the shipping route.

The fisheries part of the assessment is not based on the best available data, as the data is provided on a coarse scale (ICES rectangles). It is likely that no commercial fishing occurs within the estuary, but the data implies that it does due to the scale used (with the rectangles covering the estuary, inshore and offshore area). The data also does not show fishing from the under 10m vessels as they are not required to report landings, nor are they required to have a monitoring system (VMS).

Further strengths and weaknesses are discussed in Section 8.10 below as part of the SWOT analysis.

## 8.7 Ecosystem Approach

This study has designed the tool alongside the 12 guiding principles (some have been amalgamated for ease) for the ecosystem approach in that:

1. It identifies the relevant stakeholders, regulators and interested parties and identifies if there are potential conflicts between these parties;
2. It provides baseline information on the ecosystem to enable management and monitoring measures to be investigated and implemented;
3. Whilst it provides information of the existing users i.e. port industry, tourism etc. it does not identify the economic issues such as wealth and willingness to pay for services to inform management choices, however the information the tool provides can be used as the basis on which economic assessments are undertaken;
4. The tool enables adaptive management in that the data that drives the assessment to implement measures such as zoning or restrictions, and be adapted in the future should monitoring show either something else is required, or no change for local, transboundary and long-term goals such as MSFD;
5. It gives the user information on the conservation status of the environment to allow an assessment to be undertaken to ensure sustainable use;
6. The tool has integrated social, environmental and, to a certain extent, the economic interests of the users of the study area;
7. It connects the international requirements to the local management bodies;
8. It can be used to involve and inform stakeholders, as well as be adapted to inform different users for different purposes as confirmed by the stakeholders who tested the tool.

## 8.8 Testing of the EPSS Tool

To test the applicability, utility and accurateness of the EPSS tool, it was tested in three ways:

1. It was tested against consented projects in the Humber Estuary to ensure the outputs were accurate and correct, and in line with the assessments made in the decision-making process. The tool was updated where necessary if the outputs were not accurate when compared to the case studies;
2. It was sent out to stakeholders for testing, and improvements were made, for example the usability of the tool i.e. the file directory to ensure the user can easily install and run the tool, and use the output. The output was also updated to include an uncertainty table for transparency;
3. It was expanded (because of step 2) to the wider English waters and tested to demonstrate that the tool can be transferred to other marine areas with few updates to the data, and no updates to the script.

As a result, the tool has been developed for use by developers, stakeholders, decision-makers and policy makers to inform assessments and decisions. Feedback overall was positive, and highlighted the need for such an integrated and one-stop tool. Where improvements were recommended, these were considered and largely incorporated to improve the tool (see Chapter 6).

## 8.9 Limits of Acceptable Change

To effectively manage the marine environment, managers require certain criteria for determining if a change is significant. To provide this, thresholds are used to assess the magnitude of change on certain indicators or receptors. Here, the receptor of hydrodynamic change has been used through the $V_{max}$ and $V_{mean}$ as an indicator to determine if one threshold for varying environments can be applied.

As it has been demonstrated that the use of one threshold, demonstrated in this study by 15% of a waterbody being affected may not be an appropriate threshold to use, it is recommended that where thresholds are to be applied, these are done considering the sub-system (riverine, estuarine, open sea etc.) and not on the whole waterbody. Modelling the development scenarios allows an assessment to be made of the most acceptable trade-off between the area impacts and development extent. The tool can be used to potentially refine such thresholds, as it contains within it an impact assessment method which highlights categories of pressures/impacts and the potential increase of impacts on a receptor.

## 8.10 SWOT

To summarise the benefits of the tool alongside the limitations, a SWOT analysis has been undertaken to identify the strengths, weaknesses, opportunities and threats to the tool and study. Specific limitations, to the specific aspects of the tool are discussed in the next section.

### 8.10.1 Strengths

The tool can be used to inform and implement MSP as it can provide a strategic plan for a large area showing the current and existing plans and projects alongside the receptors, but can also include developments that are in the 'pipeline' thus enabling decision makers to take a strategic forward look. It can be used by regulators and managers, along with developers and stakeholders to determine the current level of activity, along with the type and location, and alongside the location of receptors whilst also considering the best available evidence of pressures and impacts to work towards a sustainably managed environment. It provides a transparent, standardised approach to marine impact assessment and management. Given the complexity of estuarine and marine management due to the large number of sectors, activities, receptors and regulatory requirements, a strength in the tool is bringing all this information together in a format that is easy to use by all.

### 8.10.2 Weaknesses

It is important when developing and using indicators to ensure that all the managers and stakeholders agree to them prior to any implementation. Given the restrictions on the study this was not possible, but the indicators used in this study are based on recognised indicators and available data. The aim of the study was to provide proof of concept of the integrated EPSS that can be developed and used across managers and users.

Whilst the study has increased our understanding of interactions, this study did not complete our understanding of the ecosystem interactions. It did attempt to resolve the conflicts between culturally created systems, versus climatic ecosystem services and trade off vs optimal public value, by integrating a cumulative impact assessment into the tool based on the sensitivities of the designated features. This should be updated as NE produce advice.

### 8.10.3 Opportunities

Appropriate policy (urban planning and local coastal zone planning) and improved knowledge management (vulnerability assessment result) is recommended in moving towards mitigating future coastal vulnerability, increasing the resilience and adaptive

capacity of coastal sustainability to current and future risks from rapid urbanization, such as enhancing ecosystem services in coastal areas.

More discussion is needed in the future on how the integrated framework can inform or influence the current and future policy on economic development in the region, and how the study can help reduce vulnerability due to rapid coastal urbanization. The tool also does not take into consideration mitigation or compensation regimes that are designed to avoid or reduce the potential impacts from the project, therefore the potential impacts are considered overestimated. In order to bring into the assessment, the effectiveness of mitigation of compensation methods, a study based on monitoring results must first be undertaken so they can be integrated into the EPSS script as an algorithm.

The tool has been developed as a 'proof of concept' to demonstrate that one tool can bring together the ecological components, the legislative requirements and the assessments that are required for a development. As such, the tool is not complete, and as legislations, environments and priorities change so too will the tool, but whilst it does have the capacity to be further improved by the opportunities highlighted above, these are outside the scope of the study to test further, but have been tested to some degree in Section 6.2.

#### 8.10.4 Threats

The environment is currently afforded protection through a series of legislative powers (see section 2.1), however it is often the strategic view of an environment that is lacking which is what this tool aims to fill, but as highlighted above there are threats and limitations to using such a tool. Any use should be applied in line with the caveats and uncertainty highlighted in this study, such as the tool is not a substitute for expert judgement for assessments, and not all receptors/ users are represented in the GIS database as they are not available.

### 8.11 Toolkit

This study has developed a toolkit in the form of a framework, GIS based tool and knowledge on the development and application of limits of acceptable change. The purpose of the tool that has been developed as part of this study, was to show proof of concept that a tool could be developed, in this case within ArcGIS 10.1 which brings together the 'baseline' knowledge of the area of interest and the legal obligations and requirements to inform management decisions and impact assessments. However, the tool on its own is only part of any management and should be used alongside expert knowledge of the area including historic trends, which may not be captured in a GIS based system and future aspirations for the area.

It could also be used alongside other toolkits developed such as TiDE[19] to ensure the sustainable management of the environment.

### 8.12 Next Steps/ Further Work

For a sustainable future, there is a need to sustainably manage the human/industrial systems, activities and interventions. To achieve the latter goal there is a need to predict the responses of ecosystems, and the provided services to manage developments under changing environmental conditions via ecosystem models, and to use tools to compare the estimated provided services between the different scenarios.

The tool developed as part of this study, was a proof of concept to show that an integrated EPSS framework and tool could be developed to take into consideration the environmental, social, economic and political requirements. As shown in the EPSS framework (Figure 32) any EPSS should also inform monitoring, and incorporate monitoring results to strengthen the tool by learning from experience and developing knowledge on impacts and recovery rates. The tool can be adapted to include monitoring results, which could inform the effectiveness of measures, however there is a requirement that all monitoring data should be standardised for the tool to facilitate its inclusion, and it is not currently standardised. Therefore, whilst no monitoring data have been included at this stage, the GIS tool can incorporate several different data sets, therefore can incorporate future monitoring data that will inform assessments.

The tool can be further developed as a scoping tool by identifying where activities could potentially be sited, based on a 'path of least resistance model' for policy or strategic level decisions, hence its use in marine spatial planning. For example, if a developer wants to construct a wind farm in the Northern North Sea, they can input the area of interest (input shapefile) and then in the user interface can select the project details e.g. project type, environmental considerations such as seabed depth, seabed type etc. This would require additional parameters being added to the tool, and additional data such as seabed depth data to run the tool. The tool would then identify the environmental sensitivities and potential conflicts, to identify those areas where the development is likely to be acceptable for further assessment (Figure 69).

[19] http://www.tide-toolbox.eu/ [Accessed 21/09/2016]

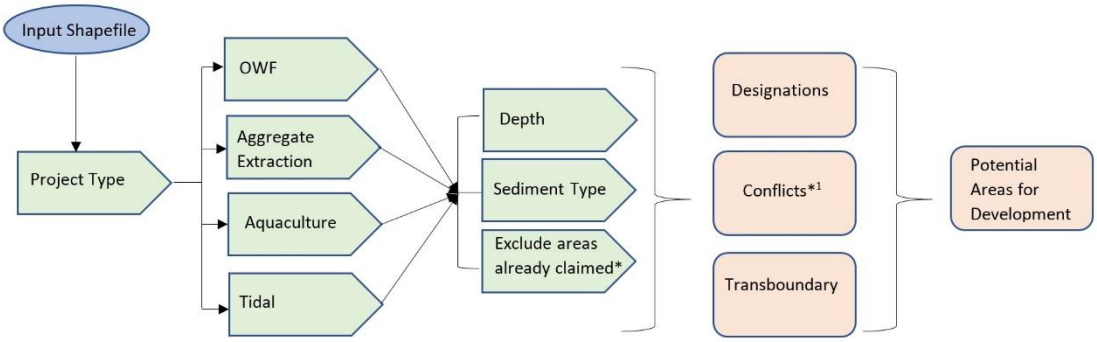



Figure 69 Concept model showing how the EPSS tool can be adapted to a scoping tool. * It determines that those areas that are designated for certain activities e.g. aggregate extraction, cannot be used for non-compatible activities such as certain offshore wind farm developments. *1 at this stage, all areas where there are identified conflicts between current activities and the proposed development are excluded.

## 9. Concluding Remarks

Oinonen *et al.* (2016) concluded that decision support tools are needed to provide a holistic view on the consequences of alternative management measures and related uncertainties. What is currently lacking is a tool that helps decision makers to select a cost-effective set of measures to meet a given multidimensional environmental objective.

This study developed an EPSS framework to identify the relevant legislative requirements and how to move through the processes. The EPSS framework has been divided into two main sectors, one for policies and responses, and one for plans or projects. In either case, the EPSS framework demonstrates that the primary step in any project development or decision-making process, is to define the problem or aims and objectives, and to be able to focus the assessment and where necessary the surveys. By defining the aims and objectives of the plan, it allows the developer/ manager to start identifying the legislation that may be applicable. This study further developed the framework into an integrated EPSS tool in ArcGIS 10.1 and whilst it provides a consistent method for developers and decision makers and assists them in understanding legislative requirements, it still retains some flexibility and adaptability to incorporate new science and legislative requirements.

To aid different users (developers, decision makers, planners, public), this tool can aid in strategic decision-making by bringing together the different disciplines and make the best use of emerging information on potential opportunities, obstacles and change. It is acknowledged that spatial management decisions are likely to be driven by the value of the resource to society, versus the cost of management and value to the environment. This study has used the Humber Estuary as a case study as it is a data rich area, but the EPSS, or the approach to developing an EPSS, does not require a data rich site for it to be effective or useful to users. The EPSS informs the user of the steps to take to identify what data are required, when they should be obtained and how to progress through to submission and/or the decision.

Whilst no model can fully replace expert judgment and local knowledge, no expert can accurately predict the outputs of an assessment, and therefore the two will always be needed and integral to the process. The EPSS helps as it identifies the risk to decision makers of any change or management implication, but it does not take away the need for detailed species-specific studies to be undertaken, site-specific assessments prior to any application being made to the regulators, or a policy decision being made on any area.

To ensure the continued use of the tool and for effective management, a better understanding of ecosystem thresholds and limits is needed, as well as qualitative analysis (in the absence of quantified social and/or economic values) of the impacts of marine planning on human activities and of human activities on marine ecosystem services. Additionally, a developed analysis of the cumulative impacts of human activities on the marine environment, and developing knowledge of marine ecosystem services and how these will change in response to marine management, particularly marine planning.

This project should be viewed as a 'proof of concept' in that its primary purpose is to demonstrate the potential for developing and operationalizing an approach in the field in the future. The method has the potential to integrate highly technical knowledge from scientists and the values of non-scientists, to make better-informed decisions and to provide reasonable assurance to justify those decisions

This tool can be used to prevent conflicts among stakeholders and/or between stakeholders and the environment from taking place, as it provides a conflicts matrix and cumulative impact assessment. It makes it possible to use and integrate all the existing background data in thematic maps, and identifies the human activities that use the areas, resources and services in a sustainable manner which makes it easier to identify business opportunities that can meet the set ecological targets. It makes the governance of the marine area logical, easy, fast and cost effective. The tool also makes it easier to focus and prioritize the data collection on the datasets that are most useful for the MSP process, and fill data gaps. Furthermore, the tool was initially developed for an estuarine environment and bounded by the WFD. The tool, following the stakeholder testing, was extended to English territorial waters and should consider the MSFD. The tool currently does not provide an assessment against the MSFD; however, the tool could be integrated with other tools also being developed to inform MSFD assessments such as the Cefas Marine Assessment Tool (CefMAT) (Cefas, pers. Comm.) as well as those outlined in Chapter 3.

The application of 'limits of acceptable change' has been tested on three environments within the Humber Estuary demonstrates that the application of one threshold is not appropriate for one geographical location such as the Humber Estuary and therefore a national or international scale. The approach used here to test the thresholds can be used in other areas, and other types of thresholds such as changes in sediment transport. It is a useful approach for ecosystem management in understanding how systems will change relative to baselines, and natural variability are key for ecosystem management

Overall, this study has presented a toolbox to be used by developers, decision makers and stakeholders (including the public) by developing a framework, GIS based tool and highlighted the use of the application of limits of acceptable of change. These are a starting point for other applications (see SWOT analysis) for how these can be used, and further developed to incorporate a holistic approach for marine management.

It reaffirms the conclusions by Lucrezi *et al.* (2016), although on a larger scale, that there is virtually no aspect of the environment that does not require some degree of management, and due to the state of any considered aspect being likely to be depend upon the state of another, that it would be as non-beneficial as it would be difficult, to manage single attributes of the ecosystem. The EPSS has been developed to be flexible in its approach, to allow it to be used elsewhere internationally, but also to allow for it to be adaptable for future changes and as science develops. The EPSS identifies some of the legislation that would be applicable to the Humber Estuary, but these can be replaced with legislation that is relevant to other sites, and where steps are not applicable can be modified or, if redundant, removed. In order to make the tool transportable to other areas, the tool needs to have the following updates made:

- the look-up table which sets the thresholds of the developments needs updating to reflect similar legislation;
- the code needs updating if names etc. are changed in the look-up table;
- Data needs to be added to the relevant layers with the same naming convention to ensure the reconciliations still work to provide, for example, the ecosystem goods and services that an area provides.

In addition, to keep the tool up date, the data behind the GIS data layers and look-up tables need updating as new data become available. As legislation gets updated, the relevant look-up tables require amending (thresholds for determining which legalisation the development falls under) and provided no names are changed the script will not require updating.

In marine management, there will always be a need for robust, and scientifically and legally defendable science to inform management. The increasingly large spatial scales that are addressed by policy makers, and the reduction in funding, means that new methods are needed to provide the evidence base which this tool helps to provide, and this can be applied worldwide.

## References


ABPHES. 2011. Humber Estuary: Maintenance Dredge Protocol and Water Framework Compliance Baseline Document, Report R.1872

ABPmer and Cefas. 2015. Validating an Activity-Pressure Matrix, Report for Department for Environment, Food and Rural Affairs, Report R.2435.

Alvarez, M.C., Franco, A., Pérez-Domínguez, R., Elliott, M. 2013. Sensitivity analysis to explore responsiveness and dynamic range of multimetric fish-based indices for assessing the ecological status of estuaries and lagoons. *Hydrobiologia*. 704(1): 347-362.

AMEP. 2011. Environmental Statement for the Able Marine Energy Park, Revision 0. (Available from https://infrastructure.planninginspectorate.gov.uk/projects/yorkshire-and-the-humber/able-marine-energy-park/?ipcsection=docs&stage=app&filter1=Environmental+Statement) [viewed 09/07/2017].

Antonson, H., Isaksson, K., Storbjörk, S., Hjerpe, M. 2016. Negotiating climate change responses: Regional and local perspectives on transport and coastal zone planning in South Sweden, *Land Use Policy*, 52: 297-305.

Anderson, J.H., Halpern, B.S., Korpinen, S., Murray, C., Reker, J. 2015. Baltic sea biodiversity status vs cumulative human pressures, *Estuarine, Coastal and Shelf Science,* 161:88-92.

Apitz, S., Black, K. 2010. ME1104 Research and Support for Developing a UK Strategy for Managing Contaminated Sediments: An Analysis of Project Findings. 108 pp.

Apitz, S., White, S. 2003. A conceptual framework for River-Basin-Scale sediment management: Discussion Article, *Journal of Soils and Sediments*, 3(3): 132-138.

Apitz, S.E., Elliott, M., Fountain, M., Galloway, T.S. 2006. European environmental management: Moving to an ecosystem approach, *Integrated Environmental Assessment and Management*, 2(1): 80-85.

Arbo, P., Thuy, P.T.T. 2016. Use conflicts in marine ecosystem-based management- The case of oil versus fisheries, *Ocean and Coastal Management*, 122: 77-86.

Arkema, K.K., Verutes, G.M., Wood, S.A., Clarke-Samuels, C., Rosado, S., Canto, M., Rosenthal, A., Ruckelshaus, M., Guannel, G., Toft, J., Fairies, J., Silver, J.M., Griffin, R., Guerry, A.D. 2015. Embedding ecosystem services in coastal planning leads to better outcomes for people and nature, *Proceedings of the National Academy of Sciences*, doi:10.1073/pnas.1406483112/-/DCSupplemental.

Arrow, K., Daily, G., Dasgupta, P., Levin, S., Mäler, K-G., Maskin, E., Starrett, D., Sterner, T., Tietenberg, T. 2000. Managing ecosystem resources, *Environmental Science and Technology*, 34: 1401-1406

Astrium. 2011. Creation of a high resolution Digital Elevation Model (DEM) of the British Isles continental shelf: Final Report. Prepared for Defra, Contract Reference: 13820.

Atkins, J.P., Burdon, D., Elliott, M., Gregory, A.J. 2011. Management of the marine environment: Integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach, *Marine Pollution Bulletin*, 62: 215-226.

Atkins, J.P., Burdon, D., Elliott, M., Gregory, A.J. 2010. Systemic insights into the management of ecosystem services in the marine environment, Proceedings of the 54th Meeting of the International Society for the Systems Sciences, Wilfrid Laurier University, Waterloo, ON, Canada, July 18-23, 2010; ISSN: 1999-6918.

Aubry, A., Elliott, M., 2006. The use of environmental integrative indicators to assess seabed disturbance in estuaries and coasts: application to the Humber Estuary, UK. *Marine Pollution Bulletin*, 53(1): 175-185.

Austen, M.C., Hattam, C., Lowe, S., Mangi, S.C., Richardson, K. 2009. Quantifying and valuing the impacts of marine aggregate extraction on ecosystem goods and services.

Australian Government. 2012. Limits of Acceptable Change. (Available from https://www.environment.gov.au/water/wetlands/publications/factsheet-limits-acceptable-change). [viewed 09/07/2017]

Badreddine, A., Amor, N.B. 2013. A Bayesian approach to construct bowtie diagrams for risk evaluation, *Process Safety and Environmental Protection*, 91: 159-171.

Baldwin, K., Schill, S., Zenny, N., Blake, D. 2014. Developing ecosystem-based information for Marine Spatial Planning on the Pedro Bank, Jamaica. Proceedings of the 67th Gulf and Caribbean Fisheries Institute, November 3-7 2014, Christ Church, Barbados.

Barbanti, A., Campostrini, P., Musco, F., Sarretta, A., Gissi, E. (eds.) 2015 Developing a Maritime Spatial Plan for the Adriatic-Ionian Region. CNR-ISMAR, Venice, IT. ISBN 978-88-941335-4-7.

Barbier, E. 2009 Ecosystem as natural assets: foundations and trends in microeconomics, 4(8) (forthcoming).

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., Silliman, B.R. 2011. The value of estuarine and coastal ecosystem services, *Ecological Monographs*, 81(2): 169-193.

Barnard, S., Elliott, M. 2015. The 10-tenets of adaptive management and sustainability: An holistic framework for understanding and managing the socio-ecological system, *Environmental Science and Policy*, 51: 181-191.

Barnard, S., Tillin, H., Piroddi, C., Thomson, S. 2015. Prioritising Pressures for Benthic Habitats in UK Marine Regions. Unpublished JNCC Report. The Institute of Estuarine and Coastal Studies, University of Hull report for JNCC Peterborough.

Barnes, C., McFadden, K.W. 2008. Marine ecosystem approaches to management: challenges and lesson in the United States, *Marine Policy*, 32: 387-392.

Batista, M.I., Henriques, S., Pais, M.P., Csbral, H.N. 2014. Assessment of cumulative human pressures on a coastal area: Integrated information for MPA planning and management, *Ocean and Coastal Management*, 102: 248-257.

Beaumont, N.J., Austen, M.C., Atkins, J.P., Burdon, D., Degraer, S., Dentinho, T.P., Derous, S., Holm, P., Horton, T., van Ierland, E., Marboe, A.H., Starkey, D.J., Townsend, M., Zarzycki, T. 2007. Identification, definition and quantification of goods and services provided by marine biodiversity: Implications for the Ecosystem Approach, *Marine Pollution Bulletin*, 53: 253-265.

Begum, D. A. 1999. Analysis of the surge phenomena in the Humber estuary, North-Sea coast of eastern England. *Indian Journal of Marine Sciences*. 28: 17-23

Berger, A.R., Hodge, R.A., 1998. Natural change in the environment: a challenge to the pressure-state-response concept. *Social Indicators Research*, 44(2): 255-265.

Bhatia, N. 2012. Ecological and economic valuation of managed realignment sites, Humber Estuary, UK: benefits for society, *PhD Thesis*, University of Hull.

Bidone, E.D., Lacerda, L.D. 2004. The use of DPSIR framework to evaluate sustainability in coastal areas. Case study: Guanabara Bay basin, Rio de Janeiro, Brazil, *Regional Environmental Change*, 4: 5-16.

Biggs, R., Carpenter, S.R. Brock, W.A. 2009. Turning back from the brink: detecting an impending regime shift in time to avert it. *Proceedings of the National academy of Sciences*, 106(3): 826-831.

Bingham, G., Bishop, R., Brody, M., Bromley, D., Clark, E.T., Cooper, W., Costanza, R., Hale, T., Hayden, G., Kellert, S., Norgaard, R., Norton, B., Payne, J., Russel, C., Suter, G. 1995. Issues in ecosystem valuation: improving information for decision-making, *Ecological Economics*, 14: 73-90.

Birchenough, A., Pacitto, S. 2013. Dredge material disposal sites and marine protected areas around the English coast: Initial desk review. Final Report, Report for Natural England, Cefas contract report C5852B

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

Börger, T., Beaumont, N.J., Pendleton, L., Boyle, K.J., Cooper, P., Fletcher, S., Haab, T., Hanemann, M., Hooper, T.L., Hussain, S.S., Portela, R., stithou, M., Stockill, J., Taylor, T., Austen, M.A. 2014. Incorporating ecosystem services in marine planning: The role of valuation, *Marine Policy*, 46: 161-170.

Borja, Á., Elliott, M. 2013. Marine monitoring during an economic crisis: the cure is worse than the disease, *Marine Pollution Bulletin*, 68: 1-3.

Borja, Á., Elliott, M., Henriksen, P., Marbà, N. 2013a. Transitional and coastal waters ecological status assessment: advances and challenges resulting from implementing the European Water Framework Directive, *Hydrobiologia*, 704(1): 213-229.

Borja, A., Elliott, M., Anderson, J.H., Cardoso, A.C., Carstensen, J., Ferreira, J.G., Heiskanen, A-S., Marques, J.C., Neto, J.M., Teixeira, H., Uusitalo, L., Uyarra, M.C., Zampoukas, N. 2013b. Good Environmental Status of marine ecosystems: What is it and how do we know when we have attained it? *Marine Pollution Bulletin*, 76: 16-27.

Borja, Á., Basset, A., Bricker, S., Dauvin, J-C., Elliott, M., Harrison, T., Marques, J-C., Weisberg, S.B., West, R. 2011. Section 1.08: Classifying Ecological Quality and Integrity of Estuaries, In: Volume 1, Classification of Estuarine and Nearshore Coastal Ecosystems, Simenstad, C. and Yanagi, T. (Eds) In: Wolanski, E., and McLusky, D.S. (Eds*) Treatise on Estuarine & Coastal Science*, Elsevier, Amsterdam, 125-162 pp.

Borja, Á., Dauer, D.M., Elliott, M., Simenstad, C.A. 2010a. Medium and long-term recovery of estuarine and coastal ecosystems: Patterns, rates and restoration effectiveness, *Estuaries and Coasts*, 33: 1249-1260.

Borja, Á., Elliott, M., Carstensen, J., Heiskanen, A-S., van de Bund, W. 2010b. Marine management- towards an integrated implementation of the European marine strategy framework and the water framework directives, *Marine Pollution Bulletin*, 60: 2175-2186.

Borja, Á., Dauer, D.M. 2008. Assessing the environmental quality status in estuarine and coastal systems: Comparing methodologies and indices, *Ecological Indicators*, 8(4): 331-337.

Borja, Á., Bricker, A.B., Dauer, D.M., Demetriades, N.T., Ferreira, J.G., Forbes, A.T., Hucthings, P., Jia, X., Kenchington, R., Marques, J.C., Zhu, C. 2008. Overview of integrative tools and methods in assessing ecological integrity in estuarine and coastal systems worldwide, *Marine Pollution Bulletin*, 56: 1519-1537.

Borja, Á., Elliott, M. 2007. What does 'good ecological potential' mean within the European water framework directive, *Editorial Marine Pollution Bulletin*, 54: 1559-1564.

Borja, Á.,Galparsoro, I., Solaun, O., Muxika, I., Tello, E.M., Uriarte, A., Valencia, V. 2006. The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status, *Estuarine, Coastal and Shelf Science,* 66: 84-96.

Borja, Á., 2005. The European Water Framework Directive: a challenge for nearshore, coastal and continental shelf research. *Continental shelf research*, 25(14):1768-1783.

Bowen, R.E., Riley, C. 2003. Socio-economic indicators and integrated coastal management, *Ocean and Coastal Management*, 46: 299-312.

Boyd, J. 2004. What's Nature Worth? Using indicators to open the black box of ecological valuation, *Resources*, 18-22 pp.

Boyd, J., Banzhaf, S. 2007. What are ecosystem services? The need for standardized environmental accounting units, *Ecological Economics*, 63: 616-626.

Boyes, S., Elliott, M., Murillas-Maza, A., Papadopoulou, N., Uyarra, M.C. 2016. Is existing legislation fit-for-purpose to achieve Good Environmental Status in European seas? *Marine Pollution Bulletin*, 111(1-2):18-32.

Boyes, S., Elliott, M. 2015. The excessive complexity of national marine governance systems-Has this decreased in England since the introduction of the Marine and Coastal Access Act 2009? *Marine Policy*, 51: 57-65.

Boyes, S.J., Burdon, D., Cutts, N.D., Elliott, M., Thomson, S. 2006. The Humber Estuary: a case study, In: Dauvin, J.C., (Ed.), North-Atlantic Estuaries: problems and perspectives, GIP Seine Aval, Rouen, 55-62pp.

Boyes, S.J., Elliott, M., Thomson, S.M., Atkins, S., Gilliland, P. 2007. A proposed multiple-use zoning scheme for the Irish Sea. An interpretation of current legislation through the use of GIS-based zoning approaches and effectiveness for the protection of nature conservation interests, *Marine Policy*, 31: 287-298.

Brander, K.M., Florax, R.J.G.M., Vermaat, J.E. 2006. the empirics of wetland valuation: A comprehensive summary and a meta-analysis of the literature, *Environmental and Resource Economics*, 33: 223-250.

Brauman, K.A., Daily, G.C., Duarte, T.K., Mooney, H.A. 2007. The nature and value of ecosystem services: An overview highlighting hydrologic services, *Annual Review of Environment and Resources*, 32: 6.1-6.32.

Bremer, S., Glavovic, B. 2013. Exploring the science-policy interface for Integrate Coastal Management in New Zealand, *Ocean and Coastal Management*, 84: 107-118.

Brown, C.J., Saunders, M.I., Possingham, H.P., Richardson, A.J. 2014. Interactions between global and local stressors of ecosystems determine management effectiveness in cumulative impact mapping, *Diversity and Distributions,* 20: 538-546.

Bullock, J.M., Aronson, J., Newton, A.C., Pywell, R.F., Rey-Benayas, J.M. 2011. Restoration of ecosystem services and biodiversity: conflicts and opportunities, *Trends in Ecology and Evolution*, 1-9 pp.

Cabral, H., Marques, J.C., Guilhermino, L., de Jonge, V., Elliott, M. 2016. Coastal systems under change: Tuning assessment and management tools, *Estuarine, Coastal and Shelf Science,* 167: 1-3.

Carapuço, M.M., Taborda, R., Silveira, T.M., Psuty, N.P., Andrade, C., Freitas, M.C. 2016. Coastal geoindicators: Towards the establishment of a common framework for sandy coastal environments, *Earth-Science Reviews*, 154: 183-190.

Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., DeFries, R.S., Díaz, S., Dietz, T., Duraiappah, A.K., Oteng-Yehoah, A., Pereira, H.M., Perrings, C., Reid, W.V., Sarukhan, J., Scholes, R.J., Whyte, A. 2009. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment, *Proceedings of the National Academy of Sciences*, 106(5):1305-1312.

Cave, R.R., Andrews, J.E., Jickells, T., Coombes, E.G. 2005. A review of sediment contamination by trace metals in the Humber catchment and estuary, and the implications for future estuary water quality, *Estuarine, Coastal and Shelf Science*, 62: 547-557.

Cave, R.R., Ledoux, L., Turner, K., Jickells, T., Andrews, J.E., Davies, H. 2003. The Humber catchment and its coastal area: from UK to European perspectives, *Science of The Total Environment*, 314-316: 31-52.

Chang, Y., Lin, B-H. 2016. Improving marine spatial planning by using an incremental amendment strategy: The case of Anping, Taiwan, *Marine Policy*, 68: 30-38

Chapin, F.S., Torn, M.S., Tateno, M. 1996. Principles of ecosystem sustainability, *American Naturalist*, 148(6): 1016-1037.

Chee, Y.E. 2004. An ecological perspective on the valuation of ecosystem services, *Biological Conservation*, 120: 549-565.

Cicin-Sain, B. 1993. Sustainable development and integrated coastal management, *Ocean and Coastal Management*, 21: 11-43.

Cicin-Sain, B., Belifiore, S. 2005. Linking marine protected areas to integrated coastal and ocean management: A review of theory and practice, *Ocean and Coastal Management*, 48: 847-868.

Clarke Murray, C., Mach, M.E., Martone, R.G. 2014. Cumulative effects in marine ecosystems: scientific perspectives on its challenges and solutions. WWF- Canada and Center for Ocean Solutions. 60 pp.

Cole, D.N., Stankey, G.H. 1997. Historical development of limits of acceptable change: Conceptual clarifications and possible extensions, (available from: http://www.fs.fed.us/rm/pubs_int/int_gtr371/int_gtr371_005_009.pdf) [viewed 09/07/2017].

Cooper, K. 2013. Setting limits for acceptable change in sediment particle size composition: Testing a new approach to managing marine aggregate dredging, *Marine Pollution Bulletin*, 73: 86-97.

Cooper, P. 2012. The DPSWR Social-Ecological Accounting Framework: Notes on its definition and Application. Policy Brief No. 3. EU FP7 KNOWSEAS Project. ISBN 0-9529089-5-6

Cooper, L.M., Sheate, W.R. 2002. Cumulative effects assessment: A review of UK environmental impact statements, *Environmental Impact Assessment Review*, 22: 415-439.

Cormier, R., Elliott, M. 2017. SMART marine goals, targets and management – Is SDG 14 operational or aspirational, is 'Life Below Water' sinking or swimming? *Marine Pollution Bulletin*, In Press. https://doi.org/10.1016/j.marpolbul.2017.07.060

Cormier, R., Kannen, A., Elliott, M., Hall, P., Davies, I.M. (Eds). 2013. Marine and Coastal Ecosystem-based Risk Management Handbook. ICES Cooperative Research Report, No. 317, March 2013, International Council for the Exploration of the Sea, Copenhagen, 60pp, ISBN 978-87-7472-115-1. (Available from: http://www.ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20(CRR)/crr317/CRR317%20Marine%20and%20coastal%20ecosystem%20based%20risk%20management%20handbook.pdf). [Viewed 27/12/2017]

Costanza, R., Mageau, M. 1999. What is a healthy ecosystem? *Aquatic Ecology*, 33: 105-115.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M. 1997. The value of the world's ecosystem services and natural capital, *Nature*, 387: 253-260.

Coull, K.A., Johnstone, R., Rogers, S.I. 1998. Fisheries Sensitivity Maps in British Waters. Published and distributed by UKOOA Ltd. 58 pp.

Counsell, D., Haughton, G. 2006. Sustainable development in regional planning: The search for new tools and renewed legitimacy, *Geoforum*, 37: 921-931.

Dauvin, J-C., Ruellet, T. 2009. The estuarine quality paradox: Is it possible to define an ecological quality status for specified modified and naturally stressed estuarine ecosystems? *Marine Pollution Bulletin*, 59: 38-47.

Day, J.W., Hall, C.A.S., Kemp, W.M., Yáñez-Arancibia, A. 1989. Estuarine Ecology, Wiley, USA.

Defra. 2013a. Payments for Ecosystem Services: A Best Practice Guide [available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/200920/pb13932-pes-bestpractice-20130522.pdf [viewed 02/07/2017].

Defra. 2013b. Marine Programme Evidence Plan [available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/221067/pb13919-evidenceplan-marine-programme.pdf] [viewed 02/07/2017].

Defra. 2013c. A Coastal Concordat for England. (Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/256234/coastal-concordat-20131111.pdf). [Viewed 27/12/2017]

Defra. 2011b. A description of the marine planning system in England. (Available from www.defra.gov.uk) [viewed 18/08/2017].

De Groot, R.S., Wilson, M.A., Boumans, R.M.J. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services, *Ecological Economics*, 41: 393-408.

De Jonge, V.N., Elliott, M., Orive, E. 2002. Causes, historical development, effects and future challenges of a common environmental problem: eutrophication, *Hydrobiologia*, 475(1):1-19.

Delbaere, B. 2003. An Inventory of Biodiversity Indicators in Europe, 2002, European Environment Agency Technical Report Number 92.

Deltares, 2011. Simulation of multi-dimensional hydrodynamic flos and transport phenomena, including sediments, User manual, version 3.15, revision 14499

DfT. 2015. Table PORT0301 'Key port statistics, top 30 UK ports by tonnage' (Available online at: https://www.gov.uk/government/statistics/port-freight-statistics-2015-final-figures [Accessed 16/11/2017])

Diedrich, A., Tintoré, J., Navinés, F. 2010. Balancing science and society through establishing indicators for integrated coastal zone management in the Balearic Islands, *Marine Policy*, 34: 772-781.

Douvere, F. 2008. The importance of marine spatial planning in advancing ecosystem-based sea use management, *Marine Policy*, 32: 762-771.

Douvere, F., Ehler, C.N. 2009. New perspectives on sea use management: Initial findings from European experience with marine spatial planning, *Journal of Environmental Management*, 90: 77-88

Dowe., N.K., Ryan, K.L. 2003. The faulty three-legged-stool model of sustainable development, *Conservation Biology*, 17(5): 1458-1460.

Duarte, C.M., Borja, A., Carstensen, J., Elliott, M., Krause-Jensen, D., Marbà, N. 2015. Paradigms in the Recovery of Estuarine and Coastal Ecosystems. *Estuaries and Coasts,* 38(4): 1202-1212. DOI 10.1007/s12237-013-9750-9

Dunstan, P.K., Bax, N.J., Dambacher, J.M., Hayes, K.R., Hedge, P.T., Smiht, D.C., Smith, A.D.M. 2016. Using ecologically or biologically significant marine areas (EBSAs) to implement marine spatial planning, *Ocean and Coastal Management,* 121: 116-127.

Eassom, A., Church, N. 2013. Progress towards the development of a standardised UK pressure-activities matrix, Paper for HBDSEG Meeting - 9th-10th October 2013.

(Available from: http://jncc.defra.gov.uk/pdf/Final_HBDSEG_P-A_Matrix_Paper_28b_Website_edit[1].pdf) [Accessed 09/07/2017]

Edwards, A.M.C., Winn, P.S.J. 2006. The Humber Estuary: Strategic planning of flood defences and habitats, *Marine Pollution Bulletin*, 53: 165-174.

Edwards, A.M.C., Freestone, R.J., Crockett, C.P. 1997. River management in the Humber Catchment, *The Science of the Total Environment*, 194-195: 235-246.

EFTEC. 2005. The Economic, Social and Ecological Value of Ecosystem Services: A Literature Review, Final report for the Department for the Environment, Food and Rural Affairs, (Available at https://www.cbd.int/financial/values/unitedkingdom-valueliterature.pdf) [viewed 02/07/2017].

Ehler, C.N., 2003. Indicators to measure governance performance in integrated coastal management. *Ocean & Coastal Management*, 46(3):335-345.

Elliott, M., Burdon, D., Atkins, J.P., Borja, A., Cormier, R., de Jonge, V.N., Turner, R.K. 2017. "And DPSIR begat DAPSI(W)R(M)!" - A unifying framework for marine environmental management, *Marine Pollution Bulletin*, 118(1-2): 27-40.

Elliott, M., Mander, L., Mazik, K., Simenstad, C., Valesini, F., Whitfield, A., Wolanski, E. 2016. Ecoengineering with ecohydrology: successes and failures in estuarine restoration. *Estuarine, Coastal and Shelf Science*, 176:12-35.

Elliott, M. 2014 Integrated marine science and management: Wading through the morass, *Marine Pollution Bulletin*, 86: 1-4.

Elliott, M. 2013. The 10-*tenets* for integrated, successful and sustainable marine management, *Marine Pollution Bulletin*, 74: 1-5.

Elliott, M., Borja, A., McQuatters-Gollop, A., Mazik, K., Birchenough, S., Andersen, J.H., Painting, S., Peck, M. 2015. Force majeure: Will climate change affect our ability to attain Good Environmental Status for marine biodiversity? *Marine Pollution Bulletin*, 95(1): 7-27. doi: 10.1016/j.marpolbul.2015.03.015

Elliott, M., Mazik, K., Papdopoulou, N., Smith, C., Little, S., Strong, J. 2013. Definition and lists of hazards, activities and pressures adopted for DEVOTES, report for Devotes.

Elliott, M. 2011. Marine science and management means tackling exogenic unmanaged pressures and endogenic managed pressures- A number guide, *Marine Pollution Bulletin*, 62: 651-655.

Elliott, M., Whitfield, A. 2011. Challenging paradigms in estuarine ecology and management, *Estuarine, Coastal & Shelf Science*, 94: 306-314.

Elliott, M., Ducrotoy, J-P. 2010. Management plans for four North Sea estuaries: the Elbe, the Weser, the Humber and the Scheldt, Bulletin of the *Estuarine & Coastal Sciences Association*, 55: 15-22.

Elliott, M., Quintino, V. 2007. The estuarine quality paradox, environmental homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas, *Marine Pollution Bulletin*, 54: 640-645.

Elliott, M., Burdon, D., Hemingway, K.L., Apitz, A.E. 2007. Estuarine, coastal and marine ecosystem restoration: Confusing management and science- A revision of concepts, *Estuarine, Coastal and Shelf Science*, Vol. 74, Pages 349-366.

Elliott, M., Burdon, D., Hemingway, K.L. 2006. Marine ecosystem structure, functioning, health and management and potential approaches to marine ecosystem recovery: a synthesis of current understanding, An unpublished report to CCW, Institute of Estuarine and Coastal Studies, University of Hull, Report: YBB092-F-2006.

Elliott, M., McLusky, D.S. 2002. The need for definitions in understanding estuaries. *Estuarine, Coastal and Shelf Science*, 55(6): 815-827.

English Nature. 2003. English Nature's advice given under Regulation 33(2) of the conservation (Natural Habitats &c.) Regulations 1994, The Humber Estuary European Marine Site, Interim Advice, 2003

Environment Agency. 2015. Humber river basin district River basin management plan. (Available from: https://www.gov.uk/government/publications/humber-river-basin-district-river-basin-management-plan) [viewed 01/05/2017].

Environment Agency. 2012a. Clearing the Waters: A user guide for marine dredging activities- understanding the implications for decision-making. (Available from: https://www.gov.uk/government/publications/complying-with-the-water-framework-directive-marine-dredging) [Viewed 09/07/2017].

Environment Agency. 2012b. Clearing the Waters: A user guide for marine dredging activities-Stage one: the screening stage. (Available from: https://www.gov.uk/government/publications/complying-with-the-water-framework-directive-marine-dredging) [Viewed 09/07/2017].

Environment Agency. 2012c. Clearing the Waters: A user guide for marine dredging activities-Stage two: the new projects process. (Available from: https://www.gov.uk/government/publications/complying-with-the-water-framework-directive-marine-dredging) [Viewed 09/07/2017].

Environment Agency. 2012d. Clearing the Waters: A user guide for marine dredging activities-Stage three: assessment. (Available from: https://www.gov.uk/government/publications/complying-with-the-water-framework-directive-marine-dredging) [Viewed 09/07/2017].

Environment Agency. 2012e. Clearing the Waters: A user guide for marine dredging activities- Stage four: identification and evaluation of measures. (Available from: https://www.gov.uk/government/publications/complying-with-the-water-framework-directive-marine-dredging) [Viewed 09/07/2017].

Environment Agency. 2009. Ecosystem services case studies, ISBN 978-1-84911-042-6.

Environment Agency. 2008a. The Humber Flood Risk Management Strategy: Summary Document.

Environment Agency. 2008b. The Humber Flood Risk Management Strategy.

Fabbri, K.P. 1998. A methodology or supporting decision-making in integrated coastal zone management, *Ocean and Coastal Management*, 39: 51-62.

Fearnly, H., Liley, D., Cruickshanks, K. 2012. Results of the Recreational Visitor Surveys Across the Humber Estuary, Footprint Ecology, Unpublished Report for the Humber Management Scheme.

Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. *Ecological economics*, 68(3):643-653.

Fisher, B., Turner, R.K., 2008. Ecosystem services: classification for valuation. *Biological conservation*, 141(5): 1167-1169.

Foley, M.M., Martone, R.G., Fox, M.D., Keppel., C.V., Mease, L.A., Erickson, A.L., Halpern, B.S., Selkoe, K.A., Taylor, P., Scarborough, C. 2015. Using ecological thresholds to inform resource management: Current options and future possibilities*, Frontiers in Marine Science*, 2(95): 1-12

Fothergill, J., King, J., Murphy, J., Owen, J., Smith, S., Spurgeon, J., Treweek, J., Venn, O., White, A. 2012. Considering ecosystem services in Environmental Impact Assessment, iema e-brief Issue 6.

Freestone, D., Jones, N., North, H., Pethick, J., Symes, D., Ward, R. 1987. The Humber Estuary: Environmental Background, *A Report for Shell UK Exploration and Production*.

Freire-Gibb, L.C., Koss, R., Margonski, P., Papadopoulou, N. 2014. Governance strengths and weaknesses to implement the marine strategy framework directive in European waters, *Marine Policy*, 44: 172-178.

Fujii, T. 2007. Spatial patterns of benthic macrofauna in relation to environmental variables in an intertidal habitat in the Humber Estuary, UK: Developing a tool for estuarine shoreline management, *Estuarine, Coastal and Shelf Science*, 75: 101-119.

Gabrielsen, P., Bosch, P. 2003. Environmental Indicators: Typology and Use in Reporting, EEA Internal Working Paper.

Galler, C., Albert, C., von Haaren, C. 2016. From regional environmental planning to implementation: Paths and challenges of integrating ecosystem services, *Ecosystem Services*, 18: 18-129.

García-Alonso, J., Greenway, G.M., Munshi, A., Gómez, J.C., Mazik, K., Knight, A.W., Hardege, J.D., Elliott, M. 2011. Biological responses to contaminants in the Humber Estuary: disentangling complex relationships. *Marine environmental research*, 71(4): 295-303.

Gilliland, P.M., Laffoley, D., 2008. Key elements and steps in the process of developing ecosystem-based marine spatial planning. *Marine Policy*, 32(5):787-796.

Goodsir, F., Bloomfield, H.J., Judd, A.D., Kral, F., Robinson, L.A., Knights, A.M. 2015. A spatially resolved pressure-based approach to evaluate combined effects of human activities and management in marine ecosystems, *ICES Journal of Marine Science*, doi:10.1093/icesjms/fsc080

Grant, D., Elliott, M. 2016. A proposed framework for managing environmental causes and consequences of ocean traffic and ports. European Decision Sciences Institute (EDSI2016), 7th Annual Conference: The Water Footprint in Decision Sciences, Helsinki May 24-27 2016, Conference Proceedings, Aalto University School of Business, p 204-217, ISBN 978-952-60-1102-8.

Gregory, A.J., Atkins, J.P., Burdon, D., Elliott, M. 2013. A problem structuring method for ecosystem-based management: The DPSIR modelling process, *European Journal of Operational Research*, 227: 558-569.

Gross, J.E. 2003. Developing Conceptual Models for Monitoring Programs, (available from http://science.nature.nps.gov/im/monitor/docs/Conceptual_modelling.pdf) [viewed 09/07/2017].

Guarnieri, G., Bevilacqua, S., De Leo, F., Farella, G., Maffia, A., Terlizzi, A., Fraschetti, S. 2016. The challenge of planning conservation strategies in threatened seascapes: Understanding the role of fine scale assessments of community response to cumulative human pressures, *PLOSone*, 11(2) 1-15.

Gupta, A.K., Gupta, S.K., Patil, R.S. 2005. Environmental management plan for port and harbour projects, *Clean Technologies and Environmental Policy*, 7: 133-141.

Haines-Young, R., Potschin, M. 2011. Integrated Coastal Zone Management and the Ecosystem Approach, Deliverable D2.1. PEGASO Grant agreement no. 244170. CEM Working Paper No. 7, 17 Pages.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R. 2008. A global map of human impact on marine ecosystems, *Science*, 319: 948-952.

Harbasins. 2008. Step towards harmonized transitional management strategy for coastal and transitional waters.

Hardisty, J. 1999 (reported in Vermeulen, 2004). 'Physical processes in the Humber estuary', paper submitted to the Environment Agency

Harley, C.D.G., Hughes, A.R., Hultgren, K.M., Miner, B.G., Sorte, C.J.B., Thornber, C.S., Rodriguez, L.F., Tomanek, L., Williams, S.L. 2006. The impacts of climate change in

coastal marine systems, *Ecology Letters*, 9: 228-241. doi: 10.1111/j.1461-0248.2005.00871.x

Harris, J.R.W. 2003. Apparent homeostasis in the surface salinity of a turbid macrotidal estuary, *The Science of the Total Environment*, 314-316: 651-663.

Hartje, V., Klaphake, A., Schliep, R. 2003. The international debate of the ecosystem approach: Critical review, International Actors, Obstacles and Challenges. (Available from http://www.bfn.de/fileadmin/MDB/documents/skript80.pdf) [viewed 02/07/2017].

Helsinki and OSPAR. 2003. Statement on the Ecosystem Approach to the Management of Human Activities: Towards an Ecosystem Approach to the Management of Human Activities- Joint Meeting of the Helsinki and OSPAR commissions.

Hemingway, K., Cutts, N., Perez-Dominguez, R. 2008. Managed Realignment in the Humber Estuary, UK. Institute of Estuarine and Coastal Studies (IECS) University of Hull, UK. Report produced as part of the European Interreg IIIB HARBASINS project.

Hering, D., Borja, A., Carstensen, J., Carvalho, L., Elliott, M., Feld, C.K., Heiskanen, A.S, Johnson, R.K., Moe, J., Pont, D., Solheim, A.L, van de Bund, W. 2010. The European Water Framework Directive at the age of 10: A critical review of the achievements with recommendations for the future, *Science of the Total Environment*, 408(19): 4007-4019.

HM Government. 2012. Marine Strategy Part One: UK Initial Assessment and Good Environmental Status.

HM Government. 2011. UK Marine Policy Statement, London: The Stationary Office.

HM Treasury. 2003. The Green Book. Appasial and Evaluation in Central Government.

Holman, I.P., Rounsevell, M.D.A., Shackley, S., Harrison, P.A., Nicholls, R.J., Berry, P.M., Audsley, E. 2005. A regional, multi-sectoral and integrated assessment of the impacts of climate and socio-economic change in the UK: Part 1 Methodology, *Climatic Change*, 71: 9-41.

Hu, K., Ding, P., Wang, Z., Yang, S., 2009. A 2D/3D hydrodynamic and sediment transport model for the Yangtze Estuary, China. *Journal of Marine Systems* 77: 114–136

Hu, K., Ding, P. 2009. The Effect of Deep Waterway Constructions on Hydrodynamics and Salinities in Yangtze Estuary, China. Journal of Coastal Research, *Special Issue No. 56. Proceedings of the 10thInternational Coastal Symposium ICS 2009*, Vol. II: 961-965

Hyder, K., Townhill, B., Anderson, L.G., Delany, J., Pinnegar, J.K. 2015. Can citizen science contribute to the evidence-base that underpins marine policy? *Marine Policy*, 59: 112-120.

Islam, M.S., Tanaka, M. 2004. Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis, *Marine Pollution Bulletin*, 48: 624-649.

Jacobs, S., Vandenbruwaene, W., Vrebos, D., Beauchard, O., Boerema, A., Wolfstein, K., Maris, T., Saathoff, S., Meire, P. 2012. Ecosystem service assessment of TiDE estuaries available at http://www.tide-toolbox.eu/reports/ecosystem_service_assessment_of_tide_estuaries/ [viewed 02/07/17].

Jarvie, H.P., Neal, C., Robson, A.J. 1997. The geography of the Humber Catchment, *The Science of the Total Environment*, 194-195: 87-99.

Jay, S., Klenke, T., Janben, H. 2016. Consensus and variance in the ecosystem approach to marine spatial planning: German perspectives and multi-actor implications, *Land Use Policy*, 54: 129-138.

JBA Consulting. 2011. Review of the Geomorphological Dynamics of the Humber Estuary. Final report, 7th November 2011.

JNCC. 2013. Pressures-Activities Database (Available from: http://jncc.defra.gov.uk/default.aspx?page=7136) [Viewed 02/07/17].

Johnston, S.A. 1981. Estuarine dredge and fill activities: A review of impacts*, Environmental Management*, 5(5): 427-440.

Juda, L. 1998. Considerations in developing a functional approach to the governance of large marine ecosystems, *Ocean Development and International Law*, 30: 89-125.

Judd, A.D. Backhaus, T., Goodsir, F. 2015. An effective set of principles for practical implementation of marine cumulative effect assessment, *Environmental Science and Policy*, 54: 254-262.

Judd, A., Hart, A., Prpich, G., Whelan, M., Jude, S. 2013. Guidelines for Marine Environmental Risk Assessment, Final Report by Cefas, Fera and Cranfield University.

Judd, A. 2011. Exploring Options for Risk Based Approaches for Regulatory Advice within Cefas (and wider application by regulators) Final Report for Seedcorn Project.

Karman, C.C., Jongbloed, R.H. 2008. Assessment of the Cumulative Effects of Activities in the Maritime Area, Report Number C018/08. 67pp.

Katsanevakis, S., Stelzenmüller, V., South, A., Sørensen, T.K., Jones, P.J., Kerr, S., Badalamenti, F., Anagnostou, C., Breen, P., Chust, G., D'Anna, G. 2011. Ecosystem-based marine spatial management: review of concepts, policies, tools, and critical issues. *Ocean & Coastal Management*, 54(11): 807-820.

Kelly, C., Gray, L., Shucksmith, R.J., Tweddle, J.F. 2014. Investigating options on how to address cumulative impacts in marine spatial planning, *Ocean and Coastal Management*, 102: 139-148.

Kettle, N.P., Dow, K. 2016. The role of perceived risk, uncertainty, and trust on coastal climate change adaptation planning, *Environment and Behavior*, 48(4): 579-606.

Khakzad, N., Khan, F., Amyotte, P. 2013. Dynamic safety analysis of process systems by mapping bow-toe into Bayesian Network, *Process Safety and Environmental Protection*, 91: 46-53

Koss, R.S., Knights, A.M., Eriksson, A., Robinson. L.A. 2011. ODEMM Linkage Framework Userguide. ODEMM Guidance Document Series No.1. EC FP7 project (244273) 'Options for Delivering Ecosystem-based Marine Management'. University of Liverpool, ISBN: 978-0-906370-66-7.

Kramer, D.L. 1987. Dissolved oxygen and fish behaviour, *Environmental Biology of Fishes*, 18(2): 81-92.

Kyozuka, Y. 2004. Numerical Modeling of Environmental Impact Assessment of Ocean Structures, in Proceedings of The Fourteenth International Offshore and Polar Engineering Conference, Toulon, France, May 23-28, 2004

Law, M., Wass, P., Grimshaw, D. 1997. The hydrology of the Humber Catchment, *The Science of the Total Environment*, 194-195: 119-128.

Le Dimet, F.-X. 1993. Hight Performance Computing in the Geosciences. Proceedings of the NATO Advanced Research Workshop on Hight Performance Computing in the Geosciences, Centre de Physique, Les Houches, France, 21-25 June 1993.

Lee, N. 2006. Bridging the gap between theory and practice in integrated assessment, Environmental Impact Assessment Review, 26:57-78.

Leon, L. F., Lam, D. C., McCrimmon, C., Swayne. D.A., 2003. Watershed management modelling in Malawi: application and technology transfer, *Environmental Modelling & Software* 18: 531–539

Leopold, L.B., Clarke, F.E., Hanshaw, B.B, Balsley, J.E. 1971. A procedure for evaluating environmental impact, U.S. Geological Survey Circular 645.

Leorri, E., Mulligan, R., Mallinson, D. Cearreta, A., 2011. Sea-level rise and local tidal range changes in coastal embayments: An added complexity in developing reliable sea-level index points, Revista de Gestão Costeira Integrada *Journal of Integrated Coastal Zone Management* 11(3):307-314

Leth, J.O., 2008. Baltic Sea marine landscapes and habitats: Mapping and modelling. Report for BALANCE, Technical Summary Report, part 2/4

Little, S., Wood, P.J., Elliott, M. 2017. Quantifying salinity-induced changes on estuarine benthic fauna: the potential implications of climate change. *Estuarine, Coastal and Shelf Science,* 198: 610-625.

Liu, S., Costanza, R., Farber, S., Troy, A. 2010. Valuing ecosystem services: Theory, practice, and the need for transdisciplinary synthesis, *Annals of the New York Academy of Sciences*, 1185: 54-78.

Lonsdale, J., Weston, K., Blake, S., Edwards, R., Elliott, M., 2017. The Amended European Environmental Impact Assessment Directive: UK marine experience and recommendations. *Ocean & Coastal Management*, 148:131-142.

Lonsdale, J-A., Weston, K., Barnard, S., Boyes, S., Elliott, M. 2015. Integrating Management Tools and Concepts to Develop an Estuarine Planning Support System: A case study of the Humber Estuary, Eastern England, *Marine Pollution Bulletin*, 100(1): 393-405.

Lonsdale, J., Birchenough, A. 2014. Dredge material disposal sites and Marine Protected Areas around the English Coast: Desk Review – Part 2, Final Report, Report for Natural England, Cefas contract report C6230

Lonsdale, J. 2013. The Potential Uses of Dredged Material in the Humber Estuary, MSc Thesis, University of Hull funded by TiDE (available from: http://www.tide-project.eu/downloads/Pilot_project_Humber_estuary.pdf) [viewed 02/07/2017]

Loomis, J., Kent, P., Strange, L., Fausch, K., Covich, A. 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey, *Ecological Economics*, 33: 103-117.

Lotze, H. K., 2010. Historical reconstruction of human-induced changes in U.S. estuaries. *Oceanography and Marine Biology: an Annual Review*, 48: 267-338

Low, B., Costanza, R., Ostrom, E., Wilson, J., Simon, C.P. 1999. Human-ecosystem interactions- a dynamic integrated model, *Ecological Economics*, 31: 227-242.

Lucrezi, S., Saayman, M., Van der Merwe, P. 2016. An assessment tool for sandy beaches: A case study for integrating beach description, human dimension, and economic factors to identify priority management issues, *Ocean and Coastal Management*, 121: 1-22.

Luisetti, T., Turner, R.K., Jickells, T., Andrews, J., Elliott, M., Schaafsma, M., Beaumont, N., Malcolm, S., Burdon, D., Adams, C., Watts, W. 2014. Coastal zone ecosystem services: From science to values and decision-making; a case study, *Science of the Total Environment*, 493: 682-693.

Luisetti, T., Jackson, E.L., Jackson, Turner, R.K. 2013. Valuing the European 'coastal blue carbon' storage benefit, *Marine Pollution Bulletin*, 71: 101-106.

Maltby, E. 2000. Ecosystem approach: From principle to practice, Ecosystem Service and Sustainable Watershed Management in North China International Conference, Beijing PR China, August 23-25.

Manson, S., Pinnington, N. 2012a. 'Chowder Ness' (Humber estuary). Measure analysis in the framework of the Interreg IVB project TIDE, Measure 33, 17pp, Hull.

Manson, S., Pinnington, N. 2012b. 'Donna Nook' (Humber estuary). Measure analysis in the framework of the Interreg IVB project TIDE, Measure 38, 13pp, Hull.

Manson, S., Pinnington, N. .2012c. 'Skeffling' (Humber estuary). Measure analysis in the framework of the Interreg IVB project TIDE, Measure 38, 12pp, Hull.

Manson, S., Pinnington, N. 2012d. 'South Humber Gateway Roosting Mitigation' (Humber estuary). Measure analysis in the framework of the Interreg IVB project TIDE, Measure 36, 20pp, Hull.

Marine Management Organisation. 2014a. East Inshore and Offshore Marine Plans-Executive Summary

Marine Management Organisation. 2014b. East Inshore and Offshore Marine Plans: Implementation and Monitoring Plan

Marine Management Organisation. 2014c. Practical Framework for Outlining the Integration of the Ecosystem Approach into Marine Planning in England. A report produced for the Marine Management Organisation, pp. 181. MMO Project Number: 1048. ISBN: 978-1-909452-33-6.

Marine Management Organisation. 2014d. A Strategic Framework for Scoping Cumulative Effects, MMO Project No. 1055. 244pp.

Marine Management Organisation. 2011. Coastal Typologies: Detailed Method and Outputs, (available at http://www.marinemanagement.org.uk/marineplanning/key/documents/se_typologies.pdf) [Accessed 12/05/2014]

Marine Scotland. 2012. Marine Impact Assessment Tool (Available at http://www.marine-impact.co.uk/) [Accessed 02/07/17]

Marshall, S., Elliott, M. 1998. Environmental influences on the fish assemblage of the Humber Estuary, U.K., *Estuarine, Coastal and Shelf Science*, 46: 175-184.

Masselink, G., Anthony, E.J. 2000. Location and height of intertidal bars on macrotidal ridge and runnel beaches, *Earth Surfaces Processes and Landforms*, 26: 759-774.

Mateus, M., Campuzano, F.J. 2008. The DPSIR framework applied to the integrated management of coastal areas, *Perspectives on Integrated Coastal Zone Management in South America*, Neves, R., Baretta, J.W., Mateusm. M. (Eds) 1st Press.

Maxim, L., Spangenberg, J.H., O'Connor, M. 2009. An analysis of risks for biodiversity under the DPSIR framework, *Ecological Economics*, 69: 12-23.

Mazik, K., Smith, J.E., Leighton, A. Elliott, M. 2007. Physical and biological development of a newly breached managed realignment site, Humber estuary, UK. *Marine Pollution Bulletin*, 55(10): 564-578.

McNie, E.C., Parris, A., Sarewitz, D. 2016. Improving the public value of science: A typology to inform discussion, design and implementation of research, *Research Policy*, 45: 884-895

McLusky, D.S., Elliott, M. 2004. The Estuarine Ecosystem: Ecology, Threats and Management, Oxford University Press, New York, USA.

Mee, L.D., Jefferson, R.L., Laffoley, D., Elliott, M. 2008. How good is good? Human values and Europe's proposed Marine Strategy Directive, *Marine Pollution Bulletin*, 56: 187-204.

Meißner, K., Schalbelon, H., Bellebaum, J., Sordyl, H. 2006. Impacts of submarine cables on the marine environment- A literature review. pp. 96. (Available from: https://www.bfn.de/fileadmin/BfN/meeresundkuestenschutz/Dokumente/BfN_Literaturstudie_Effekte_marine_Kabel_2007-02_01.pdf) [Viewed 16/08/2017].

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

Mitchell, S.B., West, J.R., Arundale, A.M.W., Guymer, I., Couperthwaites, J.S. 1998. Dynamics of the turbidity maxima in the upper Humber estuary system, UK, *Marine Pollution Bulletin*, 37(3-7): 190-205.

Nash, S., Phoenix, A. 2017. A review of the current understanding of the hydro-environmental impacts of energy removal by tidal turbines, *Renewable and Sustainable Energy Reviews*, 80: 648–662

Natural England, 2017, Solent Maritime SAC Advice on Operations. Available from: https://designatedsites.naturalengland.org.uk/Marine/FAPMatrix.aspx?SiteCode=UK0030059&SiteName=solent&SiteNameDisplay=Solent+Maritime+SAC&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=. Viewed 31/05/2017

Natural England. 2012. Agricultural Land Classification: protecting the best and most versatile agricultural land, Natural England Technical Information Note TIN049, 2nd Edition.

Ness, B., Anderberg, S., Olsson, L. 2010. Structuring problems in sustainability science: The multi-level DPSIR framework, *Geoforum*, 41(3): 479-488.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., Chan, K., Daily, G.C., Goldstein, J., Kareiva, P.M. and Lonsdorf, E., 2009. Modeling multiple ecosystem

services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment,* 7(1): 4-11.

Newton, A., Elliott, M. 2016. A typology of stakeholders and guidelines for engagement in transdisciplinary, participatory processes, *Frontiers in Marine Science*, 3(230). Doi: 10.3389/fmars.2016.00230

Nunn, A.D., Cowx, I.G. 2012. Restoring River Connectivity: Prioritizing Passage Improvements for Diadromous Fishes and Lampreys*. Ambio*. 41(4):402-409

Nyberg, J., Lindberg, T., Holmberg, J., Zetterlund, S., Stölen, L.K. 2007. Marine environmental data, availability and harmonisation. Report for BALANCE, Technical Summary Report, 37 pp.

O'Boyle, R., Jamieson, G. 2006. Observations on the implementation of ecosystem based management: Experiences on Canada's east and west coasts, *Fisheries Research*, 79: 1-12.

Oinonen, S., Hyytiäinen, K., Ahlvik, L., Laamanen, M., Lehtoranta, V., Salojärvi, J., Virtanen, J. 2016. Cost-effective marine protection- A pragmatic approach, *PLOSone*, 11(1): 1-19.

Official Journal of European Commission. 2000. Directive 2000/60/EC of the European Parliament and of the Council, Page 3.

Oliver, J. 1995. Is the "limits of acceptable change" concept useful for environmental managers? A case study from the Great Barrier Reef Marine Park. IN Grigg, G.C., Hale, P.T., Lunney, D. (Eds) Conservation Through Sustainable Use of Wildlife. Centre for Conservation Biology, The University of Queensland. Pages 131-139.

OSPAR Commission. 2014. OSPAR Guidelines for the Management of Dredged Material at Sea, Agreement 2014-06, (Available online: http://www.ospar.org) [Viewed: 09/07/2017]

OSPAR Commission. 2013. Meeting of the Environmental Impacts of Human Activities Committee (EEIHA) Gent (Belgium): 15-19 April 2013.

OSPAR Commission. 2010. The OSPAR System of Ecological Quality Objectives for the North Sea (Available online: http://www.ospar.org) [Viewed: 09/07/2017]

OSPAR Commission. 2008. Assessment of the Cumulative Effect of Activities in the Maritime Area. ISBN 978-1-906840-12-9.

Palmer, M.A., Filoso, S. 2009. Restoration of ecosystem services for environmental markets, *Science,* 325: 575-576.

Panditharatne, C. 2016. Institutional barriers in adapting to climate change: A case study in Sri Lanka, *Ocean and Coastal Management*, 130: 73-78.

Perminova, T., Laratte, B., Sirina, N., Baranovskaya, N., Rikhvanov, L. 2016. Methods for land use impact assessment: A review, *Environmental Impact Assessment Review*, 60: 64-74.

Pethick, J. 2002. Estuarine and tidal wetland restoration in the United Kingdom: Policy versus practice, *Restoration ecology*, 10(3): 431-437

Pickaver, A.H., Gilbert, C., Breton, F. 2004. An indicator set to measure the progress in the implementation of integrated coastal zone management in Europe. *Ocean & Coastal Management*, 47(9):449-462.

Pontee, N.I., Cooper, N.J. 2005. The incorporation of estuaries within a strategic shoreline management framework. Proceedings of the Institution of Civil Engineers, *Maritime Engineering Journal,* 158 (30-40).

Pontee, N.I., Whitehead, P.A., Hayes, C.M. 2004. The effect of freshwater flow on siltation in the Humber Estuary, north east UK, *Estuarine, Coastal and Shelf Science*, 60: 241-249.

Prestrelo, L., Vianna, M. 2016. Identifying multiple-use conflicts prior to marine spatial planning: A case study of A multi-legislative estuary in Brazil, *Marine Policy*, 67: 83-93.

Quilliam, N. 2015. Environmental consequences of large infrastructure: Role of integrated estuarine planning, MSc Thesis, University of Hull.

Ranganathan, J., Raudsepp-Hearne, C., Lucas, N., Irwin, F., Zurek, M., Bennett, K., Ash, N., West, P. 2008. Ecosystem Services: A Guide for Decision Makers, World Resources Institute.

Renewable UK. 2013. Cumulative Impact Assessment Guidelines: Guiding Principles for Cumulative Impacts Assessment in Offshore Windfarms.

Rickard, C., Day, R., Purseglove, J., 2003. River Weirs–Good Practice Guide Guide-Section A. Unpublished report for Environment Agency. (Available from: https://s3.amazonaws.com/academia.edu.documents/35096632/River_Wier_design_guide.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1514389935&Signature=bDX8d3tk02PyLcRWuJfRtQBFOeY%3D&response-content-disposition=inline%3B%20filename%3DRiver_Weirs_Good_Practice_Guide_Guide_-S.pdf) [Viewed 27/12/2017]

Robins, P.E., Skov, M.W., Lewis, M.J., Giménez, L., Dacies, A.G., Malham, S.K., Neill, S.P., McDonald, J.E., Whitton, T.A., Jackson, S.E., Jago, C.F. 2016. Impact of climate change on UK estuaries: A review of past trends and potential projections, *Estuarine, Coastal and Shelf Science*, 169: 119-135.

Robinson L.A., Knights, A.M. 2011. ODEMM Pressure Assessment Userguide. ODEMM Guidance Document Series No.2. EC FP7 project (244273) 'Options for Delivering

Ecosystem-based Marine Management'. University of Liverpool. ISBN: 978-0-906370-62-9, 12 pp.

Rogers, S.I., Tasker, M.L., Earll, R., Gubbay, S. 2007. Ecological objectives to support the UK vision for the marine environment, *Marine Pollution Bulletin*, 54: 128-144.

Rowland, P., Neal, C., Sleep, D., Vincent, C., Scholefield, P. 2011. Chemical Quality Status of Rivers for the Water Framework Directive: A Case Study of Toxic Metals in North West England, *Water*, 3: 649-666

Rosenberg, A.A., McLeod, K.L. 2005. Implementing ecosystem-based approaches to management for the conservation of ecosystem services IN Browman, H.I., Stergiou, K.I., [*eds*]. 2005. Politics and socio-economics of ecosystem-based management of marine resources, *Marine Ecology Progress Series*, 300: 241-296.

Ruckelshaus, M., Kilinger, T., Knowlton, N., DeMaster, D.P. 2008 Marine ecosystem based management in practice: Scientific and governance challenges, *Bioscience*, 58(1): 53-63

Runhaar, H. 2016. Tools for integrating environmental objectives into policy and practice: What works where?, *Environmental Impact Assessment Review*, 59: 1-9.

RYA. 2008. UK Coastal Atlas of Recreational Boating: Recreational cruising routes, sailing and racing areas around the UK coast, 2nd Edition, RYA.

Secretariat of the Convention on Biological Diversity. 2004. The Ecosystem Approach, ISBN: 92-9225-023-x (available online at: https://www.cbd.int/doc/publications/ea-text-en.pdf) [Viewed 09/07/2017]

Scharin, H., Ericksdotter, S., Elliott, M., Turner, K.R., Niiranen, S., Rockström, J., Blenckner, T., Hyytiäinen, K., Ahlvik, L., Ahtiaimem, H., Artell, J., Hasselström, L., Söderqvist, T. 2016. Processes for a sustainable stewardship of marine environments, *Ecological Economics*, 128: 55-67.

She, J., Allen, I., Buch, E., Crise, A., Johannessen, J.A., Le Traon, P.Y., Lips, U., Nolan, G., Pinardi, N., Reiβmann, J.H., Siddorn, J., Stanev, E., Wehde, H. 2016. Developing European operational oceanography for Blue Growth, climate change adaptation and mitigation and ecosystem-based management, *Ocean Science Discussions*, 59 pp.

Sheaves, M., Sporne, I., Dichmont, C.M., Bustamate, R., Dale, P., Deng, R., Dutra, L.X.C., van Putten, I., Savina-Rollan, M., Swinbourne, A. 2016. Principles for operationalising climate change adaptation strategies to support the resilience of estuarine and coastal ecosystems: An Australian perspective, *Marine Policy*, 68: 229-240.

Shepherd, G. 2004. The ecosystem approach: Five steps to implementation, IUCN Gland, Switzerland and Cambridge, UK. ISBN 2-8317-0840-0.

Shriberg, M. 2002. Toward sustainable management: the University of Michigan Housing Division's approach, *Journal of Cleaner Production*, 10: 41-45.

Small, C., Nicholls, R.J. 2003. A global analysis of human settlement in coastal zones, *Journal of Coastal Research*, 19(3): 584-599.

Smith, C., Papadopoulou, N., Barnard, S., Mazik, K., Patricio, J., Elliott, M., Solaun, O., Little, S., Borja, A., Bhatia, N., Moncheva, S., Robele, S., Can Bizsel, K., Eronat, A.H. 2014. Conceptual models for the effects of marine pressures on biodiversity, Report for DEVOTES, Work Package 1, Deliverable 1.1.

Stankey, G.H., Cole, D.N., Lucas, R.C., Petersen, M.E., Frissell, S.S. 1985. The Limits of Acceptable Change (LAC) System for Wilderness Planning. General Technical Report. Report by United States Department of Agriculture: Forest Service.

Stelzenmüller, V., Fock, H.O., Gimpel, A., Rambo, H., Diekmann, R., Probst, W.N., Callies, U., Brockelmann, F., Neumann, H., Kröncke, I. 2014. Quantitative environmental risk assessments in the context of Marine Spatial Management: Current approaches and some perspectives, *ICES Journal of Marine Science*, doi:10.1093/icesjms/fsu206.

Stelzenmüller, V., Lee, J., Rogers, S.I. 2010 Quantifying cumulative impacts of human pressures on the marine environment: A geospatial modelling framework, *Marine Ecology Progress Series*, Vol. 398, Pages 19-32.

Svarstad, H., Peterson, L.K., Rothman, D., Siepel, H., Wätzold, F. 2008. Discursive biases of the environmental research framework DPSIR, *Land Use Policy*, 25: 116-125.

Swift, M.J., Izac, A-M.V., van Noordwijk, M. 2004. Biodiversity and ecosystem services in agricultural landscapes- are we asking the right questions? *Agriculture Ecosystems and Environment*, 104: 113-134.

Tappin, A.D., Harris, J.R.W., Uncles, R.J. 2003. The fluxes and transformations of suspended particles, carbon and nitrogen in the Humber Estuarine system (UK) from 1994 to 1996: results from an integrated observation and modelling study, *The Science of the Total Environment*, 314-316: 665-713.

Tett, P., Gowen, R.J., Painting, S.J., Elliott, M., Forster, R., Mills, D.K., Bresnan, E., Capuzzo, E., Fernandes, T.F., Foden, J., Geider, R.J., Gilpin, L.C., Huxham, M., McQuatters-Gollop, A.L., Malcolm, S.J., Saux-Picart, S., Platt, T., Racault, M.-F., Sathyendranath, S., van der Molen, J., Wilkinson, M. 2013. Framework for understanding marine ecosystem health, *Marine Ecology Progress Series*, 494: 1-27.

Therivel, R., Ross, B. 2007. Cumulative effect assessment: Does scale matter? *EIA Review*, 27: 365-385.

The Crown Estate. 2015. The Crown Estate Offshore Activity (UK). (Available from: https://www.thecrownestate.co.uk/media/5545/ei-all-offshore-activity-uk-a2.pdf) [Viewed 27/12/2017]

The Crown Estate. 2012. Submarine Cables and Offshore Energy Installations- Proximity Study Report. pp. 100. (Available from: www.thecrownestate.co.uk) [viewed 16/08/2017].

Tillin, H.M., Hull, S.C., Tyler-Walters, H. 2010. Development of a Sensitivity Matrix (pressures-MCZ/MPA features). Report to the Department of Environment, Food and Rural Affairs from ABPMer, Southampton and the Marine Life Information Network (MarLIN) Plymouth: Marine Biological Association of the UK. Defra Contract No. MB0102 Task 3A, Report No. 22.

Toonen, H.M., van Tatenhove, J.P.M. 2013. Marine Scaping: The structuring of marine practices, *Ocean and Coastal Management*, 75: 43-52.

Torresan, S., Critto, A., Rizzi, J., Zabeo, A., Furlan, E., Marcomini, A. 2016. DESYCO: A decision support system for the regional risk assessment of climate change impacts in coastal zones, *Ocean and Coastal Management*, 120: 49-63.

Townsend, M., Thrush, S.F., Carbines, M.J. 2011. Simplifying the complex: an "Ecosystem Principles Approach" to goods and services management in marine coastal ecosystems, *Marine Ecology Progress Series*, 434: 291-301.

Townend, I., Whitehead, P. 2003. A preliminary net sediment budget for the Humber Estuary, *The Science of the Total Environment*, 755-767.

Townend, I.H. 2004. Identifying change in estuaries, *Journal of Coastal Conservation*, 10: 5-12.

Trosin, B., Smythe, T., McCann, J., Fox, C., Andrescavage, N. 2016. A case study of the Washington Coast Marine Spatial Planning Process, 2010-2015. In McCann, J. 2016. Case Studies of Marine Spatial Planning Report Series. Coastal Resources Center and Rhode Island sea Grant College Program, URI Graduate School of Oceanography. Narragansett, R.I. 57pp.

Turner, R.K., Schaafsma, M. eds., 2015. Coastal zones ecosystem services: from science to values and decision making (Vol. 9). Springer.

Turner, K., Schaafsma, M., Elliott, M., Burdon, D., Atkins, J., Kickells, T., Tett, P., Mee, L., van Leeuwen, S., Barnard, S., Luisetti, T., Paltriguera, L., Palmieri, G., Andrews, J. 2014. UK National Ecosystem Assessment Follow-on. Work Package Report 4: Coastal and marine ecosystem services: principles and practice. UNEP-WCMC, LWEC, UK

Turner, K., Morse-Jones, S., Fisher, B. 2010. Ecosystem Valuation: A sequential decision support system and quality assessment issues, *Annals of the New York Academy of Sciences*, 1185: 79-101.

Turner, R.K., Subak, S., Adger, W.N. 1996. Pressures, trends, and impacts in coastal zones: Interactions between socioeconomic and natural systems, *Environmental Management*, 20(2): 159-173.

UK Technical Advisory Group on the Water Framework Directive. 2008. Criteria and Guidance Principles for the designation of heavily modified waterbodies, Article 4 WP11s.

UK Technical Advisory Group on the Water Framework Directive, 2003, Guidance on Morphological Alterations and the Pressures and Impacts Analyses (Final Working Paper). (Available from: https://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Morphological%20alterations%20and%20the%20pressures%20and%20impact%20analyses_Draft_251103.pdf). [Viewed 31/05/2017]

Uncles, R.J., Howland, R.J.M., Easton, A.E., Griffiths, M.L., Hams, C., King, R.S., Moms, A.W., Plummer, D.H., Woodward, E.M.S. 1998. Concentrations of dissolved nutrients in the tidal Yorkshire Ouse River and Humber Estuary, *The Science of the Total Environment*, 210-211: 377-388.

United Nations. 2015. Resolution adopted by the General Assembly on 25 September 2015: Transforming our world: the 2030 Agenda for Sustainable Development (Available at: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E) [viewed 15/08/2017].

URS Scott-Wilson. 2011. Green Port Hull Environmental Statement (Available at: https://marinelicensing.marinemanagement.org.uk/mmo/fox/live/MMO_PUBLIC_REGISTER/search?area=5) [viewed 09/07/2017].

Uusitalo, L., Korpinen, S., Andersen, J.H., Niiranen, S., Valanko, S., Heiskaen, A-S., Dikey-Collas, M. 2016. Exploring methods for predicting multiple pressures on ecosystem recovery: A case study on marine eutrophication and fisheries, *Continental Shelf Research*, 121: 48-60.

Vandenbruwaene, W., Plancke, Y., Verwaest,T., Mostaert, F. 2013. Interestuarine comparison: Hydro-geomorphology Hydro- and geomorphodynamics of the TIDE estuaries Scheldt, Elbe, Weser and Humber. Interreg IVB North Sea Region Programme.

Van Hoey, G., Borja, Á., Birchenough, S., Buhl-Mortensen, L., Degraer, S., Fleischer, D., Kerckhof, F., Magni, P., Muxika, I., Reiss, H., Schröder, A., Zettler, M.L. 2010. The use of benthic indicators in Europe: From the water framework directive to the marine strategy framework directive, *Marine Pollution Bulletin*, 60: 2187-2196.

Varghese, K., Ganesh, L.S., Mani, M., Anilkumar, P.P., Murthy, R., Subramaniam, B.R. 2008. Identifying critical variables for coastal profiling in ICZM planning- A systems approach, *Ocean and Coastal Management*, 51: 73-94.

Vermeulen, T. J. 2003. Sensitivity analysis of fine sediment transport in the Humber estuary (Doctoral dissertation). TUDelft

Villa, F., Bagstad, K.J., Voigt, B., Johnson, G.W., Portela, R., Honzák, M., Batker, D. 2014. A methodology for adaptable and robust ecosystem services assessment, *PLOS* ONE, 9(3): 1-18.

Vries, P.De, Tamis, J.E., van der Wal, R.G., Jak, D.M.E., Slijkerman, Schobben, J.H.M. 2012. Scaling human-induced pressures to population level impacts in the marine environment; Implementation of the prototype CUMULEO-RAM model, WOt-paper, pp.14

Walstra, D.J.R., Sutherland, J., Hall, L., Blogg, H., van Ormondt, M. 2009. Verification and comparison of two hydrodynamics area models for an inlet system. Proceedings of the Fourth Conference on Coastal Dynamics, June 11-15, 2001, Lund Sweden

Ware, S., Langman, R., Lowe, S., Weiss, L., Walker, R., Mazik, K. 2010. The applicability of environmental indicators of change to the management of marine aggregate extraction.

Whitfield, A.K., Elliott, M., Basset, A., Blaber, S.J.M., West, R.J. 2012. Paradigms in estuarine ecology- A review of the Remane diagram with a suggested revised model for estuaries, *Estuarine, Coastal and Shelf Science*, 97: 78-90.

WL¦Delft Hydraulics, 2011. Delft3D-FLOW user manual. V 3.15. WL¦Delft Hydraulics, Delft, The Netherlands

Wolanski, E., Elliott, M. 2015. Estuarine Ecohydrology: an introduction. Elsevier, Amsterdam; ISBN 978-0-444-63398-9, p320.

Woods, J.S., Veltman, K., Huijbregts, M.A.J., Verones, F., Hertwich, E.G. 2016. Towards a meaningful assessment of marine ecological impacts in life cycle assessment (LCA) *Environment International*, 89-90: 48-61.

Zaucha, J., Conides, A., Klaoudatos, D., Norén, K. 2016. Can the ecosystem services concept help in enhancing the resilience of land-sea social-ecological systems? *Ocean and Coastal Management*, 124: 33-41

Zaucha, J., Breedveld, G. 2013. State-of-the-Lagoon. ARCH Work Package 2; Deliverable D2.2. Revision 0. 44pp.

Zeldis, J., Felsing, M., Wilson, J. 2006. Limits of acceptable change: a framework for managing marine farming, *Water and Atmosphere*, 14(2): 16-17.

Websites

OTPS7.2, 2005 http://volkov.oce.orst.edu/tides/otps.html, accessed March 2017

Appendix 1

Figures

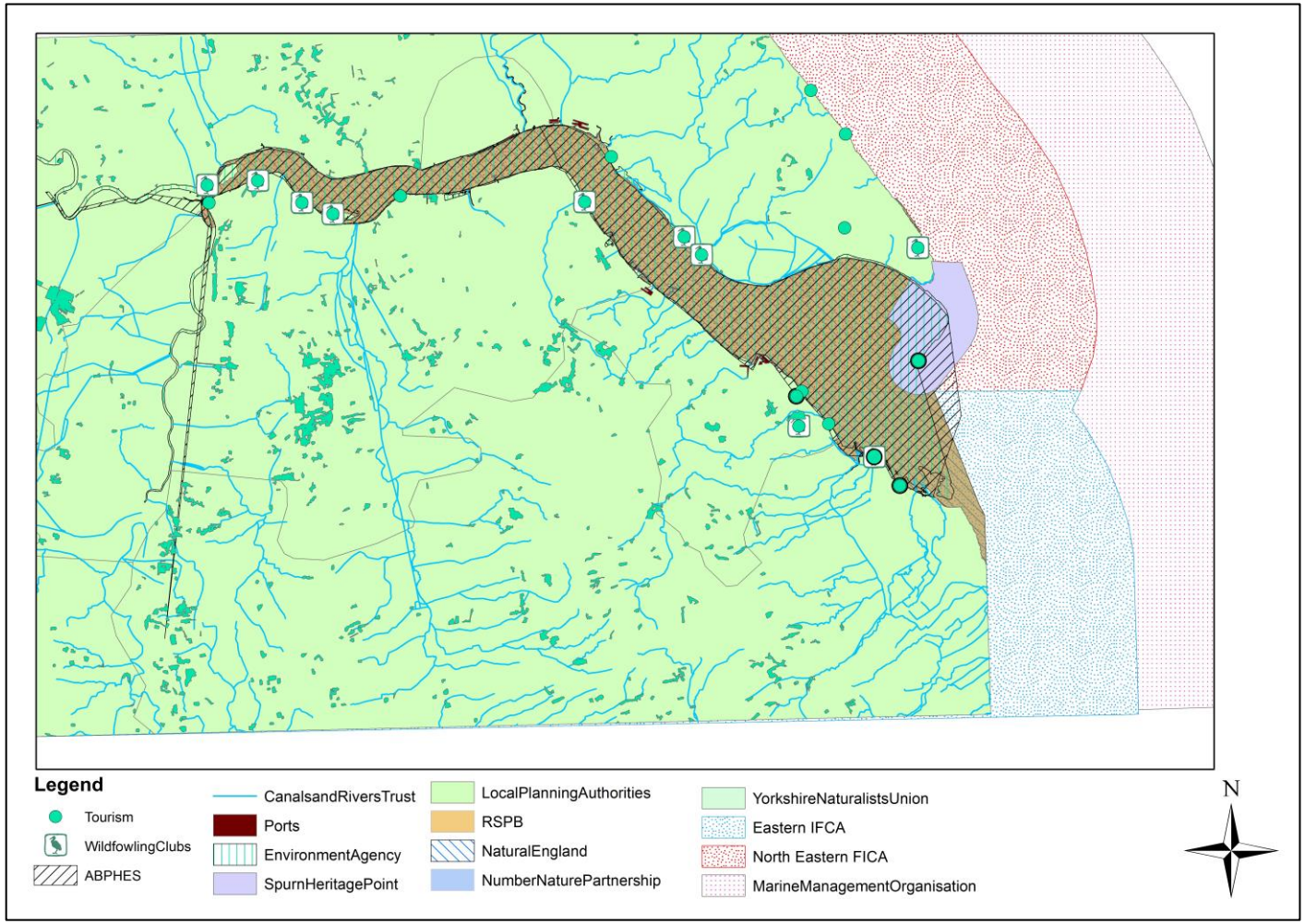



Figure A 1 Map showing the different management agencies and their jurisdictions

Figure A 2 Humber Basin Management Plan From Environment Agency (2015) (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/500465/Humber_RBD_Part_1_river_basin_management_plan.pdf ) [Viewed 14/01/2018]

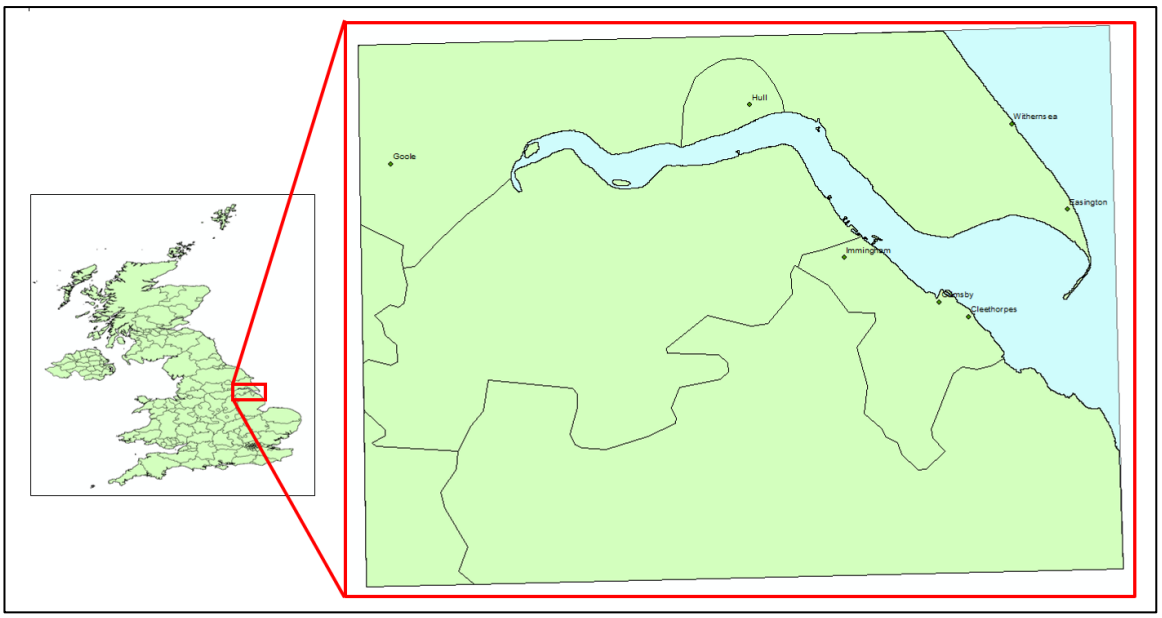



Figure A 3 Location of the Humber Estuary

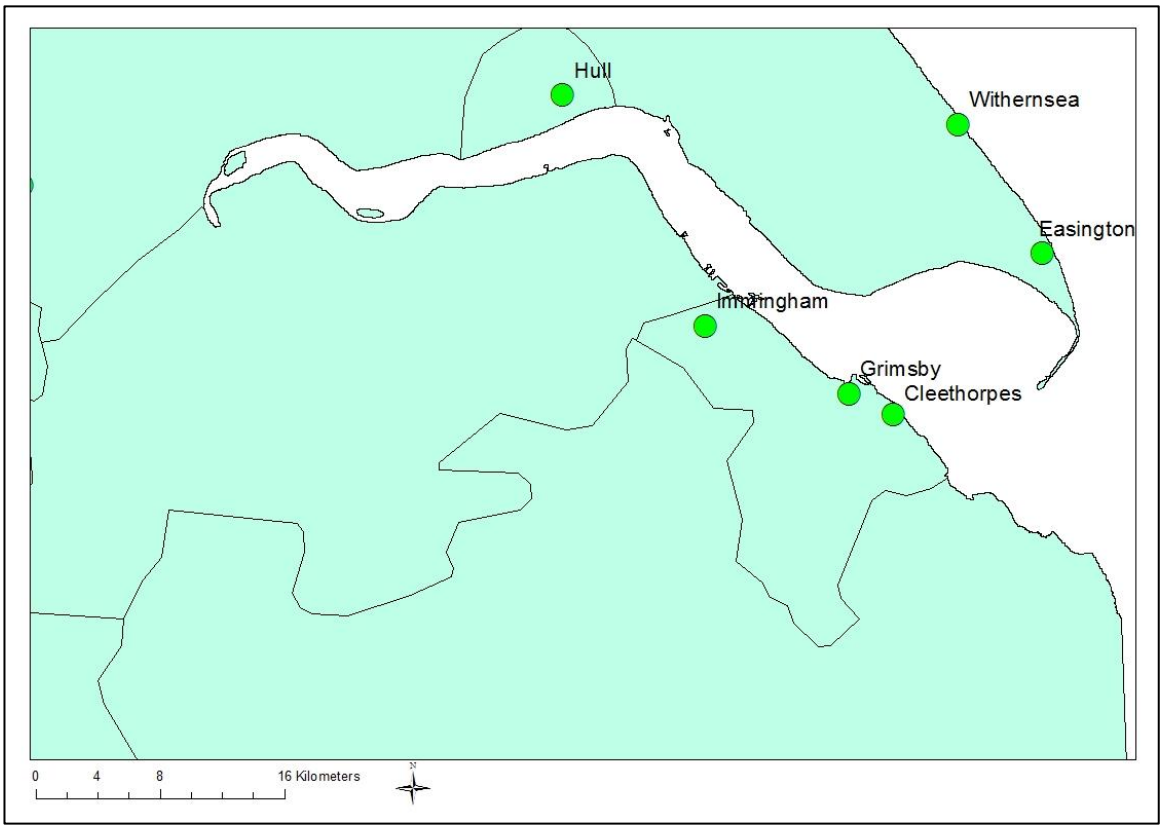



Figure A 4 Case Study Area and main towns

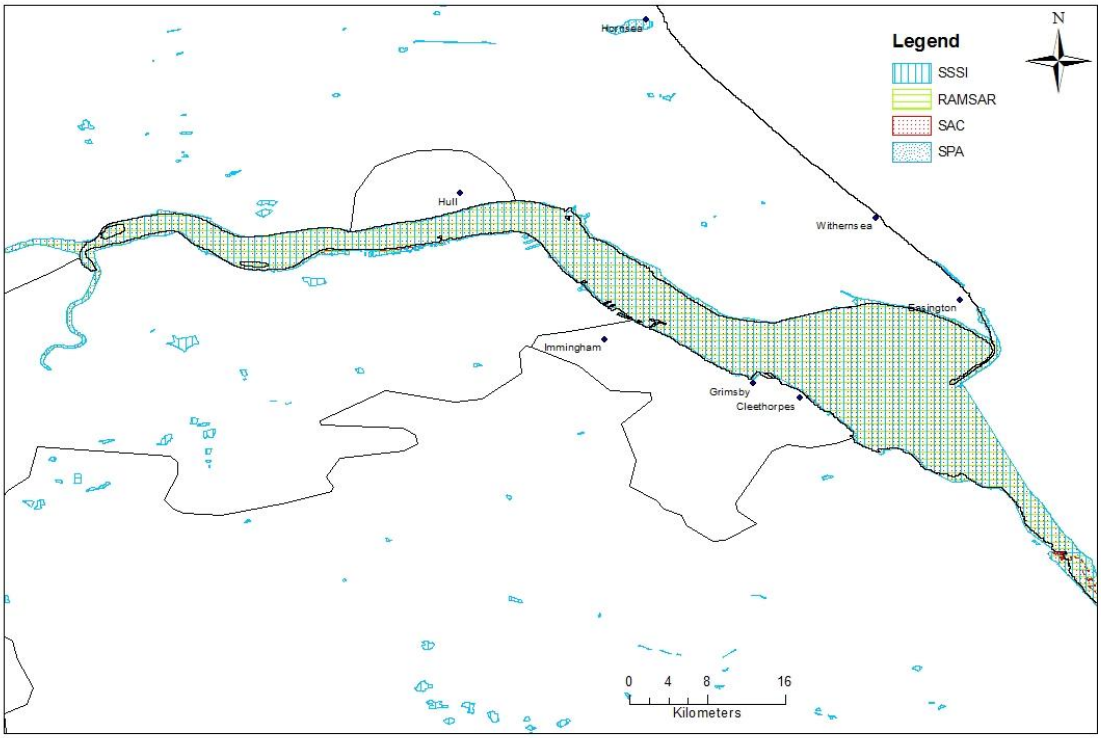



Figure A 5 Designations of the Humber Estuary

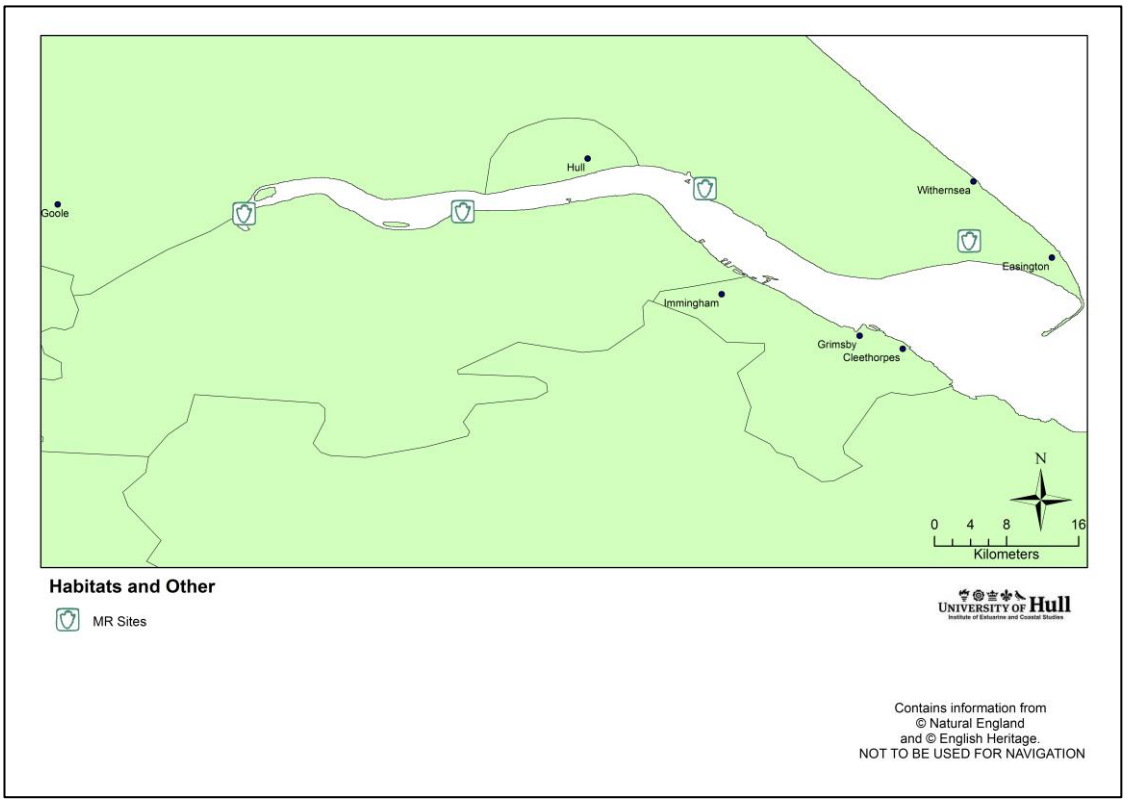



Figure A 6 Managed Realignment Sites

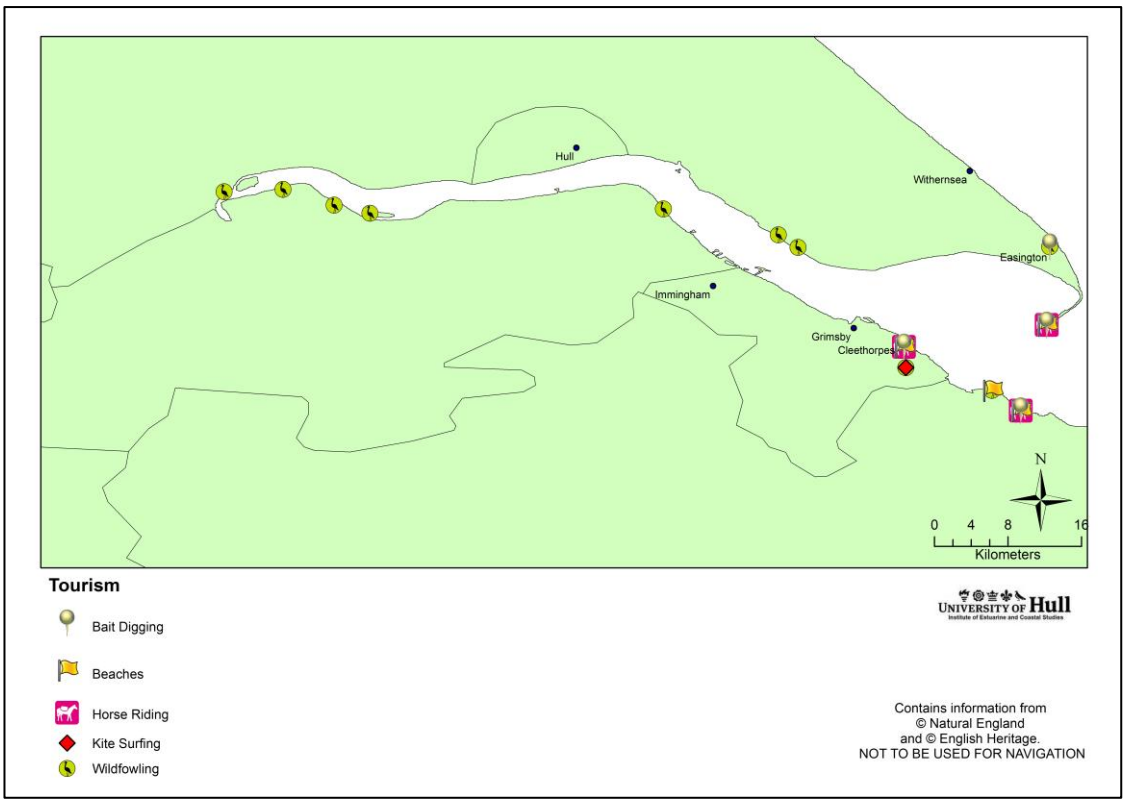



Figure A 7 Tourism and Leisure Activities of the Humber Estuary

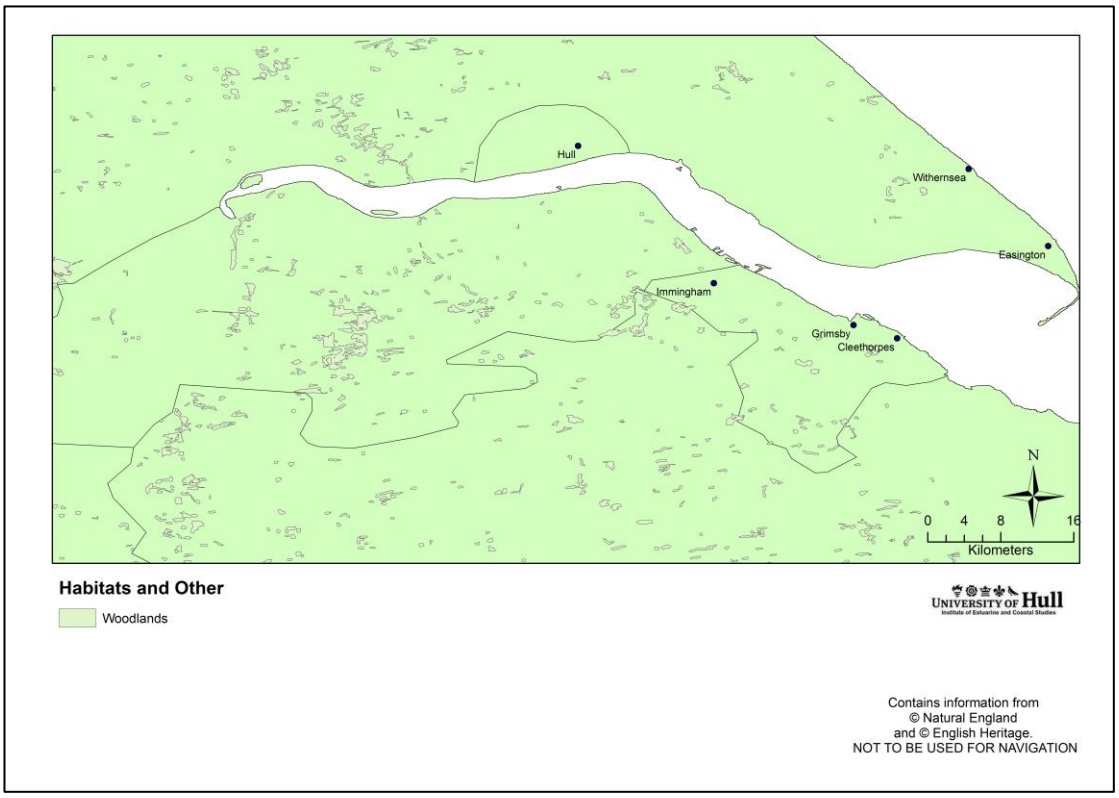



Figure A 8 Woodlands of the Humber Estuary

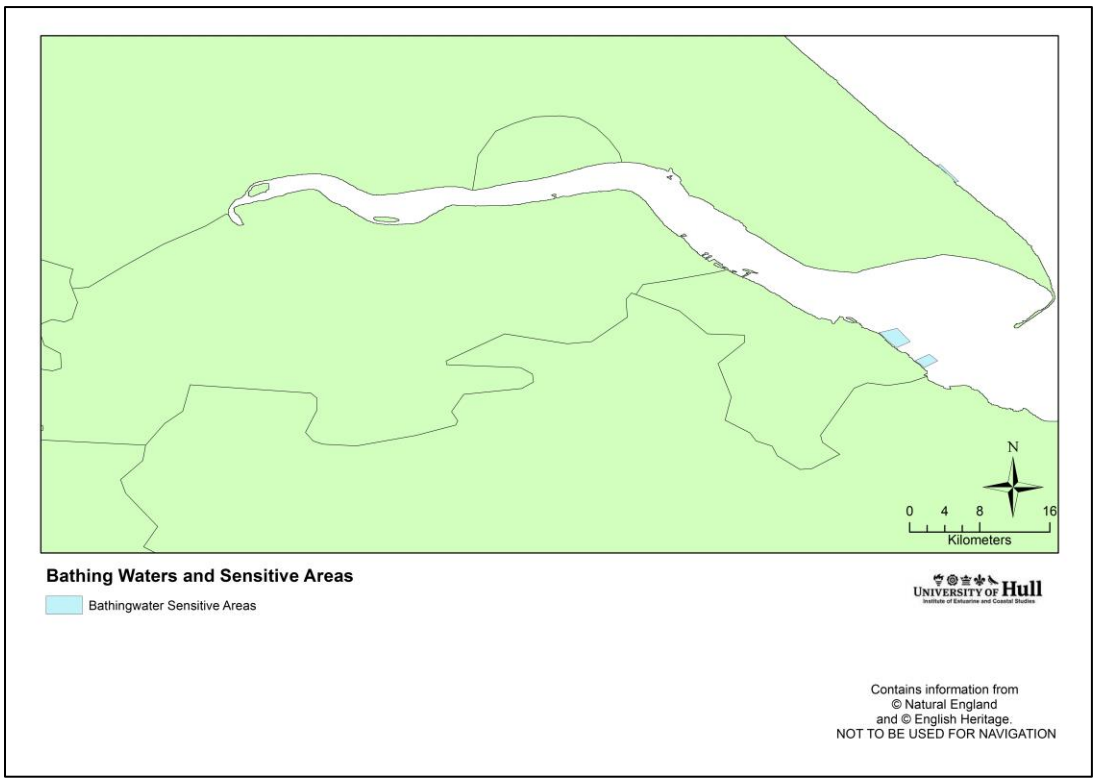



Figure A 9 Bathing waters (sensitive areas) in the Humber Estuary

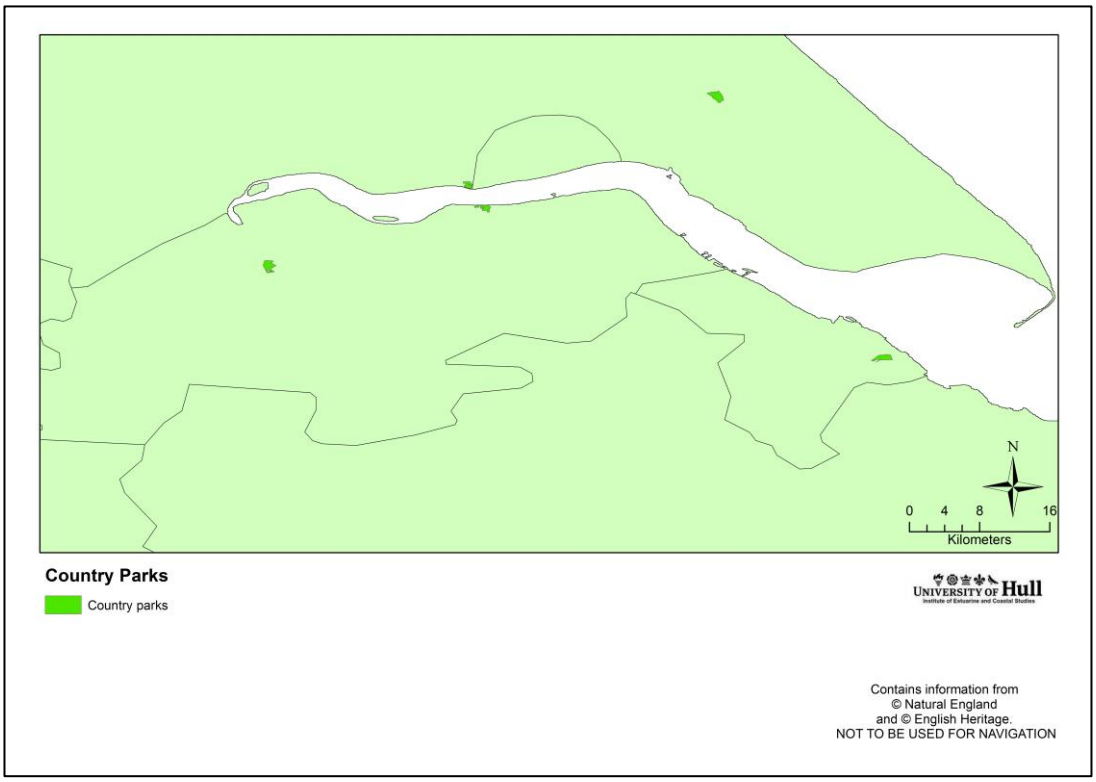



Figure A 10 Country Parks around the Humber Estuary

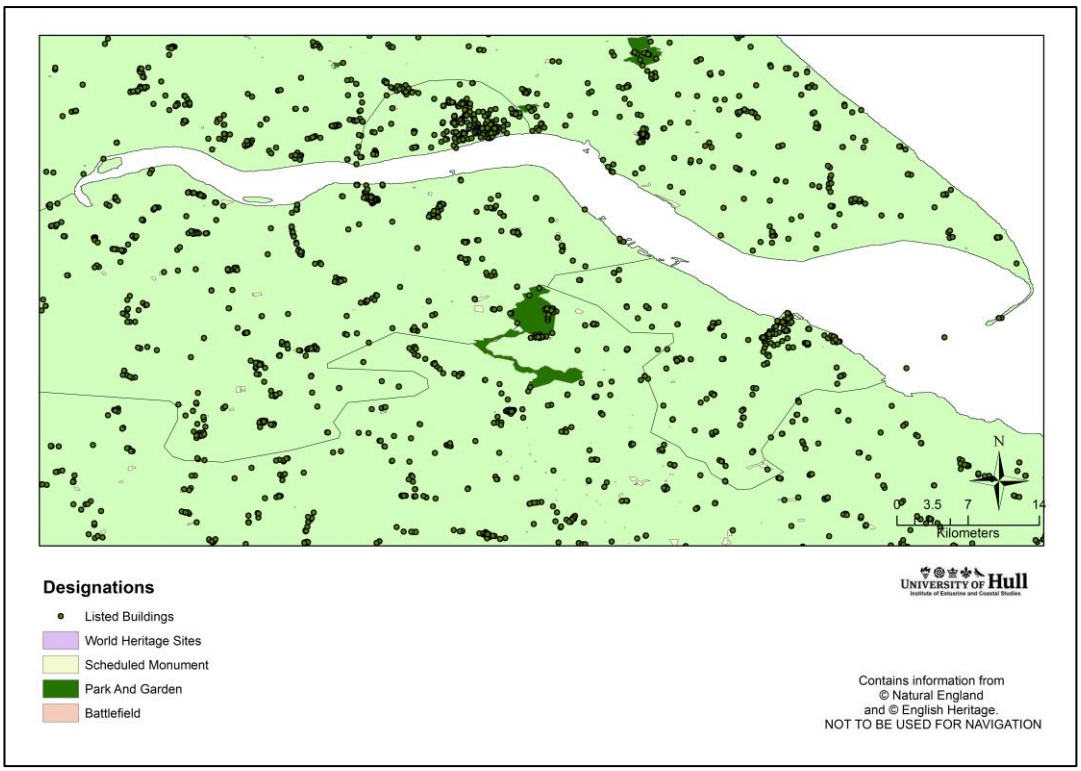



Figure A 11 English Heritage Sites of the Humber Estuary

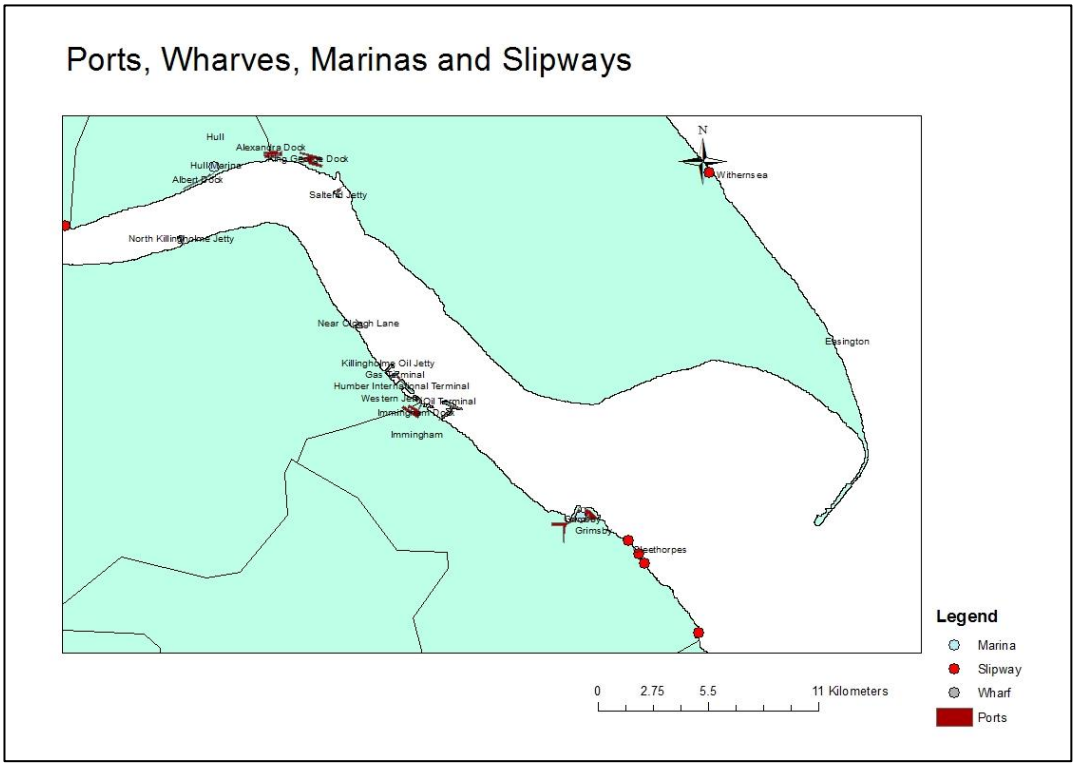



Figure A 12 Ports and Wharves of the Humber Estuary

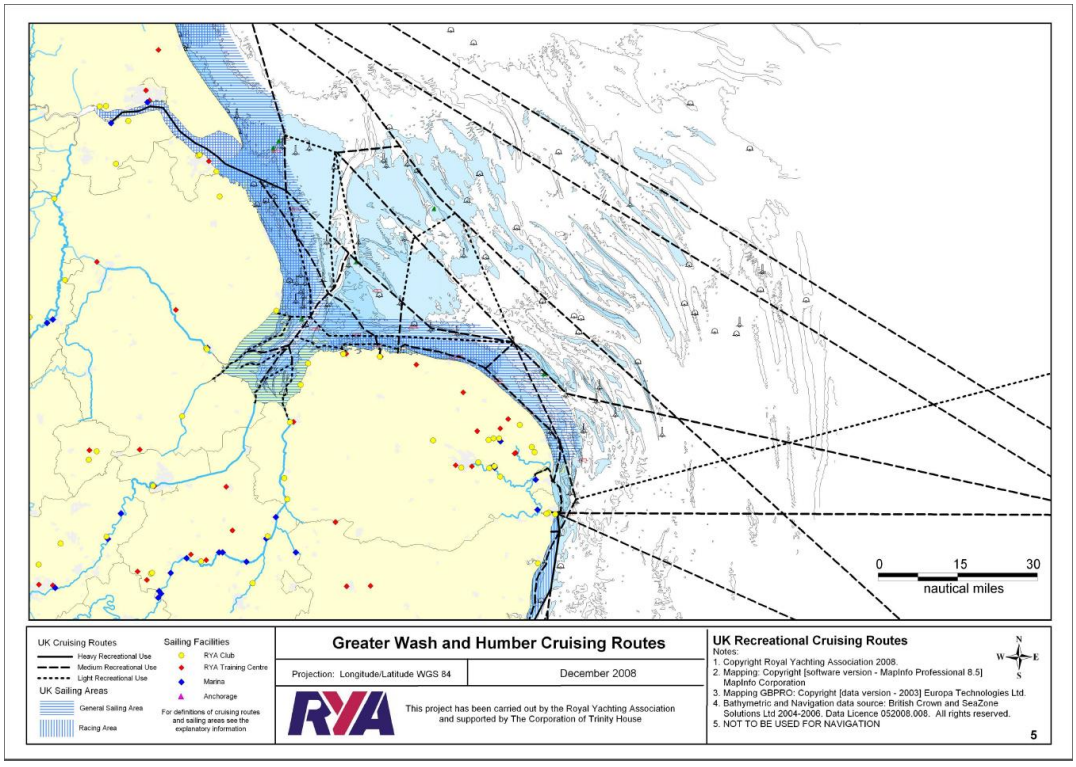



Figure A 13 RYA Cruising Routes for the Humber (from RYA, 2008)

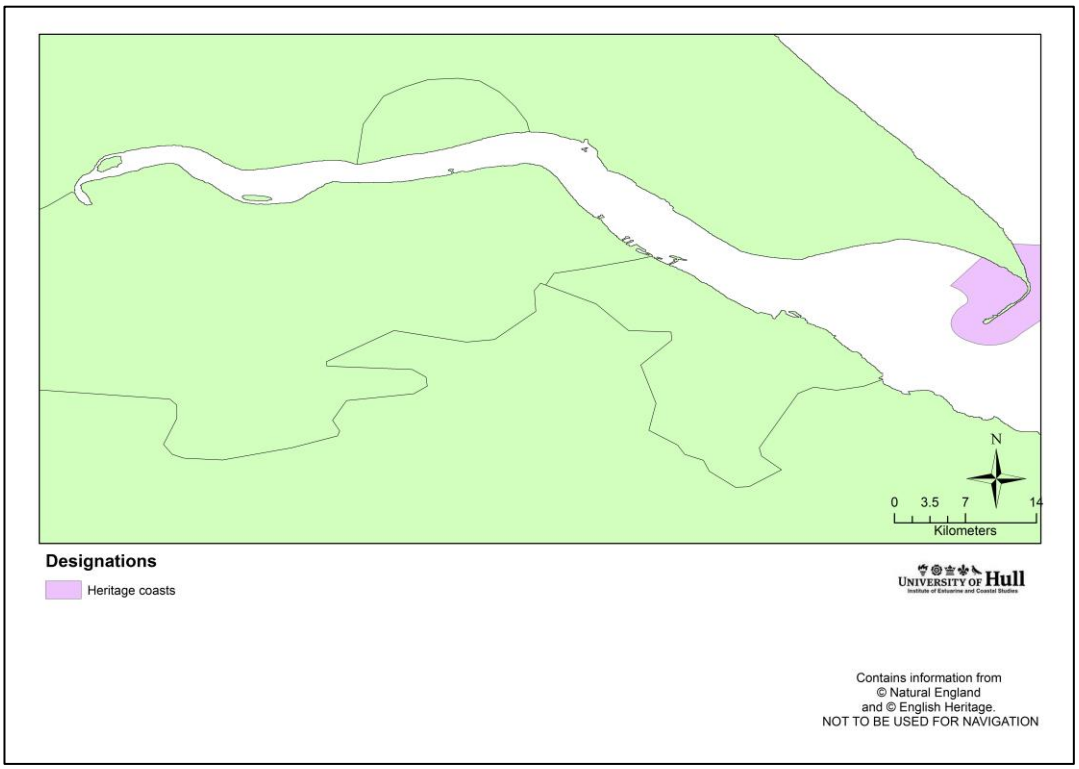



Figure A 14 Heritage Coasts of the Humber Estuary

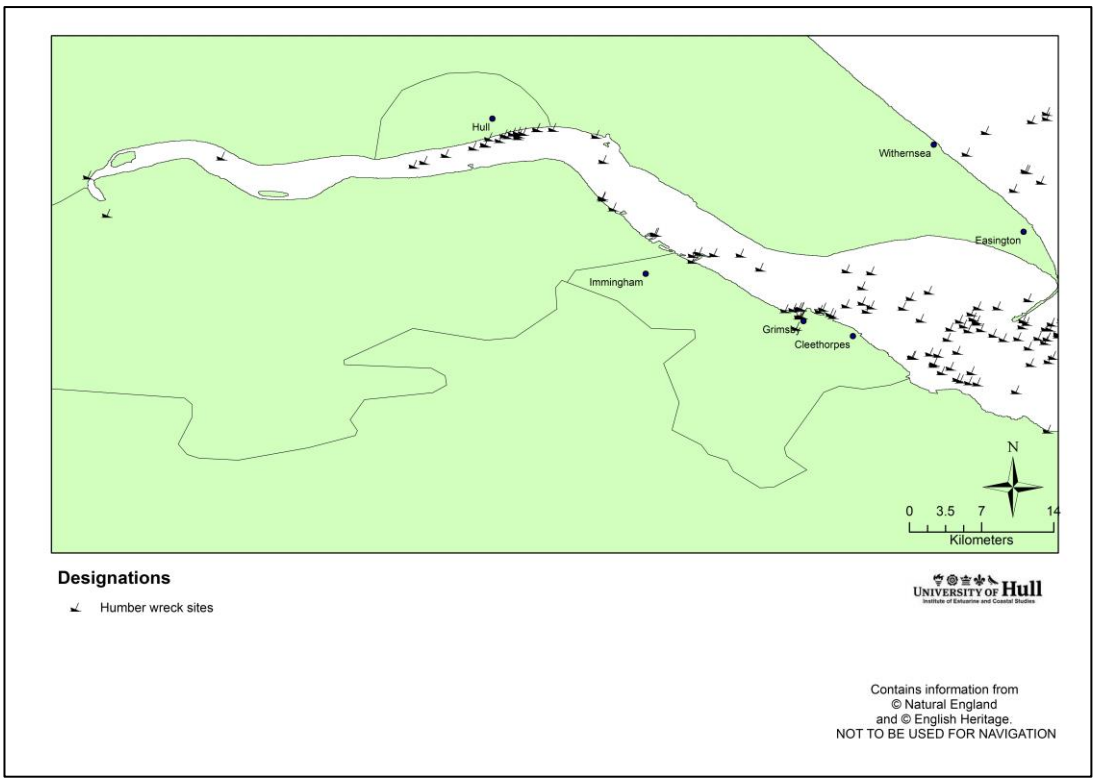



Figure A 15 Wrecks of the Humber Estuary

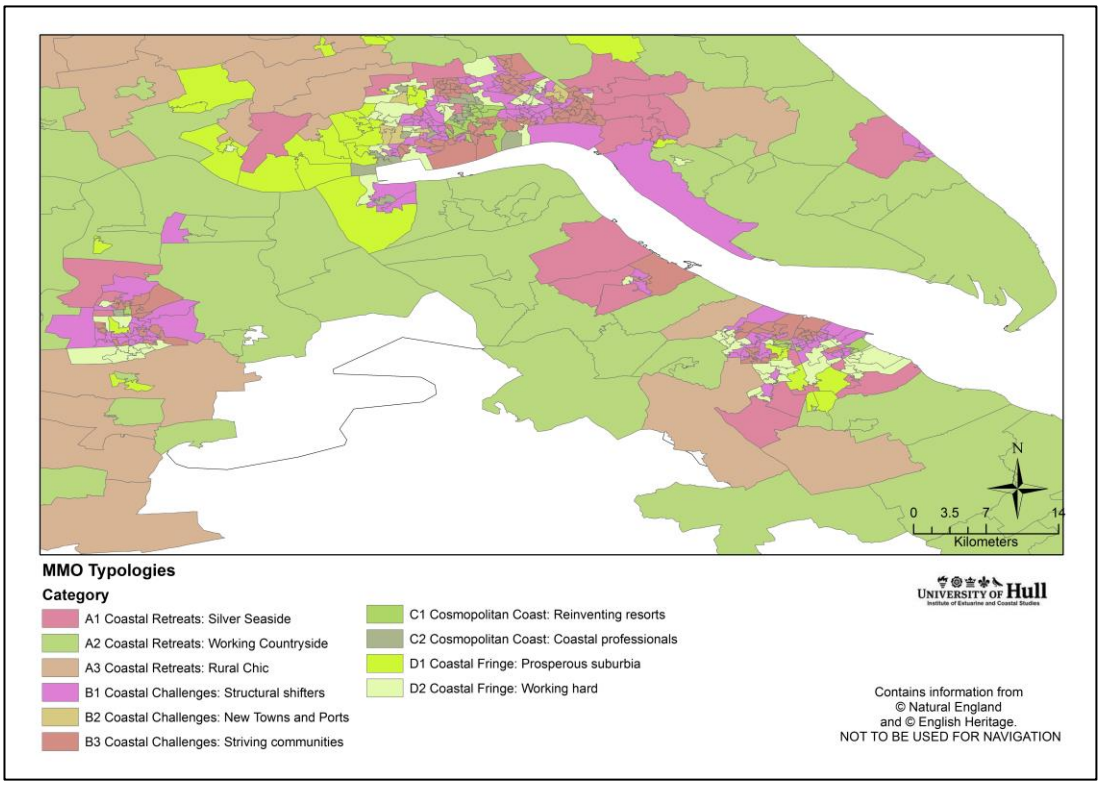



Figure A 16 MMO Typologies

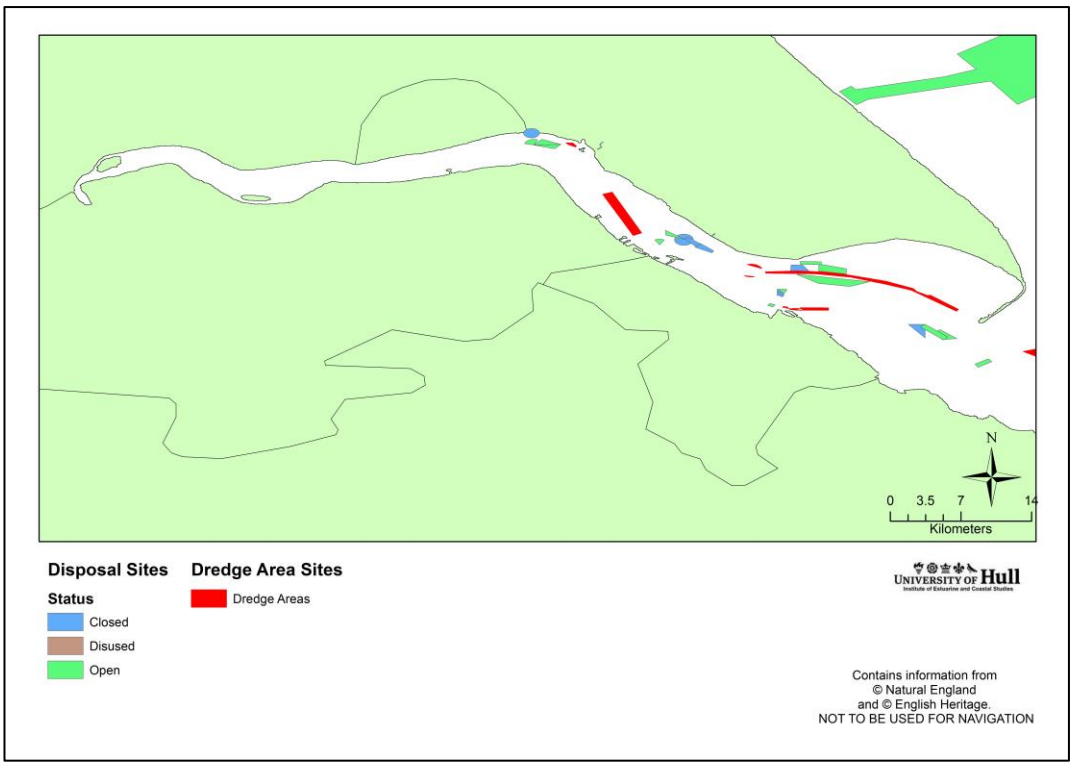



Figure A 17 Dredge and Disposal Sites of the Humber Estuary

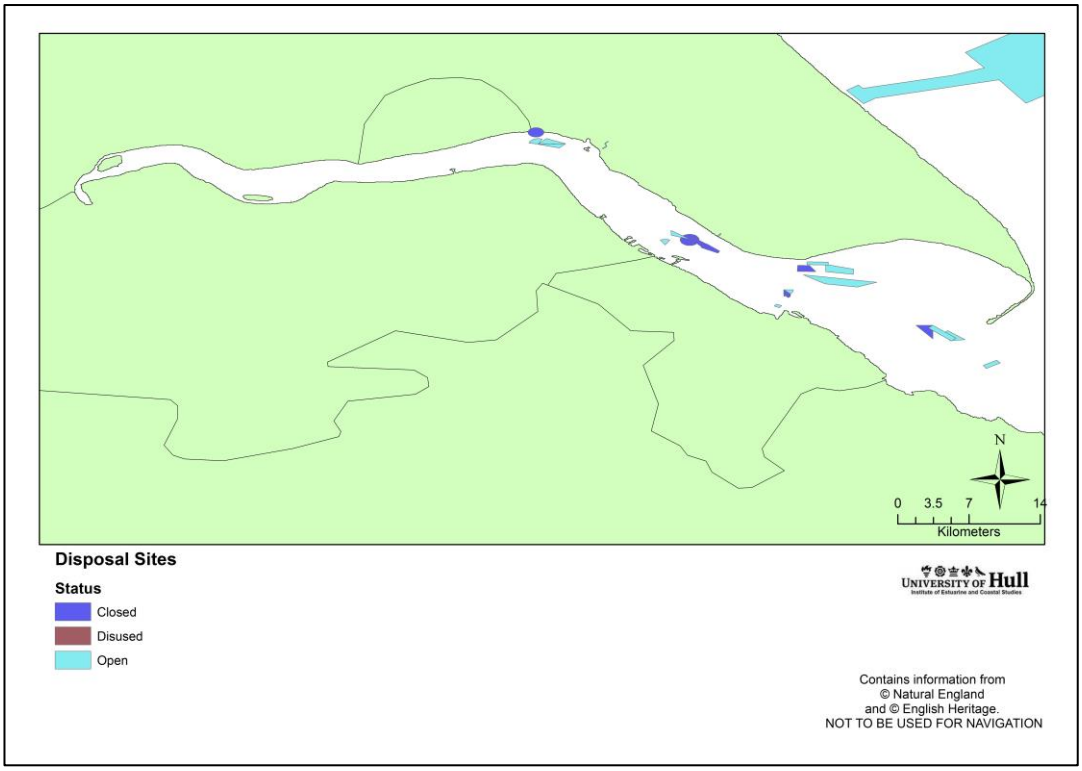
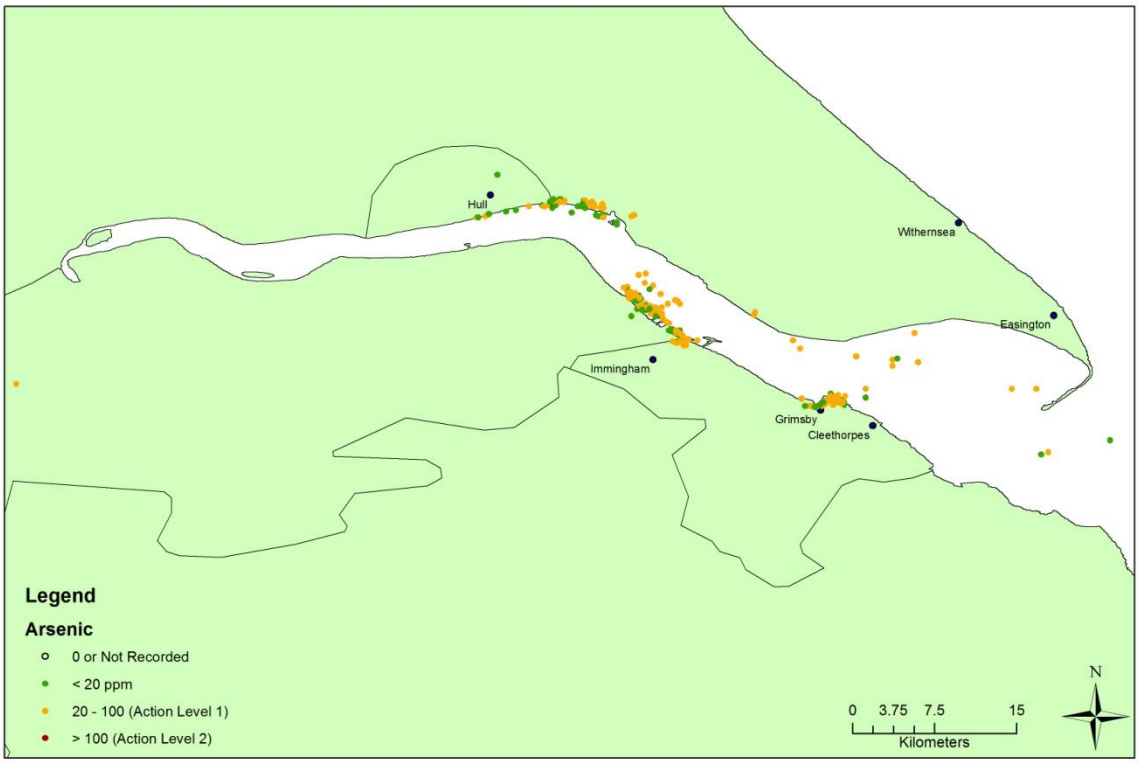
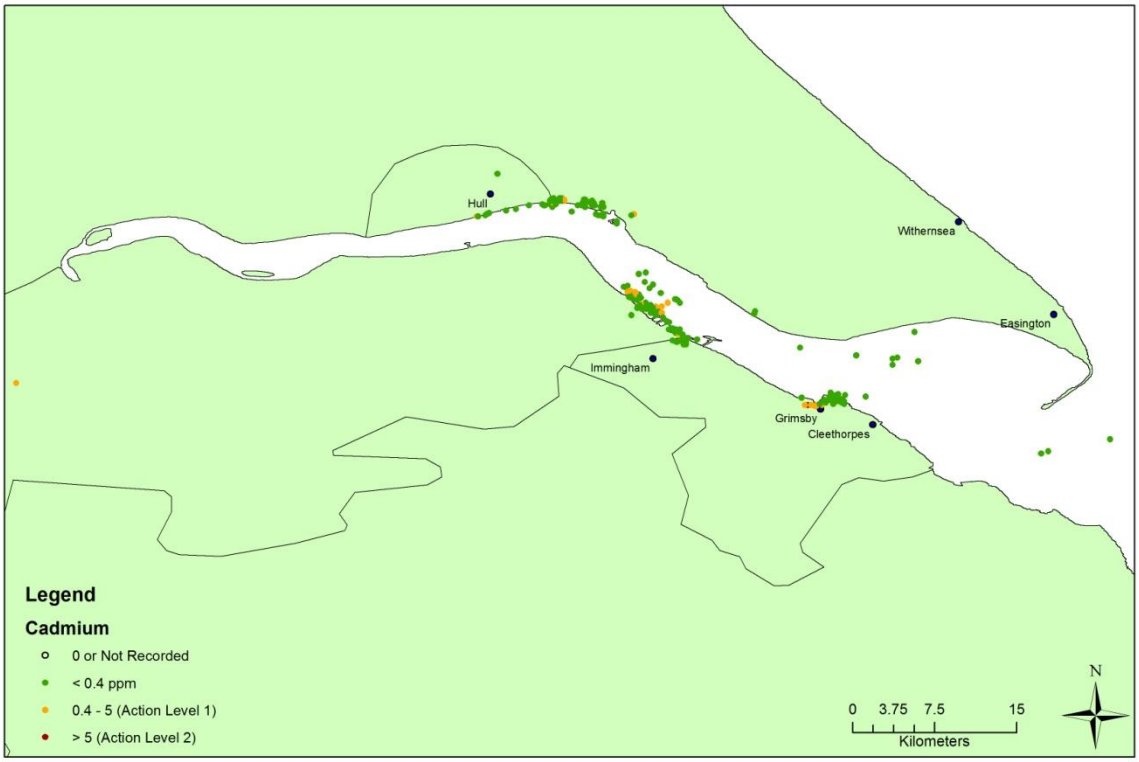


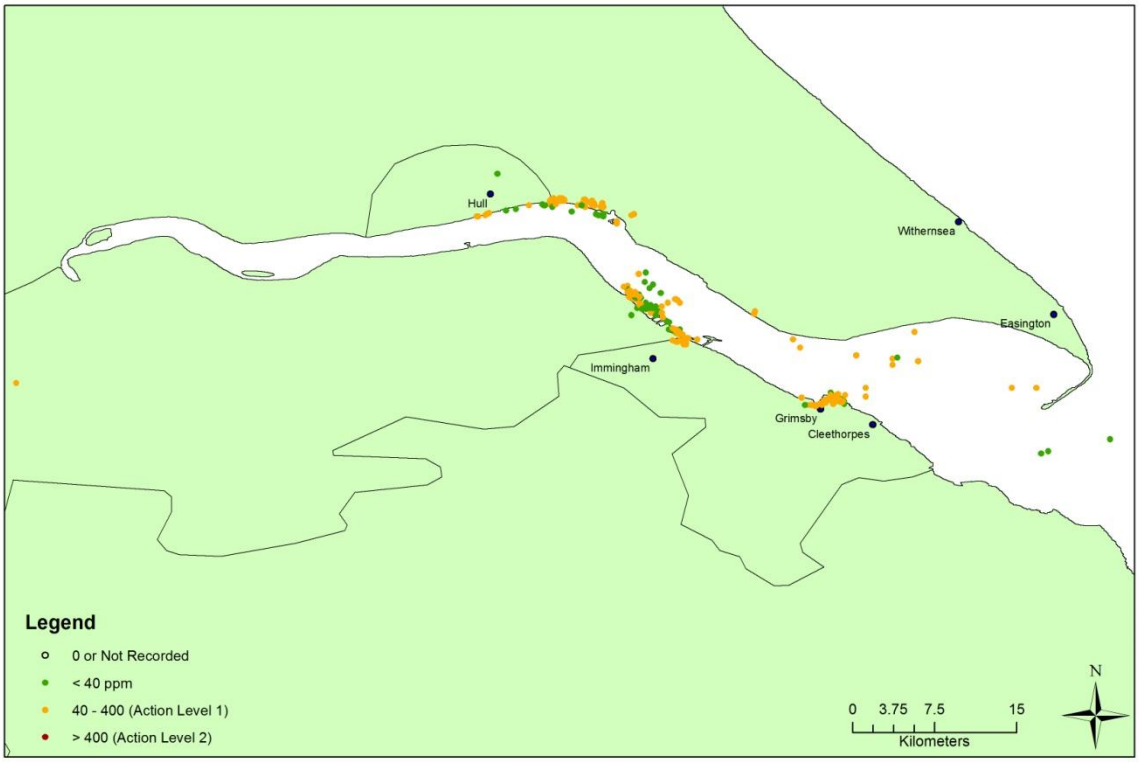

Figure A 18 Disposal sites and their status of the Humber Estuary

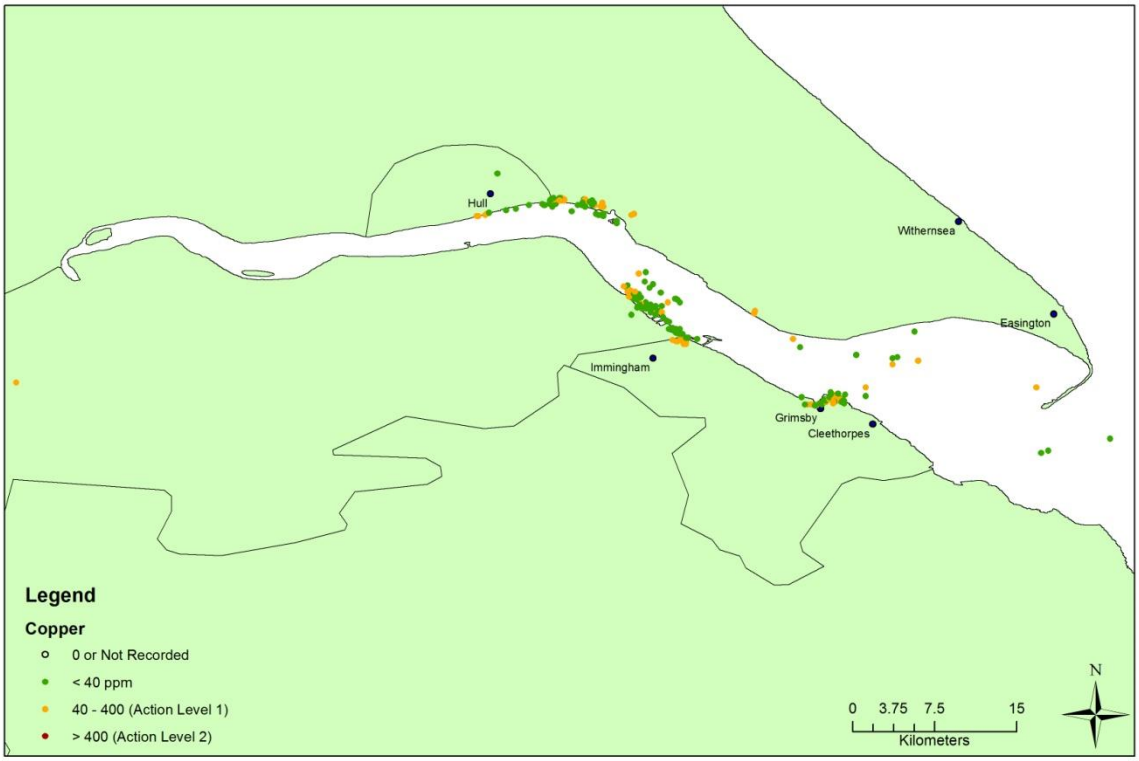
Figure A 19 Contamination of the Humber Estuary

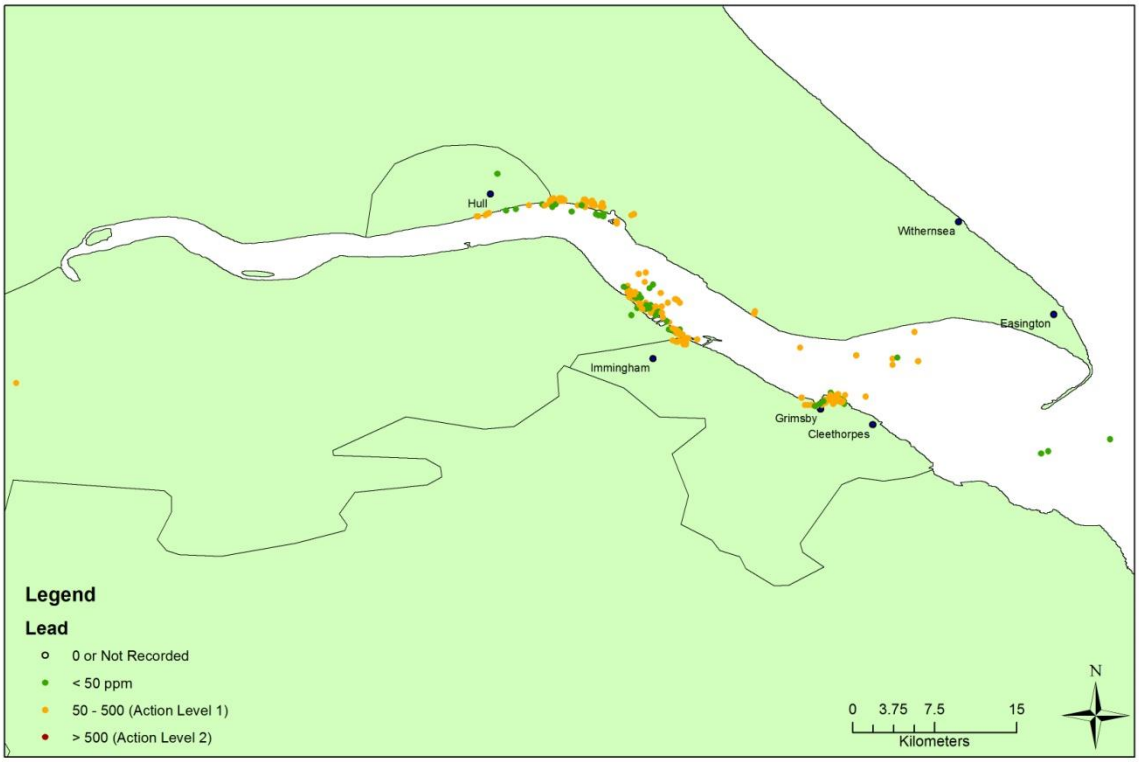
## Trace Metals




Hull
Withernsea
Easington
Immingham
Grimsby
Cleethorpes
Legend
0 or Not Recorded
< 40 ppm
40 - 400 (Action Level 1)
> 400 (Action Level 2)
0 3.75 7.5 15
Kilometers
N


Hull
Withernsea
Easington
Immingham
Grimsby
Cleethorpes
Legend
Copper
0 or Not Recorded
< 40 ppm
40 - 400 (Action Level 1)
> 400 (Action Level 2)
0 3.75 7.5 15
Kilometers
N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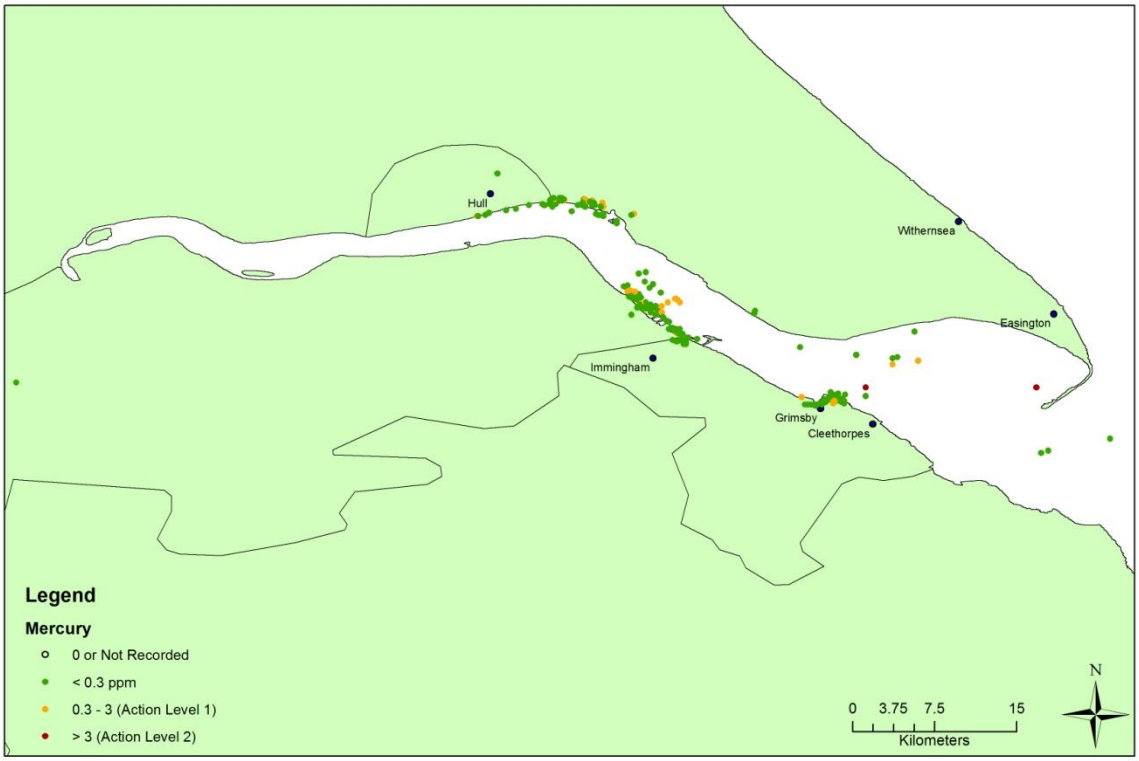
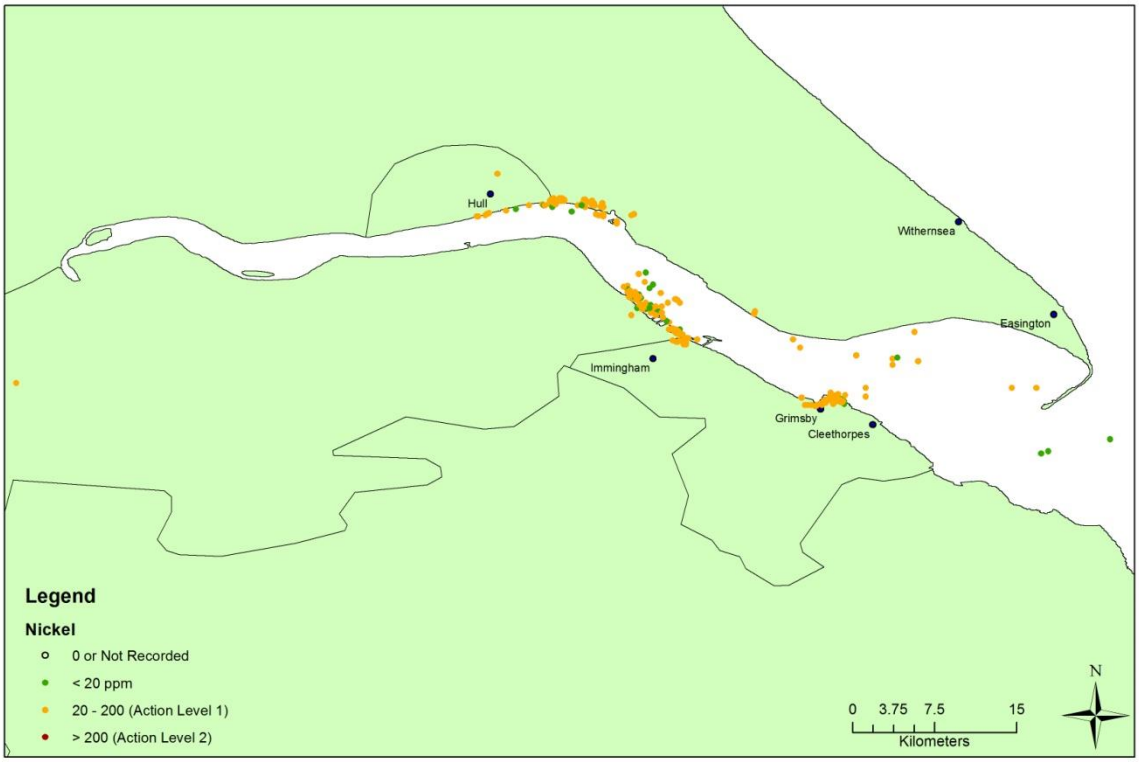
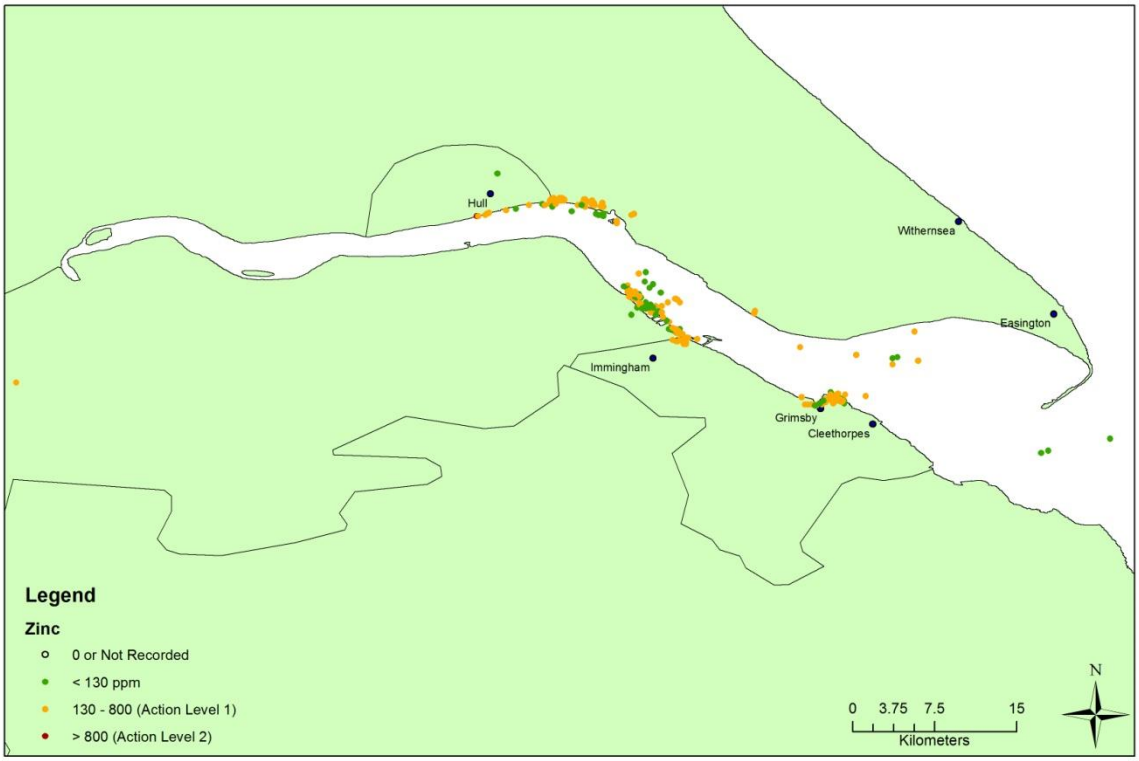
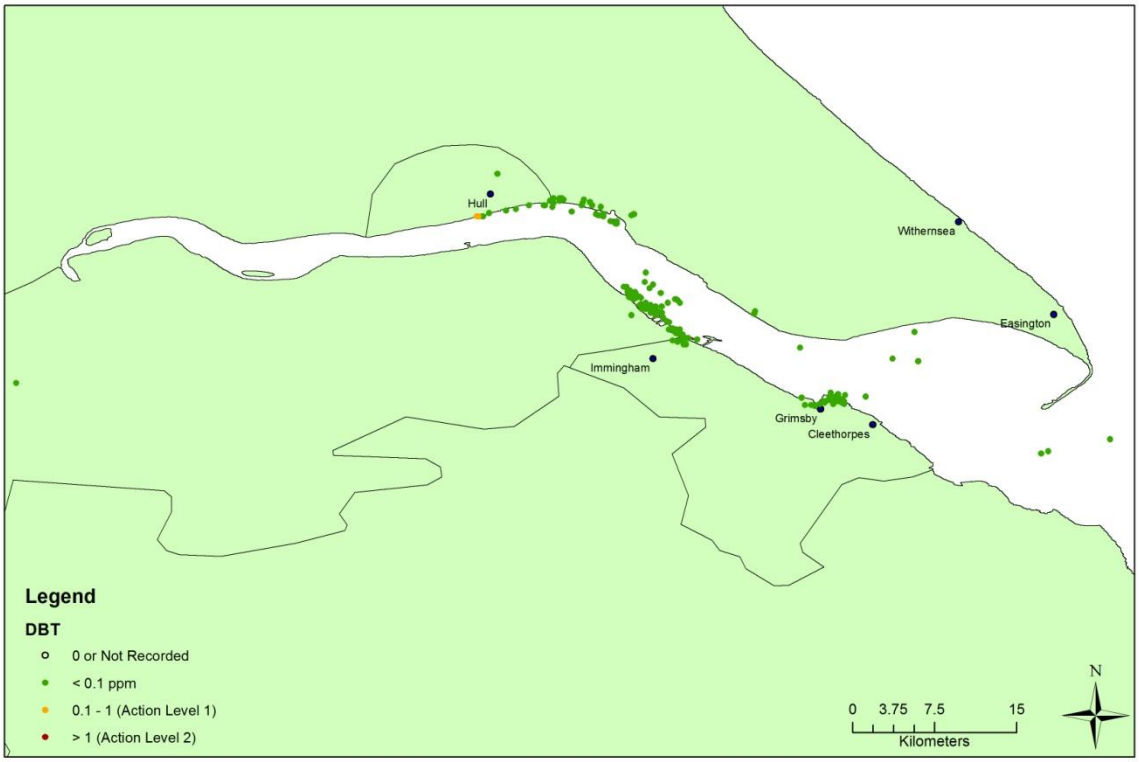
Withernsea
Easington
Immingham
Grimsby
Cleethorpes
Legend
Lead
0 or Not Recorded
< 50 ppm
50 - 500 (Action Level 1)
> 500 (Action Level 2)
0 3.75 7.5 15
Kilometers
N


Hull
Withernsea
Easington
Immingham
Grimsby
Cleethorpes
Legend
Mercury
0 or Not Recorded
< 0.3 ppm
0.3 - 3 (Action Level 1)
> 3 (Action Level 2)
0 3.75 7.5 15
Kilometers
N


Hull
Withernsea
Easington
Immingham
Grimsby
Cleethorpes
Legend
Nickel
0 or Not Recorded
< 20 ppm
20 - 200 (Action Level 1)
> 200 (Action Level 2)
0 3.75 7.5 15
Kilometers
N


Hull
Withernsea
Easington
Immingham
Grimsby
Cleethorpes
Legend
Zinc
0 or Not Recorded
< 130 ppm
130 - 800 (Action Level 1)
> 800 (Action Level 2)
0 3.75 7.5 15
Kilometers
N

Organotins


Hull
Withernsea
Easington
Immingham
Grimsby
Cleethorpes
Legend
DBT
0 or Not Recorded
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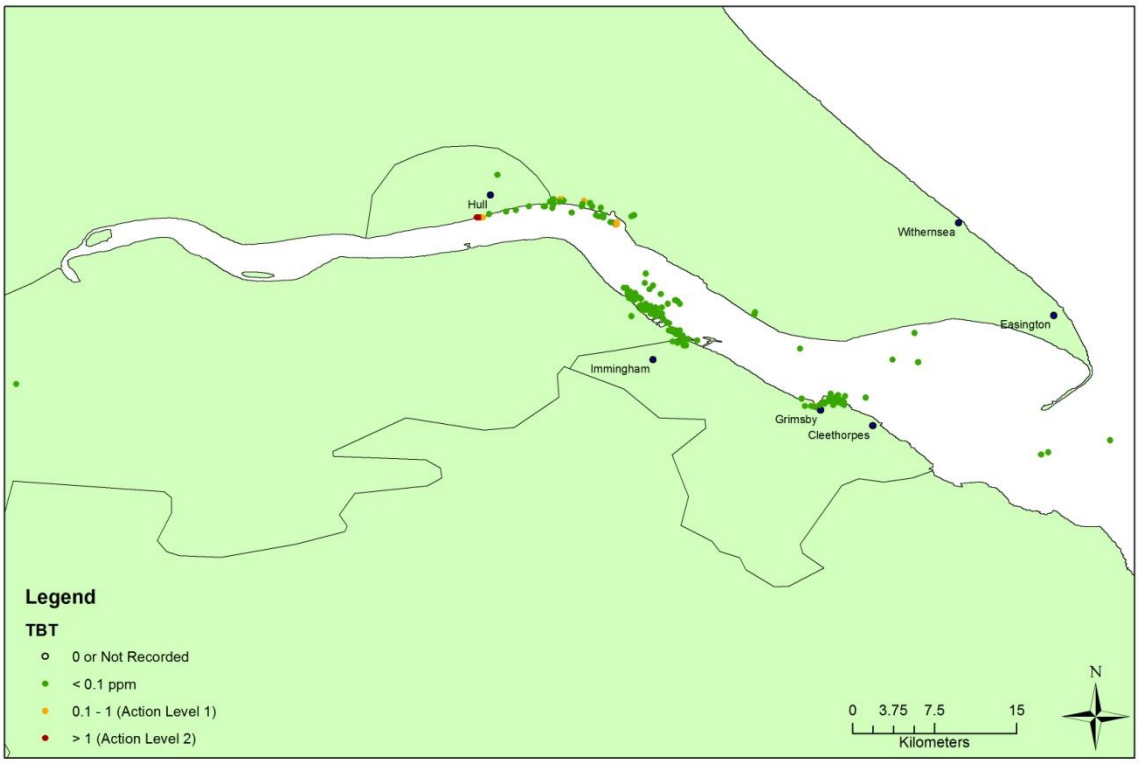
0.1 - 1 (Action Level 1)
> 1 (Action Level 2)
0 3.75 7.5 15
Kilometers
N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Withernsea
Easington
Immingham
Grimsby
Cleethorpes
Legend
TBT
0 or Not Recorded
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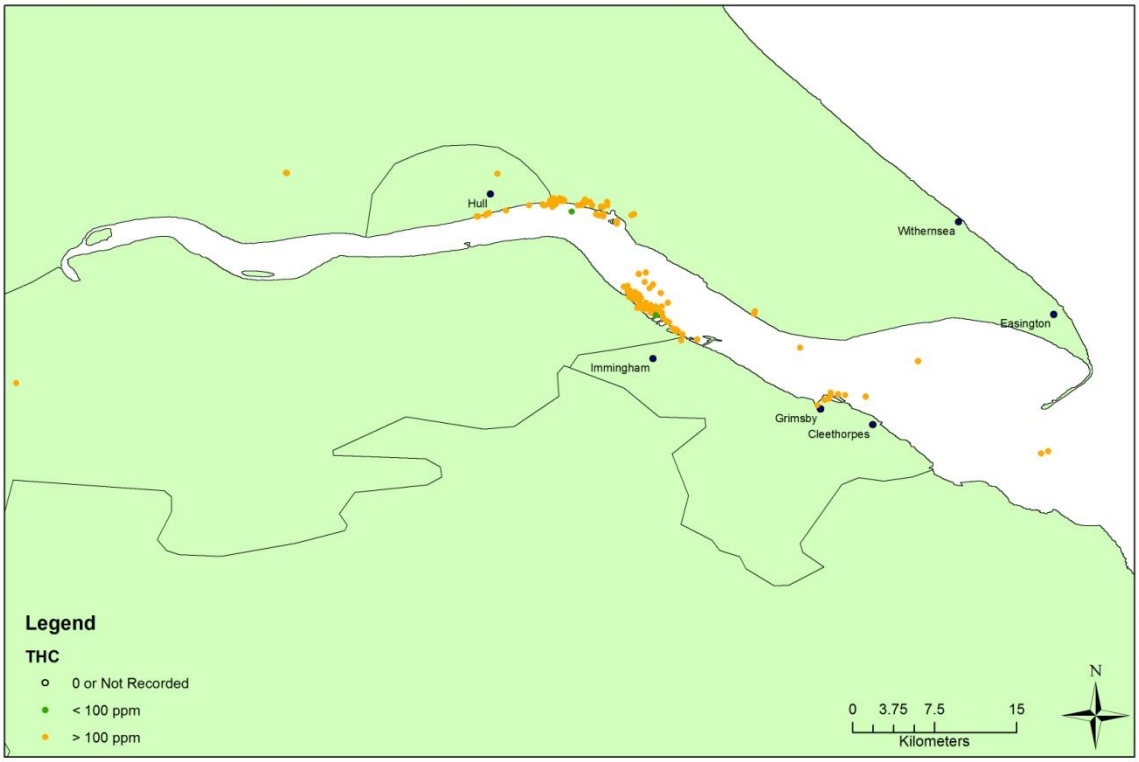
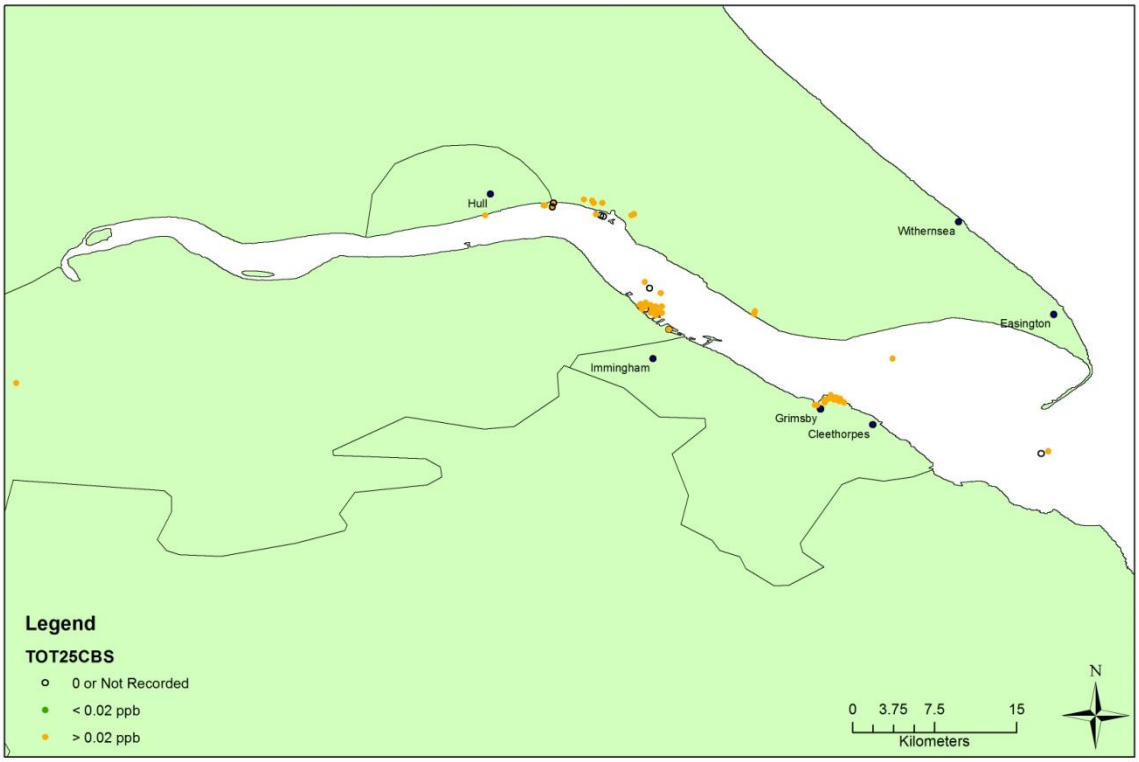
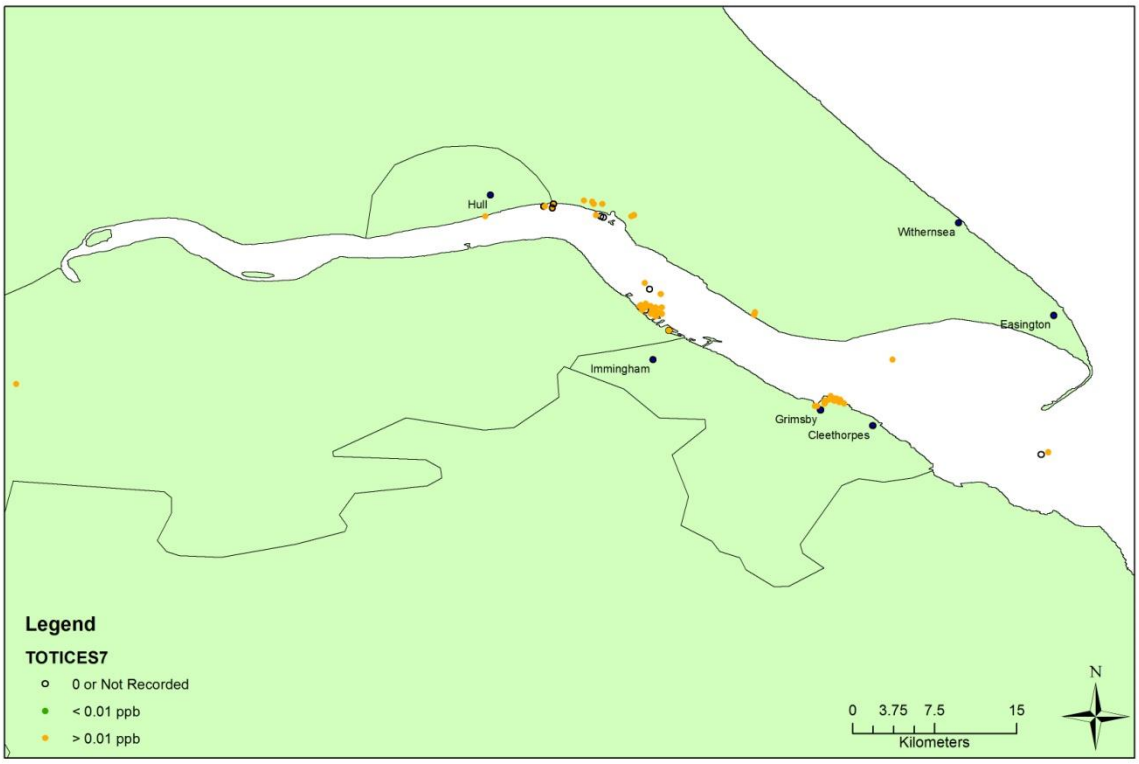
0.1 - 1 (Action Level 1)
> 1 (Action Level 2)
0 3.75 7.5 15
Kilometers
N

Hydrocarbons



PCBs


Hull
Withernsea
Easington
Immingham
Grimsby
Cleethorpes
Legend
TOT25CBS
0 or Not Recorded
< 0.02 ppb
> 0.02 ppb
0 3.75 7.5 15
Kilometers
N


Hull
Withernsea
Easington
Immingham
Grimsby
Cleethorpes
Legend
TOTICES7
0 or Not Recorded
< 0.01 ppb
> 0.01 ppb
0 3.75 7.5 15
Kilometers
N

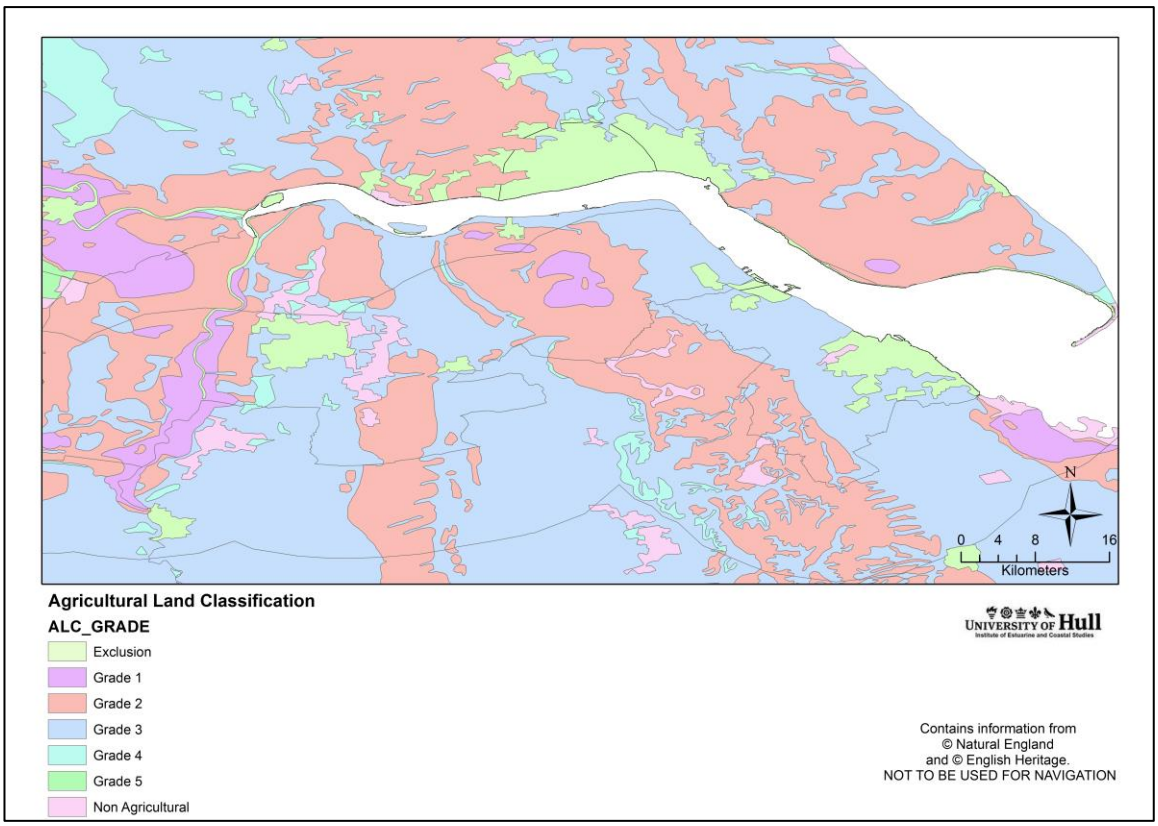



Figure A 20 Agriculture

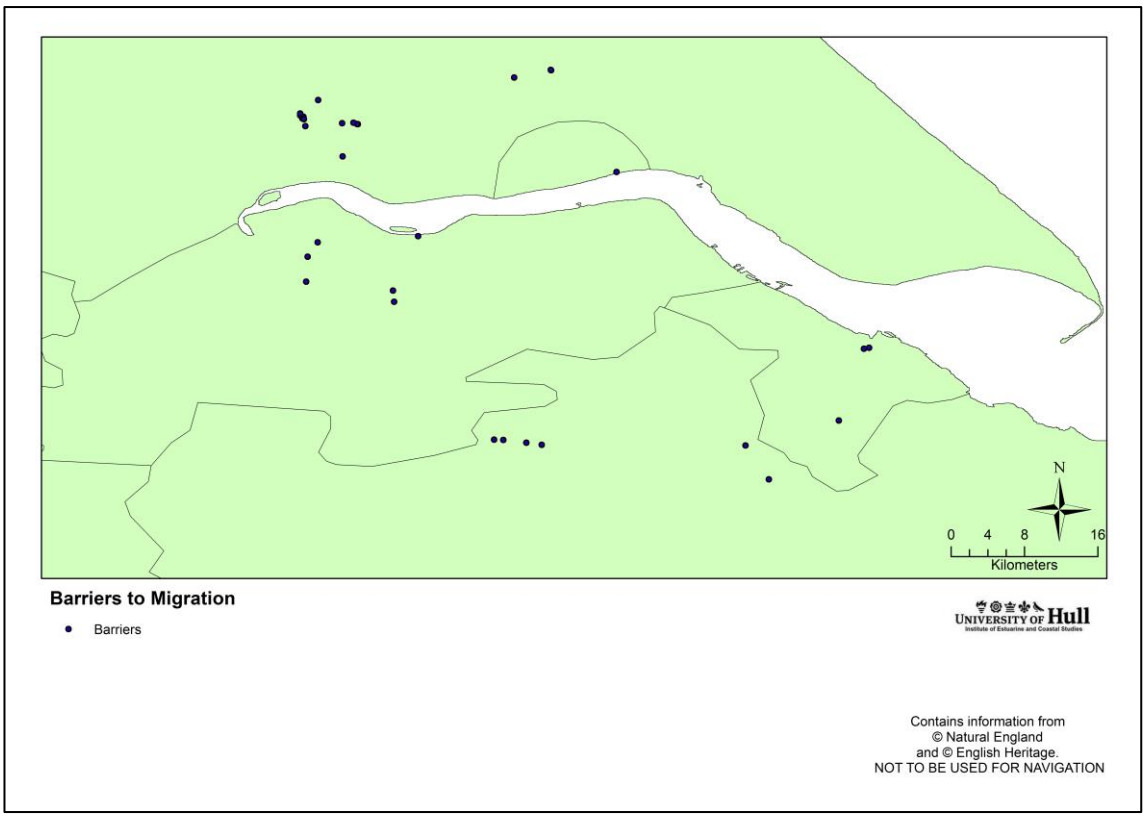



Figure A 21 Barriers of the Humber Estuary to migration

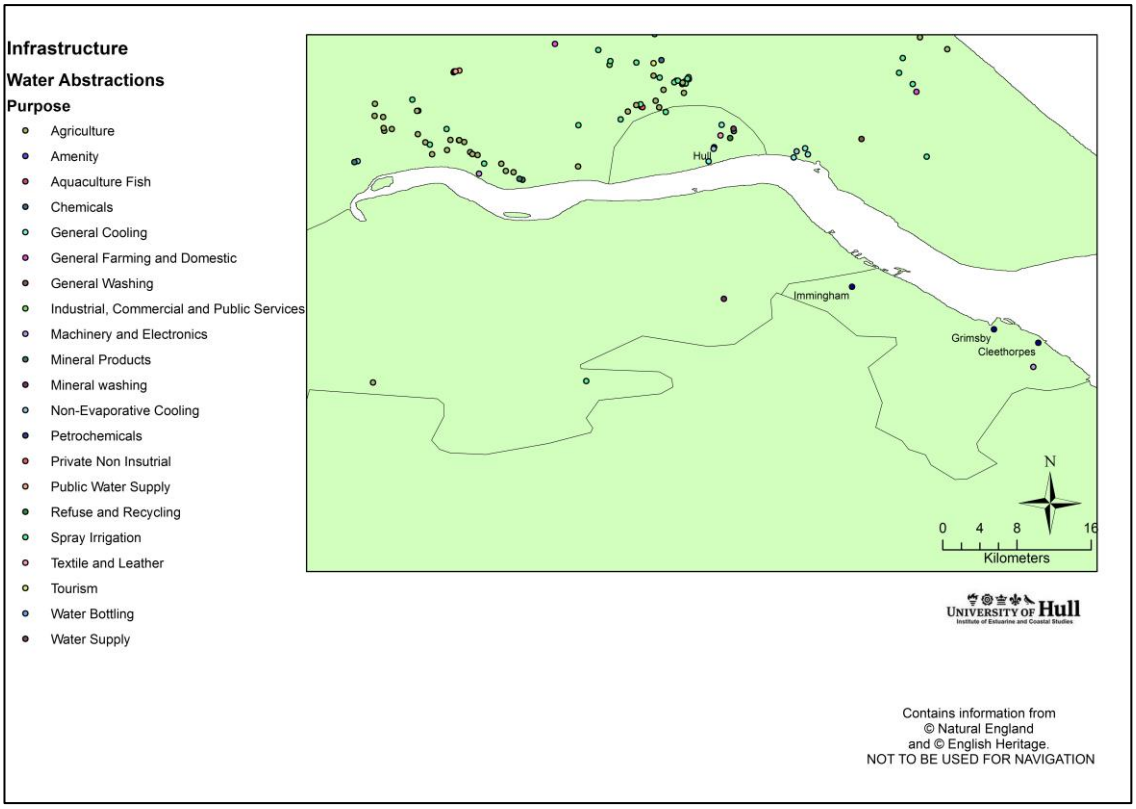



Figure A 22 Water abstraction points of the Humber Estuary

Appendix 2

Source Data Table

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| Port Locations for the Humber Estuary | Gridreferencefinder.co.uk | This layer shows the locations of the ports, docks and jetties in the Humber Estuary. | N/A |
| Shipping Density | www.gov.uk | This data shows the import and export in tonnages for the UK and specific Humber ports. | 13/02/2014 |
| UK Bathing Waters | Environment Agency | These data consist of 5 shapefiles showing the extent of Urban Wastewater Treatment Directive sensitive areas (eutrophic, bathing waters and nitrate) in England and Wales. Bathing Waters shows areas currently designated as UWWTD bathing water sensitive areas. Downloaded from http://www.geostore.com/environment-agency | 07/01/2014 |
| Protected Wreck Point | Environment Agency | The dataset shows the location of protected wrecks as designated by the MCA under The Protection of Wrecks Act 1973- section 1 and 2. Downloaded from http://www.geostore.com/environment-agency | 07/01/2014 |
| Wrecks in the Humber | English heritage | This dataset shows the wrecks, protected and otherwise, in the Humber Estuary and those that lie just outside of the mouth. The data is English Heritage, National Record of the Historic Environment (NRHE) and should be acknowledged as such. | 25/01/2014 |
| Heritage Coast in England | Natural England | This dataset represents the sections of coast that are defined as Heritage Coast in England. Heritage Coast areas are stretches of outstanding, undeveloped coast in England and Wales and were identified through agreement with local authorities. Data downloaded from NE website. The data is NE Copyright and should be acknowledged as such. | 07/01/2014 |
| Mean High Water Mark | Marine Resource System (Origin Ordnance Survey) | This dataset shows the location of the mean high water mark for the English, Welsh and Scottish coastlines, but does not include Northern Ireland. It is based on large scale Ordnance Survey Great Britain MasterMap Topographic line data. This dataset was provided by Ordnance Survey via CD. | 01/02/2014 |
| RYA Marinas | RYA (2008) | The dataset displays the location of the RYA marinas. The dataset was first created in 2006. Marina berth holders will be permanently based at that marina but most also have a high | Atlas published 2008 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| | | proportion of visitor berths available for passing craft. The data is RYA Copyright and should be acknowledged as such. | |
| RYA Racing Areas | RYA (2008) | This dataset displays the location of the RYA Racing Areas. These are areas in frequent use by large numbers of racing craft normally under sail but also power. Such areas are generally under the control of nearby Sailing Clubs and may contain temporary or permanent race course marking buoys. The data is RYA Copyright and should be acknowledged as such. | Atlas published 2008 |
| RYA Clubs | RYA (2008) | This dataset displays the location of the RYA clubs. The dataset was first created in 2006.These are areas in extensive use for general day sailing by all types of craft. The data is RYA Copyright and should be acknowledged as such. | Atlas published 2008 |
| RYA Sailing Areas | RYA (2008) | This dataset displays the location of the RYA sailing areas. The dataset was first created in 2006. The data is RYA Copyright and should be acknowledged as such. | Atlas published 2008 |
| RYA Training Centres | RYA (2008) | This dataset displays the location of the RYA Training Centres. The dataset was first created in 2006. The data is RYA Copyright and should be acknowledged as such. | Atlas published 2008 |
| Sites of Special Scientific Interest | Natural England | This dataset displays areas of land and water that are designated as a Site of Special Scientific Interest (SSSI). A SSSI is the land notified as an SSSI under the Wildlife and Countryside Act (1981), as amended. Sites notified under the 1949 Act only are not included in the Data set. SSSI are the finest sites for wildlife and natural features in England, supporting many characteristic, rare and endangered species, habitats and natural features. The data do not include "proposed" sites. Data downloaded from NE website. The data is NE Copyright and should be acknowledged as such. | 05/01/2014 |
| Ramsar Sites | Natural England | This dataset displays areas of land and water that are designated as a Ramsar site. A Ramsar site is the land listed as a Wetland of International Importance under the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (the Ramsar Convention) 1973. Data supplied has the status of "Listed". The data does not include | 05/01/2014 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| | | "proposed" sites. Data downloaded from NE website. The data is NE Copyright and should be acknowledged as such. | |
| Special Areas of Conservation | Natural England | This dataset displays areas of land and water that are designated as a Special Area of Conservation (SAC). SAC is the land designated under Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora. Data supplied has the status of "Candidate". The data does not include "proposed" Sites. Data downloaded from NE website. The data is NE Copyright and should be acknowledged as such. | 05/01/2014 |
| Special Protection Areas | Natural England | This dataset displays areas of land and water that are designated as a Special Protection Area (SPA). SPA is the land classified under Directive 79/409 on the Conservation of Wild Birds. Data supplied has the status "Classified". The data does not include "proposed" sites. Boundaries are mapped against Ordnance Survey MasterMap. Data downloaded from NE website. The data is NE Copyright and should be acknowledged as such. | 05/01/2014 |
| Agricultural Land Classification | Natural England | This dataset shows the classifications of agricultural land as set out in the National Policy Planning Framework. Class 1 being excellent and Class 5 being very poor. Data downloaded from Environment Agency website. The data is NE Copyright and should be acknowledged as such. | 05/01/2014 |
| Country Parks | Natural England | This dataset shows the country parks asdefined under the 1968 Countryside Act. Natural England recognises country parks as significant places that contribute to England's accessible natural greenspace. Data downloaded from NE website. The data is NE Copyright and should be acknowledged as such. | 07/12/2013 |
| Woodland | Natural England | This dataset shows the areas designated as woodland in the UK. Data downloaded from NE website. The data is NE Copyright and should be acknowledged as such. | 07/12/2013 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| Managed Realignment Sites | ABPmer | This layer shows the location of the managed realignment sites on the Humber Estuary. Coordinates provided by ABPmer (Website 1) and points plotted. Only shows points not the entire area of the site | 07/12/2013 |
| Dredge Sites | Taken from ABP Humber, Humber Estuary Services (2011); ABPmer (2011); ABPmer and Scott Wilson (2010); ABPmer (2009a,b); Environmental Resource Management (2011) and Scott Wilson (2011) | This layer shows the maintenance dredge sites and proposed capital dredge projects in the Humber Estuary | 15/03/2014 |
| Disposal Sites | Cefas | This dataset shows the designated disposal sites for the disposal of dredged material in the Humber Estuary | 14/02/2014 |
| Wildfowling | Fearnley *et al.*, 2012 | The areas of wildfowling were collected by the HINCA through interviews and with local British Shooting Association offices as part of the Fearnley *et al.*(2012) study. General locations were provided in the report therefore the locations are indicative. | July 2012 |
| Population | Office for National Statistics | This dataset contains information on the population estimates, births and deaths for the four local authorities adjacent to the Humber Estuary: East Riding of Yorkshire Council; Kingston-Upon-Hull; North East Lincolnshire Council and North Lincolnshire council. The data is ONS Copyright and should be acknowledged as such. | 04/01/2014 |
| Outfall Discharge Points | Environment Agency | A point dataset showing outfalls and discharges into Canal and Rivers Trust network. Downloaded from http://www.geostore.com/environment-agency | 07/01/2014 |
| Water Abstractions | Environment Agency | This layer shows the locations of the water abstractions licensed from the Environment Agency, the purpose of the abstraction and the rates. | 15/03/2014 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| Pollution incidents | Environment Agency | This layer shows the locations and types of pollution incidents in the Humber Estuary and catchment. | 15/03/2014 |
| Number of any physical barriers to fish migration | Environment Agency | This layers shows the location of barriers to fish migration in the Humber Estuary and catchment | 15/03/2014 |
| Locations of artificial flood defences | Environment Agency | Maps (in Appendix XX) provided by the Environment Agency (*pers. Comm.*) show where the flood defences are located for the Humber Estuary. | 01/03/2014 |
| Bait Digging | Fearnley *et al.*, 2012 | The areas of bait digging were collected by the HINCA through interviews. General locations were provided in the report therefore the locations are indicative. | July 2012 |
| Beaches | Fearnley *et al.*, 2012 | The areas of beaches were collected by the HINCA through interviews and with local knowledge. General locations were provided in the report therefore the locations are indicative. | July 2012 |
| Kitesurfing | Fearnley *et al.*, 2012 | The areas of kitesurfing were collected by the HINCA through interviews. General locations were provided in the report therefore the locations are indicative. | July 2012 |
| Marine Benthic Invertebrate Species | Environment Agency | Information regarding the presence, and abundance, of benthic invertebrate species at specific marine monitoring points. Note: only data from 2007 onwards is subject to NMBAQC quality assurance. Downloaded from http://www.geostore.com/environment | 07/01/2014 |
| Saltmarsh Extents | Environment Agency | Polygon data layer showing the extent of Saltmarsh in Coastal and Transitional waters for use by both Flood and Coastal Risk Management and the implementation of Water Framework Directive. Downloaded from http://www.geostore.com/environment | 07/01/2014 |
| Saltmarsh Species | Environment Agency | Information regarding the presence, and percentage cover, of saltmarsh angiosperms (flowering plants) at specific marine monitoring points. Downloaded from http://www.geostore.com/environment | 07/01/2014 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| Sensitive Area Maps-Eutrophic Coastal Areas | Environment Agency | These data consist of 5 shapefiles showing the extent of Urban Wastewater Treatment Directive sensitive areas (eutrophic, bathing waters and nitrate) in England and Wales. Eutrophic Harbours and Estuaries shows harbours and estuaries currently designated as UWWTD eutrophic sensitive areas. Downloaded from http://www.geostore.com/environment | 07/01/2014 |
| UK Water Quality Sampling Harmonised Monitoring Scheme Detailed Data | Environment Agency | This dataset contains individual determinand results for all 230 sites from 1974 onwards. The sites are mainly located at the tidal limits of major rivers or at the points of confluence of significant tributaries and the information held within include data on: Oxygen and ammonia, Nutrients, List II metals and Pesticides. Downloaded from http://www.geostore.com/environment | 07/01/2014 |
| WFD Rocky Shore Macro-algal Species | Environment Agency | Information regarding the presence of macroalgal species on rocky shores monitored for the Water Framework Directive ecological assessment of transitional and coastal waters of England and Wales. Downloaded from http://www.geostore.com/environment | 07/01/2014 |
| MMO Socio-economic Typologies of Coastal Communities | Environment Agency | The data differentiates between different coastal areas on the basis of their socio-economic characteristics. Downloaded from http://www.geostore.com/environment | 07/01/2014 |
| UK Fish Landings by ICES Rectangles 2007-2011 | Environment Agency | Annual statistics for commercial fishing activity by UK registered fishing vessels for the year indicated. Statistics covering fishing effort (kilowatt/days), landings by value (pounds sterling) and landings by live weight (tonnes) are provided for the North East Atlantic (FAO Major Area 27), referenced to ICES statistical rectangles.<br><br>Downloaded from http://www.geostore.com/environment | 07/01/2014 |
| Canal and Rivers Trust –Docks | Environment Agency | Polygonal dataset depicting Canal and River Trust docks<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| Canal and Rivers Trust- Outfall/Discharge Points | Environment Agency | A point dataset showing outfalls and discharges into Canal and River Trust network<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| Canal and Rivers Trust- Wharves | Environment Agency | Point dataset depicting the location of Canal and River Trust wharves<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| Administrative Boundaries- Public Face Areas | Environment Agency | Environment Agency Public Face Areas administrative boundaries at 1:10,000 scale<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| Administrative Boundaries- Water Management Areas | Environment Agency | Environment Agency Water Management Areas administrative boundaries at 1:10,000 scale<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| Shoreline Management Plan Extents | Environment Agency | Shoreline Management Plans (SMP2) are large-scale assessments of the risks associated with coastal processes which help to reduce these risks to people and the developed, historic and natural environments.<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| WFD Coastal Waterbodies | Environment Agency | The dataset contains the extents of waterbodies identified as "coastal" under the Water Framework Directive. Based on River Basin Characterisation 2 (RBC2) data. Environment Agency copyright and/or database right 2008. All rights reserved<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| WFD Coastal Waterbodies- Cycle 2 DRAFT | Environment Agency | The 'WFD Coastal Waterbodies Cycle 2 Draft' are the WFD coastal waterbodies which have undergone a small amount of update since cycle 1 to make them more logical coastal management units.<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| WFD Management Catchments Cycle 2 DRAFT | Environment Agency | Management Catchments are the geographical units for which action plans are drafted in implementing the Water framework Directive (WFD). Catchments have an action plan published that relates to all waterbodies that fall within<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| WFD River Basin Districts Cycle 2 DRAFT | Environment Agency | River Basin Districts are the geographical units showing the area of land and sea, made up of one or more neighbouring river basins together with their associated groundwaters and coastal waters for assessment and action under the Water Framework Directive (WFD).<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| WFD River Waterbody Waterbodies Cycle 2 DRAFT | Environment Agency | The 'WFD River Waterbodies Cycle 2 Draft' are the river waterbodies which are based on the Agency's Detailed River Network, and have undergone significant QA since Cycle 1.<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| WFD River Waterbody Catchments Cycle 2 DRAFT | Environment Agency | The 'WFD River Waterbody Catchments Cycle 2 Draft' are a series of non-overlapping polygon catchments based on the extents of the Cycle 2 river waterbodies<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| WFD Transitional Waterbodies | Environment Agency | The dataset contains the extents of the waterbodies identified as "transitional" under the Water Framework Directive. Environment Agency copyright and/or database right 2008. All rights reserved. | 06/11/2014 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| | | Downloaded from http://www.geostore.com/environment | |
| WFD Transitional Waterbodies Cycle 2 DRAFT | Environment Agency | The WFD Transitional Waterbodies Cycle 2 Draft are the WFD transitional (estuarine) waterbodies which have undergone a small amount of update since cycle 1 to make them more logical management units.<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| EUNIS habitat map | European Marine Observation and Data Network | The EUNIS habitat map layer was compiled by JNCC on behalf of the MESH and MESH Atlantic projects to produce a single layer of EUNIS habitat maps with overlaps between mapping studies removed. Areas of maps are removed if a map having a higher overall confidence score overlaps them. Updated 9/12/2013. | 31/01/2015 |
| OSPAR Threatened and/or Declining Habitats 2013 | European Marine Observation and Data Network | A compilation of OSPAR habitat data for the northeast Atlantic, compiled on behalf of the OSPAR Commission by JNCC, working with representatives from each of the OSPAR coastal contracting parties. Updated 18/02/2013. | 31/01/2015 |
| UK Sea Map Seabed | European Marine Observation and Data Network | Shows the harmonised predictive benthic habitat layers across the Celtic Seas, Greater North Sea and Baltic Sea, as well as undertaking broad-scale mapping of the western Mediterranean. Downloaded from www.emodnet-geology.eu | 31/01/2015 |
| SAC and sensitivity | JNCC | See Appendix 6 for methodology of developing the SAC and sensitivity layer. This dataset displays areas of land and water that are designated as a Special Area of Conservation (SAC). SAC is the land designated under Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora. Data supplied has the status of "Candidate". The data does not include "proposed" Sites. Data downloaded from NE website. The data is NE Copyright and should be acknowledged as such. Sensitivities from Tillin *et al.*(2010). | 05/01/2014 |
| Construction layers (in points, lines and polygons) | MARINE MANAGEMENT ORGANISATION,Cefas | Based on the Marine Licence applications made to the MMO and held by Cefas as part of their assessments. All data is freely available on the MMO's Marine Case Management System | N/A |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| Tracer Application | MARINE MANAGEMENT ORGANISATION,Cefas | Based on the Marine Licence applications made to the MMO and held by Cefas as part of their assessments. All data is freely available on the MMO's Marine Case Management System | N/A |
| Flow Gauges | Environment Agency | Provide by the Environment Agency | 06/11/2014 |
| Horse Riding | Fearnley *et al.*, 2012 | The areas of wildfowling were collected by the HINCA through interviews. General locations were provided in the report therefore the locations are indicative. | July 2012 |
| Bathing- Eutrophic sensitive areas | Environment Agency | These data consist of 5 shapefiles showing the extent of Urban Wastewater Treatment Directive sensitive areas (eutrophic, bathing waters and nitrate) in England and Wales. Eutrophic Harbours and Estuaries shows harbours and estuaries currently designated as UWWTD eutrophic sensitive areas. Environment Agency copyright and/or database right 2008. All rights reserved.<br><br>Downloaded from http://www.geostore.com/environment | 06/11/2014 |
| Harbour Authority | ABP HES (2011) | Taken from the Humber Maintenance Dredge Protocol and plotted on Arc GIS 10.1 | 06/11/2014 |
| Towns | Cefas | Data from OS but provided by Cefas. | 06/11/2014 |
| Counties | Cefas | Data from OS but provided by Cefas. | 06/11/2014 |
| Listed Building | Historic England | This shapefile shows the listed buildings for England. Downloaded from http://www.historicengland.org.uk/listing/the-list/data-downloads/ | 06/11/2014 |
| Park and Garden | Environment Agency | Parks and Gardens as included on the Register of Historic Parks and Gardens, with the location of each one recorded as a polygon. English Heritage data, downloaded from http://www.geostore.com/environment | 06/11/2014 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| Scheduled Monument | Historic England | This shapefile shows the listed scheduled monuments for England. Downloaded from http://www.historicengland.org.uk/listing/the-list/data-downloads/ | 06/11/2014 |
| World Heritage Site | Historic England | This shapefile shows the world heritage sites for England. Downloaded from http://www.historicengland.org.uk/listing/the-list/data-downloads/ | 06/11/2014 |
| Nursery Grounds | Cefas | Based on the report by Coull *et al.*, (1998) which includes maps of the main spawning and nursery grounds for 14 commercially important species (cod, haddock, whiting, saithe, Norway pout, blue whiting, mackerel, herring, sprat, sandeels, plaice, lemon sole, sole and Norway lobster). Provided by Cefas. | 06/11/2014 |
| Spawning Grounds | Cefas | Based on the report by Coull *et al.*, (1998) which includes maps of the main spawning and nursery grounds for 14 commercially important species (cod, haddock, whiting, saithe, Norway pout, blue whiting, mackerel, herring, sprat, sandeels, plaice, lemon sole, sole and Norway lobster). Provided by Cefas. | 06/11/2014 |
| WFD Reason for Failure | Environment Agency | This layer was produced by using the WFD (WFD_COAST_WBS_CYCLE2_DRAFT) layer and the ("Reasons for Failure" spreadsheet provided by the Environment Agency) and combining the relevant reasons for failure and measures to the Humber sub-zones for use in the WFD assessment | March 2015 |
| Coastal Design Sea Level | Environment Agency | GIS dataset and supporting information providing design / extreme sea level and typical surge information around the coastline of England and Wales under present day conditions. Data for Scotland is available from the Scottish Environment Protection Agency (SEPA). This is a specialist dataset which informs on work commenced around the coast ranging from coastal flood modelling, scheme design, strategic planning and flood risk assessments. Environment Agency copyright and/or database right 2008. All rights reserved.<br><br>Downloaded from http://www.geostore.com/environment | 02/04/2015 |
| Flood Alert Areas | Environment Agency | A Flood Alert Area is generally a large expanse of floodplain (up to and including the extreme flood outline which defines the Flood Warning Service Limit), within a catchment, | 02/04/2015 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| | | sub-catchment or group of catchments, that is/are at risk from low impact flooding (from main rivers, ordinary watercourses and the sea).Environment Agency copyright and/or database right 2008. All rights reserved.<br><br>Downloaded from http://www.geostore.com/environment | |
| Flood Risk Areas | Environment Agency | Flood Risk Areas have been defined by Lead Local Flood Authorities, based on combining risk to people, critical services and commercial and public assets, and detailed flood modelling. These areas cover surface water flooding only. Groundwater, coastal, reservoir failure, water main and river flooding are not covered. Environment Agency copyright and/or database right 2008. All rights reserved.<br><br>Downloaded from http://www.geostore.com/environment | 02/04/2015 |
| Flood Warning Areas | Environment Agency | Locations within the Flood Warning Service Limit (FWSL) that represent a single or aggregation of Flood Warning Sub Areas (FWSAs) or Flood Warning Flood Risk Areas (FWFRAs) containing a discrete community at risk of flooding. Environment Agency copyright and/or database right 2008. All rights reserved.<br><br>Downloaded from http://www.geostore.com/environment | 02/04/2015 |
| Risk of Flooding from Rivers and Sea | Environment Agency | Previously known as NaFRA Spatial Flood Likelihood Category Grid. This national assessment of flood risk for England shows the chance of flooding from rivers and/or the sea, based on cells of 50m. Each cell is allocated one of four flood risk categories, taking into account flood defences and their condition. Environment Agency copyright and/or database right 2008. All rights reserved.<br><br>Downloaded from http://www.geostore.com/environment | 02/04/2015 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| Flood Defences | Environment Agency | ArcGis shapefile (Defence_Polyline) showing the Flood Defence Assets on the North bank of the River Humber. Provided by correspondence (see Appendix 4). Environment Agency copyright and/or database right 2008. All rights reserved. | 05/05/2015 |
| Hull Barrier | Environment Agency | Shapefile that shows the Hull Barrier (Structure_Polyline). Provided by correspondence (see Appendix 4). Environment Agency copyright and/or database right 2008. All rights reserved. | 05/05/2015 |
| CMS_AllData | Cefas | This layer shows the locations of any samples that underwent analysis in support of dredging applications that were analysed at the Cefas laboratory and the results. | 14/05/2015 |
| PSAData | Cefas | This layer shows the locations of any samples that underwent particle size analysis in support of dredging applications that were analysed at the Cefas laboratory and the results. | 14/05/2015 |
| Salinity | Environment Agency | Data provided by the Humber Estuary- converted to a GIS point shapefile. Provided by correspondence (see Appendix 4). Environment Agency copyright and/or database right 2008. All rights reserved. | 17/06/2015 |
| pH | Environment Agency | Data provided by the Humber Estuary- converted to a GIS point shapefile. Provided by correspondence (see Appendix 4). Environment Agency copyright and/or database right 2008. All rights reserved. | 17/06/2015 |
| Turbidity | Environment Agency | Data provided by the Humber Estuary- converted to a GIS point shapefile. Provided by correspondence (see Appendix 4). Environment Agency copyright and/or database right 2008. All rights reserved. | 17/06/2015 |
| Water Depth | Environment Agency | Data provided by the Humber Estuary- converted to a GIS point shapefile. Provided by correspondence (see Appendix 4). Environment Agency copyright and/or database right 2008. All rights reserved. | 17/06/2015 |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| Water Temperature | Environment Agency | Data provided by the Humber Estuary- converted to a GIS point shapefile. Provided by correspondence (see Appendix 4). Environment Agency copyright and/or database right 2008. All rights reserved. | 17/06/2015 |
| Mean maximum temperature/ Mean Air Temperature/ Precipitation (mm) | Met Office | The data is on a 5km grid. The monthly and annual data sets and the 5 km version of the 1961-1990 baseline average data. The daily temperature data sets, the rainfall data sets derived from daily rainfall grids and the 25 km and regional versions of the 1961-1990 baseline average data sets. From: http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/ [downloaded 21/11/2015] | |
| Gas Pipes | National Grid | This dataset shows the gas pipes around the UK. From http://www2.nationalgrid.com/uk/services/land-and-development/planning-authority/shape-files/ [downloaded 21/11/2015] | |
| Cables | National Grid | This dataset shows the cables around the UK. From http://www2.nationalgrid.com/uk/services/land-and-development/planning-authority/shape-files/ [downloaded 21/11/2015] | |
| Crown Estate Wind Farm Export Cable Agreement Licence Areas | The Crown Estate | This dataset shows the areas that are agreed by the Crown Estate for export cables for wind farms around the UK. From http://www.thecrownestate.co.uk/energy-and-infrastructure/downloads/maps-and-gis-data/ [downloaded 21/11/2015] | |
| Crown Estate Tidal Export Cable Agreement Licence Areas | The Crown Estate | This dataset shows the areas that are agreed by the Crown Estate for export cables for tidal devices around the UK. From http://www.thecrownestate.co.uk/energy-and-infrastructure/downloads/maps-and-gis-data/ [downloaded 21/11/2015] | |

| Name | Provider | Abstract | Download Date |
|---|---|---|---|
| Telecommunication Cables | National Grid | This dataset shows the telecommunication cables around the UK. From http://www2.nationalgrid.com/uk/services/land-and-development/planning-authority/shape-files/ [downloaded 21/11/2015] | |
| Humber Estuary Bathymetry Data | ABP Hull | Provided by ABP Hull. Under the limitations this data set cannot be used for commercial work nor can it be published. Should you require such data please contact ABP Hull. | 29/05/2016 |
| Time series of water elevation in the estuary | ABP Hull | Provided by ABP Hull. Under the limitations this data set cannot be used for commercial work nor can it be published. Should you require such data please contact ABP Hull. | 29/05/2016 |
| BODC time-series with the following code:<br><br>b0031232<br><br>b0046046 | BODC | It is BODC's policy to encourage the use of data holdings for science, education and industry, as well as the wider public. Data are made available, in line with the Natural Environment Research Council (NERC) Data Policy, under a licence agreement. | April 2017 |

## References


ABPHES. 2011. Humber Estuary: Maintenance Dredge Protocol and Water Framework Compliance Baseline Document, Report R.1872

Coull, K.A., Johnstone, R., Rogers.S.I. 1998. Fisheries Sensitivity Maps in British Waters. Available at: http://www.cefas.defra.gov.uk/publications-and-data/miscellaneous-publications/fisheries-sensitivity-maps.aspx Accessed 06/11/2014.

RYA. 2008. UK Coastal Atlas of Recreational Boating: Recreational cruising routes, sailing and racing areas around the UK coast, 2nd Edition, RYA.

Fearnly, H., Liley, D., Cruickshanks, K. 2012. Results of the Recreational Visitor Surveys Across the Humber Estuary, Footprint Ecology, Unpublished Report for the Humber Management Scheme.

Tillin, H.M., Hull, S.C., Tyler-Walters, H. 2010. Development of a Sensitivity Matrix (pressures-MCZ/MPA features). Report to the Department of Environment, Food and Rural Affairs from ABPMer, Southampton and the Marine Life Information Network (MarLIN) Plymouth: Marine Biological Association of the UK. .Defra Contract No. MB0102 Task 3A, Report No. 22.

Website 1: http://www.omreg.net/

Appendix 3

## Use of Action Levels in Dredged Material Assessments

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

In general, contaminant levels in dredged material below Action Level 1 are of no concern and are unlikely to influence the licensing decision. However, dredged material with contaminant levels above Action Level 2 is generally considered unsuitable for sea disposal. The latter situation most often applies only to a part of a proposed dredging area and so that area can be excluded from disposal at sea and disposed of by other routes e.g. landfill. Dredged material with contaminant levels between Action Levels 1 and 2 requires further consideration and testing before a decision can be made.

| ACTION LEVELS | | |
|---|---|---|
| Contaminant / Compound | Action Level 1 | Action Level 2 |
| | | |
| | mg/kg Dry Weight (ppm) | |
| As | 20 | 100 |
| Hg | 0.3 | 3 |
| Cd | 0.4 | 5 |
| Cr | 40 | 400 |
| Cu | 40 | 400 |
| Ni | 20 | 200 |
| Pb | 50 | 500 |
| Zn | 130 | 800 |
| | | |
| Organotins; TBT DBT MBT | 0.1 | 1 |
| PCB's, sum of ICES 7 | 0.01 | none |
| PCB's, sum of 25 congeners | 0.02 | 0.2 |
| | | |
| *DDT | *0.001 | |
| *Dieldrin | *0.005 | |
| | *these levels were set in 1994 | |
| | | |

*Cefas is an Executive Agency of Defra*

Appendix 4
Correspondence

***Request to Natural England to test EPSS and additional data***

From: Quigley, Mike (NE) [Mike.Quigley@naturalengland.org.uk]
Sent: 16 December 2014 16:15
To: Jemma-Anne Lonsdale
Subject: RE: PhD Thesis- Planning Support System

Hi Jemma,
Attached is an annotated copy of your proposal. Hopefully these provide the answers you need.
I asked a GIS specialist to provide a view so you should have some confidence in the answers.
Cheers,
Mike

***Attachment on Next Page***

I am currently undertaking a PhD with Prof. Mike Elliott at the University of Hull that is funded by the Seedcorn funds from the Centre for the Environment, Fisheries and Aquaculture Science (Cefas). The title of my PhD is "Development of an Estuarine Planning Support System: A case study for the Humber Estuary, UK".

As an introduction, estuaries have multiple uses and users due to their importance in a variety of sectors. This often makes them challenging to manage since management must strike a balance between the needs of users and the site's ecological and economic value against the context of multiple legislative drivers. To facilitate management an Estuarine Planning Support System (EPSS) framework needs to be developed, using the Humber Estuary as a case study by reviewing the current legislation tools and concepts and integrating into an EPSS. This integrated EPSS will be an improvement on previous models for assessing cumulative impacts because it takes into account legislative drivers, management tools and other plans/projects specific to the estuary. It will therefore enable managers and users to assess both the current state and the way in which a new industrial, port or urban development could impact an estuary in an accessible and understandable framework.

My PhD is to develop the EPSS into software to help decision makers and applicants determine what needs to be considered when a development is going forward. Currently I envisage a two stage process: firstly an online interactive GIS which highlights potential receptors and jurisdiction of the works i.e. WFD, Marine Works EIA Regulations etc and provides an output in csv format (or similar); and secondly a database where the csv file is uploaded and uses code and look up tables to provide more detailed guidance on what is required and advises on where high risk activities are.

After thinking about how to develop this, I have a few initial questions for Natural England below:

- Can I use the conservation layers in the software as outlined above or do I need additional permission to use these in the software?
- Can I use the layers showing the location of the features of conservation interest for the Humber Estuary or do I need additional permission to use these in the software? Can these be provided?

  The layers are freely available via the Natural England data download pages

- Would you be able to provide me with a contact for possibly creating a group who will be used firstly as a sounding board and to test the software to ensure it is in line with Natural England's policies?

Claire Edwards Claire.edwards@naturalengland.org.uk

- And if this is possible, any details of charges that may be required in assisting with my PhD studies in this manner?

  Not that I am aware of. In providing views and support we would expect you to minimise where possible the amount of things you request. But we don't typically charge for officer time within reason.

For the purposes of the PhD study, the aim is to develop the software to determine if this concept is feasible for a specific area i.e. the Humber Estuary. It may be that following the development, it could be expanded to England and Wales for the public, regulators and decision makers to use however this is beyond the scope of the current study and would require additional conversations between the interested parties with regards to agreement and use of the data.

***Request to Co-Author to supply and use excel data tables from Tillin et al.(2010) Report***

**From:** Stephen C Hull [mailto:shull@abpmer.co.uk]
**Sent:** 02 January 2015 11:23
**To:** Jemma Lonsdale (Cefas)
**Subject:** FW: Query: Report No 22 Task 3 Development of a Sensitivity Matrix

Jemma

Defra approval below and copies of Excel matrices attached. The simplified matrix defaults to the highest sensitivity in circumstances where the biotopes within a habitat category have differing levels of sensitivity.

Kind regards

Steve

**From:** Kelly, Carole (Defra) [mailto:Carole.Kelly@defra.gsi.gov.uk]
**Sent:** 02 January 2015 11:14
**To:** Stephen C Hull
**Subject:** RE: Query: Report No 22 Task 3 Development of a Sensitivity Matrix

Hi Steve

Happy New Year!

Yes please provide Cefas with the spreadsheet, I am sure they have received it before. Would probably also be worth letting Cefas now that JNCC/NE may have updated this now and that MarLIN are looking to do more work on sensitivity over the next 2 years.

Best regards

Carole

From: Duke, James [james.duke@environment-agency.gov.uk]
Sent: 26 February 2015 09:44
To: Jemma-Anne Lonsdale
Subject: Emailing: YNE_WAP_V12 - Humber Estuary

Hi Jemma,

Apologies, this feels like it's taking forever to get to chat....

I'm on my mobile from 4.30pm if you are still around. In the meantime I have attached a raw data sheet with the failures on the Humber Estuary.

I would have liked to have talked you through it but at least you can take a look.

In answer to your question about classification they are decided on a one-out-all-out basis. If a single element fails for example fish or phosphate the whole waterbody will be classified based on that failure.

For things like phosphate there is a sliding scale for water quality (in mg/l) that will slot the waterbody into a specific class (good, moderate, poor etc.)

I'll also send you over some other bits when I get the chance.

James

Your message is ready to be sent with the following file or link attachments:
YNE_WAP_V12 - Humber Estuary

| Row Completed | Last Updated (dd/mm/yy) | Local Unique ID | ID for upload | Fail Validation | Validation | RFF ID | Waterbody id | Waterbody name | Management Catchment | Operational Catchment | Historic Sub Catchment | WB Type | HMWB Desig | Failing Element | Pressure | 2009 Class | 2012 Class | Confidence Worse than Good 2012 | Waterbody Flow Class 2012 | 2015 Class (based on measures in first plan) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 26-Nov-13 | | 1 | | | | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive | HMWB | Ecological Status | X | Moderate | Moderate | | | Moderate |
| | | | 2 | | | GB530402609201-J | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | | | | | | | |
| Yes | 23-Dec-13 | | 3 | | | GB530402609201-A | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Invertebrates Moderate 2009, Good 2010, | Flood Protection/ Navigation | Moderate | Moderate | Uncertain | | Moderate |
| | 26-Nov-13 | | 4 | | | GB530402609201-B | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Mitigation Measures Assessment | Flood Protection/ Navigation | Moderate | Moderate | | | Moderate |
| Yes | 23-Dec-13 | | 5 | | | GB530402609201-B-1 | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | MMA - Removal of hard bank reinforcement / | Flood Protection/ Navigation | | | | | |
| Yes | 23-Dec-13 | | 6 | | | GB530402609201-B-2 | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | MMA - Set-back embankments | Flood Protection/ Navigation | | | | | |
| Yes | 23-Dec-13 | | 7 | | | GB530402609201-B-3 | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | MMA - Preserve and where possible | Flood Protection/ Navigation | | | | | |
| Yes | 23-Dec-13 | | 8 | | | GB530402609201-C | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Fish Good 2009, Good 2010, | | | | | | |
| Yes | 23-Dec-13 | | 9 | | | GB530402609201-D | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Zinc | | Fail | Good | | | |
| Yes | 23-Dec-13 | | 10 | | | GB530402609201-E | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Tributyltin Compounds | | Fail | Fail | Very Certain | | Fail |
| Yes | 04-Feb-14 | | 11 | | | GB530402609201-G | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Diffuse Organic Pollution | Poor bulk handling at port operations | | | | | |
| Yes | 23-Dec-13 | | 12 | | | GB530402609201-F | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Dissolved Inorganic Nitrogen | Flood Protection/ Navigation | Moderate | Moderate | Very Certain | | |
| Yes | 23/12/2013 | | 13 | | | GB530402609201-H | GB530402609201 | Humber Lower | Hull and East Riding | | HMWB | Mixed, Macro, Extensive Intertidal | HMWB | Leachate | Storage of RDF waste | | | | | |
| | 26-Nov-13 | | 14 | | | | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive | HMWB | Ecological Status | X | | Moderate | Very Certain | | Moderate |
| Yes | 23-Dec-13 | | 15 | | | GB530402609202-H | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Invasive species | Invasive Species | Fail | Fail | | | |
| Yes | 23-Dec-13 | | 16 | | | GB530402609202-I | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Multiple and various heavy | landfills | | | | | |
| Yes | 23-Dec-13 | | 17 | | | GB530402609202-A | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | AWB | Mitigation Measures Assessment | Flood Protection | Moderate | Moderate | | | Moderate |
| Yes | 23-Dec-13 | | 18 | | | GB530402609202-A-1 | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | MMA - Removal of hard bank reinforcement / | Flood Protection | | | | | |
| Yes | 23-Dec-13 | | 19 | | | GB530402609202-A-2 | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | MMA - Set-back embankments | Flood Protection | | | | | |
| Yes | 23-Dec-13 | | 20 | | | GB530402609202-A-3 | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | MMA - Preserve and where possible | Flood Protection | | | | | |
| Yes | 23-Dec-13 | | 21 | | | GB530402609202-D | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Copper | Unknown | Fail | Good | Very Certain | | |
| Yes | 23-Dec-13 | | 22 | | | GB530402609202-E | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Zinc | Unknown | Fail | Good | Very Certain | | |
| Yes | 23-Dec-13 | | 23 | | | GB530402609202-F | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Zinc | Unknown | Fail | Good | Very Certain | | |
| Yes | 23-Dec-13 | | 24 | | | GB530402609202-G | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Fish Moderate 2011 (Uncertain) | Unknown | Good | Good | | | |
| Yes | 23-Dec-13 | | 25 | | | GB530402609202-B | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Dissolved Inorganic Nitrogen | Unknown | Moderate | Moderate | Very Certain | | Moderate |
| Yes | 23-Dec-13 | | 26 | | | GB530402609202-C | GB530402609202 | Humber Middle | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Tributyltin Compounds | Unknown | Fail | Fail | Quite Certain | | Fail |
| | 26-Nov-13 | | 27 | | | | GB530402609203 | Humber Upper | Hull and East Riding | | | Mixed, Macro, Extensive | HMWB | Ecological Status | X | Moderate | Moderate | Moderate | Moderate | Moderate |
| | 23-Dec-13 | | 28 | | | GB530402609203-F | GB530402609203 | Humber Upper | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Dissolved Inorganic Nitrogen | Sewage Treatment and Agriculture | | | | | |
| Yes | 23-Dec-13 | | 29 | | | GB530402609203-G | GB530402609203 | Humber Upper | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Invasive species | Invasive Species | Fail | Fail | | | |
| Yes | 23-Dec-13 | | 30 | | | GB530402609203-A | GB530402609203 | Humber Upper | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Mitigation Measures Assessment | Flood Protection | Moderate | Moderate | | | Moderate |
| Yes | 23-Dec-13 | | 31 | | | GB530402609203-A-1 | GB530402609203 | Humber Upper | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | MMA - Removal of hard bank reinforcement / | Flood Protection | | | | | |
| Yes | 23-Dec-13 | | 32 | | | GB530402609203-A-2 | GB530402609203 | Humber Upper | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | MMA - Set-back embankments | Flood Protection | | | | | |
| Yes | 23-Dec-13 | | 33 | | | GB530402609203-A-3 | GB530402609203 | Humber Upper | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | MMA - Preserve and where possible | Flood Protection | | | | | |
| Yes | 23-Dec-13 | | 34 | | | GB530402609203-D | GB530402609203 | Humber Upper | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Copper | Industrial Process | Fail | Good | Quite Certain | | High |
| Yes | 23-Dec-13 | | 35 | | | GB530402609203-E | GB530402609203 | Humber Upper | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Phosphate - Poor (Very Certain) 2010 | Industrial Process | Not Assessed | Not Assessed | | | No Data |
| Yes | 23-Dec-13 | GB530402609203_RFF001 | 36 | | | GB530402609203_RFF001 | GB530402609203 | Humber Upper | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Cypermethrin | Industrial Process | Fail | Not Assessed | | | Moderate |
| Yes | 23-Dec-13 | GB530402609203_RFF003 | 37 | | | GB530402609203_RFF003 | GB530402609203 | Humber Upper | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Tributyltin Compounds | Shipping | Fail | Not Assessed | | | Fail |
| | 26-Nov-13 | | 38 | | | | GB560402916600 | Barrow Clay Pits | Hull and East Riding | | | Transitional | Natural? | Ecological Status | X | Moderate | Moderate | Uncertain | | |
| Yes | 26-Nov-13 | | 39 | | | GB560402916600-A | GB560402916600 | Barrow Clay Pits | Hull and East Riding | | | Transitional Lagoon | Natural? (not designated A/HMWB) | Expert Judgement | | Moderate | Moderate | Uncertain | | Moderate |
| | 26-Nov-13 | | 40 | | | | GB560402916700 | North Killingholme Haven Pits | Hull and East Riding | | | Transitional | AWB | Ecological Status | X | Good | Good | Uncertain | | |
| Yes | 26-Nov-13 | | 41 | | | GB560402916700-A | GB560402916700 | North Killingholme Haven Pits | Hull and East Riding | | | Transitional Lagoon | AWB | Expert Judgement | Coastal Protection | Moderate | Moderate | Uncertain | | |
| | 26-Nov-13 | | 42 | | | | GB560402917500 | North Coates Point Lagoon | Hull and East Riding | | | Transitional | Natural? (not designated A/HMWB) | Ecological Status | X | Moderate | Moderate | Uncertain | | Good |
| Yes | 27-Nov-13 | | 43 | | | GB560402917500-A | GB560402917500 | North Coates Point Lagoon | Hull and East Riding | | | Transitional Lagoon | Natural? (not designated A/HMWB) | Expert Judgement | Unknown | Moderate | Moderate | Uncertain | | Moderate |
| | 26-Nov-13 | | 44 | | | | GB560402616500 | Welton Waters | Hull and East Riding | | | Transitional | AWB | Ecological Status | X | Moderate | Moderate | Uncertain | | Moderate |
| Yes | 27-Nov-13 | | 45 | | | GB560402616500-A | GB560402616500 | Welton Waters | Hull and East Riding | | | Transitional Lagoon | AWB | Expert Judgement | Unknown | Moderate | Moderate | Uncertain | | Moderate |
| Yes | 23-Dec-13 | | 46 | | | GB530402609201-G | GB530402609201 | Humber Lower | Hull and East Riding | | | Mixed, Macro, Extensive Intertidal | HMWB | Diffuse Organic Pollution | Poor bulk handling at port operations | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| X | X | | | | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

| ID for upload | RFF Tier 1 SWMI | Tier1 Conf | RFF Tier 2 Activity / Source | Tier 2 Conf | RFF Tier 3 Sector | Tier3 Conf | Significant Water Managment Issue | RFF Free Text | Rank | Investigations for this failing element | Investigation KPIs | Investigation Lead | Investigation Outcome | Brief Description of action needed to address this failure | Measures needed to address this reason for failure - National Pick List Tier 1 | Measures needed to address this reason for failure - National Pick List Tier 2 | Measures needed to address this reason for failure - National Pick List Tier 3 | Measure Detailed Desciption | expected effect of this measure | Benefit wider than operational catchment (Y/N) | Is this measure included in preferred package of measures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | X | X | X | X |
| 2 | | | | | | | | | | | | | | No action needed | To improve modified habitat | Sediment management strategies | Not Applicable | | | | |
| 3 | Unknown | Not Applicable | Unknown | Not Applicable | Unknown | Not Applicable | | Type 2 investigation (causes of | | | | | | Action required to identify cause of failure and feasible measures | To improve modified habitat | | | Type 2 investigation (causes of failure) created during migration to support a RFF without an investigation. Further investigation and review of sample points and | | | |
| 4 | Physical Modification | Confirmed | TraC Flood Protection - Structures | Confirmed | Central Government, Environment | Confirmed | Physical Modification | | | AN2009-22563 | 1350J | Virginie Chotard | Measures Identified | Of the 3 potential mitigation measures identified, 1 has been taken forward | | | | Investigation ID 12132 N:\FP\Vision Strategy and Policy\Strategic Planning\WFD\10. WFD Northern\Mitigation Measures | | | |
| 5 | | | | | | | | | | | | | | Identify options for coastal squeeze and habitat compensation | To improve modified habitat | Improvement to condition of channel/bed | Removal or replacement of hard bank | NEAS leading on project at moment. Erosion protection strategy needs to be refered to and needs to be dynmamic. Care to include compensation in all 3 Humber | Action to prevent deterioration | Yes | Yes |
| 6 | | | | | | | | | | | | | | See RFF GB530402609201-B-1 | | | | | | | |
| 7 | | | | | | | | | | | | | | Ensure best practice partnership working e.g. encourage SUDS | To improve modified habitat | Improvement to condition of channel/bed | Bank rehabilitation / re-profiling | Ensure best practice partnership working e.g. consenting and work with development control type colleagues to encourage SUDS and similar. | Action to prevent deterioration | Yes | Yes |
| 8 | | | | | | | | | | | | | | Align MMO Inshore and Offshore Plans with WFD for migratory fish species. Further more extensive fish monitoring required. (Stocking | To improve modified habitat | Improvement to condition of riparian zone | Habitat Management | Align MMO Inshore and Offshore Plans with WFD for migratory fish species. Further more extensive fish monitoring required. | Action to prevent deterioration | Yes | Yes |
| 9 | | | | | | | | | | | | | | Action required to identify cause of failure and feasible measures | | | | Metals sampled at Blacktoft, BAE, Ellerker and Saltend Jetty. Clarity needed over recent sampling results. Fail 2009 (Uncertain), Fail 2010 (Uncertain), Good 2011 | | | |
| 10 | Suspect Data | | Suspect Data | | Suspect Data | | | Suspect data | | AN2009-22564 | 1340M | Sarah Swift | Reasons Identified | Further monitoring of TBT required. Also ensure prior to works in rivers that assessment is carried out to prevent re- | To control or manage diffuse source inputs | Reduce diffuse pollution at source | Improve chemical storage and use | Investigation ID 12133 N:\FP\Vision Strategy and Policy\Strategic Planning\WFD\10. WFD Northern\2010 WFD RBMP Investigations\Transitional Waters\Humber | Action to prevent deterioration | Yes | Yes |
| 11 | | | | | | | | | | | | | | Action required to identify cause of failure and feasible measures | To control or manage diffuse source inputs | Reduce diffuse pollution pathways (i.e. control entry | Surface run-off & drainage management | see AE | Within class improvement - single element | Yes | Yes |
| 12 | Unknown | Not Applicable | Unknown | Not Applicable | Unknown | Not Applicable | | Unknown (not ascertainable) | | AN2009-22565 | 1340M | Virginie Chotard | Outcome not identified (no data in load) | Action required to identify cause of failure and feasible measures | | | | Further investigation needed to determine sources of DIN. But also see Investigation ID 12134 N:\FP\Vision Strategy and Policy\Strategic Planning\WFD\10. WFD | | | |
| 13 | | | | | | | | | | | | | | Action required to identify cause of failure and feasible measures | To control or manage diffuse source inputs | Reduce diffuse pollution at source | Improve chemical storage and use | Storage of waste in North Killingholme requires investigation and enforcement. | Action to prevent deterioration | Yes | Yes |
| 14 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 15 | | | | | | | | | | | | | | Estuary wide problem but Mitten Crabs located around Isle of Ancholme. Investigation required, further monitoring and | To control or manage non native invasive/alien | Early detection, monitoring and rapid response (to | Control and eradication of selected high risk | National Project may be required. Natural England have identified a number of sites on the estuary, detailed in the following document ("N:\River Basin Management | Within class improvement - single element | Yes | Yes |
| 16 | | | | | | | | | | | | | | No action needed | To control or manage diffuse source inputs | Reduce diffuse pollution pathways (i.e. control entry | Surface run-off & drainage management | Investigate and address Cappa Pass Landfill likely to be failing for metals. Landfill not protected by Flood Defence / Erosion structures. Ensure defences at North | Action to prevent deterioration | Yes | Yes |
| 17 | Physical Modification | Confirmed | TraC Flood Protection - Structures | Confirmed | Central Government, Environment | Confirmed | Physical Modification | EA Owned structures? | | AN2009-22567 | 1350J | | Measures Identified | Of the 3 measures identified, 1 has been chosen to take forward | | | | Investigation ID 12136 N:\FP\Vision Strategy and Policy\Strategic Planning\WFD\10. WFD Northern\Mitigation Measures | | | |
| 18 | | | | | | | | | | | | | | Identify options for coastal squeeze and habitat compensation | To improve modified habitat | Improvement to condition of channel/bed | Removal or replacement of hard bank | NEAS leading on project at moment. Erosion protection strategy needs to be refered to and needs to be dymnamic. Care to include compensation in all 3 Humber | Action to prevent deterioration | Yes | Yes |
| 19 | | | | | | | | | | | | | | See RFF GB5030402609202-A-1 | To improve modified habitat | Improvement to condition of riparian zone | Improve floodplain connectivity | | | | |
| 20 | | | | | | | | | | | | | | Ensure best practice partnership working | To improve modified habitat | Improvement to condition of channel/bed | Bank rehabilitation / re-profiling | Consenting and work with development control type colleagues to encourage SUDS and similar. | Action to prevent deterioration | Yes | Yes |
| 21 | Unknown | Not assessed | Unknown | Not assessed | Unknown | Not assessed | Unknown (not ascertainable) | | | | | | | No action needed | No Action Needed | | | No Action. Now at Good. | | | |
| 22 | Point Source | Suspected | Sewage Discharge (continuous) | Suspected | Water Industry | Suspected | Point Source | All RFFs retired: Compliant with | | | | | | No action needed | No Action Needed | | | No Action. Now at Good. | | | |
| 23 | Diffuse Source | Suspected | Mixed Agricultural | Suspected | Agriculture and Rural Land Management | Suspected | Diffuse Source | All measures retired: Compliant with | | | | | | No action needed | No Action Needed | | | No Action. Now at Good. | | | |
| 24 | | | | | | | | | | | | | | No action needed | To improve modified habitat | Change to operations and maintenance | Fisheries management plan | Review sampling points for fish and methodology (Stocking with non native fish implicated in decline of macrophytes in clay pits"N:\River Basin Management | Within class improvement - single element | Yes | Yes |
| 25 | Unknown | Not assessed | Unknown | Not assessed | Unknown | Not assessed | Unknown (not ascertainable) | Andy: Extension agreed with | | AN2009-22569 | 1340M | Virginie Chotard | | Action required to identify cause of failure and feasible measures | | | | D Finnie: TBT data from RHNHLT and RHNHHT suggests this WB isnt failing for this substance. Anglian Northern doesn't have any other TBT monitoring points so | | | |
| 26 | Suspect Data | Suspected | Suspect Data | Suspected | Suspect Data | Suspected | Suspect Data | Unable to interrogate data until lab | | AN2009-22568 | 1340M | Sarah Swift | Reasons Identified | Further monitoring of TBT required. Also ensure prior to works in rivers that assessment is carried out to prevent re- | To control or manage diffuse source inputs | Reduce diffuse pollution at source | Improve chemical storage and use | Humber Middle is not designated for navigation so dredging cannot or should not be carried out without licence. EA and MMO to liase and licence appropriately. | Within class improvement - single element | Yes | Yes |
| 27 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 28 | | | | | | | | | | | | | | Action required to identify cause of failure and feasible measures | | | | Goole STW / Goole Car lane pumping station gets flooded regularly and this contributes to DIN probs. Flood Protection of works may be required. Also sugar | | | |
| 29 | | | | | | | | | | | | | | Removal of invasive plant species. | To control or manage non native invasive/alien | Mitigation, control and eradication (to reduce extent) | Eradication and control of invasive non-native species | Himalayan Balsam and Japanese Knotweed on Upper Humber at Swinefleet (Jknotweed) and Balsam is everywhere. Natural England have identified a number | Within class improvement - single element | Yes | Yes |
| 30 | Physical Modification | Confirmed | TraC Flood Protection - Structures | Confirmed | Central Government, Environment | Confirmed | Physical Modification | | | AN2009-22571 | 1350J | Unknown in data load | Measures Identified | | | | | Investigation ID 12140 N:\FP\Vision Strategy and Policy\Strategic Planning\WFD\10. WFD Northern\Mitigation Measures | | | |
| 31 | | | | | | | | | | | | | | Identify options for coastal squeeze and habitat compensation | To improve modified habitat | Improvement to condition of channel/bed | Removal or replacement of hard bank | NEAS leading on project at moment. Consider enhancement of wider managed wetland habitats. Work with NE and LNP. Erosion protection strategy needs to | Action to prevent deterioration | Yes | Yes |
| 32 | | | | | | | | | | | | | | See RFF GB530402609203-A-1 | To improve modified habitat | Improvement to condition of riparian zone | Improve floodplain connectivity | | | | |
| 33 | | | | | | | | | | | | | | Ensure best practice partnership working | To improve modified habitat | Improvement to condition of channel/bed | Bank rehabilitation / re-profiling | Consenting and work with development control type colleagues to encourage SUDS and similar. | Action to prevent deterioration | Yes | Yes |
| 34 | Unknown | Not assessed | Unknown | Not assessed | Unknown | Not assessed | Unknown (not ascertainable) | | | | | | | Action required to identify cause of failure and feasible measures | | | | Historic issue. Copper now at Good but TATA factory site may require investigation. Copper domenstic plumbing was suggested???? Fail 2009 (Quite Certain), | | | |
| 35 | | | | | | | | | | | | | | Action required to identify cause of failure and feasible measures | To control or manage diffuse source inputs | Reduce diffuse pollution pathways (i.e. control entry | Surface run-off & drainage management | Investigate impact of port operations at Howdendyke upon Phosphate levels. | Within class improvement - single element | Yes | Yes |
| 36 | Point Source | Confirmed | Industrial Discharge (EPR) | Confirmed | Industry | Confirmed | Point Source | Failure confirmed due to industry | Major | AN2009-22570 | 1340M | Trevor Hardy | | Work with wool factories and YWS to reduce source of Cypromethrin | To control or manage point source inputs | Reduce point source pollution at source | Prohibit/control uses of certain substances/chemi | Work with wool factories and YWS to reduce source of Cypromethrin from 2 wool factory sites on Aire. Andy: 2 woolscourers (Haworth and Standard Wool) via | Within class improvement - single element | Yes | Yes |
| 37 | Suspect Data | Suspected | Not Applicable | Suspected | Not Applicable | Suspected | Suspect Data | Unable to interrogate data until lab | | AN2009-22572 | 1340M | Sarah Swift | Reasons Identified | Further monitoring of TBT required | To control or manage diffuse source inputs | Reduce diffuse pollution at source | Improve chemical storage and use | Further monitoring of TBT required. Also ensure prior to works in rivers that assessment is carried out to prevent re-mobilisation. Check permits at boat breaker | Within class improvement - single element | Yes | Yes |
| 38 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | X | X | | |
| 39 | Suspect Data | Suspected | Not Applicable | Suspected | Not Applicable | Suspected | Suspect Data | No data but hydromorph is good. Expert | | | | | Other Outcome (in data load) | Action required to identify cause of failure and feasible measures | | | | 'Expert judgement indicates this waterbody will fail. Chemical/biological monitoring in place/to be instigated to confirm if any element fails. Investigation will follow | No direct improvement to water body or | | |
| 40 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | X | X | | |
| 41 | Suspect Data | Suspected | Not Applicable | Suspected | Not Applicable | Suspected | Suspect Data | No date but Expert Judgement | | | | | Other Outcome (in data load) | Action required to identify cause of failure and feasible measures | | | | 'Expert judgement indicates this waterbody will fail. Chemical/biological monitoring in place/to be instigated to confirm if any element fails. Investigation will follow | No direct improvement to water body or | | |
| 42 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | X | X | | |
| 43 | Suspect Data | Suspected | Not Applicable | Suspected | Not Applicable | Suspected | Suspect Data | No data but hydrology is good. Expert | | | | | Other Outcome (in data load) | Action required to identify cause of failure and feasible measures | | | | 'Expert judgement indicates this waterbody will fail. Chemical/biological monitoring in place/to be instigated to confirm if any element fails. Investigation will follow | No direct improvement to water body or | | |
| 44 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | X | X | | |
| 45 | Suspect Data | Suspected | Not Applicable | Suspected | Not Applicable | Suspected | Suspect Data | Not Northern area, North Humber Bank | | | | | Other Outcome (in data load) | Action required to identify cause of failure and feasible measures | | | | 'Expert judgement indicates this waterbody will fail. Chemical/biological monitoring in place/to be instigated to confirm if any element fails. Investigation will follow | No direct improvement to water body or | | |
| 46 | | | | | | | | | | | | | | Action required to identify cause of failure and feasible measures | To control or manage diffuse source inputs | Reduce diffuse pollution pathways (i.e. control entry | Surface run-off & drainage management | see AE | Within class improvement - single element | Yes | Yes |
| | | | | | | | | | | | | | | | | | | | | | |
| | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

| ID for upload | Will this measure need extra monitoring to asess its effectiveness | Pathway to good for this Element (indicate which measures | primary method of measure implementation (regulatory | expected confidence of this measure | Years to implement action (enter number of years if known) | Element Improvement Expected By | Indicative NGR | EA Contact (team) | Lead Organisation | Lead Sector | Capital Cost Band | Acurate Capital Cost | Annual Maintenance Cost | Number of Years Maintanance Required (Default 40) | RWQ To Complete | Protected Areas | Action status | cost beneficial actions | Scale of measure to resolve this reason for failure (password | To be uploaded to CPS April 2014 | Added to CPS (Y/N) | Protected Area Name | Protected Area Reason | Number of Characters in column AF Brief >80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | New | | X | | X | X | X | 1 |
| 2 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | | | | New | | | | | | | 16 |
| 3 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | Habitats and Species Directive | New | | | | | Humber estruary SAC and SPA | birds | 66 |
| 4 | | | | | | | | | | | | | | | | Wild Birds Directive | | | | | | Humber Flates, Marshes and Coast - Phase | Protection of habitats or species | 75 |
| 5 | | | Project | Very certain | 10 | 31/12/2027 | | NE Yorkshire, Partnerships & Strategic | Environment Agency | Central Government | More than £5,000,000 | | | 40 | | Habitats and Species Directive | New | | | | | Humber Estuary SPA, SAC | | 62 |
| 6 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | | New | | | | | | | 27 |
| 7 | | | EA routine work | Quite certain | | 31/12/2027 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | | | | 40 | | Habitats and Species Directive | New | | | | | Humber Estuary SPA and SAC | Birds. Quary Economically Significant | 61 |
| 8 | | | EA routine work | Very certain | | 31/12/2027 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | | | | 40 | | Habitats and Species Directive | New | | | | | Humber Estuary SPA and SAC | Birds. | 327 |
| 9 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | | New | | | | | | | 66 |
| 10 | | | Project | Quite certain | | 31/12/2027 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | Less than £10,000 | | | 40 | | Urban Waste Water Treatment | New | | | | | Louth Canal | Nutrient Sensitive Area | 459 |
| 11 | | | Project | Quite certain | 2 | 31/12/2021 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | Less than £10,000 | | | | | Habitats and Species Directive | New | | | | | Humber Estuary SAC and SPA | birds | 66 |
| 12 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | Bathing Waters Directive | New | | | | | Cleethorpes | Recreatoinal Waters | 66 |
| 13 | | | enforcement | Quite certain | | 31/12/2027 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | | | | | | Habitats and Species Directive | New | | | | | Humber Estuary SAC and SPA | birds | 66 |
| 14 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | New | | X | | X | X | X | 1 |
| 15 | | | Project | Quite certain | | 31/12/2027 | | NE Yorkshire, Fisheries, Recreation & | Environment Agency | Central Government | £500,001 - £1,000,000 | | | | | Habitats and Species Directive | New | | | | | Humber Estuary SPA and SAC | Birds | 134 |
| 16 | | | EA routine work | Quite certain | | 31/12/2027 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | | | | | | Habitats and Species Directive | New | | | | | Humber Estuary SPA and SAC | Humber Estuary SPA and SAC | 16 |
| 17 | | | | | | | | | | | | | | | | | | | | | | | | 63 |
| 18 | | | Project | Very certain | 10 | 31/12/2027 | | NE Yorkshire, Partnerships & Strategic | Environment Agency | Central Government | More than £5,000,000 | | | 40 | | Habitats and Species Directive | New | | | | | Humber Estuary SPA, SAC | | 61 |
| 19 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | | New | | | | | | | 27 |
| 20 | | | EA routine work | Quite certain | | 31/12/2027 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | | | | 40 | | Habitats and Species Directive | New | | | | | Humber Estuary SPA and SAC | Birds. Quary Economically Significant | 42 |
| 21 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | | New | | | | | | | 16 |
| 22 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | | New | | | | | | | 16 |
| 23 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | | New | | | | | | | 16 |
| 24 | | | Project | Very certain | | 31/12/2027 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | £10,001 - £25,000 | | | 40 | | Habitats and Species Directive | New | | | | | Humber Estuary SPA and SAC | Birds. | 16 |
| 25 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | | New | | | | | | | 66 |
| 26 | | | Project | Quite certain | | | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | Less than £10,000 | | | 40 | | Habitats and Species Directive | New | | | | | Humber Estuary SPA and SAC | Birds | 436 |
| 27 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | New | | X | | X | X | X | 1 |
| 28 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | | | | New | | | | | | | 66 |
| 29 | | | Project | Quite certain | 2 | 31/12/2027 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | £10,001 - £25,000 | | | | | Habitats and Species Directive | New | | | | | Humber Estuary SPA and SAC | Birds | 35 |
| 30 | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| 31 | | | Project | Very certain | 10 | 31/12/2027 | | NE Yorkshire, Partnerships & Strategic | Environment Agency | Central Government | More than £5,000,000 | | | 40 | | Habitats and Species Directive | New | | | | | Humber Estuary SPA, SAC | | 61 |
| 32 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | | New | | | | | | | 26 |
| 33 | | | EA routine work | Quite certain | | 31/12/2027 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | | | | 40 | | Habitats and Species Directive | New | | | | | Humber Estuary SPA and SAC | Birds. Quary Economically Significant | 42 |
| 34 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | | New | | | | | | | 66 |
| 35 | | | EA routine work | Quite certain | | 31/12/2021 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | | | | 40 | | Habitats and Species Directive | New | | | | | Humber Estuary SPA and SAC | Birds. | 66 |
| 36 | | | EA routine work | Very certain | 2 | 31/12/2021 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | | | | 40 | | Habitats and Species Directive | New | | | Yes | | Humber Estuary SPA and SAC | Birds. | 65 |
| 37 | | | EA routine work | Quite certain | 2 | | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | | | | 40 | | Habitats and Species Directive | New | | | Yes | | Humber Estuary SPA and SAC | Birds. | 34 |
| 38 | | X | | | X | | X | X | X | X | X | X | X | X | | | New | | | | | X | X | 1 |
| 39 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | Wild Birds Directive | New | | | | | Humber Flats, Marshes and Coast | Protection of habitats or species | 66 |
| 40 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | | | | New | | | | | | | 1 |
| 41 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | Wild Birds Directive | New | | | | | Humber Flats, Marshes and Coast - Phase | Protection of habitats or species | 66 |
| 42 | | X | | | X | | X | X | X | X | X | X | X | X | | | New | | | | | X | X | 1 |
| 43 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | Wild Birds Directive | New | | | | | Humber Flats, Marshes and Coast - Phase | Protection of habitats or species | 66 |
| 44 | | X | | | X | | X | NE Yorkshire, EM Land & Water | X | | X | X | X | X | | | New | | | | | X | X | 1 |
| 45 | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | 40 | | | New | | | | | | | 66 |
| 46 | | | Project | Quite certain | 2 | 31/12/2021 | | NE Yorkshire, EM Land & Water | Environment Agency | Central Government | Less than £10,000 | | | | | Habitats and Species Directive | New | | | | | Humber Estuary SAC and SPA | birds | 66 |
| | | | | | | | | NE Yorkshire, EM Land & Water | | | | | | | | | New | | | | | | | 0 |
| | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | | X | X | X | |

***Request to the Environment Agency for data on salinity, pH and turbidity for the Humber Estuary***

**Our Ref:** RFI/2015/ 33126 FO

**Your Ref:**

Dear Jemma

**RE: Data for the Humber Estuary**
**Request for information under the Freedom of Information Act 2000 (FOIA) / Environmental Information Regulations 2004 (EIR)**

Please find attached the spreadsheet which will hopefully be helpful.

Criteria used for the query –
Open Sample points within the area TA4409037006 and SK7193382542
Only Estuary or Sea water
Sampling between 17/6/2012 and 17/6/2015
Salinity, pH and Turbidity plus some other determinands which might be useful

I hope that we have correctly interpreted your request. Please see the attached Standard Notice or licence for details of permitted use.

We respond to requests for recorded information that we hold under the Freedom of Information Act 2000 (FOIA) and the associated Environmental Information Regulations 2004 (EIR).

If you are not satisfied with our response to your request for information you can contact us within 2 calendar months to ask for our decision to be reviewed.

**We would be really grateful if you could spare five minutes to help us improve our service. Please click on the link below and fill in our survey – we use every piece of feedback we receive:**
http://feedback1.environmentagency.uk.com/s3/YCustomer

If you require any further help, please do not hesitate to contact me.
**Debbie Milner**
Customers and Engagement Team

Microsoft Excel 97-2003 Worksheet

Adobe Acrobat Document

Appendix 5

Comparison of Indicators

Below is a comparison of the indicators used in this study and those proposed by Aubry and Elliott (2006)

EII 1

| **Indicator** | **Relevant to Humber Estuary?** | **Relevant to this Study?** | **Relevant GIS Layer/ Data** |
|---|---|---|---|
| Interidal area lost | Yes | No | - |
| Realignment Sites | Yes | Yes | Managed Realignment Sites |
| Land claim | Yes | Yes | Developments<br>Flood Defences<br>Managed Realignment Sites<br>Ports |
| Gross change in bathymetry and topography | Yes | No | - |
| Interference with the hydrographic regime | Yes | Yes | Construction Licences<br>Flood Defences<br>Managed Realignment Sites<br>Ports |
| Gross change in coastline shape | Yes | No | - |
| Relative sea level rise | Yes | Yes | No data available |

EII 2

| **Indicator** | **Relevant to Humber Estuary?** | **Relevant to this Study?** | **Relevant GIS Layer/Data** |
|---|---|---|---|
| Anthropogenically affected coastline | Yes | Yes | Developments<br>Flood Defences<br>Managed Realignment Sites<br>Ports |
| Construction licences | Yes | Yes | Developments |
| Direct discharges | Yes | Yes | Discharge points |
| Maintenance dredging-areas | Yes | Yes | Maintenance Dredge |
| Maintenance dredging-disposal area | Yes | Yes | Disposal Sites |
| Capital dredging | Yes | Yes | Capital Dredge Areas |
| Beneficial use | No | No | - |
| Intensity of wind farm development | No | No | - |
| Aquaculture | No | No | - |

| | | | |
|---|---|---|---|
| Other fisheries activities causing nearshore seabed disturbance | No | No | - |
| Intensity of marina developments | Yes | Yes | Marinas<br>Slipways |
| Intensity of port developments | Yes | Yes | Ports<br>Developments |
| Area covered by pipelines and cables | Yes | Yes | No data available |
| Oil and gas exploration and production | No | No | - |
| Water pollution incidents | Yes | Yes | Water Pollution Incidents |
| Tourism and recreation | Yes | Yes | Bait digging<br>Bathing waters<br>Beaches<br>Horse riding<br>Kitesurfing<br>Managed Realignment Sites<br>Wildfowling<br>Country parks<br>Woodlands<br>Listed buildings<br>Battlefields<br>Heritage coast<br>Parks and gardens<br>Protected wrecks<br>Scheduled monument<br>World heritage site |

EII3

| **Indicator** | **Relevant to Humber Estuary?** | **Relevant to this Study?** | **Relevant GIS Layer/Data** |
|---|---|---|---|
| Water chemical quality | Yes | Yes | WFD Reasons for Failure |
| Sediment chemical quality | Yes | Yes | WFD Reasons for Failure<br>CDMS |
| Water quality-biological effects | Yes | Yes | WFD Reasons for Failure |
| Water quality-microbial assay | Yes | Yes | WFD Reasons for Failure |
| Benthos | Yes | Yes | Species Richness macrobenthic. |
| Shellfish quality | No | No | - |
| Loss of habitats | Yes | Yes | No data available |
| Aesthetic pollution | Yes | Yes | Bathing waters<br>Beaches |

| | | | |
|---|---|---|---|
| | | | Bathing eutrophic sensitive areas<br>Coast eutrophic sensitive areas |
| Interference with fish migration routes- physical barriers | Yes | Yes | Barriers<br>Outfall discharge points<br>Water abstraction<br>Water pollution incidents |
| Interference with fish migration routes- Chemical barriers | Yes | Yes | Outfall discharge points<br>Water abstraction<br>Water pollution incidents |

# Appendix 6
# Methodology for the Sensitivity of Conservation Features

The lookup table, which assigns the sensitivity of the conservation features against certain pressures, is adapted from Tillin *et al.* (2010) and the Regulation 33 advice (English Nature, 2003). Both approaches are outlined here.

**A6.1 SAC Sensitivities based on the Tillin *et al.* (2010).**

The project undertaken by Tillin *et al.* (2010) developed a pressure-feature sensitivity matrix through a workshop-based approach for all EUNIS Level 3 broad-scale habitats, OSPAR threatened and/or declining habitats and species and the UK BAP habitats and species although a site-specific assessment should also be undertaken.

The features were categorised on a 4-point semi-quantitative scale for both their tolerance to a pressure (defined as resistance) and the ability to recover from the subsequent impact (defined as resilience). The information on resistance and resilience was combined consistently to assess sensitivity, scored as 'high', 'medium', 'low' or 'not sensitive'.

Tillin *et al.* (2010) defined the degree of vulnerability of a habitat as a product of sensitivity (a measure of resistance and resilience) and exposure. As the intensity and/or duration of the impact (the exposure) determines the magnitude of effect, measures of vulnerability often consider the probability of an impact and the probable characteristics of impacts.

For each feature, the resistance and resilience were assessed against each pressure using available evidence and/or expert judgement and where possible a series of benchmark levels of intensity, where intensity reflects the magnitude, extent and duration of each pressure (full definitions are provided in Tillin *et al.* (2010).

The approach taken by Tillin *et al.* (2010) was only able to assess single pressures and does not consider cumulative risks associated with multiple pressures of the same type or different types at a single location. When considering multiple pressures of the same or different types at a given location, a judgment will need to be made on the extent to which those pressures might act synergistically, independently or antagonistically.

It should also be highlighted here that the approach by Tillin *et al.* (2010) was undertaken primarily by expert judgement and these assessments are based on the knowledge and the experience of the person and may therefore have some subjectivity associated. It should be noted that this would also be true for assessments where available empirical evidence is lacking or not comparable.

Estuaries

| Pressure theme | Climate change | | | | | | | Hydrological changes (inshore/local) | | | | | | Pollution and other chemical changes | | | | | | | Physical loss | | Physical damage | | | | | | Other physical pressures | | | | | | Biological pressures | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure<br>Broadscale Habitats | Atmospheric climate change | pH changes | Temperature changes - regional/ national | Salinity changes - regional/ national | Water flow (tidal current) changes - regional/ national | Emergence regime changes (sea level) - regional/ national | Wave exposure changes - regional/ national | Temperature changes - local | Salinity changes - local | Water flow (tidal current) changes - local | Emergence regime changes - local | Wave exposure changes - local | Water clarity changes | Non-synthetic compound contamination (inc. heavy metals, hydrocarbons, | Synthetic compound contamination (inc. pesticides, antifoulants, pharmaceuticals) | Radionuclide contamination | Introduction of other substances (solid, liquid or gas) | De-oxygenation | Nitrogen& phosphorus enrichment | Organic enrichment | Physical change (to another seabed type) | Physical loss (to land or freshwater habitat) | Siltation rate c2 | Siltation rate changes (high) | Smothering and disturbance of the substrate below the surface of the seabed | Physical abrasion: damage to seabed surface and penetration | Surface abrasion: damage to seabed surface features | Physical removal (extraction of substratum) | Electromagnetic changes | Litter | Introduction of light | Underwater noise | Barrier to species movement | Death or injury by collision | Visual disturbance | Introduction or translocation of indigenous species | Introduction of microbial pathogens | Introduction or spread of non-indigenous species | Removal of target species | Removal of non-target species |
| High energy intertidal rock | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 0.5 | 1.5 | 0.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 1 | 1 | 2 | 2 | 1.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 1.5 | 0.5 |
| Moderate energy intertidal rock | 1.5 | 0.5 | 1.5 | 0.5 | 1.5 | 0.5 | 1.5 | 1 | 1 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 1 | 2 | 2 | 2 | 1.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1.5 | 0.5 |
| Low energy intertidal rock | 1.5 | 0.5 | 1.5 | 0.5 | 2 | 0.5 | 2 | 2 | 1 | 2 | 1.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1.5 | 0.5 |
| Intertidal coarse sediment | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 1 | 1 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 |
| Intertidal sand and muddy sand | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 2 | 1.5 | 1 | 1 | 0.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 1.5 | 1.5 | 1.5 | 2 | 2 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1.5 |
| Intertidal mud | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 2 | 1.5 | 2 | 2 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 2 | 1.5 | 2 | 2 | 2 | 1.5 | 3 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 2 |
| Intertidal mixed sediments | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 1.5 | 2 | 2 | 2 | 1.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1.5 |
| Coastal saltmarshes and saline reedbeds | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 1.5 | 1.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 1.5 |
| Intertidal sediments dominated by aquatic angiosperms | 2 | 0.5 | 2 | 0.5 | 2.5 | 2.5 | 1.5 | 1 | 1 | 2.5 | 2 | 1.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 2 | 3 | 2 | 2 | 2.5 | 3 | 1.5 | 2.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 1.5 | 3 |
| Intertidal biogenic reefs | 1.5 | 0.5 | 1.5 | 0.5 | 1.5 | 2 | 2 | 2 | 0.5 | 1.5 | 1.5 | 2 | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 1 | 2 | 2 | 2 | 1.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 2.5 |
| High energy infralittoral rock | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 0.5 | 2 | 1.5 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 2 | 1.5 |
| Moderate energy infralittoral rock | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 0.5 | 2 | 2 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 1.5 |
| Low energy infralittoral rock | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 1 | 2 | 2 | 2 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2.5 | 1.5 |
| High energy circalittoral rock | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 0.5 | 0.5 | 0.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 1.5 |
| Moderate energy circalittoral rock | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 2 | 0.5 | 0.5 | 1.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2.5 | 2.5 |
| Low energy circalittoral rock | 0.5 | 0.5 | 1.5 | 0.5 | 1 | 0.5 | 1 | 0.5 | 1.5 | 1 | 0.5 | 1 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 2 |
| Subtidal coarse sediment | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 1.5 | 1.5 | 1.5 | 1.5 | 2 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 1.5 |
| Subtidal sand | 0.5 | 0.5 | 1.5 | 0.5 | 1 | 0.5 | 0.5 | 0.5 | 1.5 | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 2 | 1.5 | 2 | 1.5 | 1.5 | 1.5 | 2.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 2.5 |
| Subtidal mud | 0.5 | 0.5 | 1.5 | 0.5 | 1 | 0.5 | 1 | 1.5 | 1.5 | 1 | 0.5 | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 1.5 | 2 | 1 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1.5 |
| Subtidal mixed sediments | 0.5 | 0.5 | 1.5 | 0.5 | 1 | 0.5 | 1 | 1.5 | 2 | 1 | 0.5 | 1 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 0.5 | 1.5 | 2 | 2 | 1.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 2 | 2 |
| Coastal saltmarshes and saline reedbeds | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 1.5 | 1.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 1.5 |
| Saline lagoons | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 2 | 0.5 | 1 | 1.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2.5 | 2 | 2.5 | 2 | 1.5 | 1.5 | 1.5 | 2.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 1.5 |
| Intertidal mudflats | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 2 | 1.5 | 2 | 2 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 2 | 1.5 | 2 | 2 | 2 | 2 | 2.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2.5 | 2.5 | 2 |
| Average | 1.043 | 0.5 | 1.478 | 0.5 | 0.826 | 1 | 1.087 | 1.196 | 1.37 | 1 | 0.957 | 1.087 | 1.109 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.565 | 0.913 | 1.891 | 2.13 | 1.413 | 1.804 | 1.804 | 1.826 | 1.63 | 2.065 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.696 | 1.587 | 1.609 | 1.652 |
| ROUNDED | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| Relates to | L | L | L | L | L | L | L | L | L | L | L | L | L | L | L | L | L | L | L | L | M | M | L | M | M | M | M | M | L | L | L | L | L | L | L | L | L | M | M | M |

Sandflats

| Pressure theme | Climate change | | | | | | | Hydrological changes (inshore/local) | | | | | | Pollution and other chemical changes | | | | | | | Physical loss | | Physical damage | | | | | | Other physical pressures | | | | | | Biological pressures | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure / Broadscale Habitats | Atmospheric climate change | pH changes | Temperature changes - regional/ national | Salinity changes - regional/ national | Water flow (tidal&ocean current) changes - regional/ national | Emergence regime changes (sea level) - regional/ national | Wave exposure changes - regional/ national | Temperature changes - local | Salinity changes - local | Water flow (tidal current) changes - local | Emergence regime changes - local | Wave exposure changes - local | Water clarity changes | Non-synthetic compound contamination (inc. heavy metals, hydrocarbons, produced water) | Synthetic compound contamination (inc. pesticides, antifoulants, pharmaceuticals) | Radionuclide contamination | Introduction of other substances (solid, liquid or gas) | De-oxygenation | Nitrogen& phosphorus enrichment | Organic enrichment | Physical change (to another seabed type) | Physical loss (to land or freshwater habitat) | Siltation rate c2 | Siltation rate changes (high) | Penetration and/or disturbance of the substrate below the surface of the seabed | Shallow abrasion/penetration: damage to seabed surface and penetration | Surface abrasion: damage to seabed surface features | Physical removal (extraction of substratum) | Electromagnetic changes | Litter | Introduction of light | Underwater noise | Barrier to species movement | Death or injury by collision | Visual disturbance | Genetic modification & translocation of indigenous species | Introduction of microbial pathogens | Introduction or spread of non-indigenous species | Removal of target species | Removal of non-target species |
| Intertidal coarse sediment | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 1 | 1 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 |
| Intertidal sand and muddy sand | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 2 | 1.5 | 1 | 1 | 0.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 1.5 | 1.5 | 1.5 | 2 | 2 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1.5 |
| Intertidal mixed sediments | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 1.5 | 2 | 2 | 2 | 1.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1.5 |
| Coastal saltmarshes and saline reedbeds | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 1.5 | 1.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 1.5 |
| Average | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 1.125 | 1.25 | 1 | 0.875 | 0.75 | 1 | 1.25 | 0.75 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 1.75 | 2.25 | 1.5 | 1.63 | 1.5 | 1.625 | 1.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.375 | 1.6 | 1.5 |
| ROUNDED | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| Relates to | M | L | M | L | L | L | M | L | L | L | L | M | L | L | L | L | L | L | L | L | M | M | M | M | M | M | M | M | L | L | L | L | L | L | L | L | L | M | M | M |

Mudflats and sandflats not covered by seawater at low tide

| Pressure theme | Climate change | | | | | | | Hydrological changes (inshore/local) | | | | | | Pollution and other chemical changes | | | | | | | Physical loss | | Physical damage | | | | | | Other physical pressures | | | | | | Biological pressures | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure / Broadscale Habitats | Atmospheric climate change | pH changes | Temperature changes - regional/ national | Salinity changes - regional/ national | Water flow (tidal&ocean current) changes - regional/ national | Emergence regime changes (sea level) - regional/ national | Wave exposure changes - regional/ national | Temperature changes - local | Salinity changes - local | Water flow (tidal current) changes - local | Emergence regime changes - local | Wave exposure changes - local | Water clarity changes | Non-synthetic compound contamination (inc. heavy metals, hydrocarbons, produced water) | Synthetic compound contamination (inc. pesticides, antifoulants, pharmaceuticals) | Radionuclide contamination | Introduction of other substances (solid, liquid or gas) | De-oxygenation | Nitrogen& phosphorus enrichment | Organic enrichment | Physical change (to another seabed type) | Physical loss (to land or freshwater habitat) | Siltation rate c2 | Siltation rate changes (high) | Penetration and/or disturbance of the substrate below the surface of the seabed | Shallow abrasion/penetration: damage to seabed surface and penetration | Surface abrasion: damage to seabed surface features | Physical removal (extraction of substratum) | Electromagnetic changes | Litter | Introduction of light | Underwater noise | Barrier to species movement | Death or injury by collision | Visual disturbance | Genetic modification & translocation of indigenous species | Introduction of microbial pathogens | Introduction or spread of non-indigenous species | Removal of target species | Removal of non-target species |
| Intertidal mudflats | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 2 | 1.5 | 2 | 2 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 2 | 1.5 | 2 | 2 | 2 | 2 | 2.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2.5 | 2.5 | 2 |
| Sandflats | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 1.13 | 1.25 | 1 | 0.88 | 0.75 | 1 | 1.3 | 0.8 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 1.8 | 2.3 | 1.5 | 1.6 | 1.5 | 1.6 | 1.5 | 2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.4 | 1.6 | 1.5 |
| Average | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 1.6 | 1.4 | 1.5 | 1.4 | 1.1 | 1.3 | 1.4 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 1.9 | 2.1 | 1.5 | 1.8 | 1.8 | 1.8 | 1.8 | 2.3 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.9 | 2.1 | 1.8 |
| Round | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| Relates to | M | L | M | L | L | L | L | L | L | L | L | L | L | L | L | L | L | L | L | L | M | M | M | M | M | M | M | M | L | L | L | L | L | L | L | L | L | L | M | M |

Coastal Lagoons

| Pressure theme | Climate change | | | | | | | Hydrological changes (inshore/local) | | | | | | Pollution and other chemical changes | | | | | | | Physical loss | | Physical damage | | | | | | Other physical pressures | | | | | | Biological pressures | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure / Broadscale Habitats | Atmospheric climate change | pH changes | Temperature changes - regional/ national | Salinity changes - regional/ national | Water flow (tidal&ocean current) changes - regional/ national | Emergence regime changes (sea level) - regional/ national | Wave exposure changes - regional/ national | Temperature changes - local | Salinity changes - local | Water flow (tidal current) changes - local | Emergence regime changes - local | Wave exposure changes - local | Water clarity changes | Non-synthetic compound contamination (inc. heavy metals, hydrocarbons, produced water) | Synthetic compound contamination (inc. pesticides, antifoulants, pharmaceuticals) | Radionuclide contamination | Introduction of other substances (solid, liquid or gas) | De-oxygenation | Nitrogen& phosphorus enrichment | Organic enrichment | Physical change (to another seabed type) | Physical loss (to land or freshwater habitat) | Siltation rate c2 | Siltation rate changes (high) | Penetration and/or disturbance of the substrate below the surface of the seabed | Shallow abrasion/penetration: damage to seabed surface and penetration | Surface abrasion: damage to seabed surface features | Physical removal (extraction of substratum) | Electromagnetic changes | Litter | Introduction of light | Underwater noise | Barrier to species movement | Death or injury by collision | Visual disturbance | Genetic modification & translocation of indigenous species | Introduction of microbial pathogens | Introduction or spread of non-indigenous species | Removal of target species | Removal of non-target species |
| Saline lagoons | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 2 | 0.5 | 1 | 1.5 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2.5 | 2 | 2.5 | 2 | 1.5 | 1.5 | 1.5 | 2.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 1 | 2 |
| Round | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 |
| Relates to | L | L | M | L | L | M | L | L | M | L | L | L | M | L | L | L | L | L | L | M | H | M | H | M | M | M | M | H | L | L | L | L | L | L | L | L | L | M | L | M |

Saltmarsh

| Pressure theme | Climate change | | | | | | | Hydrological changes (inshore/local) | | | | | | Pollution and other chemical changes | | | | | | | Physical loss | | Physical damage | | | | | | Other physical pressures | | | | | | Biological pressures | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure / Broadscale Habitats | Atmospheric climate change | pH changes | Temperature changes - regional/ national | Salinity changes - regional/ national | Water flow (tidal&ocean current) changes - regional/ national | Emergence regime changes (sea level) - regional/ national | Wave exposure changes - regional/ national | Temperature changes - local | Salinity changes - local | Water flow (tidal current) changes - local | Emergence regime changes - local | Wave exposure changes - local | Water clarity changes | Non-synthetic compound contamination (inc. heavy metals, hydrocarbons, produced water) | Synthetic compound contamination (inc. pesticides, antifoulants, pharmaceuticals) | Radionuclide contamination | Introduction of other substances (solid, liquid or gas) | De-oxygenation | Nitrogen& phosphorus enrichment | Organic enrichment | Physical change (to another seabed type) | Physical loss (to land or freshwater habitat) | Siltation rate c2 | Siltation rate changes (high) | Penetration and/or disturbance of the substrate below the surface of the seabed | Shallow abrasion/penetration: damage to seabed surface and penetration | Surface abrasion: damage to seabed surface features | Physical removal (extraction of substratum) | Electromagnetic changes | Litter | Introduction of light | Underwater noise | Barrier to species movement | Death or injury by collision | Visual disturbance | Genetic modification & translocation of indigenous species | Introduction of microbial pathogens | Introduction or spread of non-indigenous species | Removal of target species | Removal of non-target species |
| Coastal saltmarshes and saline reedbeds | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 1.5 | 1.5 | 0.5 | 0.5 | 1.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 2 |
| Round | 2 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| Relates to | M | L | M | L | L | M | M | L | L | M | M | M | L | L | L | L | L | L | L | L | M | H | M | M | M | M | M | H | L | L | L | L | L | L | L | L | L | M | M | M |

Dunes

| Pressure theme | Climate change | | | | | | | Hydrological changes (inshore/local) | | | | | | Pollution and other chemical changes | | | | | | | Physical loss | | Physical damage | | | | | | Other physical pressures | | | | | | Biological pressures | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pressure / Broadscale Habitats | Atmospheric climate change | pH changes | Temperature changes - regional/ national | Salinity changes - regional/ national | Water flow (tidal&ocean current) changes - regional/ national | Emergence regime changes (sea level) - regional/ national | Wave exposure changes - regional/ national | Temperature changes - local | Salinity changes - local | Water flow (tidal current) changes - local | Emergence regime changes - local | Wave exposure changes - local | Water clarity changes | Non-synthetic compound contamination (inc. heavy metals, hydrocarbons, produced water) | Synthetic compound contamination (inc. pesticides, antifoulants, pharmaceuticals) | Radionuclide contamination | Introduction of other substances (solid, liquid or gas) | De-oxygenation | Nitrogen& phosphorus enrichment | Organic enrichment | Physical change (to another seabed type) | Physical loss (to land or freshwater habitat) | Siltation rate c2 | Siltation rate changes (high) | Penetration and/or disturbance of the substrate below the surface of the seabed | Shallow abrasion/penetration: damage to seabed surface and penetration | Surface abrasion: damage to seabed surface features | Physical removal (extraction of substratum) | Electromagnetic changes | Litter | Introduction of light | Underwater noise | Barrier to species movement | Death or injury by collision | Visual disturbance | Genetic modification & translocation of indigenous species | Introduction of microbial pathogens | Introduction or spread of non-indigenous species | Removal of target species | Removal of non-target species |
| Intertidal coarse sediment | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 1 | 1 | 0.5 | 0.5 | 0.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 |
| Intertidal sand and muddy sand | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 2 | 1.5 | 1 | 1 | 0.5 | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 1.5 | 1.5 | 1.5 | 2 | 2 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.5 | 2 | 2 |
| average | 1.5 | 0.5 | 1.5 | 0.5 | 0.5 | 1.25 | 1 | 1.5 | 1.3 | 0.5 | 1 | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.75 | 2 | 1.3 | 1.3 | 1 | 1.25 | 1.25 | 1.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 2 | 2 |
| rounded | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| relates to | M | L | M | L | L | L | L | M | L | L | L | L | L | L | L | L | L | L | L | L | M | M | L | L | L | L | L | M | L | L | L | L | L | L | L | L | L | L | M | M |

**A6.2 Updating the SAC, SPA and Ramsar Sensitivities using the Regulation 33 Advice (English Nature, 2003).**

To include the sensitivities of the protected features under the other international designations (SPA and Ramsar, along with SAC) the regulation 33 advice was used which provides the features of the designations, alongside potential impacts and their exposure to the impact, the sensitivity and the vulnerability.

The assessments provided matrices showing the results as high, medium or low or as numeric format. To combine these into one overall assessment of the sensitivity of the features to the potential impact, all results were translated into numeric format (i.e. high =3, medium =2, low=1, no level detected =0). An average was then taken and the numbers translated back into a high (3), medium (2), low (1) and no detectable level (0) for the assessment. These are provided in the tables below.

The advice was published in 2003; Natural England should always be consulted prior to an environmental impact assessment being carried out. The advice is specific to Humber Estuary and therefore even though many estuaries have similar but not the same characteristics or pressures applied to them. Therefore this specific part of the EPSS is not generic but site specific and should the EPSS be considered for wider use, additional site specific impacts would need to be incorporated and additional code to point to the relevant layers and associated look up tables.

Table A6.1 SAC Sensitivity

**Assessment of Exposure**

| | Estuaries | coastal lagoons | altlantic salt meadows | | | Salicornia and other annuals | | Mudflats and sandflats not covered by seawater at low tide | | | | Sandbanks which are slightly covered by seawater all the time | | River and Sea Lamprey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Subtidal sediment communities | | low to mid marsh communities | mid to high marsh communities | transitional communities | annual alicornia saltmarsh communities | suaeda maritima saltmarsh communities | Intertidal gravel and sand communities | intertidal muddy sand communities | Intertidal mud communities | Eelgrass bed communities | Subtidal gravels and sands | subtidal muddy sands | |
| physical loss-removal | 2 | 1 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 3 | 1 | 2 | 2 | 3 |
| physical loss- smothering | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 |
| physical damage- siltation | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| physical damage- abrasion | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 0 |
| physical damage- selective extraction | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Non-pysical disturbance- noise | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| non-pysical disturbance- visual presence | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Toxic contamination- intro of synthetic | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Intro of non synthetic | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Introduction of redionucleides | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in nutrient loading | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Changes in organic loading | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Changes in thermal regime | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in turbidity | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| Changes in salinity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of microbial pathogens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of aliens | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Selective extraction of species | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |

**Assessment of Sensitivity**

| | Estuaries | coastal lagoons | altlantic salt meadows | | | Salicornia and other annuals | | Mudflats and sandflats not covered by seawater at low tide | | | | Sandbanks which are slightly covered by seawater all the time | | River and Sea Lamprey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Subtidal sediment communities | | low to mid marsh communities | mid to high marsh communities | transitional communities | annual alicornia saltmarsh communities | suaeda maritima saltmarsh communities | Intertidal gravel and sand communities | intertidal muddy sand communities | Intertidal mud communities | Eelgrass bed communities | Subtidal gravels and sands | subtidal muddy sands | |
| physical loss-removal | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| physical loss- smothering | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 4 | 3 | 3 | 4 | 4 | 3 | 2 |
| physical damage- siltation | 2 | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 2 | 2 |
| physical damage- abrasion | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 2 | 2 |
| physical damage- selective extraction | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 3 |
| Non-pysical disturbance- noise | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| non-pysical disturbance- visual presence | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| Toxic contamination- intro of synthetic | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 3 |
| Intro of non synthetic | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 3 |
| Introduction of redionucleides | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Changes in nutrient loading | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 4 | 3 | 3 | 2 |
| Changes in organic loading | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| Changes in thermal regime | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 3 | 3 | 4 |
| Changes in turbidity | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 3 | 2 | 3 | 2 |
| Changes in salinity | 2 | 3 | 2 | 2 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 |
| Introduction of microbial pathogens | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 |
| Introduction of aliens | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 2 | 3 |
| Selective extraction of species | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 |

**Assessment of Vulnerability**

| | Estuaries | coastal lagoons | altlantic salt meadows | | | Salicornia and other annuals | | Mudflats and sandflats not covered by seawater at low tide | | | | Sandbanks which are slightly covered by seawater all the time | | River and Sea Lamprey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Subtidal sediment communities | | low to mid marsh communities | mid to high marsh communities | transitional communities | annual alicornia saltmarsh communities | suaeda maritima saltmarsh communities | Intertidal gravel and sand communities | intertidal muddy sand communities | Intertidal mud communities | Eelgrass bed communities | Subtidal gravels and sands | subtidal muddy sands | |
| physical loss-removal | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 |
| physical loss- smothering | 2 | 1 | | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 2 | 3 | 1 | 1 |
| physical damage- siltation | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| physical damage- abrasion | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 1 |
| physical damage- selective extraction | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 |
| Non-pysical disturbance- noise | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| non-pysical disturbance- visual presence | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Toxic contamination- intro of synthetic | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 2 |
| Intro of non synthetic | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 2 |
| Introduction of redionucleides | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in nutrient loading | 3 | 2 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| Changes in organic loading | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| Changes in thermal regime | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| Changes in turbidity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 |
| Changes in salinity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of microbial pathogens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of aliens | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Selective extraction of species | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Overall Assessment**

| | Estuaries | coastal lagoons | altlantic salt meadows | | | Salicornia and other annuals | | Mudflats and sandflats not covered by seawater at low tide | | | | Sandbanks which are slightly covered by seawater all the time | | River and Sea Lamprey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Subtidal sediment communities | | low to mid marsh communities | mid to high marsh communities | transitional communities | annual alicornia saltmarsh communities | suaeda maritima saltmarsh communities | Intertidal gravel and sand communities | intertidal muddy sand communities | Intertidal mud communities | Eelgrass bed communities | Subtidal gravels and sands | subtidal muddy sands | |
| physical loss-removal | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 |
| physical loss- smothering | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 1 |
| physical damage- siltation | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| physical damage- abrasion | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| physical damage- selective extraction | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Non-pysical disturbance- noise | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| non-pysical disturbance- visual presence | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| Toxic contamination- intro of synthetic | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 2 |
| Intro of non synthetic | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 2 |
| Introduction of redionucleides | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in nutrient loading | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| Changes in organic loading | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| Changes in thermal regime | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 2 |
| Changes in turbidity | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| Changes in salinity | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 |
| Introduction of microbial pathogens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 |
| Introduction of aliens | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 2 |
| Selective extraction of species | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 |

Table A6.2 SPA Sensitivity

| Assessment of Exposure | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Internationally important populations of regularly occurring Annex I Species | | | | Internationally important migratory species and wildfowl assemblage | | | |
| | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons |
| physical loss-removal | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 |
| physical loss- smothering | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| physical damage- siltation | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| physical damage- abrasion | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| physical damage- selective extraction | 1 | 2 | 1 | 0 | 1 | 2 | 1 | 0 |
| Non-pysical disturbance- noise | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 1 |
| non-pysical disturbance- visual presence | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 1 |
| Toxic contamination- intro of synthetic | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Intro of non synthetic | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Introduction of redionucleides | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in nutrient loading | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Changes in organic loading | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Changes in thermal regime | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| Changes in turbidity | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 |
| Changes in salinity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of microbial pathogens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of aliens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Selective extraction of species | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 1 |

**Assessment of Sensitivity**

| | Internationally important populations of regularly occurring Annex I Species | | | | Internationally important migratory species and wildfowl assemblage | | | |
|---|---|---|---|---|---|---|---|---|
| | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons |
| physical loss-removal | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| physical loss- smothering | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| physical damage- siltation | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 3 |
| physical damage- abrasion | 2 | 3 | 4 | 3 | 2 | 3 | 4 | 3 |
| physical damage- selective extraction | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Non-pysical disturbance- noise | 4 | 4 | 3 | 4 | 4 | 4 | 3 | 4 |
| non-pysical disturbance- visual presence | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Toxic contamination- intro of synthetic | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 |
| Intro of non synthetic | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Introduction of redionucleides | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Changes in nutrient loading | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 3 |
| Changes in organic loading | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 3 |
| Changes in thermal regime | 2 | 1 | 1 | 3 | 2 | 1 | 1 | 3 |
| Changes in turbidity | 2 | 2 | 1 | 3 | 2 | 2 | 1 | 3 |
| Changes in salinity | 2 | 2 | 3 | 3 | 2 | 2 | 3 | 3 |
| Introduction of microbial pathogens | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Introduction of aliens | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 2 |
| Selective extraction of species | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

**Assessment of Vulnerability**

| | Internationally important populations of regularly occurring Annex I Species | | | | Internationally important migratory species and wildfowl assemblage | | | |
|---|---|---|---|---|---|---|---|---|
| | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons |
| physical loss-removal | 3 | 2 | 2 | 3 | 3 | 2 | 2 | 2 |
| physical loss- smothering | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| physical damage- siltation | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| physical damage- abrasion | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 1 |
| physical damage- selective extraction | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Non-pysical disturbance- noise | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 2 |
| non-pysical disturbance- visual presence | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 |
| Toxic contamination- intro of synthetic | 2 | 3 | 1 | 2 | 2 | 3 | 1 | 2 |
| Intro of non synthetic | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Introduction of redionucleides | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in nutrient loading | 3 | 1 | 2 | 2 | 3 | 1 | 2 | 2 |
| Changes in organic loading | 3 | 1 | 2 | 2 | 3 | 1 | 2 | 2 |
| Changes in thermal regime | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in turbidity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in salinity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of microbial pathogens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of aliens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Selective extraction of species | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 1 |

**Overall Assessment**

| | Internationally important populations of regularly occurring Annex I Species | | | | Internationally important migratory species and wildfowl assemblage | | | |
|---|---|---|---|---|---|---|---|---|
| | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons |
| physical loss-removal | 3 | 2 | 2 | 3 | 3 | 2 | 2 | 2 |
| physical loss- smothering | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| physical damage- siltation | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 2 |
| physical damage- abrasion | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| physical damage- selective extraction | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Non-pysical disturbance- noise | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 2 |
| non-pysical disturbance- visual presence | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 |
| Toxic contamination- intro of synthetic | 2 | 3 | 2 | 2 | 2 | 3 | 2 | 2 |
| Intro of non synthetic | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Introduction of redionucleides | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in nutrient loading | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Changes in organic loading | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Changes in thermal regime | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in turbidity | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 |
| Changes in salinity | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| Introduction of microbial pathogens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of aliens | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Selective extraction of species | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 2 |

Table A6.3 Ramsar Sensitivity

**Assessment of Exposure**

| | Internationally important populations of regularly occurring Annex I Species | | | | | Internationally important migratory species and wildfowl assemblage | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Unvegetated sand and shingle | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons |
| physical loss-removal | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 |
| physical loss- smothering | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| physical damage- siltation | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 |
| physical damage- abrasion | 3 | 3 | 3 | 1 | 1 | 3 | 3 | 1 | 1 |
| physical damage- selective extraction | 1 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 1 |
| Non-physical disturbance- noise | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 3 |
| non-physical disturbance- visual presence | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 3 |
| Toxic contamination- intro of synthetic | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Intro of non-synthetic | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Introduction of radionuclides | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in nutrient loading | 1 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Changes in organic loading | 1 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Changes in thermal regime | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| Changes in turbidity | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 |
| Changes in salinity | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of microbial pathogens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of aliens | 1 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 1 |
| Selective extraction of species | 2 | 2 | 2 | 1 | 1 | 3 | 3 | 2 | 2 |

**Assessment of Sensitivity**

| | Internationally important populations of regularly occurring Annex I Species | | | | | Internationally important migratory species and wildfowl assemblage | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Unvegetated sand and shingle | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons |
| physical loss-removal | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| physical loss- smothering | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| physical damage- siltation | 1 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 3 |
| physical damage- abrasion | 4 | 2 | 3 | 4 | 3 | 2 | 3 | 4 | 3 |
| physical damage- selective extraction | 4 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Non-physical disturbance- noise | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 3 | 4 |
| non-physical disturbance- visual presence | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Toxic contamination- intro of synthetic | 2 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 |
| Intro of non-synthetic | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Introduction of radionuclides | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Changes in nutrient loading | 1 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 3 |
| Changes in organic loading | 1 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 3 |
| Changes in thermal regime | 1 | 2 | 1 | 1 | 3 | 2 | 1 | 1 | 3 |
| Changes in turbidity | 1 | 2 | 2 | 1 | 3 | 2 | 2 | 1 | 3 |
| Changes in salinity | 1 | 2 | 2 | 3 | 3 | 2 | 2 | 3 | 3 |
| Introduction of microbial pathogens | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Introduction of aliens | 2 | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 2 |
| Selective extraction of species | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

**Assessment of Vulnerability**

| | Internationally important populations of regularly occurring Annex I Species | | | | | Internationally important migratory species and wildfowl assemblage | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Unvegetated sand and shingle | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons |
| physical loss-removal | 2 | 2 | 3 | 2 | 2 | 2 | 3 | 2 | 2 |
| physical loss- smothering | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| physical damage- siltation | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| physical damage- abrasion | 3 | 2 | 3 | 2 | 1 | 2 | 3 | 2 | 1 |
| physical damage- selective extraction | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Non-physical disturbance- noise | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 3 |
| non-physical disturbance- visual presence | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Toxic contamination- intro of synthetic | 1 | 2 | 3 | 1 | 2 | 2 | 3 | 1 | 2 |
| Intro of non-synthetic | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Introduction of radionuclides | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in nutrient loading | 1 | 3 | 1 | 2 | 2 | 3 | 1 | 2 | 2 |
| Changes in organic loading | 1 | 3 | 1 | 2 | 2 | 3 | 1 | 2 | 2 |
| Changes in thermal regime | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in turbidity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in salinity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of microbial pathogens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of aliens | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 |
| Selective extraction of species | 3 | 2 | 2 | 1 | 1 | 3 | 3 | 2 | 2 |

Overall Assessment

| | Internationally important populations of regularly occurring Annex I Species | | | | | Internationally important migratory species and wildfowl assemblage | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Unvegetated sand and shingle | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons | Intertidal mudflats and sandflats | Saltmarsh communities | Reedbeds | Lagoons |
| physical loss-removal | 2 | 2 | 3 | 2 | 2 | 2 | 3 | 2 | 2 |
| physical loss- smothering | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| physical damage- siltation | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 |
| physical damage- abrasion | 3 | 2 | 3 | 2 | 2 | 2 | 3 | 2 | 2 |
| physical damage- selective extraction | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Non-physical disturbance- noise | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 3 |
| non-physical disturbance- visual presence | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Toxic contamination- intro of synthetic | 1 | 2 | 3 | 2 | 2 | 2 | 3 | 2 | 2 |
| Intro of non-synthetic | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Introduction of radionuclides | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in nutrient loading | 1 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Changes in organic loading | 1 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Changes in thermal regime | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Changes in turbidity | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 |
| Changes in salinity | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| Introduction of microbial pathogens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Introduction of aliens | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Selective extraction of species | 3 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 |

Appendix 7

Letter to Stakeholders for Testing of the EPSS Tool

From: Jemma-Anne Lonsdale
Cefas, Lowestoft, NR33 0HT
Email: jemma.lonsdale@cefas.co.uk
Tel: 01502 524491
Date: 13th January 2017

Dear XXX,

I am writing to you to request your expert input in validating an Estuarine Planning Support System (EPSS) tool. This is a novel approach in providing an interactive method for decision makers and developers to understand the multiple legislative requirements and aiding in risk assessment. Your expertise makes you a potential future user of the tool. We would therefore appreciate you testing the tool to determine its accurateness, effectiveness and usability.

The tool is being developed as an interactive tool using GIS. It provides guidance on the risk of a construction, dredge or disposal project within the Humber Estuary, identifies the legal requirements, and where possible identify if mitigation (whether through licence conditions, compensation or monitoring) is required. The tool is being developed as part of my PhD at the Institute of Estuarine and Coastal Studies, University of Hull (under the supervision of Professor Mike Elliott), funded by the Centre for Environment, Fisheries and Aquaculture Science (Cefas) (under the supervision of Dr Keith Weston). This is therefore a research project and is not being carried out on behalf of any other company or organisation.

If you are willing to test the tool and the outputs can you please let me know (or if you are not so I do not send reminder emails) either by phone (01502 524491) or email (jemma.lonsdale@cefas.co.uk) stating which method of testing you prefer, *i.e.*:

1) If you have access to ArcGIS, a link to the files will be sent to you via Dropbox or on CD with the appropriate geodatabase, instructions and the questionnaire; or
2) If you do not have GIS, please complete and return the form below and the tool will then be run on your behalf and the output report will be emailed to you to show the results. The questionnaire will also be emailed for you to provide your feedback.

If there are any questions, please contact me using the contact details above. After you have tested the tool or the report, if you would more information on the tool's methodology, please contact me and an informal follow up meeting can be arranged.

The questionnaire takes less than 10 minutes to complete. It would be greatly appreciated if you could complete the questionnaire and return it within 4 weeks on receipt of either the tool (via Dropbox) or the output report.

A seminar on the tool will take place at the University of Hull, in Cohen Building, from 11am-12pm on the 25th January 2017 to go through the background to the tool, how it works and the outputs which you are welcome to attend. Access to the computers to run the tool will be available from 1-4pm. If you can attend, please can you let me know by 24th January 2017.

If you are not available to test the tool, I would appreciate it if you could provide contact details of an alternative member in your organisation who would be suitable.

Thank you in advance for your co-operation and assistance.

Your sincerely,

Jemma-Anne Lonsdale

**Appendix I- Form to be completed where tester does not have access to ArcGIS software**

# Questionnaire for Testing the EPSS Tool Without ArcGIS

Section A- Participants Details and Organisation

Name (can be left blank):_____

Organisation: _____

Job Title: _____

Type of organisation i.e. business, government etc. _____

How would you like the output sent to you (please circle): by email or post

Please insert either your email or postal address for the output to be sent to you:

_____

_

_____

_

Are you happy to be contacted in case any further information is needed (please circle) Yes/ No

If yes, please provide a contact number or email address that you can be contacted on:

_____

_

Section B- Information for a development to test the EPSS Tool

The following questions are required to determine the scope of the development and ensure the tool runs and provides the assessment output as designed.

Project Location: please provide the coordinates of the project below.

Type of Project: Please give details of

the project activities i.e. port development, offshore wind farm etc. Depending on the project type, **please also provide the scale** (please see Appendix II) for the scales to be

| |
|---|
| |

Duration of Works:_____

Area of works ($m^2$): _____

*Depending on the project type (Construction, dredge, disposal and/or beneficial use disposal) please fill in the relevant sections below (construction Section B1, Dredge Section B2, Disposal B3, Beneficial B3.1). If the project falls into more than one project type, please fill in all relevant sections.*

**Section B1: Construction**

Construction Methods (please circle those that apply):

- Percussive Piling
- Jetting
- Trenching
- Horizontal Directional Drilling
- Vibro-piling
- Sheet Piling

Construction Materials (please circle those that apply):

- Rock armour
- Concrete matresses
- Geotextile bags
- Chemicals
- Timber
- Iron/Steel

**Section B2: Dredge**

Is the dredge maintenance or capital? _____

Dredge depth: _____

Quantity of material to be dredged (m3): _____

Dredger type to be used: _____

Does an Maintenance Dredge Protocol Document or Appropriate Assessment exist for the project? (Please circle) Yes/ No

**Section B3: Disposal**

Will the disposal be beneficial use or to a disposal site? If a disposal site please specify the sites to be used, if beneficial use please go to section B3.1 below_____

Quantity of material to be disposed of (m3): _____

**Section B3.1: Disposal Beneficial Use**

What is the material to be used at the beneficial use site? (please circle those that apply)?

- Saltmarsh and mudflat
- Sanddune
- Shingle and sand beach
- Rock.cliff face

Quantity of material to be disposed of (tonnes): _____

Area of works ($m^2$): _____

**Section B4.1: Project**

Please provide a summary of the project e.g. wind farm, harbour development etc. with details on the size of the development such as footprint or in the terms of energy generation the maximum energy to be generated in MW.

Appendix 8

EPSS Tool Instructions

# Instructions for Testing the Estuarine Planning Support System Tool

Jemma-Anne Lonsdale

Contributors:
Prof. Mike Elliott- University of Hull
Dr Keith Weston- Cefas
Rose Nicholson- Cefas

January 2017

Background to the Tool

The Estuarine Planning Support System (EPSS) tool has been developed as part of a PhD research process by the University of Hull and funded by the Centre for the Environment, Fisheries and Aquaculture Science (Cefas). Its aim is to enable managers and users to assess and address both the current state and the way in which a new industrial, port or urban development could impact an estuary in an accessible and understandable way.

The tool is based on an EPSS framework developed as part of the same PhD process and is using the Humber Estuary as a case study. It aims in taking the information from the location and size of the project (based on input into the GIS) and then using the inputs from the user, provides guidance on the potential receptors that could be affected by the project, the risk of the project and if applicable, a WFD assessment will be undertaken and provided (up to and including the scoping stage).

This is a consultation to ask certain stakeholders to test the tool and provide feedback on the assessment itself, the user friendliness of the tool and the usefulness of the output. A questionnaire has been sent via email to provide feedback on but a copy is also provided in Appendix 1 should you wish to fill this in and send via post to:

Jemma-Anne Lonsdale
Cefas
Pakefield Road
Lowestoft
NR33 7LS

Any queries can be sent via email to jemma.lonsdale@cefas.co.uk, post to the above address or via phone: 01502 524491.

## 1.1. Methods of Testing

The EPSS tool has been developed in ArcGIS 10.1. For those stakeholders that do not have access to ArcGIS software please go to section 2. For those stakeholders that do have access to ArcGIS software, please go to section 3. Both methods of testing can be used and feedback can be provided on the questionnaire provided in Appendix II.

## 1.2. Limitations of Use

This tool is to test the proof of concept for a PhD thesis; the tool is not for commercial use or for further development. This tool is only for developments in

the marine and estuarine environment and should not be used for riverine, open ocean or terrestrial assessments. Any results may not be a true representative of reality and consultation with the relevant authorities and regulators should always be undertaken. Following completion of the testing, the tool should not be used as following testing, the tool and data that underpins the assessment may be updated.

1. Instructions for Testing the Tool for those without ArcGIS

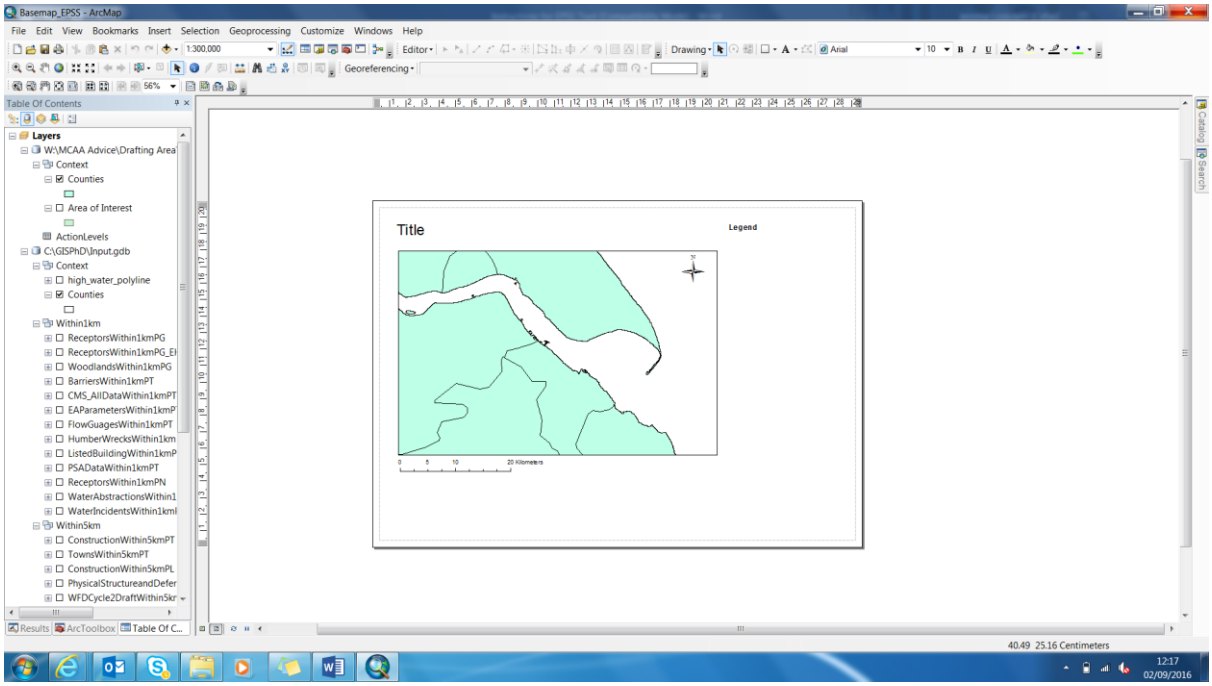
If you do not have ArcGIS software, please fill in the form in Appendix I, which can be sent either by post or email (both addresses are provided on the form). The tool will then be run on your behalf and the report will be sent by email or post (as indicated on the form) for you to review. Once you have reviewed the report, please fill in the Appendix II and send back either by email or post (see section 1 for the postal address and email address).

2. Instructions for using the Tool

The basemap, geodatabase containing the layers and look up tables and the tool itself is found in the dropbox or CD that accompany these instructions.

2.1 Opening the map and tool

From the dropbox or CD, open the zip file and save the files to an area of your computer (for ease it is recommended you use your C Drive). Once saved, navigate to the basemap (C:\EPSS_Tool\Basemap_EPSS) and open. The basemap should look like the below:



In order to start the tool, go to ArcCatalog ( ) and navigate to the C drive. You may need to connect to the C drive by clicking on the 'Connect to Folder' logo (Figure 1) and navigate to the drive. Once connected, go to the toolbox and double click the tool: "Main Tool".

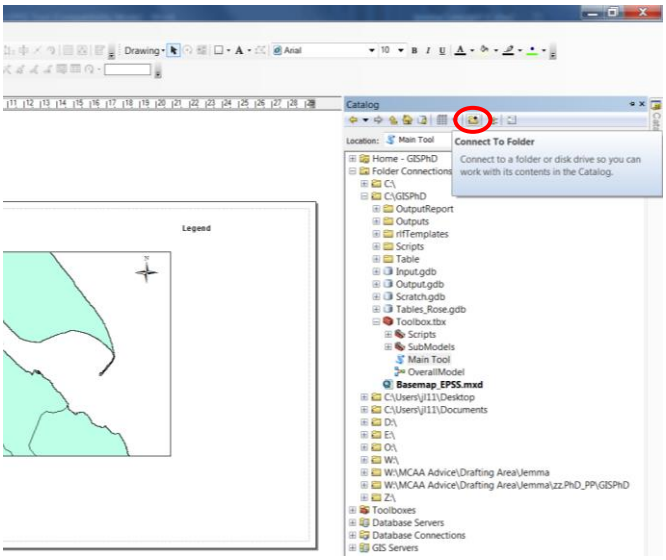



**Figure 1 Diagram showing the location of the 'Connect to Folder' logo**

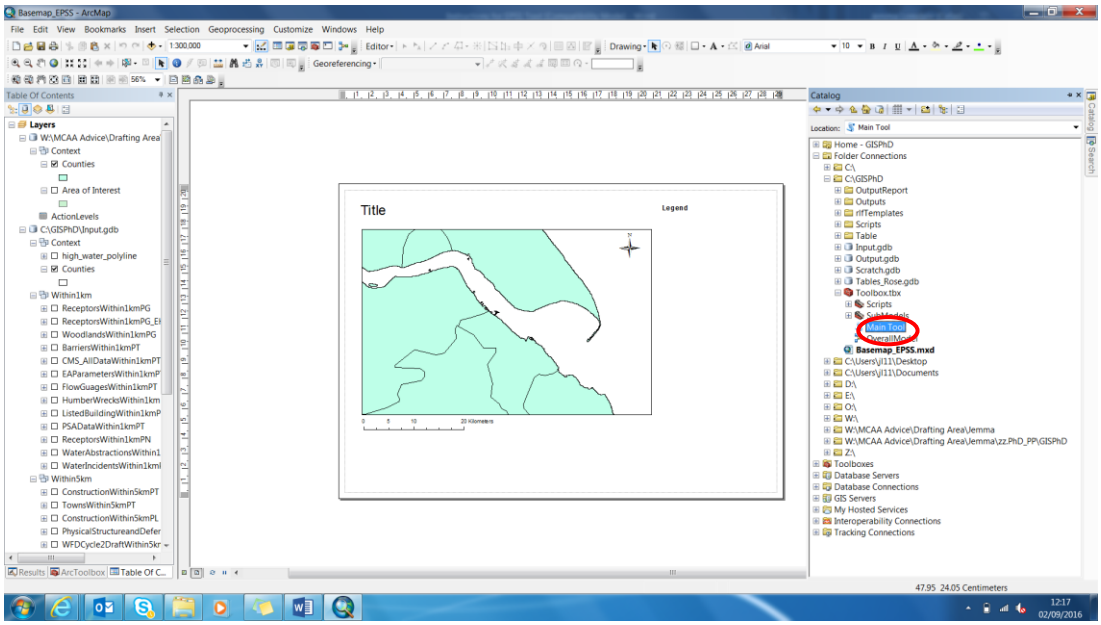



**Figure 2 Location of the tool**

## 2.2 Starting the Tool

The tool can be opened by either double clicking on the tool icon or you can right click and select 'open'. Once opened, you should see the below interface:

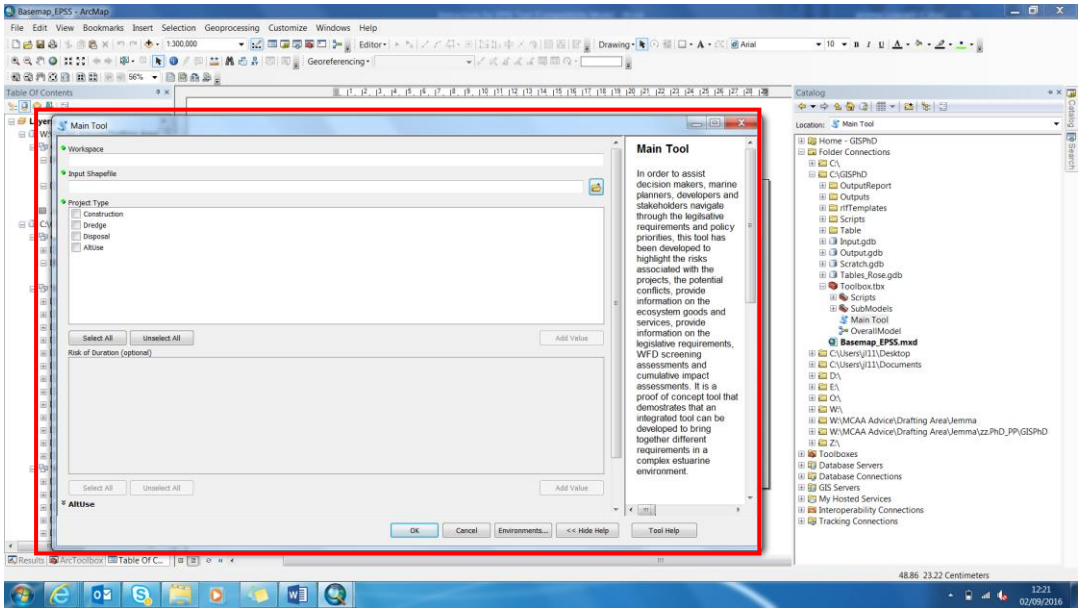



**Figure 3 Tool Interface**

## 2.3 User Input

In the first space, input the workspace area, if you have saved this to your C drive, this will be 'C\EPSS_Tool' (Figure 4).

In the second space, navigate to the input shapefile that will be used to form the assessment (please note that a limitation of the tool is that only one shapefile can be applied at any one time so either you can run the tool multiple times for the different types of development or add the one shapefile and have the potential impacts overestimated). You can do this by selecting your selected shapefile and dragging to the input area. If you do not have a shapefile on which to test, there is a shapefile called 'InputTest' in the input geodatabase.

Select the 'Project Type' and 'Duration of Works'

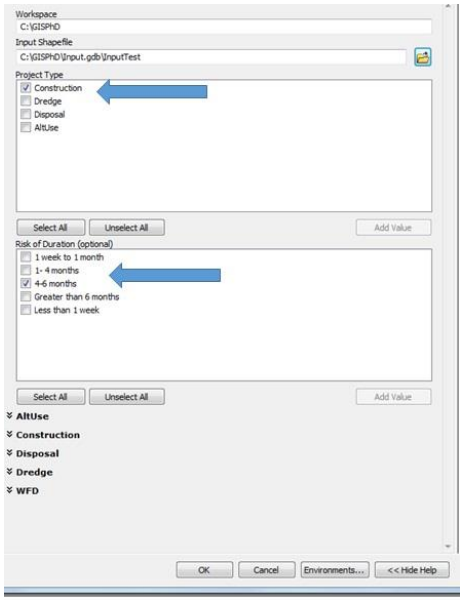



Figure 4 Tool Interface partially filled in.

Once the 'Project Type(s)' has been selected, the corresponding selections below (see red arrow below) will be available for selection.

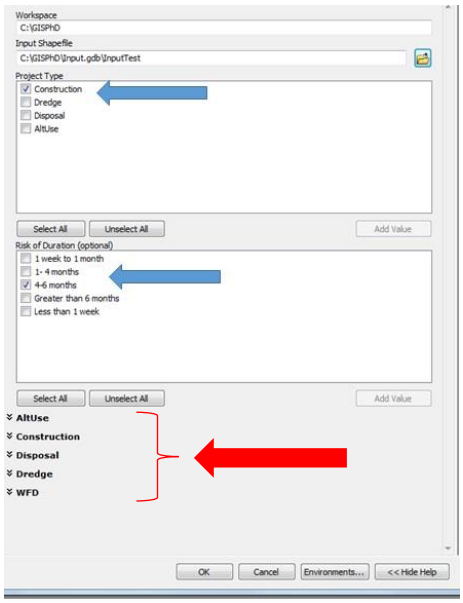


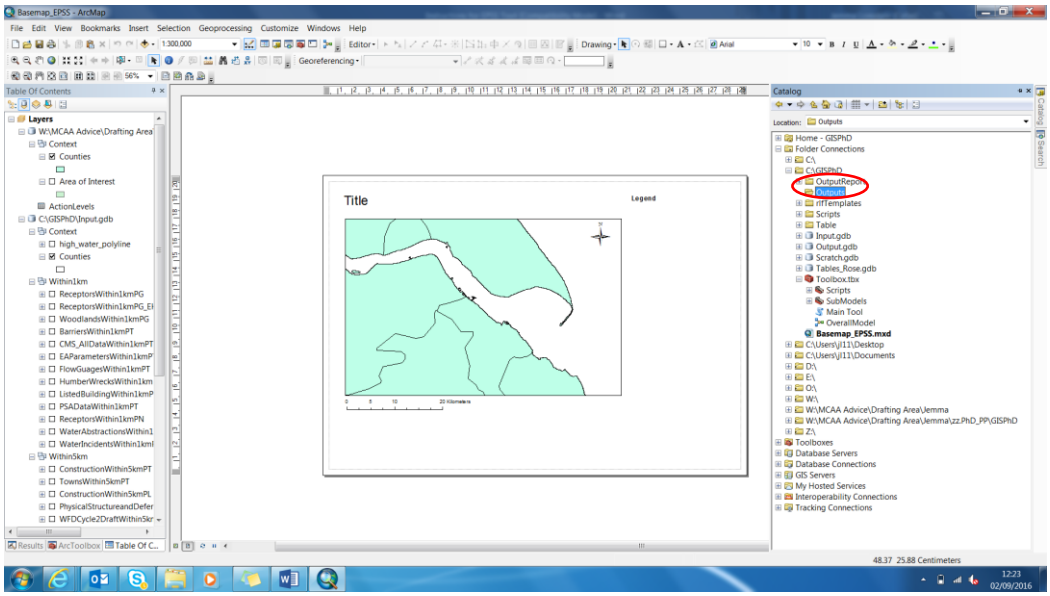

Figure 5 Additional options based on Project Type selection.

Go through the all of the options and select those options that correspond to your project. Once all selections have been made, select 'ok' at the bottom. If you are unsure of any option, select 'Show Help' (bottom right) and a window to the right opens explaining each option.

## 2.4 Output

The tool will take a few minutes to run. Once complete, the pdf report will be saved in the folder structure in 'Outputs'. The report name will be time stamped in the following format 'Year, month, day, hours, minutes, seconds' to differentiate between different runs should multiple runs be made.

Figure 5 Location of the output report




The report contains the following:

1. Title Page
2. The next set of pages outline the risks associated with the selections made in the tool interface provided in a set of tables based on the work of Judd *et al.* (2013; 2011) and show what legislation the development falls under.
3. The next set of pages show several maps showing the location of the development and either a 1km or 5km buffer and the potential receptors that fall within these buffer areas.
4. The report then has a set of tables for the WFD Assessment (if applicable to the development) which undertakes the screening and assessment part of the WFD Assessment to allow a consistent method going forward.
5. Finally, the report shows the output of the cumulative impact assessment.

3. References

Judd, A., Hart, A., Prpich, G., Whelan, M., Jude, S. 2013. Guidelines for Marine Environmental Risk Assessment, Final Report by Cefas, Fera and Cranfield University.

Judd, A. 2011. Exploring Options for Risk Based Approaches for Regulatory Advice within Cefas (and wider application by regulators), Final Report for Seedcorn Project.

Appendix I- Form to be completed where tester does not have access to ArcGIS software

# Questionnaire for Testing the EPSS Tool Without ArcGIS

Section A- Participants Details and Organisation

Name (can be left blank):_____

Organisation: _____

Job Title: _____

Type of organisation i.e. business, government etc. _____

How would you like the output sent to you (please circle): by email or post

Please insert either your email or postal address for the output to be sent to you:

_____
_

_____
_

Are you happy to be contacted in case any further information is needed (please circle) Yes/ No

If yes, please provide a contact number or email address that you can be contacted on:

_____
_

Section B- Information for a development to test the EPSS Tool

The following questions are required to determine the scope of the development and ensure the tool runs and provides the assessment output as designed.

Project Location: please provide the coordinates of the project below.

| |
|---|
| |

*Please use additional sheets if required.*

*Please return to: Jemma Lonsdale, Cefas, Pakefield Road, Lowestoft, NR33 0HT or* jemma.lonsdale@cefas.co.uk

Type of Project: Please give details of the project activities i.e. port development, offshore wind farm etc. Depending on the project type, please also provide the scale (please see Appendix III) for the scales to be provided.

Duration of Works:_____

Area of works ($m^2$): _____

*Depending on the project type (Construction, dredge, disposal and/or beneficial use disposal) please fill in the relevant sections below (construction Section B1, Dredge Section B2, Disposal B3, Beneficial B3.1). If the project falls into more than one project type, please fill in all relevant sections.*

**Section B1: Construction**

Construction Methods (please circle those that apply):

- Percussive Piling
- Jetting
- Trenching
- Horizontal Directional Drilling
- Vibro-piling
- Sheet Piling

Construction Materials (please circle those that apply):

- Rock armour
- Concrete matresses
- Geotextile bags
- Chemicals
- Timber
- Iron/Steel

**Section B2: Dredge**

Is the dredge maintenance or capital? _____

Dredge depth: _____

Quantity of material to be dredged (m3): _____

Dredger type to be used: _____

**Section B3: Disposal**

Will the disposal be beneficial use or to a disposal site? If a disposal site please specify the sites to be used, if beneficial use please go to section B3.1 below_____

Quantity of material to be disposed of (m3): _____

**Section B3.1: Disposal Beneficial Use**

What is the material to be used at the beneficial use site? (please circle those that apply)?

- Saltmarsh and mudflat
- Sanddune
- Shingle and sand beach
- Rock.cliff face

Quantity of material to be disposed of (tonnes): _____

Area of works ($m^2$): _____

**Section B4.1: Project**

Please provide a summary of the project e.g. wind farm, harbour development etc. with details on the size of the development such as footprint or in the terms of energy generation the maximum energy to be generated in MW.

*Please use additional sheets if required.*

*Please return to: Jemma Lonsdale, Cefas, Pakefield Road, Lowestoft, NR33 0HT or* jemma.lonsdale@cefas.co.uk

Appendix II- Questionnaire for Feedback

*Please use additional sheets if required.*

*Please return to: Jemma Lonsdale, Cefas, Pakefield Road, Lowestoft, NR33 0HT or* jemma.lonsdale@cefas.co.uk

# Feedback Questionnaire for the EPSS Tool Testing

Section A- Participants Details and Organisation

Name (can be left blank):_____

Organisation: _____

Job Title: _____

Type of organisation i.e. business, government etc. _____

Section B- Feedback on the Tool & Output

1. Which route did you use?

a) The GIS tool (provided on CD). *Move to question 2*
b) The online form. *Move to question 4.*

2. Was the tool user friendly?

| *If no, what would you like to change?* |
|---|
| |

3. Was the tool fast sufficiently quick in your opinion?

| |
|---|
| |

4. Was the output report clear and contents clear?

| *If no, what would you like to change?* |
|---|
| |

*Please use additional sheets if required.*

*Please return to: Jemma Lonsdale, Cefas, Pakefield Road, Lowestoft, NR33 0HT or* j.lonsdale@2013.hull.ac.uk

5. Do you feel the background and assessment is accurate?

| |
|---|
| *If no, what would you like to change?* |

6. Any other comments?

| |
|---|
| |

7. Do you think you would find the tool useful if accessible for your area?

| |
|---|
| |

8. Would you propose any changes to the tool or output?

| |
|---|
| *If yes, what would you like to change?* |

*Please use additional sheets if required.*

*Please return to: Jemma Lonsdale, Cefas, Pakefield Road, Lowestoft, NR33 0HT or* j.lonsdale@2013.hull.ac.uk

Section C: Contact Details

9. Do you agree to have your comments used?

(A) Attributed
(B) Anonymously

10. Are you happy for the details regarding the 'project' you have provided to be used in validating the tool?

(A) Yes
(B) No

If you would be willing for me to contact you directly with any further questions I may have, please provide your preferred contact details below. Your contact details will only be used for the purposes of this project and will remain confidential.

Name: _____

Address: _____

Tel: _____

E-mail: _____

**I will be pleased to share the results of the survey with you. Please contact me should you wish to see the final report.**

Contact:
Jemma-Anne Lonsdale
Cefas Laboratory, Pakefield, Lowestoft, Suffolk, NR33 0HT
J.lonsdale@2013.hull.ac.uk; tel: 01502 524491

Professor Mike Elliott
Institute of Estuarine and Coastal Studies, University of Hull, Hull, HU6 7RX
Mike.elliott@hull.ac.uk; tel: 01482 466773

*Please use additional sheets if required.*

*Please return to: Jemma Lonsdale, Cefas, Pakefield Road, Lowestoft, NR33 0HT or* j.lonsdale@2013.hull.ac.uk

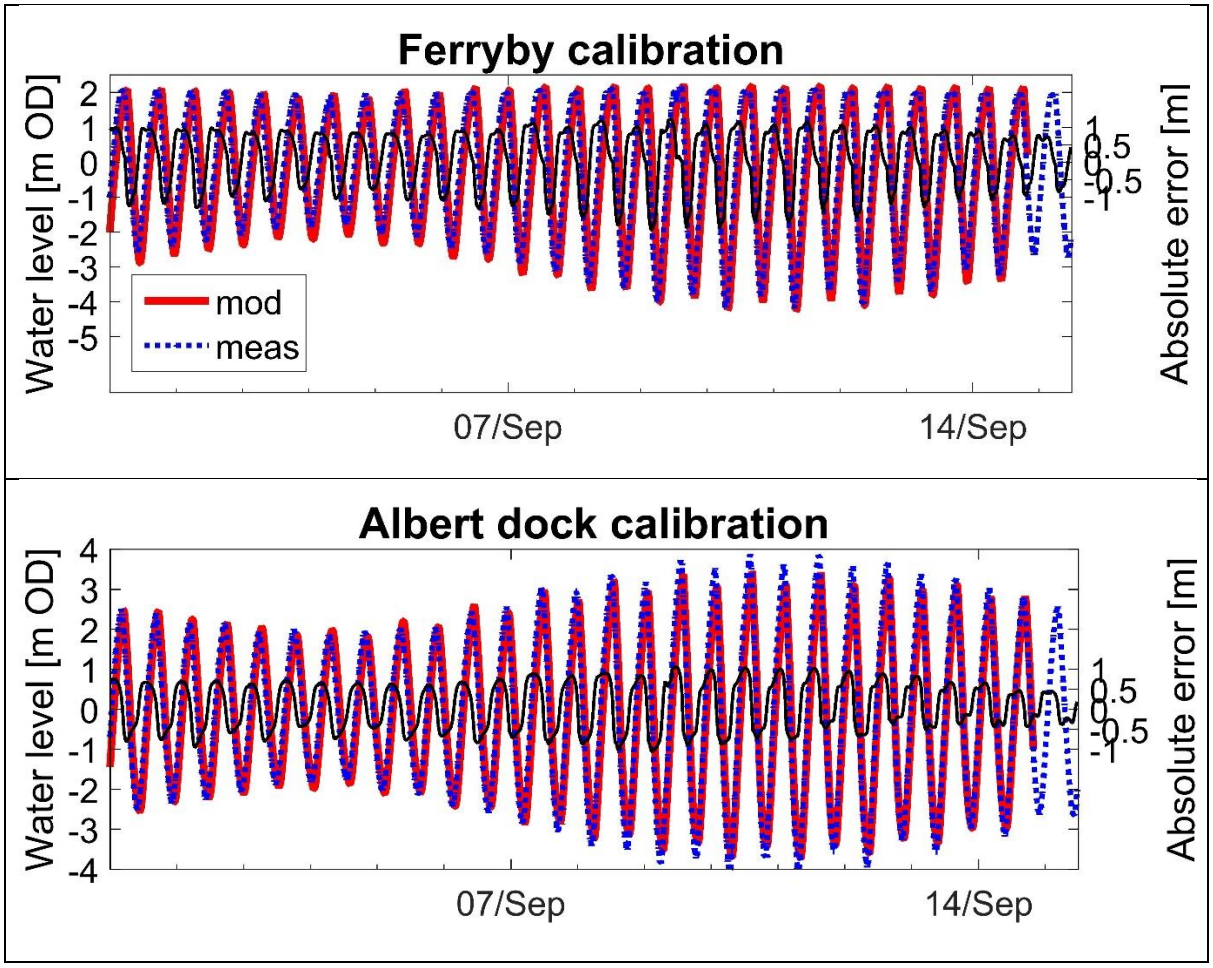
# Appendix 9
# Responses for the EPSS Testing

A presentation was provided to stakeholders and interested parties at the university of Hull on the 25th January 2017 and the following comments were provided:

- Can ecosystem goods and services valuations be incorporated for sites where an assessment has been carried out with reference into the tool.
- Can certain points be taken e.g. the legislation part?
- Can the tool weight sensitivity based on density such as bird or marine mammal data?
- Can the tool incorporate data where high resolution date is available but not others?
- Can confidence be incorporated such as age of data, date inferred from expert opinion and qualify data source rather than apply a confidence score.
- The tool can be commercialised with additional features in order to support the free version therefore only one tool needs maintaining and updating.
- Data gaps need to be flagged i.e. identify the information that needs to be available before the tool can be used
- Following on, can a checklist be provided to address the above.
- The tool needs to be able to function based on expert opinion only in the scenario where there is no data
- Needs to consider the wider marine spatial plan area and wider developments such as offshore wind farms i.e. impacts over much larger scale for a large area.

## Appendix 10
## Calibration Figures

Figure 70 and Figure 71 compare water elevation predicted by the model (mod) and measured at gauging stations (meas) during the calibration and validation steps, respectively. “Noise” in the measurements can be noticed for example in Figure 71 on the 16th of September; over those periods, the absolute error or difference between observation and prediction are not reliable. The absolute error sinusoidal curve reveals a small shift in phase but good match of maximum and minimum water-level.



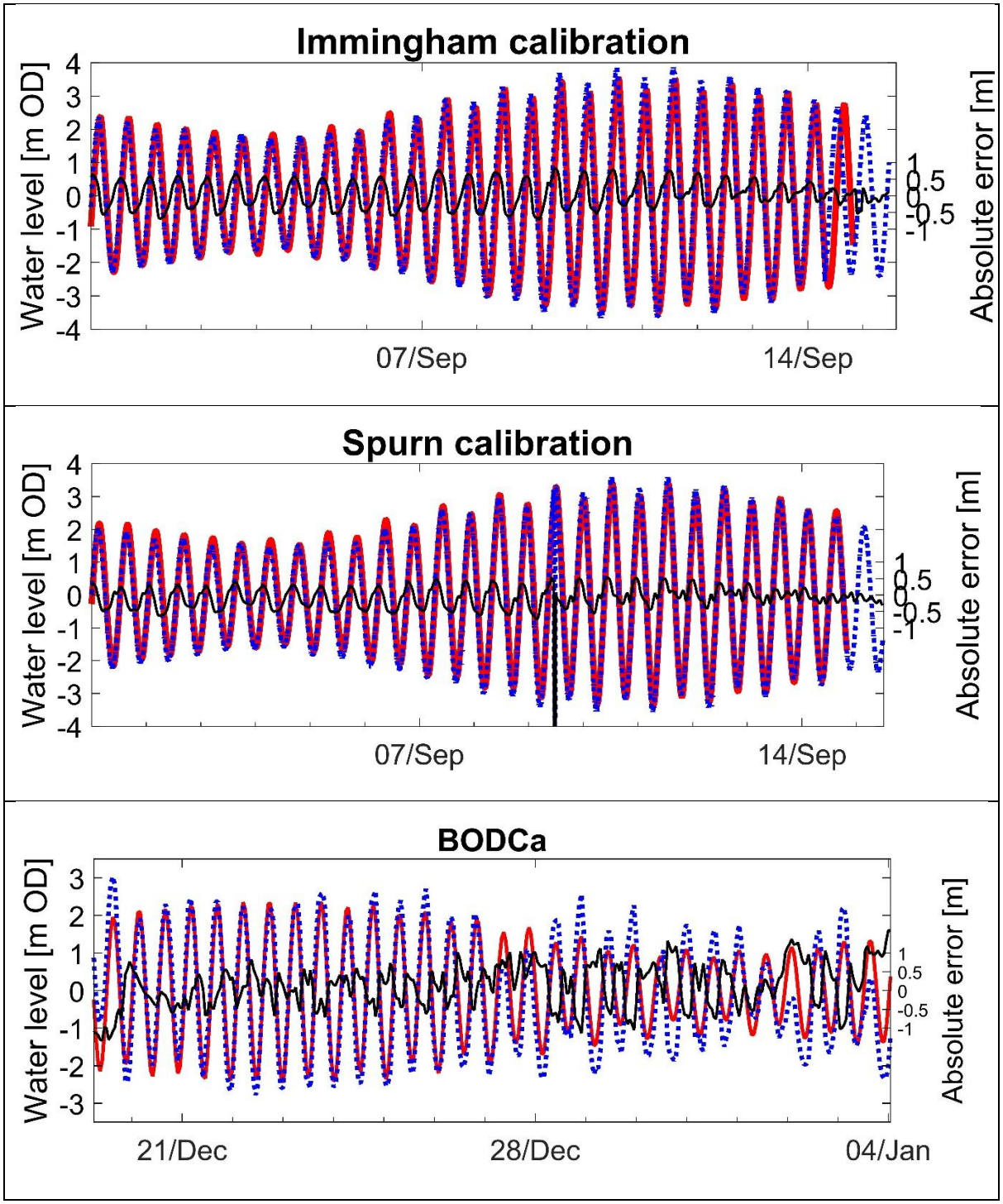
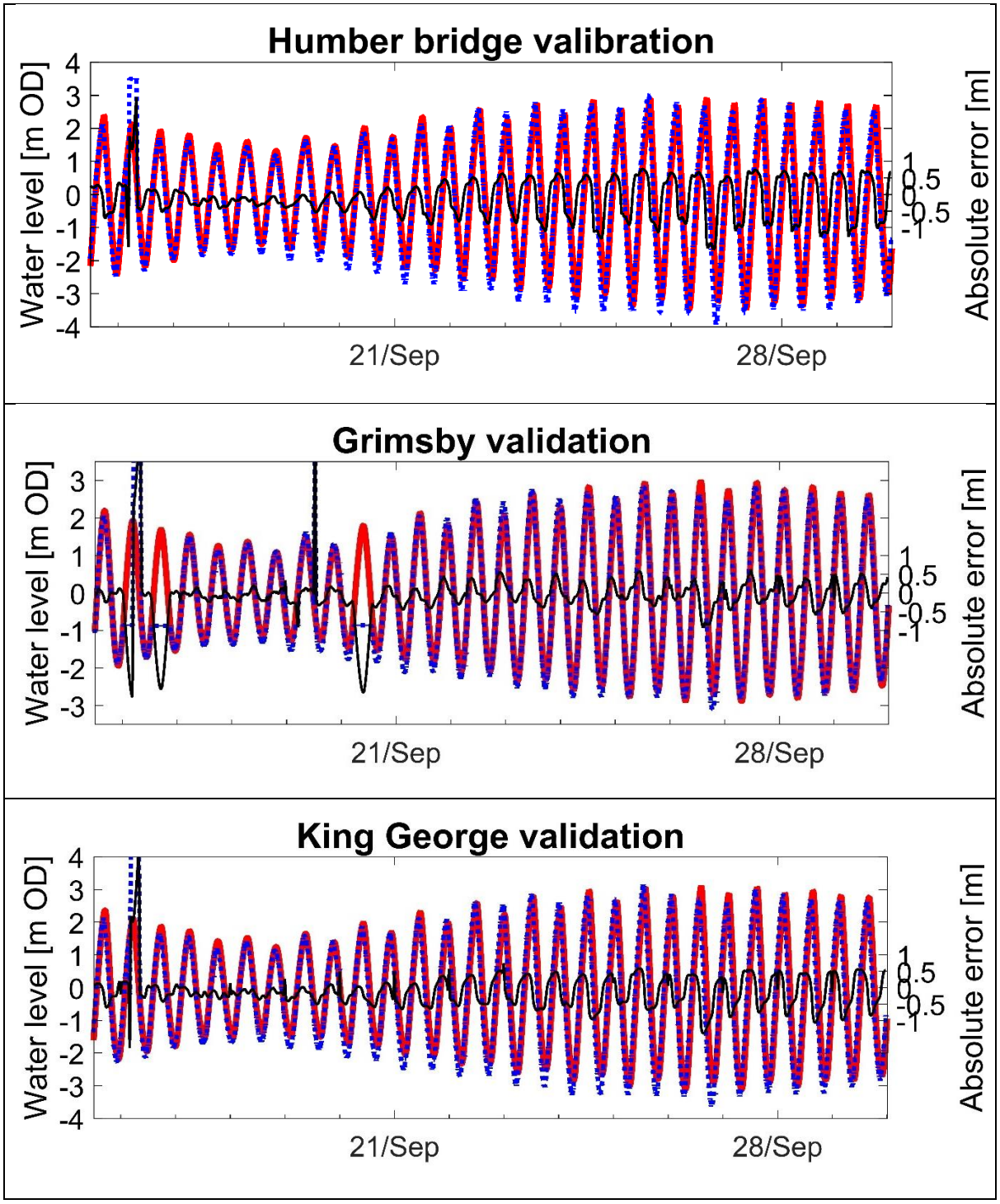



Figure 70- Model calibrated over the estuary and offshore BODCa locations against observed water elevation time series. The legend with red solid line for model prediction, blue dotted line for observations and black solid line as absolute error between model and observation is applied for all the plots.


Humber bridge valibration
Water level [m OD]
Absolute error [m]
21/Sep
28/Sep
Grimsby validation
Water level [m OD]
Absolute error [m]
21/Sep
28/Sep
King George validation
Water level [m OD]
Absolute error [m]
21/Sep
28/Sep

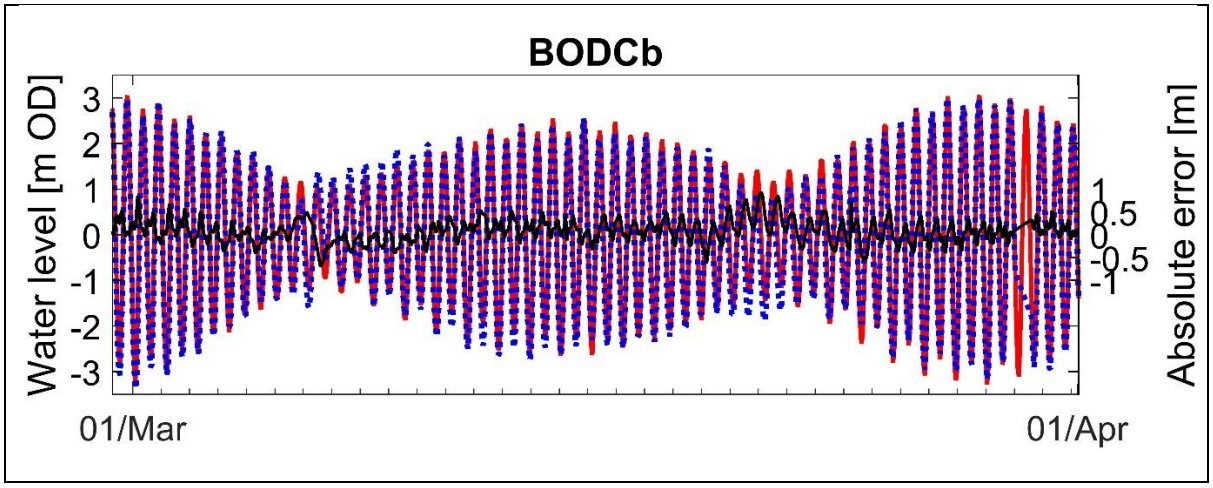



Figure 71- Model validation over the estuary and offshore BODCb locations against observed water elevation time series. The legend with red solid line for model prediction, blue dotted line for observations and black solid line as absolute error between model and observation is applied for all the plots.