Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme

Development and Demonstration of Systems-Based Estuary Simulators (EstSim)

EstSim Management Questions

R&D Project Record FD2117/PR5



Environment Agency

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Prepared by ABP Marine Environmental Research for the Estuaries Research Programme (ERP Phase 2) within the Defra and Environment Agency Joint Broad Scale Modelling Theme

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Contract Statement
This report describes work commissioned by Defra under Project FD2117 Development and Demonstration of Systems Based Estuary Simulators (EstSim). The Funders' Nominated Project Officer was Kate Scott (Environment Agency: kate.scott@environment-agency.gov.uk). The ABPmer Project Number was R/3434 and the Project Manager at ABPmer was Alun Williams (Email: awilliams@abpmer.co.uk).

Collaboration Statement
This report was prepared by the EstSim Consortium comprising: ABP Marine Environmental Research Ltd (lead), University of Plymouth (School of Engineering), University College London (Coastal & Estuarine Research Unit), HR Wallingford, WL | Delft Hydraulics and Discovery Software.

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Keywords

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EXECUTIVE OVERVIEW OF FD2117: DEVELOPMENT AND DEMONSTRATION OF SYSTEMS-BASED ESTUARY SIMULATORS (EstSim)

Development of Management Questions, July 2007

Purpose

The Broad Scale Modelling Theme of the Defra/EA Joint Thematic R&D Programme for Flood & Coastal Defence has funded three contracts under the Estuaries Research Programme, Phase 2 (FD2107, FD2116 and FD2117). FD2117 (EstSim) started in April 2004 and has the following headline aims:

- To extend the ability to simulate estuary response to change.
- Facilitate knowledge exchange through accessibility of simulation results.

The Project

ABPmer, University College London, University of Plymouth, WL | Delft Hydraulics and Discovery Software are undertaking the project. The project was originally of 3 years duration (April 2004 – April 2007), but had an extension for completion in June 2007. There are nine Scientific Objectives as follows:

1. System Conceptualisation: Boundary setting and focusing of research effort.
2. Development of Management Questions: Rationalisation of management questions that can be informed through application of systems approach.
3. Development of Behavioural Statements: Formal definition of the estuarine system in terms of systems approach and behavioural statements.
4. Mathematical Formalisation: Development of behavioural statements into a logically consistent mathematical framework.
5. Development of System Simulation: Development of architecture for estuary simulation based on the mathematical formulation of the system definition.
6. Manager System Interface: Explore the use of decision support systems and visualisation techniques for proof of concept testing.
7. Pilot Testing: Performance evaluation of estuary simulator.
8. Dissemination: Increase awareness of function and utility of research.
9. Peer Review: Ensure research lines deliver against Scientific Objectives.

This report will be used to provide scenarios for the pilot testing of estuaries within Objective 7, and to guide the development of the simulator itself.

Contact Details

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1. INTRODUCTION

1.1 Background

On 1st April 2004 ABP Marine Environmental Research Ltd (ABPmer) and its Project Partners were awarded research contract FD2117 (CSA 6064) within the Broad Scale Modelling Theme of the Defra/EA Joint Thematic R&D Programme for Flood & Coastal Defence.

The contract for FD2117 was awarded on the basis of a 'contract won in competition' after submission of a CSG7 (revised CSG7 submitted on 8th March 2004).

Entitled 'Development and Demonstration of Systems-Based Estuary Simulators' (hereafter EstSim), this research contract forms one of three contracts awarded under Phase 2 of the Estuary Research Programme (ERP). The two other contracts under the umbrella of ERP Phase 2 are (i) FD2107: Development of Estuary Morphological Models, and (ii) FD2116: Review and Formalisation of Geomorphological Concepts and Approaches.

The three phases of the Estuaries Research Programme seek to improve our understanding and prediction of estuarine morphological change over the medium to long-term, thereby facilitating strategic and sustainable decisions regarding flood and coastal defence.

The EMPHASYS Consortium undertook Phase 1 of this programme by evaluating existing morphological modelling approaches with the most promising of these approaches being developed within ERP Phase 2. It is anticipated that Phase 3 will seek to incorporate prior ERP research into an 'Integrated Estuary Management System'.

1.2 Project Aims

The overall aim of EstSim is to extend the ability to simulate estuarine response to change. This will be achieved through the delivery of research into the systems-based approach as an alternative yet complementary methodology to those research lines being undertaken within the other ERP Phase 2 projects (morphological concepts, bottom-up, top-down and hybrid methods). EstSim will also explore the simulation process in order to facilitate knowledge exchange between the systems-based tools and estuary managers. Integration of the systems based approach and existing methods is shown conceptually within Figure 1.

1.3 Project Structure

The project has been structured in to nine Scientific Objectives, covering the required lines of research and dissemination:

1. System Conceptualisation: Boundary setting and focusing of research effort.
2. Development of Management Questions: Rationalisation of management questions that can be informed through application of systems approach.
3. Development of Behavioural Statements: Formal definition of estuarine system in terms of systems approach and behavioural statements.
4. Mathematical Formalisation: Development of behavioural statements into a logically consistent mathematical framework.
5. Development of System Simulation: Development of architecture for the estuary simulation based on the mathematical formulation of the system definition.
6. Manager System Interface: Explore the use of decision support systems and visualisation techniques for proof of concept testing.
7. Pilot Testing: Performance evaluation of estuary simulator.
8. Dissemination: Increase awareness of function and utility of research.
9. Peer Review: Ensure research lines deliver against Scientific Objectives.

1.4 Management Questions

The role of the Management Questions Objective was refocused from the original workplan during the Conception phase of the project, as stated in the Conceptualisation report (APBmer, 2004), and further refocused following the completion of Objectives 4 (Mathematical Formalisation) and 5 (System Simulation). The purpose of revising the task was to enable the Management Questions Objective to capture and apply the emergent properties of the systems approach.

The key task within this Objective is the work described within Task 2.1 below (Table 1), i.e. capturing the predictive abilities of the approach being developed. This is a critical initial step and the remaining tasks within this Objective are dependent on its success. It is vital that the properties of the emerging system are understood in order to achieve this. This requires:

- An understanding of the requirements and output of the mathematical framework (Objective 4); and also importantly,
- An understanding of the nature of the simulation method developed within Objective 5.

Table 1. Objective 2 tasks

Task	Description
2.1	Review of the outputs from Objective 3 (Behavioural Statements), together with an understanding of the methods developed within Objective 4 (Mathematical Formalisation) and Objective 5 (System Simulation), with the aim of capturing the predictive abilities of the developing systems approach. Summary of the limitations of the prototype Simulator approach and methods in the context of the requirements of estuary managers.
2.2	Mapping of the predictive end-points against initiating events / interventions to identify the range of management questions that could be informed, the degree to which they are addressed and the role those questions have in UK coastal planning and consents procedures (as prescribed within the Conceptualisation Report, ABPmer, 2004). The requirements of estuary managers in terms of legislation are provided, with an update of the relevant legislation and literature, progressing from that produced for the EMPHASYS project (Posford Duvivier, 2000), and incorporating information of relevant legislation from estuary managers consulted under Task 2.3.
2.3	A targeted and focussed consultation with key identified stakeholders. A list of those consulted has been agreed with Defra's project officer and has drawn upon existing ABPmer contacts. This allows the range of management questions identified in Task 2.2 to be confirmed and refined as appropriate, in terms of current legislation, and the requirements of estuary managers.
2.4	Development of management questions into format used to initiate simulation of the systems approach (as prescribed within the Conceptualisation Report, (ABPmer, 2004), and for use within the pilot testing of the Simulator (Objective 7 of EstSim).
2.5	Production of technical report on above Tasks.

1.5 Report Structure

This report is divided into the following sections:

- Section 2: A summary of the systems-based approach;
- Section 3: An assessment of capabilities of the EstSim Simulator;
- Section 4: The mapping of predictive end-points / management questions, including a review of legislation applicable to the estuarine environment; the consultation exercise; and the revised management questions arising from the consultation;
- Section 5: Conclusions and recommendations; and
- Section 6: The way forward.

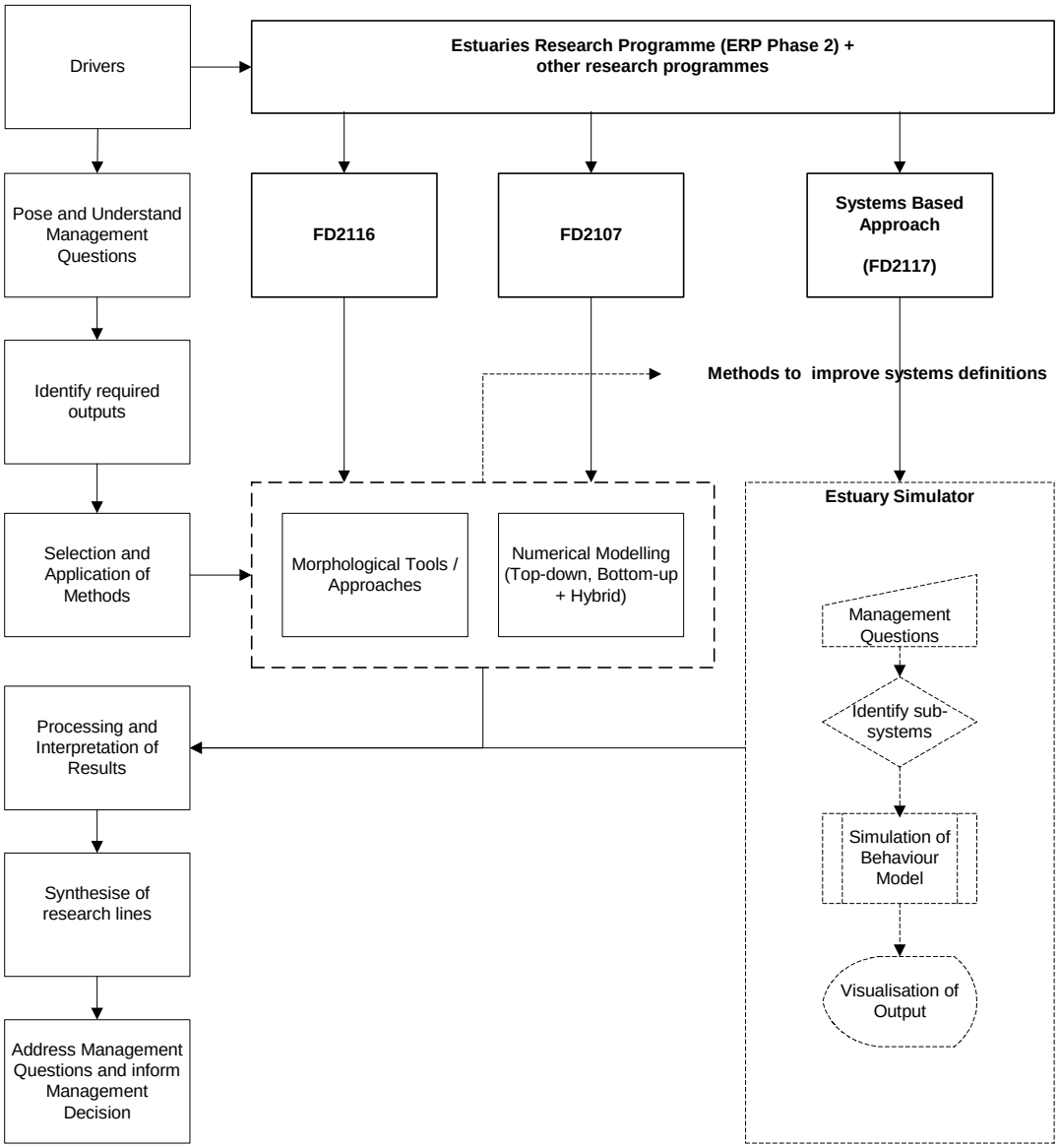

Figure 1. Integration of systems-based approach

2. SUMMARY OF SYSTEMS-BASED APPROACH

This section presents the context and background to the Management Questions Objective, providing a review of the systems approach taken within the EstSim project, as described in the outputs from Objective 3, the Behavioural Statements Report (EstSim Consortium, 2004).

The systems approach separates out sub-systems and their interactions in order to understand complex system organisation and define its behaviour. It combines the physical elements and the dynamics of the interactions between those elements to explain how the different elements within the system interact and respond to change (Cowell & Thom, 1994; Capobianco *et al.*, 1999), and these elements and interactions can be described using systems diagrams (Townend, 2003). Elements and interactions within an estuarine system can be mapped using the systems approach and systems diagrams. For full descriptions of the approach and formalisation of the model see Objective 4 (Karunarathna and Reeve, 2005) and Objective 5 (French and Burningham, 2007).

A system diagram is a flow chart representation of each of the components of the estuarine system, the representative geomorphic elements (GEs), which is suitable for modelling of longer-term and larger-scale change in complex systems where not all the relationships between components and processes can be quantified, or captured effectively in top-down models. The qualitative approach can be useful at the scales that are required for estuary management questions (French and Burningham, 2007), providing indicative, rather than quantitative, results on the behaviour of systems.

Behavioural modelling extends the basic systems approach; and the concept is to develop an understanding of the behaviour of the system by capturing the nature of the relationships between system components in a mathematical form and mapping them onto a simple model. This model does not require any relationship to underlying physical processes. The estuarine system components and their interactions are mapped as a relationship or response, which could have a variety of forms including, for example, simplified numerical models, morphological concepts, decision rules or feedbacks, with the aim of providing predictions of change.

The behavioural modelling approach has been applied to UK estuaries, using the estuary typology and classification described above. The behavioural (textural) descriptions of each estuary type identify the main behavioural attributes, and therefore its constituent components, or geomorphic elements. For each geomorphic element several types of information are required, as shown in Table 2, and each is represented in the Prototype Interface for each geomorphic element. The relationships between these elements form the systems diagram, which can represent the short, medium and long-term interactions, using the following definitions:

- Short-term: responses within a year;
- Medium-term: responses over decadal to century timescales; and
- Long-term: responses over decadal to Holocene timescales (i.e. over the 10,000 years).

The short-term can be considered as the system's responses to maintain form, typically continuous wave and tidal processes. Medium-term behavioural responses are dominated by episodic and intermittent forcing, e.g. storms, and longer-term behavioural responses are likely to be dominated by changes in relative sea level or land elevation.

Table 2. Information required for each Geomorphic Element (GE)

Type	Description
Definition	An overall description of the GE including key aspects of the form, formation, processes or location within the estuary system.
Function	Defining the role of the GE within the physical system in terms of exchanges of energy and mass.
Formation and evolution	Details of the processes that lead to formation of the GE, and how the GE develops and changes over time.
General form	Describing the characteristic shape of the GE, and where appropriate highlighting the prevailing conditions under which a particular form will be adopted.
General behaviour	Described in terms of how the GE may respond to forcing factors.
Forcing factors	Describes the key processes responsible for shaping the GE, with details provided where appropriate of the role of the forcing factors.
Evolutionary constraints	Factors that may alter or constrain the development of the GE leading to a different evolution.
Behavioural timescales	Landforms respond to forcing over a range of time and space scales, and exhibit characteristic responses for differing scales.
Interactions with other GEs	Each GE will be linked to other GEs present within a particular estuary system, and this identifies these interactions in terms of flows of energy and / or matter between GEs. These can be general interactions or interaction with specific geomorphic elements.

Behavioural statements provide a mapping of the estuary system and its components capturing present behaviour, and for each generic estuary type, there is a generic systems diagram / behavioural statement, showing each of the constituent elements and the linkages between them. Figure 2 shows an example of a generic systems diagram, with its constituent geomorphic elements and linkages (EstSim Consortium, 2004).

At the whole estuary scale and represented within the Prototype Interface, a systems diagram was produced for each estuary, highlighting all the elements present and key linkages, and an estuary scale textural description of the key characteristics and influences on behaviour. For each identified geomorphic element present within the estuary, a textural description is also produced, covering behaviour over a range of timescales. Behavioural statements of specific estuaries must include anthropogenic activities, as these will have had an influence on estuary behaviour, and this is also a key aspect of the application of this approach to real estuaries. This approach has been tested on two estuaries, Southampton Water and the Humber, both of which have good datasets and have been extensively studied in the past (EstSim Consortium, 2004).

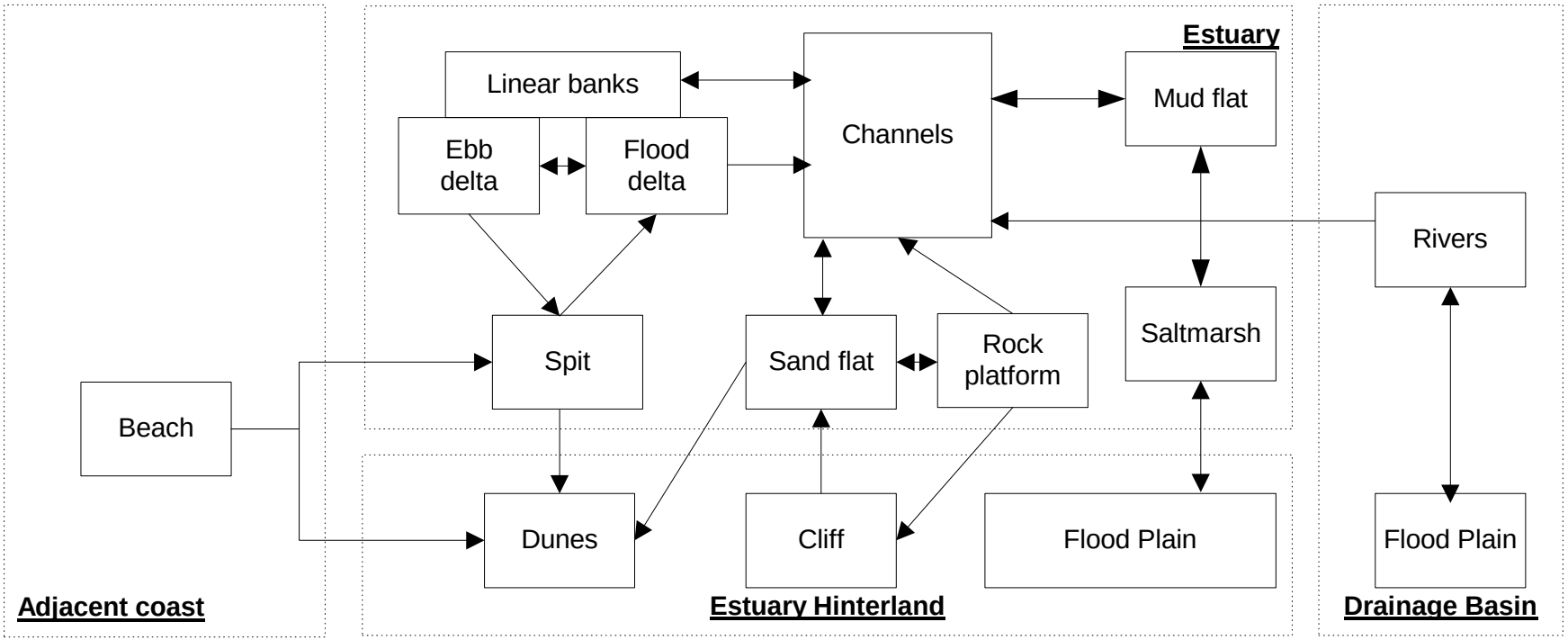

Figure 2. Generic estuary morphological elements and linkages (EstSim Consortium, 2004)

3. ASSESSMENT OF CAPABILITIES

The aim of this section is to present an assessment of the capabilities and limitations of the Prototype Simulator and Prototype Interface, in terms of the Management Questions Objective and the requirements of estuary managers, as outlined in Task 2.1 (Table 1).

Through the Scientific Objectives outlined in Section 1.3 the EstSim Project has developed and evolved a methodology, which has produced various outputs at different stages of the project. In assessing the capabilities here, to assist in this Management Questions Objective, this report specifically refers to the Prototype Simulator, produced as an output of the System Simulation Objective (Objective 5; French and Burningham, 2007). This is available as standalone MatLab code or alternatively within the Prototype Interface developed within the Manager System Interface Objective (Objective 6). The Prototype Interface includes the UK estuaries typology and database produced within the Behavioural Systems Objective (Objective 3; EstSim Consortium, 2004).

There are two distinct capabilities or functions of the Prototype Interface and the systems based approach; the first is the development and provision of an enhanced estuary database and reference tool, and the second is a behavioural systems-based predictive tool for estuary evolution and simulation. The following sections introduce the concepts used and then describe the two identified capabilities, with reference to the previous outputs of the EstSim project.

3.1 Database and Reference Tool for UK Estuaries

As stated in the Objective 3 report (Behavioural Systems, EstSim Consortium, 2004) the purpose of the estuary typology produced within the EstSim project is to develop a systems-based approach to understanding estuaries, by identifying the range of geomorphological elements present within each estuary behavioural type within the UK. This enables the development of behavioural descriptions for each estuary type and systems diagrams for each Geomorphic Element within each estuary type.

Several different estuary classification systems and databases have been developed in the UK for a variety of purposes, including those produced within EMPHASYS and Futurecoast, and the JNCC Inventory of UK Estuaries. For the purposes of this project, each of these systems has been reviewed and revised into one combined estuary typology for all UK estuaries. This approach ensures that the behavioural systems methodology produced within FD2117 is applicable to all estuaries and to each type of estuarine Geomorphic Element found within the UK.

For each estuary type a list of eleven relevant geomorphic elements was produced. Subsequently, a rule-base resulting from this was tested against the three UK estuary databases listed above. The rules are listed in Table 3. An estuary typology has been developed based on the presence or absence of the component geomorphological elements. This typology is able to classify the seven generic estuary types for the UK. A simple protocol has been developed to present statements of the seven estuary types and eleven component geomorphological elements (EstSim Consortium, 2004). The

estuary typology identifies the range of geomorphological elements present in each of the seven estuary types; the understanding of the estuary behaviour combines these geomorphological elements, forcing parameters such as tidal and wave energy and the dynamics of the interactions between them. Behavioural statements have been developed for the seven generic estuary types, as have textural descriptions for each of the eleven component geomorphological elements. Systems diagrams have been produced to represent each of the behavioural statements and over both the short/medium-term and long-term timescales for the geomorphological elements. The systems diagrams are shown in the Objective 3, Behavioural Statements report (EstSim Consortium, 2004).

Table 3. Rules to identify estuary type

Type	Behavioural Type	Rule
1	Fjord	Glacial origin, exposed rock platform set within steep-sided relief and with no significant mud or sand flats
2	Fjard	Glacial origin, low lying relief, with significant area of sand or mud flats
3	Ria	Drowned river valley in origin, with exposed rock platform and no linear banks
4	Spit enclosed	Drowned river valley in origin, with one or more spits and not an embayment
5	Funnel shaped	Drowned river valley in origin, with linear banks or no ebb / flood delta and not an embayment.
6	Embayment	River or marine in origin (i.e. not glacial), with multiple tidal rivers meeting at or near mouth and a bay width / length ratio[1] of 1 or greater, and no exposed rock platform[2]
7	Tidal inlet	Drowned coastal plain in origin, with barrier beaches or spits

Notes:
1. Where bay extends from sea opening to the confluence of the rivers
2. This condition was only needed to exclude the Plymouth Sound

The resulting typology for each of the UK estuaries is shown in Table 5 of the Objective 3 report (EstSim Consortium, 2004) and has been applied within the EstSim Manger System Interface (Objective 6). The classification of the UK estuaries includes the representation of the geomorphic elements for each generic estuary type, as well as for each specific estuary, both of which can be viewed within the Interface. A database tool loads the relevant content stored within the estuaries database into the Prototype Interface, such as the estuary name and geomorphological content and once this is loaded, it is possible to view additional related information, including documents, photos, maps and system diagrams. The additional files are simply linked to the various features within the application and are retrieved by the user requests.

It is therefore possible to display individual estuaries within the Simulator Interface and to view the geomorphic elements that make up the estuary and the linkages between them, for each estuary within the UK. This provides an excellent resource for users of the Prototype Interface to view information for each estuary within the UK according to the classification, as well as an understanding of each estuary in systems terms.

3.2 Predictive Systems-Based Tool for Estuary Evolution

In addition to the estuary database functionality, there is also the possibility of using the Simulator aspect of the Interface and the behavioural approach in a predictive capacity for each estuary in the UK; applying different forcing factors, management decisions and legislation for example, to examine future evolution of estuaries.

The different methodologies and approaches for developing the predictive capability were assessed in Karunarathna and Reeve (2005) and explored further in French and Burningham (2007).

The aim was to develop a mathematical formalisation to describe the connectivity and flow of complex estuarine systems using a systems-based approach (Karunarathna and Reeve, 2005). Three approaches: Boolean, networks dynamics and ASMITA, were all explored as a means of system simulation, and the view was reached that the Boolean approach could provide a suitable and flexible method to model the long-term morphodynamic evolution of extremely complex estuarine systems.

Boolean networks have been developed that combine geomorphological elements within the estuary system with the external forcing factors that drive the estuary's morphological evolution; and Boolean expressions have then been derived to define the interactions between the elements of the network. The aim of this use of the Boolean approach is to describe the dynamics of a complex system with a simple representation of relevant geomorphological concepts.

Under the Boolean approach the estuary is schematised into a number of geomorphic elements as explained in Section 2, and the state of each element, including forcing factors such as tides and waves, is described by discrete Boolean logic using low = 0, and high = 1 for each variable. The state of an element in a Boolean network at a future time is governed by a logical rule or Boolean function, the aim of which is to interpret the complex feedbacks between various elements of the estuary system. The Boolean function for each variable is defined by combining Boolean variables within a logical schematic for an estuary, developed by considering the types of feedback between the physical elements of the estuary and the physical forcing. The future state of each element in the network depends on the states of the other elements in the network that are designated as that element's inputs, as determined by the Boolean function. Human influences can be included by the addition of control structures and management policies as new elements of the network. The logical framework is then transformed into a Boolean matrix and different potential behavioural pathways of estuary morphology are identified.

French and Burningham (2007) developed the Boolean network approach initially suggested by Karunarathna and Reeve (2005) to achieve a more realistic representation of estuary behaviour at the system level, incorporating a larger set of morphological and process components.

French and Burningham (2007) addressed the limitations of the Karunarathna and Reeve (2005) proof of concept in the development of the prototype Simulator using MatLab. An important issue of the aspatial representation of an estuary has been addressed by the separation of the estuary model into an outer estuary sub-system that

interacts with the coastal system, and an inner estuary sub-system. Each sub-system contains the appropriate geomorphic components, therefore the outer could include spits, dunes and tidal deltas, and the inner sub-system sub-tidal channels and intertidal flats.

The generic scheme of the prototype Simulator developed in French and Burningham (2005) is shown in Figure 3. Figure 3 also shows the three types of system component devised and further developed in Objective 5:

- external forcing and interventions, where interventions can include anthropogenic changes;
- process state variables, which change as the estuary evolves, e.g. in the outer estuary, estuary waves, swell, tidal prism, accommodation space, tidal asymmetry and erosion of coastal cliffs; and in the inner estuary, estuary waves and tidal asymmetry; and
- morphological components, which is an extended set of components initially derived from FD2117 Project Record PR2 (EstSim Consortium, 2004).

The system simulation using this Boolean network approach involves assessment of the evolution of the system from specified initial conditions and interpretation of the evolutionary tendencies in the context of the Boolean functions and systems diagram (French and Burningham, 2007). The functions derived under Objective 5 and tested within the Prototype Simulator are able to determine each of the seven generic estuary types.

For an individual estuary, recorded historic behaviour can be used to validate the Boolean variables and functions, and scenarios can be applied to test specific management issues. Model validation has been carried out for both the Ribble (a funnel-shaped estuary; EstSim estuary type 5) and Southampton Water (a spit enclosed estuary; EstSim estuary type 4), against previous records of historic change. The recent evolution of both estuaries was essentially recreated using the appropriate generic rule base, however, some estuary-specific aspects were outside the capability of the model without modification.

Accelerated sea level rise associated with climate change is a scenario that would constitute a significant change in external forcing for an estuary, and this can be combined with appropriate management scenarios in order to examine impacts on the estuary components and system. The accelerated sea level rise scenario has been tested for a generic tidal inlet, where a ‘hold the line’ policy resulted in loss of morphological components due to both a sediment deficit and ‘coastal squeeze’, where migration of the intertidal is prevented by defences. If the policy is then switched to one of ‘do nothing’, when defences reach the end of their life (defined by the use of a decay term) the estuary is free to evolve towards a cyclical equilibrium, unconstrained state, involving lower marshes in the inner and outer estuary (French and Burningham, 2007).

There are a number of limitations associated with the Boolean network approach and the prototype model Simulator that has been developed in FD2117. French and Burningham (2007) provide a summary of the weaknesses established during Objective 5, and pertinent points are presented here:

- Boolean variable states can be interpreted as existence or tendency; for example, existence and the Boolean states of 0 and 1 constitute negligible or significant presence (or absence or presence), which is a more consistent approach. However, provided the implementation and terminology are consistent and any user is aware, either approach is appropriate.
- The use of influence diagrams and the subsequent translation into Boolean functions for the formalisation of geomorphological systems is a subjective process, and as such different experts may produce a differing set of Boolean functions and linkages from a given set of components and variables. This could be resolved by the construction of a set of optimal representations derived through expert consensus (French and Burningham, 2007). Further to this the functions and variables contained with the Prototype Simulator are not meant to be a definitive answer to the formalisation of estuary components and processes, and may require further consideration for application to specific estuaries.

The use of the Prototype Simulator therefore requires the user (or estuary manager) to understand how the Boolean states were implemented, either as an absolute or relative measure, and to view any outputs or results appropriately. The user must also view the results of the Prototype Simulator as the implementation of expert judgement. As such, these are qualitative, rather than quantitative and should be applied appropriately.

The mathematical framework developed under the Boolean approach is a set of simple logical expressions that could be solved in any programming language, e.g. MatLab, which has been used in the development of the approach and the Prototype. However, estuary behavioural system modelling software has been evaluated and the EstSim tool is to be delivered over the web / internet, as part of the Prototype Interface, as a form of standalone estuary simulator, which in turn could form part of the Estuary Management System (EMS) being developed under FD2119 (French and Burningham, 2007; Whitehouse *et al*., 2007).

The Prototype Simulator, contained within the Interface, will be tested for two further estuaries, the Teign and the Thames in Objective 7, Pilot Testing, using management scenarios developed under Task 2.3 of this Objective.

3.3 Summary of Capabilities

The Prototype Interface and Simulator have two main capabilities: the UK estuary typology, which provides a database resource for each estuary within the UK and a systems-based understanding of each estuary; and a predictive tool for qualitative modelling of estuary evolution. The predictive tool can be used to determine direction of change within the seven generic UK estuary types and for specific user-defined estuaries, over the medium to long-term timescale.

The capabilities of the Prototype Simulator, however, are at present, generic for the seven types of UK estuary and will be tested at a more specific estuary level within the Pilot Testing Objective (Objective 7). The summary presented here draws upon the development of the approach and the proof of concept modelling carried out in Objectives 4 and 5 (Mathematic Formalisation (Karunarathna and Reeve, 2005) and System Simulation (French and Burningham, 2007), respectively.

There are various limitations associated with the use of the Prototype Simulator. The Simulator provides a generic, broad scale (estuary-wide) model of change within each type of estuary; the model is not able to define local scale issues and only produces a direction of change, rather than a quantitative definition of change, or a measure of the magnitude or timescale of change. In addition, it is not possible to determine timescale of change. Model setup for specific estuaries is currently reliant on expert geomorphological knowledge, therefore the use of the Simulator is restricted to the seven UK generic estuary types or those estuaries used within the Pilot Testing Objective (Objective 7).

This Simulator development represents a proof of concept, and an initial step in development of more sophisticated Boolean networks. The Objective 5 report (French and Burningham, 2007) provides recommendations for work to further develop this approach.

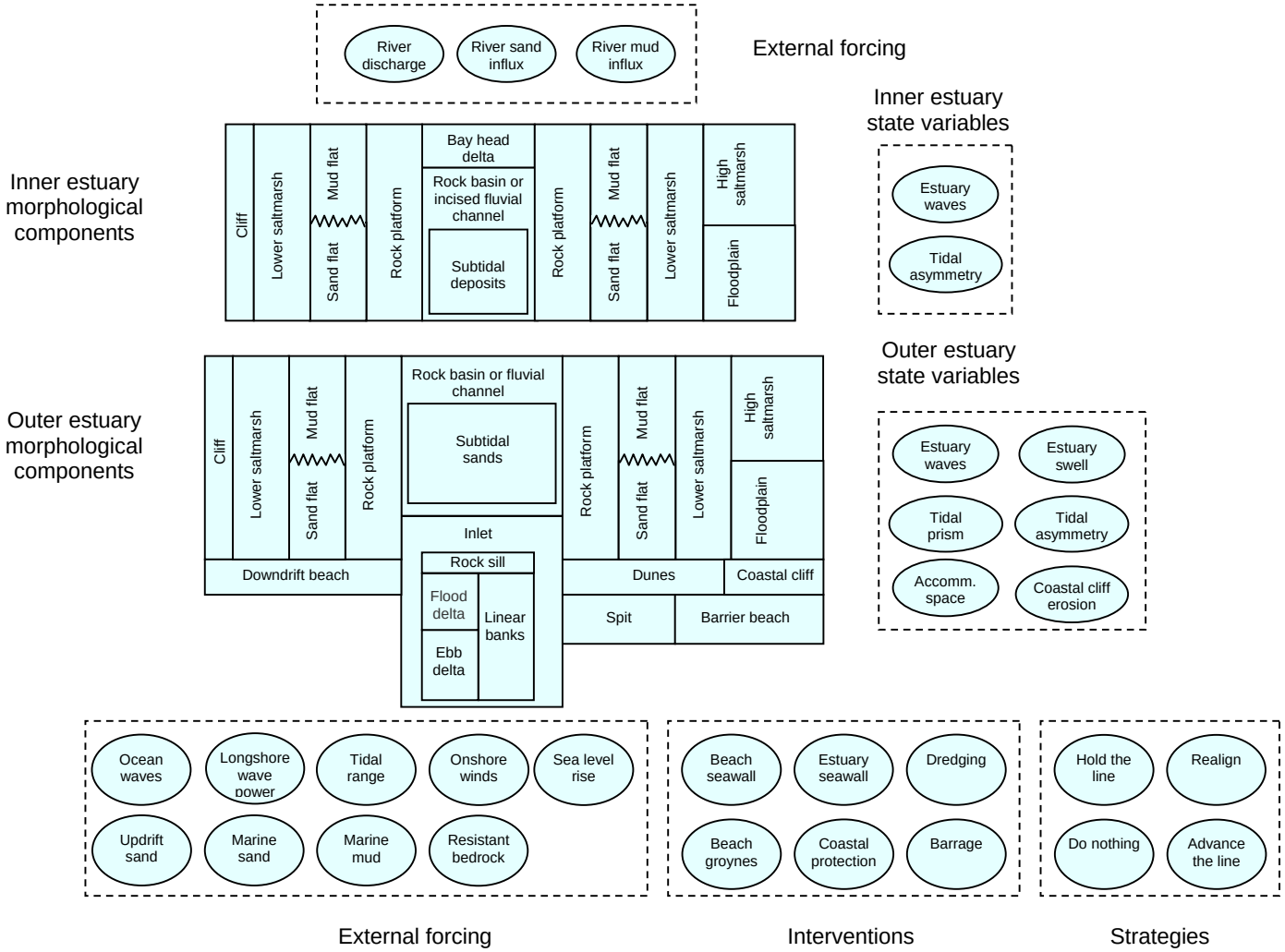

Figure 3. Generic morphological components and external forcing factors within the prototype estuary Simulator

4. MAPPING OF PREDICTIVE END-POINTS/MANAGEMENT QUESTIONS

This section aims to present the results of Task 2.2, the identification of the range of management questions that could be informed by the Prototype Simulator, the degree to which the questions could be addressed and their applicability to current legislation. Section 4.1 identifies the management questions through a review of existing and previous work, including that of the EMPHASYS project, Phase 1 of the Estuaries Research Programme. Section 4.2 reviews the relevant legislation for estuary management and provides an update of a previous EMPHASYS review. Section 4.3 presents a summary of the end-users consultation carried out under Task 2.2, the aim of which was to gather opinion on how legislation affects estuary management and how estuaries are currently managed within the UK, in order to feed relevant management questions into the pilot testing (Objective 7) of the Prototype Simulator.

The aim of the EstSim project is to extend the ability to simulate estuarine response to change, and to explore the simulation process in order to facilitate knowledge exchange between the systems-based tools and estuary managers. In order for this to be a success, this process must recognise that the requirements of the user are the starting point for estuary management (Townend, 2002).

Townend (2002) considered that there are two parallel strands for the assessment of management actions; one strand which considers the resource to be developed or protected and requires the estuary as a whole to be included; and a second strand which considers how the estuary reacts to changes and how this might impact on user interests within the estuary (Figure 4).

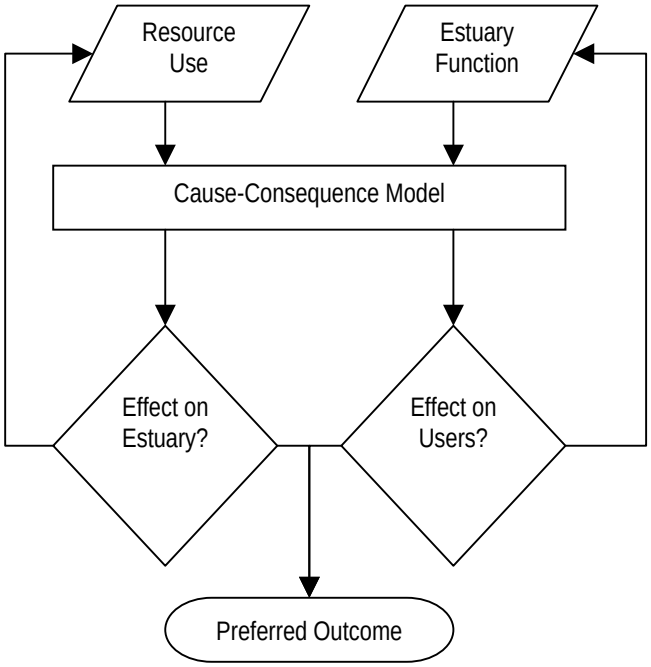

Figure 4. Parallel strands for the assessment of management actions (Townend, 2002)

A cause-consequence model (Figure 5) has been developed where the EstSim approach could be considered as one element of a set of tools for the prediction of estuary response to change.

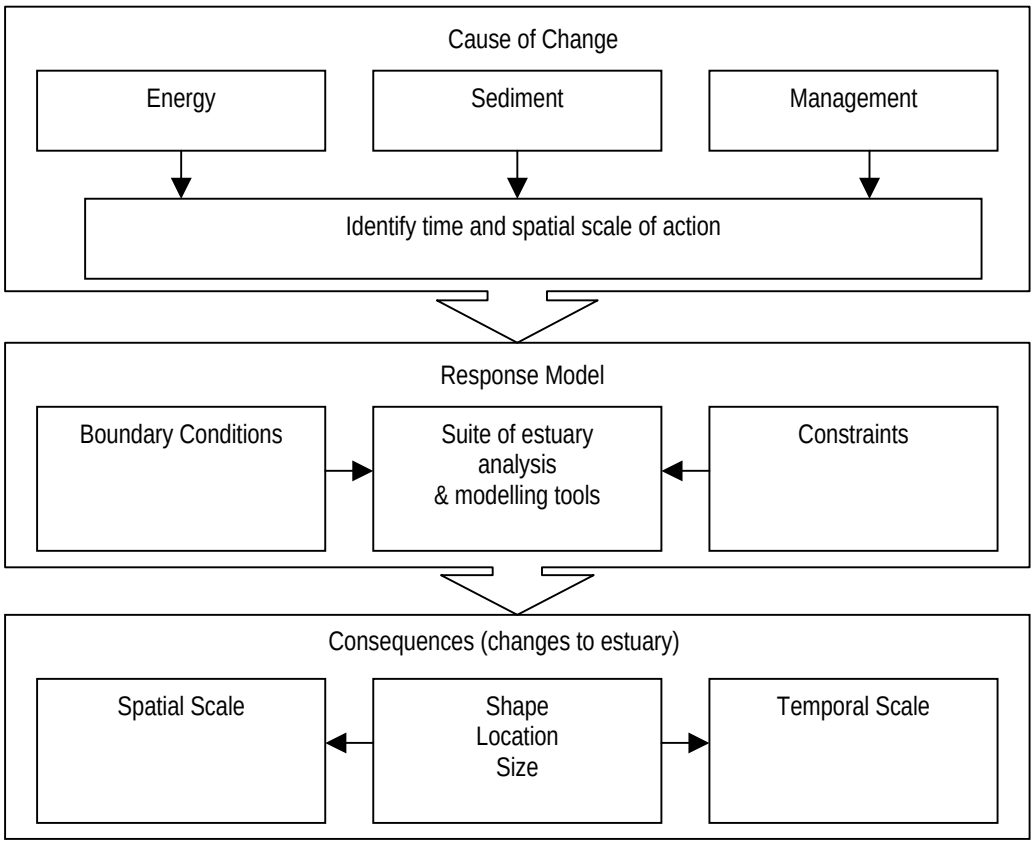

Figure 5. Estuary cause-consequence model for assessing morphological change (Townend, 2002)

Legislation to a large degree determines the management questions relevant to estuaries, including planning and consents procedures. A review of the legislation applicable to the management of estuaries is presented in Section 4.2.

Issues that affect estuaries can be 'whole estuary' or site-specific, and cover a wide range of activities, e.g. flood defence works, managed realignment, habitat creation, dredging, for which generally cumulative impacts need to be assessed. Previous work on estuary management questions has provided a starting point for this work, and this has been updated through the consultation exercise. The results of this are presented in Section 4.3.

4.1 Identified Management Questions

Management questions usually arise from a need to make a change to an estuary, or to develop a plan. This usually involves an assessment of the future of an estuary, where the change may involve a proposed construction, development or intervention that impacts on either the whole estuary or on one component of the estuary. Users'

interests might be at a strategic, whole estuary or regional level, such as the development of a new flood defence strategy or a habitat management plan, or they may be at a local level, such as the design and positioning of an outfall or a slipway.

Management questions will arise from strategic plans relevant to estuaries, which include the following (EMPHASYS Consortium, 2000):

- Estuarine elements of Shoreline Management Plans (SMPs);
- Flood and coastal defence strategies;
- Coastal Habitat Management Plans (CHaMPs); and
- Biodiversity Action Plans.

Each of these plans should also include the consideration of the impacts of climate change and sea-level rise, currently according to the Defra guidance (Defra, 2006).

Activities within estuaries that are relevant to estuary morphology include (EMPHASYS Consortium, 2000):

- Flood defence works, construction of hard defences and managed realignment;
- Habitat creation, including foreshore recharge;
- Disposal of dredged material;
- Maintenance, capital and aggregate dredging;
- Construction;
- Expansion of existing port facilities, or new port development;
- Reclamation;
- Vessel traffic, navigation issues;
- Marina development, harbour expansion, slipway development;
- Pipelines, outfalls, intakes, freshwater abstraction;
- Bridge development;
- Barrier / barrage development, alteration of position of tidal limit;
- Generation of tidal power, wind power;
- Development on floodplains;
- Removal of structures;
- Fisheries, trawling; and
- Recreational use.

For all the above, it is necessary to consider the relevance of the work within an overall management framework for the estuary if there is a strategy in place.

The types of management questions that emerge depend on who the questioner is. For example, if they are the organisation planning to make the change, the questions may be (EMPHASYS Consortium, 2000):

- Will the project achieve what is intended?
- What is the most effective and economical design for the project?
- Will the project fall within current legislation, policies and directives?
- Will it be accessible to other stakeholders, or will it be blocked by public pressure?
- What are the requirements of the consenting process?

If they are a regulator, statutory advisor or statutory stakeholder, and are not the ones making the change, the questions may be (EMPHASYS Consortium, 2000):

- How will this affect public safety (e.g. flood risk)?
- How will this affect other commercial concerns (e.g. shell fisheries, tourism)?
- How will it affect the environment, ecology and habitats?
- Will a localised project have undesirable impacts further afield?

Questions relating to changes in morphology can be general or issue-specific:

- What will the impact of climate change be on the habitat designations within an estuary?
- Will the construction of a barrage affect adjacent flood defences?
- Will dredging of a navigation channel affect the adjacent inter-tidal mudflats?
- Will a managed realignment lead to a decrease in sediment availability within the estuary?

Generic morphological questions will also be applicable at different spatial and temporal scales:

- What are the impacts of sea level rise or climate change on morphology?
- What are the influences of tidal processes on morphology?
- What are the influences of wave action on morphology?
- What are the influences of sediment supply and dynamics on morphology?
- What are the influences of the underlying geology on morphology?
- What are the influences of the associated ecology on morphology?
- What are the impacts of changes in water quality on morphology?
- How did the present morphology arise?
- What are the direct impacts of the plan, or activity, itself on the morphology?

There is a large amount of legislation, both in terms of UK (England & Wales) and EU Directives, current and future, which must be considered by estuary managers, regulators, the operating authorities, consultants and policy makers. This legislative framework determines the issues that can be of particular significance, and those most commonly experienced in estuary impact studies are (the stakeholder is listed in brackets and a key is given below) (HR Wallingford *et al*., 2006):

- Impacts on designated features (NE, RSPB, EA, CCW, EH, SNH, EHS);
- Disposal of sediment (Defra, CEFAS, NE, CCW, SNH, EHS);
- Impacts on navigation (port and harbour authorities);
- Impacts on fishing and fisheries (Defra, EA, CCW, SFC);
- Impacts on flood defences (EA, SEPA);
- Impacts on shellfish waters (EA, CCW); and
- Impacts on water quality (EA, CCW).

Key: NE – Natural England; RSPB – Royal Society for the Protection of Birds; EA – Environment Agency; CCW – Countryside Council for Wales; EH – English Heritage; SNH – Scottish Natural Heritage; EHS – Environment and Heritage Service, NI; Defra – Department for Food, Environment and Rural Affairs; CEFAS – Centre for Environment, Fisheries and Aquaculture Science; SEPA – Scottish Environment Protection Agency. SFC – Sea Fisheries Committee.

4.2 Management Questions in the Context of Legislation

The legislation pertinent to estuaries was summarised for the EMPHASYS project (Posford Duvivier, 2000) and this is updated here in light of the rapidity at which some legislation changes and new EU directives become significant and / or are transposed into UK law. The aim of this Section is to outline any changes to the legislation relevant for estuary management since 2000.

Future changes to legislation that will be relevant to estuary management include the UK Marine Bill White Paper, the draft Climate Change Bill and the Heritage Protection White Paper, both issued for consultation in March 2007; the Planning Reform White Paper and the Energy White Paper, both issued for consultation in May 2007; and in addition consultation is to be released by Natural England in spring 2007 on improved access to the coast of England. In Wales, the Welsh Assembly Government announced its plans in June 2006 to improve public access to the Welsh coastline. However, other than the draft UK Marine Bill, these future legislative instruments are not reviewed here, as each is subject to change in the near future.

EU Directives that may have an impact on coastal and estuarine management in the future include the Environmental Liability Directive (Directive 2004/35/EC), which is defined as 'environmental liability with regard to the prevention and remedying of environmental damage'. This Directive must be transposed into UK law during 2008. The Directive is aimed at the prevention and remedying of environment damage, specifically damage to habitats and species protected by EC law, damage to water resources, and land contamination which presents a threat to human health. It would apply only to damage from incidents occurring after it comes into force and is based on the polluter pays principle, i.e. polluters should bear the cost of remediation of the damage they cause to the environment, or of measures to prevent imminent threat of damage.

Increasing prominence of the devolved Welsh Assembly in decision-making has meant that some legislation now only refers to England and not Wales and where this is the case it is highlighted and the appropriate Welsh legislation is included (where it exists).

Within estuaries, legislation influences management decisions being made at a number of stages; it overarches the assessment process and provides context to the decision-making process. For example, if the activity falls under the Strategic Assessment Directive, a Strategic Environment Assessment (SEA) will be triggered at the outset of a plan or project. Therefore the legislative context must be considered throughout the management process; once the nature, scale and extent of change have been determined, legislation can then be considered with specific reference to the parameters affected.

The focus of this summary is on legislation that acts on estuary morphology and by inference ecology, water quality and other issues within estuaries. Legislation relevant to morphological change in estuaries can be divided into three categories:

- Legislation regulating an activity or operation within an estuary system that modifies existing physical processes;

- Legislation regulating operations that may result in the construction or removal of features that are part of the morphological estuary system; and
- Legislation protecting or conserving morphological features or the processes that maintain such features, either as features in their own right or as part of the system that requires their functioning.

Some legislation underpins all others, including the Strategic Environment Assessment Directive 2001/42/EC mentioned above, and the proposed Marine Bill, released as a Government White Paper in March of this year (Defra, 2007). Also relevant is the Water Framework Directive (WFD), which came into force in 2000 and is in the process of being implemented in England and Wales, by the competent authority, the Environment Agency. These legislative instruments are summarised briefly in the following sections.

Other areas where legislation has been updated or reviewed, or where new legislation has come into force are development planning and control and nature conservation and each is summarised below. In the future, changes to the management of flood and coastal defence are also proposed and this is also summarised below.

4.2.1 Marine Bill White Paper

The Marine Bill White Paper 'A Sea Change' (Defra, 2007) incorporates planning in the marine environment, covering all sectors and all activities, including licensing, and therefore requires an integrated approach at the land-sea interface. The Marine Bill is also supporting an ecosystem approach, and aims to improve marine nature conservation, with the possibility of marine protected areas for important species and habitats. The main aim of the Marine Bill is consistent and informed decision-making by relevant authorities, namely the Local Planning Authorities on land, and a Marine Management Organisation (MMO) seaward across the land-sea interface.

The purpose of the Marine Bill is to establish a mechanism that can conserve and promote the recovery of vulnerable habitats; representative species and habitats; and physical marine features and ecological processes. Additionally, it could also protect physical features of geological and geomorphological importance; historic features; important seascapes or views from land; spawning and fish nursery areas; and areas for marine ecosystem research.

These aims would be achieved via a number of mechanisms, including a new MMO; guided by a UK marine policy statement, it would deal with a range of functions including marine planning, licensing and enforcement, with the aim of providing a holistic approach to marine management. There would be a new system of marine planning, involving a strategic approach to use of the marine space and the interactions between all uses, and Marine Plans will guide decisions on licence applications and other uses. The UK marine policy statement (agreed by all UK Government departments and devolved administrations) will set out both short and longer-term objectives for the marine environment, with the clear purpose of contributing towards the sustainable use of the marine environment. The shared UK marine policy statement would bring together different policies, objectives and targets that exist at present, and therefore could incorporate other obligations as necessary, for example, under the WFD.

The UK Marine Bill is strongly supported by the European Marine Thematic Strategy, draft Marine Strategy Directive and the Maritime Green Paper, all being developed by the European Commission. The aim of the Marine Strategy Directive is to achieve good environmental status in the marine area by 2021 at the latest (the draft directive contains provisions for how the definition of this status will be achieved (http://eur-lex.europa.eu/LexUriServ/site/en/com/2005/com2005_0505en01.pdf).

Marine plans would exist from Mean High Water Springs (MHWS) to the fullest extent of the UK's marine jurisdiction. It would therefore overlap with terrestrial planning between MHWS and MLWM (Mean Low Water Mark) and would apply within the estuarine environment. Broad issues that would feature in the plans include those related to both human activities and associated infrastructure, and to natural resources, features and processes. For example, coastal land use, diffuse and point source contamination and discharges, dredging, dumping (e.g. disposal of dredged materials, sewerage and waste disposal, including associated infrastructure) would be included. Additional issues also included within the plans would include fisheries, flood and coastal erosion risk management, mineral extraction, ports and navigation, recreation activities, renewable energy, biodiversity, including genetic, species, community and habitat diversity. Climate change (adapting to impacts), geological and geomorphological features, designated sites for ecological or heritage purposes, Marine Conservation Zones (MCZ), the sea surface, water column, seabed and beneath the seabed, and sites of archaeological importance would also be considered.

The Marine Bill will incorporate wide public engagement in the marine planning process. Each Plan under the Marine Bill will also be subject to an economic, environmental and social appraisal and an assessment of the plan's sustainability, incorporating the requirements of the SEA and Public Participation Directives and Appropriate Assessment under the Habitats Directive.

In Wales any marine planning would have to integrate with the Wales Spatial Plan and the MMO will only apply to Wales for non-devolved matters. Wales will implement their own delivery arrangements for devolved matters.

The Marine Bill and marine licensing

The Marine Bill will change the marine licensing system, so that in the future more consistent licensing decisions are delivered more quickly and at less cost, and will be integrated across a range of sectors.

The Marine Bill will make changes to streamline the marine licensing process, which will be administered by the MMO in England and Northern Ireland:

- Create a reformed marine licensing regime consolidating Part II of the Food and Environmental Protection Act 1985 (FEPA) (intended to control dumping at sea and construction on the seabed to protect the marine environment) and Part II of the Coast Protection Act 1949 (CPA) (aimed at ensuring a safe environment for navigation in relation to FEPA activities);
- Including all forms of dredging, including marine minerals dredging, and currently unregulated forms of dredging;

- Enable the introduction of new rules to regulate Carbon Capture and Storage (CCS);
- Streamline licensing of offshore renewable energy installations;
- Reduce overlaps in legislation applying to harbours and ports; and
- Give powers to the MMO to deliver the above in England and Northern Ireland.

The Marine Bill and harbour legislation

Through reform of the CPA under the Marine Bill, the aim is to streamline Harbour Consents for the authorisation of marine works and to reduce the overlap between harbours and environmental legislation and therefore the duplication of licensing.

MCEU (Marine and Environment Consents Unit) has joined the Marine Fisheries Agency forming the Marine and Fisheries Agency (MFA); these functions would be passed onto the MMO in the future. The MMO will also assume responsibility for administering the regulation of harbour developments (presently DfT), including orders under the Harbours Act 1964, and the local and private harbour Acts in England, and for non-fisheries harbours in Wales.

Marine nature conservation under the Marine Bill

The Marine Bill proposes MCZ, which are a type of Marine Protected Area (MPA) for areas of national importance not covered by existing European law. There are also separate plans to consolidate the regulations that transpose the Wild Birds and Habitats Directives in the future. The proposal is to set a standard seaward limit of MLWS or limit of the lowest astronomical tide for all SSSIs, or where there is a good case it could be extended below LW, and therefore may overlap with MCZs in the intertidal. MCZs may have similar or extended protection in comparison to SPAs and SACs and may be subject to the Habitats Regulations and all that this encompasses, for example, requirements for appropriate assessments.

4.2.2 Water Framework Directive

The Water Framework Directive (WFD) came into force in December 2000, and requires all inland and coastal water bodies to reach at least ‘good status’ by 2015. Importantly for estuaries it has been decided by the UK Government that this will include all coastal and transitional waters out to one nautical mile. ‘Good status’ implies good ecological and chemical status.

The Directive does require coastal and inland waters to be managed on a river basin basis, taking into account linkages between surface and groundwater, and water quality and quantity. It also requires the water quality requirements for Natura 2000 sites designated under the Habitats and Birds Directives to be integrated into river basin plans, and this will include those within estuaries.

This has important implications for water management in the UK, and specific areas include: land use planning, where physical development can affect water resources and quality; biodiversity, where water can affect the status of designated sites and Sites of Special Scientific Interest (SSSIs); flooding, where the use of soft engineering will have benefits for water quality and biodiversity; and leisure, tourism and recreation, where

there may be conflicts between uses, but where these activities require good water quality. Each of these issues for water may affect the way estuaries are managed in the UK.

Some of the estuaries in England and Wales may be classed as Heavily Modified Water Bodies (HMWB), where the water body has been subjected to major physical changes in the past to allow for activities such as navigation, flood defence and land drainage. It is recognised that restoration to 'good ecological status' may not be possible without hindering the specified use of the water body; therefore the Directive will require these to reach 'good ecological potential' only.

4.2.3 SEA Directive

The Strategic Environmental Assessment (SEA) Directive requires a formal environmental assessment of certain plans and programmes which are likely to have significant effects on the environment, including the cumulative impacts of new and proposed activities with those already in existence or planned. Authorities which prepare and/or adopt such a plan or programme must prepare a report on its likely significant environmental effects, consult environmental authorities, including the Environment Agency and Natural England, and the public, and take the report and the results of the consultation into account during the preparation process and before the plan or programme is adopted. They must also make information available on how the plan or programme was adopted and how the environmental assessment was taken into account. The SEA Directive is transposed into UK law by the Environmental Assessment of Plans and Programmes Regulations 2004, and The Environmental Assessment of Plans and Programmes (Wales) Regulations 2004 (Welsh Statutory Instrument No 1656 (W.170)). Such plans may include Shoreline Management Plans, and current guidance from DCLG and Defra encourages SMPs to include SEA http://www.defra.gov.uk/environ/ fcd/policy/sea.htm.

4.2.4 Development Planning and Control

Development planning and control in estuaries is regulated on both the marine and terrestrial sides, and although these are considered separately at present, this may change in the future as a result of the Marine Bill. The changes that are proposed by the Marine Bill are summarised above. Other recent changes to development planning and control that may be relevant for estuary management are reviewed below.

On the terrestrial side, the Department of Communities and Local Government (DCLG, as of May 2006) in England, where the Planning and Compulsory Purchase Act 2004 introduced the concept of a Local Development Scheme (LDS) within the context of the Local Development Framework (LDF) for land-use planning. The LDS allows local planning authorities to set out a timetable for the preparation of documents as part of the LFD and to manage their production (MSPP Consortium, 2006).

Regional Spatial Strategies (RSS) form part of a statutory development plan together with local Development Plan Documents (DPD), which prescribe policy and allocations for Local Planning Authorities (LPAs), and these would need to be respected in any marine planning in the context of the Marine Bill. LPAs are also able to produce Supplementary Planning Documents (SPD), which are not part of the statutory

development, but support the policies within them. Together DPDs and SPDs constitute the LDF. SPD plans with a direct bearing on the coast could also be produced, which would be acknowledged in the LDF of the LPA, but should also be considered in any planning in the adjacent sea under the Marine Bill (MSPP Consortium, 2006).

Within England Planning Policy Guidance (PPG) notes are gradually being replaced by Planning Policy Statements (PPS). PPG20 (1992) relates to coastal planning and covers the coastal areas of England; and PPS25 (2006) relates to development in the floodplain, both fluvial and coastal.

Outside of England, the devolved administrations are responsible for planning and development control, and in Wales, the Welsh Assembly have produced the Welsh Spatial Plan (2004).

The Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999 transpose the requirements of the amended EC Directive 85/337/EC on "The assessment of the effects of certain public and private projects on the environment" for the town and country planning system in England and Wales. Under the Regulations it falls to the Local Planning Authority (LPA) in the first instance, to consider whether a proposed development is likely to have significant effects on the environment when they receive a planning application.

The Marine Works (Environmental Impact Assessment) Regulations (2007) will transpose the Environmental Impact Assessment Directive in the marine environment UK wide, so that the requirement for an Environmental Impact Assessment (EIA) is considered within a statutory framework when permission is sought for the removal or disposal of substances or articles, and the construction, alteration or improvement of certain works within the UK marine area. The recent (December 2006) consultation proposed that this is achieved. This includes the activities covered under Part II of the Food and Environment Protection Act 1985 and under Part II of the Coast Protection Act 1949.

Planning Policy Wales (Welsh Assembly Government, 2002) includes development plans and advice on development controls (including Technical Advice Notes (TANs), e.g. TAN 14 (1998) relates to coastal planning), including Unitary Development Plans (UDPs)**.** Landward pressures can include major developments, including ports, harbour works, leisure and recreational facilities, wind power generation and coastal defences. Seaward pressures can include waste disposal, sea fishing, increased leisure sailing, dredging of navigation channels, water sports / bathing, marine aggregates extraction, tidal and wave power generation. Any estuary management plans must consider the Unitary Development Plan (UDP) policy.

4.2.5 Flood and Coastal Defence

The Government's Strategy 'Making Space for Water' recommended that the Environment Agency assumes overall responsibility for the management of flood and coastal erosion risk in England and Wales, allowing the Environment Agency to have a more holistic approach to risk management. Currently, maritime local authorities are responsible for coastal protection, whereas the Environment Agency is responsible for flooding from the sea. Defra's Making Space for Water project (HA1 – Environment

Agency Strategic Overview) is currently assessing how the Environment Agency's role will be defined, including reviewing relevant legislation and institutional arrangements, as well as considering the impacts of Integrated Coastal Zone Management (ICZM), the WFD, CFMPs and SMPs.

4.2.6 Nature Conservation

Defra is responsible for nature conservation through the Government's statutory advisors (as members of JNCC, the Joint Nature Conservation Committee) Natural England, which combined English Nature with the Countryside Agency and elements of the Rural Development Service under the Natural Environment and Rural Communities Act, 2006; and Countryside Council for Wales (CCW). This Act has created a duty for public and statutory bodies to integrate biodiversity into their decision-making.

Previous Acts that are still in force and relevant for estuary management include the Directive on the Conservation of Natural Habitats of Wild Fauna and Flora (the Habitats Directive) (92/43/EEC) and the Directive on the Conservation of Wild Birds (79/409/EEC), which together were transposed into UK legislation as The Conservation (Natural Habitats &c.) Regulations 1994.

Coastal Habitat Management Plans (CHaMPs) are currently undertaken to assess the impact of sea level change and the coastal defence response on important habitats protected under the European Union Habitats Directive. CHaMPs were instigated under the LIFE project 'Living with the Sea', with seven pilot CHaMPs completed in 2002. The aim is for CHaMPs to inform second generation SMPs, by examining coastal evolution over a 30 to 100 year period, quantifying habitat change in response to coastal management and recommending measures to reduce any losses. CHaMPS already exist for several areas including estuaries on the Essex, Suffolk, North Kent and Solent coasts, and further CHaMPs are in the process of being written for the Greater Thames Estuary and the Severn Estuary.

4.2.7 Summary

Since 2000, when the EMPHASYS review of legislation relevant to estuary management (Posford Duvivier, 2000) was carried out, there have been some substantial changes made to the way activities within estuaries are managed. For example, the SEA Directive demands that the cumulative impacts of any new works, plans or programmes are assessed, which for a large estuary, such as the Humber that has a large variety of activities ongoing and planned, can be a major task.

Some new legislation is directly related to the management of estuaries, whereas some will only have an indirect effect, but may still have to be considered by some estuary managers, such as the WFD and the Environmental Liability Directive.

There are large changes proposed to the management of the marine and coastal environment that will affect estuaries, including the reallocation of responsibilities for coastal protection from the maritime local authorities to the Environment Agency, and the introduction of the MMO under the Marine Bill. However, both are aimed at achieving a more strategic and holistic management of the environment. The Marine Bill specifically is aiming for an integrated approach at the land-sea interface, and

consistent and informed decision-making. The application of the systems-based Simulator model for estuary management is consistent with the view taken within the Marine Bill and Making Space for Water, that estuaries (and the marine / coastal environment) should be managed in a holistic and integrated way.

4.3 Management Questions Consultation Exercise

A targeted and focussed consultation exercise has been carried out which engaged with key stakeholders, who were identified and agreed in advance with Defra's project officer. Sixteen consultees responded from a variety of organisations and roles, which can be summarised as policy, regulatory, research and operational; another seven people who were contacted decided not to participate. The specific roles are listed in Table 4. The aim of the consultation exercise was to gather opinions from those people concerned with estuary management on three main areas, identified below :

1. The use of existing management tools, their ease of use and presentation;
2. Familiarity with the concept of 'System Mapping' as a tool for estuary management; and
3. Importance of existing and future legislation as drivers for estuary management.

A summary of the consultation responses to each question is presented here.

Table 4. EstSim consultees

Organisation & Department (where applicable)	Role
Environment Agency, Flood Risk Management Head Office	Environmental Policy Advisors
Environment Agency, Flood Risk Management Head Office	Policy Advisors
Environment Agency, Flood Risk Management Head Office	Policy Advisor - Shoreline Management
Environment Agency, Flood Risk Management Head Office	MSfW Policy Advisor
Environment Agency, Flood Risk Management	Operations
Environment Agency, Science	R&D Project Officer
Environment Agency, Policy Development	
Environment Agency	Estuary Manager
Environment Agency, Science	Project Manager
Defra	R&D Dissemination
Defra, Marine Environment Science Division	Head
ABP, Sustainable Management	Manager
ABP, Port	Assistant Port Manager
Tyndall Centre for Climate Change Research / University of Southampton	Lecturer / Researcher
Natural England	Maritime Team

4.3.1 The Use of Existing Management Tools, Their Ease of Use and Presentation

The consultees were asked about existing tools, with the aim of addressing issues of the usability of the Prototype Interface. The two interfaces that were discussed were Futurecoast and FloodRanger, however, most of the consultees were not familiar with FloodRanger and so this has not been included in the reporting.

All consultees had heard of Futurecoast, although most had not used it in their current roles. However, it has become an important reference tool, used by different groups of people from policy makers to students, often for specific issues, rather than the broad scale. Consultees stated that it gives a useful impression of the coast and provides a good geomorphological basis for decision-making, and it has also provided information with which to compare new modelling work. One consultee pointed out that it was developed for coastal consultancies and as such was thought to be 'fit for purpose'; although it is now also used for other reasons, some of which, perhaps, it was not designed for.

The Environment Agency may use it more in the future in their revised role incorporating coastal protection. But at the moment, an Environment Agency consultee responded that they rely on the consultancy companies carrying out coastal work on their behalf to use it appropriately.

One consultee stated that Futurecoast represented a small but very important step in shoreline management planning; in the past everything was driven by an engineering approach, but it was recognised that conceptual views and qualitative modelling are very important, bringing together all knowledge of the coastal system.

It has also proved to be a useful tool in stakeholder engagement; more than one consultee used the aerial photographs within Futurecoast to show people the estuaries in which they live and to highlight flood risk issues. In this context, the map presentation was felt to be useful, rather than sole use of text. Although in contrast, another consultee felt the map resolution was disappointing.

Issues that arose surrounding Futurecoast included that it seemed to have limited interactivity for option development; the Futurecoast concept does not include the functioning of the whole coast, i.e. both open coast and estuaries. Areas where Futurecoast was felt to be lacking were in areas of the coast where there are recognised issues (which were not included) and where numerical modelling is difficult, and incorporating these areas into an assessment of the whole coast.

The format of Futurecoast was not thought to be very intuitive and the three CDs required to use it was considered time-consuming and perhaps outdated.

The timing of Futurecoast was considered to be a fundamental issue. Futurecoast was produced at the end of the first round of SMPs and intended for use in SMP2s, which were then delayed. Since then some of the information has been superseded by other studies. As SMP2s progress it should become apparent how useful Futurecoast is.

The use of public domain data and the subsequent issue of such data within tools like this is a consideration for other such tools. Free sources of data should be considered, such as MDIP, Magic, SPIRE / INSPIRE, when there are charges associated with data from British Geological Society (BGS), Ordnance Survey and Seazone / UKHO.

The results of this element of the consultation exercise were intended to be used within the development of the Prototype Interface; however, due to time constraints this will not be possible. However, these findings could be used in any further developments of the Interface.

4.3.2 System Mapping and Whole Estuary Management

The results of this element of the consultation focussed on the management of estuaries both ideally and in practice.

All consultees recognised the need for estuaries to be managed as a system, with some consultees extending this to include both rivers and the coast. However, although most felt that they considered or tried to consider the whole estuary in their own role, they did not feel that in practice this is how most estuaries are managed, for a variety of reasons. It was stated that it is Defra policy to take an holistic approach, or an ecosystem approach and to try to understand the whole system.

In addition, considering the estuary and coast as a whole is difficult, for instance, Futurecoast does not do this. Estuary modelling should also include coast and rivers, as the estuary is usually constrained by the surrounding coast. Rivers should also be considered, although perhaps to a lesser extent as fluvial influence is often less than tidal influences in UK estuaries, although it is often important for habitats.

Some felt that their work requires the consideration of the whole system, especially in terms of research and development and scientific aspects. Often, in the whole estuary, broader aspects are considered first. In particular, certain elements of legislation, including the Habitats Directive and also licensing (e.g. for dredging) require estuaries to be considered as a whole, but it may then be necessary to examine local or site specific aspects as well. For example, in terms of environmental impact assessment for works, including compensation sites, or for port management and site assessment, the whole estuary approach is the starting point, but the locally specific detail must follow.

In terms of practically managing an estuary as a whole, one consultee stated that they felt that there are currently serious limitations in estuary wide impact assessment, and that generally we are lacking in tools, although another consultee felt technology now made this possible. However, they felt that they were currently moving towards it and existing examples of whole estuary management given included the assessment of compensation / managed realignment sites as part of the Humber Flood Risk Management Strategy.

It is a requirement of CFMPs and SMPs that the system including the estuaries is managed as a whole, and this is also the case for policy development, nature conservation and flood risk, and also for the Habitats Directive. One area mentioned in which holistic estuary management would be very important is contamination, which can spread widely within an estuary system.

Several consultees stated that the Humber Estuary is an excellent example (and perhaps the only example) of an estuary that is managed in a holistic way. The Humber started with a solid foundation of using state of the art science and considering the whole estuary, but in other estuaries this is not the case, and each estuary would need to develop its own framework, choosing the relevant components from the Humber work. The Humber example could be used as a basis for an Estuary Management System.

The hope was expressed that Marine Spatial Planning will include estuaries, and in contrast it was thought that the WFD, in identifying status may split estuaries, and may split estuaries from the coast. The Marine Bill is also examining stakeholder engagement to encourage whole estuary management, but as highlighted on the Essex coast recently, stakeholders do not consider generally the whole estuary, they consider the specific area relevant to them.

One example of where the local or site specific view is still required is for engineering applications, although this must still fit in with the systematic approach.

Reasons given for not managing estuaries as a whole included lack of motivation, politics (in terms of between stakeholders) and also a failure to understand management interventions. Also there was felt to be a possible lack of experience amongst estuary practitioners in considering the whole estuary, and importantly there were still thought to be limitations in the understanding, particularly of the integration of different factors and that system-wide issues still cannot be properly assessed. Other obstacles were land ownership, commitment and belief in the science e.g. sea level rise, inertia (e.g. Southampton Water has been managed for navigation for a hundred years and it takes time to adapt to a new management approach), and an apparent lack of technical tools and the capacity to inform. If technical information is not available, it can be used as an excuse to avoid considering some options and to only consider specific options or places where there is more information. Politics is often a barrier, where parochial attitudes can override the 'bigger picture'. However, a combination of policies, appropriate structures and tools to support both would help. Procedures also need to be more flexible, to ensure consistency of approach does not have to mean that everywhere is treated in the same way.

4.3.3 Importance of Existing and Future Legislation as Drivers for Estuary Management

Within the context of the importance of existing and future legislation as drivers for estuary management each consultee was asked two main questions:

- What current legislation is / do you see as your main driver / controlling factor for estuary management (in your role)?; and
- What changes in estuary management requirements are there going to be as a result of the Water Framework Directive (in terms of hydro-geomorphology)? (or any other changes to legislation that you are aware of)?

A summary of the consultation responses is presented here.

The responses focussed strongly on a few pieces of legislation, the Habitats Regulations (arising from the Habitats and Birds Directives), the Water Framework Directive and the future Marine Bill. The possible implications of the Marine Bill are summarised in Section 4.2. There was interest in other Directives where it is not known yet what the impacts will be and the management issues that arise from transposing these Directives into UK law as required. These EU Directives are currently adopted or proposed and include the Marine Strategy Directive, the Floods Directive due for adoption in late 2007, and the Environmental Liability Directive, due to be incorporated into UK law during 2008.

Environmental legislation, in terms of the Habitats Directive and Birds Directive and the Habitats Regulations are recognised as very important for the UK's estuaries. Consultees stressed that the Birds and Habitats Directives and the Natura 2000 network tend to constrain all other management activities and legislation, and although one consultee stressed that the Directive is not as inflexible as it is often thought to be, it does tend to override / supersede other legislation. There was a view that the way that the Directives were implemented as the Habitats Regulations was wrong in the case of estuaries and that much more flexible boundaries are needed. One consultee felt that the Habitats Regulations precede the time of general acceptance of climate change and hence now require updating to accommodate a changing world. This view has also been expressed in a recent review of spatial planning policies under a changing climate (Piper *et al*., 2006).

It was felt that the Defra Strategy 'Making Space for Water' could have significant impacts on estuaries, and River Basin Management Plans will apply to estuaries. However, the extent of the influence of these Plans is not yet known.

Although there are not many specific details, the Marine Strategy Directive may become significant in the future, but it was thought that it should come from a marine spatial planning point of view, which needs to consider other uses of the marine environment and impacts on them, including impacts on resources.

The levels of appraisal required for the SEA Directive (the assessment of the effects of certain plans and programmes on the environment, European Directive 2001/42/EC) and Environmental Impact Assessment Directive was also an issue for one consultee.

The Floods Directive ('Directive on the Assessment and Management of Floods') through the required flood risk management plans has a requirement for biodiversity targets, which will impact on flood risk management. There is also overlap with the WFD.

The aim of the WFD is to establish a framework for the protection of inland surface waters, transitional waters (estuaries and brackish waters), coastal waters and groundwater. The principal objective is that such water bodies should achieve good ecological status by 2015. In order to achieve such a status, the impacts of actions in flood and erosion risk management, and other activities, must be considered, for example, how works affect habitats and sedimentation patterns.

It has become obvious through the consultation that most of the consultees are not aware of what the WFD will mean in practice for the management of estuaries and how it will impact on estuary management in the future; although there is recognition that it will have an impact and the extent of the impact will depend on how the process is managed. There is a need for more information and more technical understanding at the level of government, but also users such as the port authorities. River Basin Management Plans are a requirement of the WFD and these will include estuaries, however, it was felt that the work that is currently being done on the WFD is focussing on rivers, and has not extended to estuaries.

However, it was also believed that the WFD could help estuary management, as the introduction of new EU legislation could provide an opportunity to streamline current UK legislation, for example the Coast Protection Act (1949) and the Water Resources Act (1991); it could also encourage a more holistic view, where linkages within the system must be recognised.

The port authorities are in the process of establishing the requirements of the WFD for estuaries where large ports are located. For example, in the Humber, historic pollution may affect the programme of measures in relation to priority substances in dredged materials and could have a huge impact on the disposal of dredged material and the remediation ('the polluter pays').

Specifically, for port activities the Habitats Directive was thought to be of primary significance at the moment and the chance of judicial review for losses of designated habitat. However in the future the WFD will also be important, as above, as will the introduction of the requirement for strategic impact assessment for maintenance dredging (as a recognised as plan or project), the revision of the Waste Framework Directive (potentially important for the disposal of dredged material at sea, if classified as waste) and the Marine Bill. It was not thought that the Floods Directive would be significant in the context of port management.

Consultees were also asked about the significance of Integrated Coastal Zone Management (ICZM) in estuary management. It appears unlikely that an EU Directive will follow, however, within the UK it was felt that the principles of ICZM are being incorporated into current shoreline management planning, by linking with Regional Spatial Strategies and Local Development frameworks, partly through Making Space for Water.

4.4 Conclusions from the Identification of Management Questions

This section has presented the management questions that have been previously identified in other studies such as EMPHASYS; updated a review of the legislation relevant for estuaries; and presented the results of the end-user consultation.

Interests of estuary users may be at a strategic level such as the development of a CHaMP or may be local such as the location and impacts of a land-drainage outfall, and there are a variety of estuary management questions, which can be relevant to the whole estuary or separate components of the estuary, depending on the user and their interests.

Legislation can place considerable constraints on activities within estuaries, and provide a constantly changing impact on management of estuaries. Some legislation affects all sectors, such as the SEA Directive and Habitats Directive, whereas some legislation is applicable to limited activities or sectors within the estuary. However, there is a move towards more holistic estuary management both within existing and new legislation.

The consultation exercise, in which sixteen people concerned with estuary management were consulted, concluded that estuaries should be managed in a holistic way and as a system where possible, although this is not always the case. The adjacent coast and river(s) should also be considered as part of this system. The consultees also recognised the requirement for whole estuary management as detailed within current legislation.

However, there are various reasons why estuaries are not managed in this way, including limitations in the understanding of the estuary system and a lack of suitable tools and models.

An initial interpretation of the consultation in terms of the management questions is presented here.

General legislative questions:

- How will each of the proposed and adopted legislative measures impact on existing uses and activities within an estuary? (Here proposed and adopted legislative measures include, for example, the WFD, Floods Directive).
- What impact will there be on estuary morphology as a result of above?

Specific questions relating to climate change:

- How will climate change affect forcing factors, including tidal range, storm intensity and frequency, wave heights and direction, within an estuary?
- How will climate change affect existing uses and activities within an estuary?
- How will climate change affect the individual estuary components?
    - e.g. for ports, how will access to docks be affected?
    - What impact will there be on habitats?
    - What changes will there be to sedimentation patterns and supply?

Specific management questions, related to an activity and legislation:

- How will an activity affect the ecological status of an estuary (under the WFD)?
- How will an activity affect sedimentation patterns / habitats (under the Habitats Regulations, WFD, Floods Directive)?
- How will an activity affect flood risk (under the Floods Directive)?
- What will the cumulative impacts be of activities within the estuary (under the SEA Directive, WFD)?

These initial results of the management issues and legislation summary and the consultation exercise have been further developed into the scenarios used within the pilot testing of the Prototype Simulator, in Objective 7. The main issues can be thought of under the Drivers – Pressures – State – Impact – Response framework, where the scenario to be tested will affect the Response of the estuary. The scenarios that have been produced in this Task are presented in Table 5. Table 5 effectively interprets the information derived during the undertaking of this objective in terms of the Drivers – Pressures – State – Impact – Response framework to derive a series of management question scenarios. These are important considerations within the scenario testing. This study has found that the main drivers for estuary management currently are climate change, flood and coastal erosion risk management and development pressures. Each of these drivers has a pressure or limiting factor in the form of the relevant legislation or planning process, including the Habitats Regulations, SMPs, the WFD and the SEA Directive.

The state under each scenario can be thought of as the geomorphic state of the whole estuary, or of certain components, such as the habitat area. The impacts are those that the driver and pressure exert on the state, for example, the impact of sea level rise on habitats designated under the Habitats Regulations within an estuary; the response of the estuary to a SMP policy such as 'hold the line', or the impact on the estuary system of a development, such as a barrage or bridge. Each of these scenarios can be tested within the Prototype Simulator to examine the response of the estuary system.

5. CONCLUSIONS

The development of the Prototype Simulator provides a systems-based approach to estuary modelling, enabling the application of the estuary management questions developed by this Objective within the Prototype Interface.

The capabilities of the Prototype Simulator and Interface are two-fold: a database and reference tool for UK estuaries, and a tool for the prediction of estuary evolution. The database and reference tool is based on the estuary typology developed in the Behavioural Systems Objective. The systems-based approach has been applied to each of the seven generic UK estuary types, through the identification of the individual geomorphic elements present within each, and to each individual estuary within the UK. The database allows the generic and specific details for estuaries to be displayed within the Prototype Interface, providing an excellent resource for estuary users and managers to view information according to the typology, but also an understanding of the estuary in systems-based terms.

The predictive systems-based tool for estuary evolution enables the behavioural modelling of the seven generic UK estuary types to explore possible geomorphological change, in relation to changes in forcing factors, and in response to management questions and legislation. Legislation governing estuary management increasingly requires a holistic or strategic approach, which the systems-based model of the Prototype Simulator can provide. However, this is currently limited to an assessment of broad-scale changes of the tendency of the system, with no quantification possible of the time and space scales of change. The Prototype Simulator implements expert judgement in the construction of the behavioural rules and therefore any results must be viewed as qualitative and should be applied appropriately. Expert geomorphological input is also required to model specific, individual estuaries, which further limits use of the Prototype Simulator by end-users.

6. THE WAY FORWARD

A meeting was held with HR Wallingford on 18th May 2007 to discuss how to incorporate the findings of the management questions objective into the Pilot Testing Objective (7). The results and conclusions of this Objective have been used to develop scenarios for Objective 7, in which the Prototype Simulator developed in Objective 5 will be tested on two estuaries, the Thames and the Teign, Devon.

The overall aims of the pilot testing are:

1. To evaluate the performance of the simulator against present and emerging knowledge of estuary processes;
2. To provide a critique of the simulator's ability to help address an identified range of management issues.

The pilot testing should also inform the assessment in FD 2119 of how the behavioural approach taken in this project fits into development of the Estuary Integrated Assessment System (EIAS) and the Estuary Management System (EMS).

Initial testing of the system simulation ('Methods and software tools for estuary behavioural system simulation, Task 4) has suggested a number of potential capabilities to predict important aspects of estuary system behaviour that require further assessment. These include the potential to predict the qualitative response of a given stable state to environmental change / external forcing (e.g. sea level rise, sediment supply changes), or interventions such as dredging or the imposition of fixed defences (both flood defence and coastal protection structures) in a 'hold the line' policy, or the gradual 'decay' of defences under a 'do nothing' policy.

Generic issues that should be addressed during the pilot testing are:

1. The capabilities of the approach to determine the emergent properties of an estuary;
2. The capabilities of the approach to determine the sensitivities of an estuary to change;
3. The capabilities of the approach to determine the constraints on the evolution of the estuary.

The ability to provide a basis for evaluating quantitative models, for example, to confirm directions of change in a study such as a CHaMP examining an estuary-wide response to sea level rise, and also with a particular focus on changes to individual elements of the systems, e.g. saltmarsh or mudflats.

The generic scenarios to be tested during the pilot testing are summarised in Table 5.

Table 5. Suggested generic scenarios for pilot testing the prototype simulator

Scenario	Driver	Pressures	State	Impact	Scenario
1	Climate Change	Habitats Regulations	Habitat area / balance.	Impact of sea level rise on designated habitats	Impose sea level rise on estuary system and assess response in terms of habitat change.
2	Climate Change	Habitats Regulations Flood Risk	State of individual estuary components.	Sensitivities of each component of estuary system	Impose sea level rise on estuary system and assess response to each estuary component.
3	Flood and coastal erosion risk management	Chosen Shoreline Management Plan policies, (Habitats Regulations)	Estuary geomorphic state, habitat area / balance, sedimentation / erosion.	Response of estuary to the SMP policies	Remove flood and coastal defences throughout estuary and assess response; a 'do nothing' scenario.
4	Flood and coastal erosion risk management	Shoreline Management Planning, (Habitats Regulations)	Estuary geomorphic state, evolution.	Response of estuary to 'hold the line' SMP policies	Apply 'hold the line' throughout estuary to assess impact of constraining evolution.
5a	Development - individual impacts	WFD, consenting / licensing process	Estuary geomorphic state, habitat area / balance, sedimentation / erosion.	Impact on system as a result of development / ability of system to respond.	Apply port development to estuary in the form of dredging and assess changes to estuary.
5b	Development - individual impacts	WFD, consenting / licensing process	Estuary geomorphic state, habitat area / balance, sedimentation / erosion.	Impact on system as a result of development / ability of system to respond.	Apply port development to estuary in the form of reclamation, and assess changes to estuary.
5c	Development - cumulative impacts	SEA Directive	Estuary geomorphic state, habitat area / balance, sedimentation / erosion.	Cumulative impact on system as a result of multiple developments.	Apply both dredging and reclamation to estuary and assess cumulative changes.

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8. GLOSSARY

CCS	Carbon Capture and Storage
CCW	Countryside Council for Wales
CHaMP	Coastal Habitat Management Plan
CLG	Communities and Local Government
CPA	Coast Protection Act 1949
DCMS	Department for Culture, Media and Sport
DPD	Development Plan Document
DfT	Department for Transport
DTI	Department for Trade and Industry
EA	Environment Agency
EH	English Heritage
EHS	Environment and Heritage Service, Northern Ireland
FEPA	Food and Environmental Protection Act 1985
GE	Geomorphic Element
GV	Government View procedure
ICZM	Integrated Coastal Zone Management
LDF	Local Development Framework
LDS	Local Development Scheme
LPA	Local Planning Authority
MCEU	Marine and Environment Consents Unit
MCZ	Marine Conservation Zone
MFA	Marine and Fisheries Agency
MHWS	Mean High Water Springs
MLWM	Mean Low Water Mark
MoD	Ministry of Defence
MMO	Marine Management Organisation
MPA	Marine Protected Area
NE	Natural England
PPG	Planning Policy Guidance
PPS	Planning Policy Statement
RSPB	Royal Society for the Protection of Birds
RSS	Regional Spatial Strategy
SAC	Special Area for Conservation
SPD	Supplementary Planning Document
SEA	Strategic Environmental Assessment

SEPA	Scottish Environment Protection Agency
SFC	Sea Fisheries Committee
SNH	Scottish Natural Heritage
SMP	Shoreline Management Plan
SPA	Special Area for Conservation
SSSI	Sites of Special Scientific Interest
TAN	Technical Advice Note
UDP	Unitary Development Plan

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