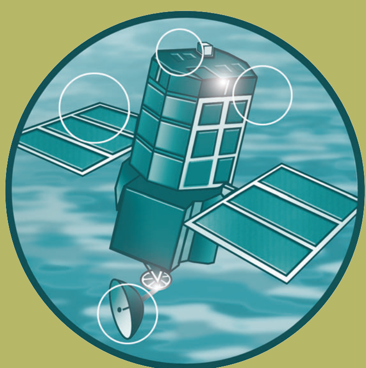
Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme

Development and dissemination of the Estuaries Research Programme

R&D Technical Report FD2119/TR3



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

Development and Dissemination of the Estuaries Research Programme

Final Report

R&D Technical Report FD2119/TR3

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This document provides information for Defra and Environment Agency Staff, researchers and consultants about the research project “Development and dissemination of the Estuaries Research Programme” and constitutes an R&D output from the joint Defra / Environment Agency Flood and Coastal Erosion R&D Programme, Modelling and Risk Theme.

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Executive summary

This report presents the current situation with respect to the development of the Enhanced Estuary Impact Assessment System (EIAS) and the scope of the integrated Estuary Management System (EMS). Consultation with key members of the estuary management community has been completed and the outcomes of the consultation are presented and have been used to inform the research carried out in the project.

The EIAS has been developed and delivered in the form of a web-based resource called the Estuary Guide: www.estuary-guide.net. This provides a comprehensive resource for anyone undertaking work in estuaries and provides help in selecting appropriate methods for evaluating and predicting morphological behaviour. The website also provides easy access to outputs from Phases 1 and 2 of the Estuaries Research Programme (ERP). Training has been provided in the use of the Estuary Guide and associated resources arising from the ERP.

The recommendations from ERP2 projects have been brought forward and synthesised in terms of further developments and research required over the next 3 to 5 years. The research is required to underpin the delivery of the EMS and associated modelling tools. The scope of an EMS which can support existing initiatives on flood risk assessment and recommendations for a programme of work in ERP3 are presented, which includes reference to developments for the next generation of modelling tools and datasets.

Contents

Figures

Tables

1. Introduction

The present project has delivered an enhanced Estuary Impact Assessment System which describes the morphological tools that can be used to underpin estuary management. It builds on the work that has taken place since 1998 in Phases 1 and 2 of the Estuaries Research Programme (ERP1 and ERP2 respectively). The timeline for ERP1 and 2 is shown in Appendix 1 and pen pictures of the projects are also provided. This report, which brings ERP2 to a conclusion, describes how to access the outputs from ERP1 and 2 through the internet resource www.estuary-guide.net, and makes recommendations on how Phase 3 (ERP3) might proceed to uptake and increase the benefits of the research carried out to date through development of an integrated Estuary Management System.

1.1 Scope of Project

The scope of the present project was summarised by its objectives, as set out below. These were grouped together under a number of Work Packages which are listed in [ ] brackets:

1. To define and specify the components of an enhanced Estuary Impact Assessment System (EIAS) as the means by which results and tools arising from ERP2 are delivered to users. [WP1]
2. To scope out the form of an integrated Estuary Management System (EMS). [WP2]
3. To scope out the next generation of estuary modelling tools necessary to deliver the EMS. [WP3]
4. To assess the needs of Operating Authorities, the flood management industry and other organisations involved in estuary management, to understand who wants/needs to know about the outputs and the best way to disseminate the tools that the programme is producing. [WP4]
5. To disseminate these via a website and face-to-face at a workshop and two training events. [WP5]

The project ran beyond the completion dates of the ERP2 projects FD2107 – on the hybrid approach to modelling estuary morphology, FD2116 – on formalising approaches for assessing and predicting estuary geomorphology, and FD2117 – on the development of an estuary simulator. The results of those three projects (see Appendix 1) have been reported and disseminated. The present project provides a platform for the uptake and further dissemination of the work completed on those projects as well as earlier ones such as EMPHASYS[1] (EMPHASYS, 2000a).

The project also built on the ERP2 research plan (French *et al*., 2002, page 25) which refined the proposed future programme at that date. French *et al.* stated that “Whilst focusing on the delivery of an enhanced EIAS, the programme preserves the original vision of an holistic Estuaries Management System (EMS) which takes account of the current and future social, economic and

[1] EMPHASYS Estuarine Morphology and Processes Holistic Assessment SYStem

environmental pressures on estuaries." French *et al.* also stated with respect to the management and delivery of the ERP (page 30) that "an ongoing scoping element should also be included to, first, formally define the requirements for an enhanced EIAS (to be delivered under ERP2), and second, set out the requirements and framework for a future EMS." The present project has scoped out the next steps in defining how the EMS can be achieved.

1.2 Purpose of Report

The purpose of the report is to present the current situation with respect to the Enhanced Estuary Impact Assessment System (EIAS) and to describe the scope of the integrated Estuary Management System (EMS). The outcomes of the consultation are presented in Chapter 2 and the EIAS development and web-based delivery in the form of the Estuary Guide are presented in Chapter 3. Training has been provided in the use of the Estuary Guide and associated resources arising from the ERP (Chapter 4). Recommendations from ERP2 projects in terms of further developments and research are summarised in Chapter 5. Chapter 6 outlines the scope of an integrated EMS and recommendations for a programme of work in ERP3 are presented in Chapter 7, which includes reference to the next generation of modelling tools and datasets.

2. Consultation

The aim of this section of the report is to bring forward a description of the consultation carried out in the project and reported in FD2119/TR2 (Beech and Whitehouse, 2007). The results from the consultation were used in conjunction with the project inception report (FD2119/TR1; Whitehouse *et al*., 2007) to refine the deliverables of the project in agreement with Defra and the Environment Agency. It was also important in that it helped to identify areas where the main improvements could be made in the future.

The **objective** of the consultation programme undertaken within R&D Project FD2119 was *to assess the needs of Operating Authorities, the flood management industry and other organisations involved in estuary management, to understand who wants/needs to know about the outputs and the best way to disseminate the tools that the programme is producing.* Further to this, by collating the responses according to four industry groups which comprised predominantly Policy Makers, Operators, Consultants and Regulators, the consultation has identified different viewpoints on what is considered to be important.

Consultation with key customers was completed to focus the development of the EIAS and ensure the needs of the estuarine management community were met.

2.1 Different layers of consultation

The project carried out various forms of consultation:

The core process was the so called Initial Consultation. The Initial Consultation took the form of a series of interviews with some thirty selected consultees covering a broad range of interests in estuaries. Further to this it was agreed to carry out an open consultation at two events in July 2007, the Estuaries Research Programme Phase 2 Dissemination Day, and the Flood and Coastal Erosion Risk Management Conference – both in York. Using a questionnaire based on the analysis of the Initial Consultation, this second exercise is referred to as the “Conference Consultation”. The results are considered alongside and integrated with those of the Initial Consultation.

The consultees represented a range of interests in estuary management and to enable identification of focus areas the results were collated under four broad headings of consultee:

- predominantly **Policy makers** – e.g: public sector policy makers; R&D programme managers;
- predominantly **Operators** – e.g: port managers and engineers; public sector regional defence and estuary managers;
- predominantly **Consultants** – e.g: private sector consultants and advisors;

- predominantly **Regulators** – e.g: environmental regulators from both public and private sectors.

In total, discussions were held with 31 **consultees** of which 30 yielded written responses, i.e. the data for the present exercise. In discussion it was understood that the individuals represented their sector groups, not just themselves. Contact was also made with some 17 other people who advised that they were no longer involved with estuaries, or their responses would be covered by others. Another 27 consultees provided feedback during the FCERM conference.

More consultations were undertaken than had been envisaged at the outset and, whilst it is always tempting to pursue more contacts and discussions, it is necessary to draw the line at a certain point. The consultation represents a reasonable cross-section of the industry but, on balance, it is probably fair to say that the Operators are slightly under-represented, in relation to Consultants for instance. However, we are of the opinion that this does not necessarily undermine the usefulness of the consultation exercise at this stage of the project because of the practical experience of the consultees in other groups.

2.2 Outcomes

The discussions raised a number of both **positive and negative issues**, based essentially on the past programme, people's experience, and their respective expectations. The feedback reiterated in this report possibly conveys a somewhat negative flavour but it may be human nature to be more vocal on the negatives rather than the positives. Whilst many positive things were said about the Estuaries Research Programme (ERP) generally, many consultees had apparently lost touch with the programme after Phase 1, EMPHASYS (EMPHASYS, 2000a).

The discussions were effectively in two parts, the first dealing with each consultee's background and their previous knowledge and experience of the ERP. The second part dealt with the future, what consultees would like to see, and how they wanted the information to be delivered. The report uses concise formats to relate a mass of advice and information and it is neither practical nor necessary to condense that information further in these concluding comments. Instead, the following bullet points highlight the key messages that emerged from each of the four response categories that dealt with **future aspirations.** These notes include feedback from the Conference Consultation:

- **Motivation** – *improved confidence* emerged overall as the dominant motivator for having a better understanding of estuary behaviour. The reasons for this were particularly strong with Operators who work closely with communities and local issues. The Conference Consultation added strength to the vote for better decision making and planning.

- **Improvements needed** – allied to the issue of Motivation, consultees generally want to see improved certainty in the results of estuary predictions and modelling. Apart from looking for reduced uncertainty, consultees want to have a much better idea about the range of answers that are produced; i.e. what boundaries are we working within? The issue of uncertainty stood out as possibly the strongest message from the whole consultation exercise. Within the improvements category, wishes for better understanding of climate change, and of muddy estuaries, also featured strongly. Though not so significantly ranked in the Initial Consultation, the Conference Consultation also pointed to the importance of better data availability.

- **Dissemination** – this category generated a strong response in favour of reports over other forms of media. Allied to this, consultees wanted to see the results of research much sooner than has been the case, and to be kept in the loop. Though not liked by some consultees, web sites were generally seen as a necessary means of communication; workshops (and personal contact) were also rated highly, thus making these the second and third most sought after means of dissemination. In the Conference Consultation the use of web sites featured most strongly overall.

- **Training** – This final category produced good coherent responses with two important messages: by far and away, the requirement is for training in the principles of estuary science rather than in the details of model operation etc; apart from the Regulators, consultees wanted training, in the first instance to be directed at those doing the operative work (e.g. graduates), rather than the managers and decision makers - it was felt that the operatives are better at conveying information to the decision makers rather than vice versa. The Conference Consultation, whilst concurring qualitatively with the preference of training in principles over training in details, yielded the opposite preference in respect of training for operative versus training decision makers; it must be concluded therefore that both groups need training that is tailored to the particular requirements and applications of each audience, and hence through separate training sessions.

This objective has been substantially met by the Initial Consultation exercise. The results from the consultation have been used in conjunction with the project inception report to refine the deliverables of the project in agreement with Defra and the Environment Agency.

Having taken on board new relevant information from the consultation the project:

- Reviewed and delivered the draft estuary guide website and supporting documentation
- Finished scoping out the integrated Estuary Management System (EMS) and associated requirement for tools that may need to be developed
- Disseminated the outcomes of the project at a seminar in the first quarter of 2008

2.3 Opportunities for Familiarisation

As well as the Main Consultation there were a number of opportunities taken to familiarise and disseminate information about the Estuary Guide during the project.

The under development version of the estuary guide was introduced at the ERP2 dissemination event in York on 2 July 2007, although the main aim of that day was to disseminate the work completed in FD2107 and FD2117. During the main FCERM conference (3-5 July 2007) a stand was hosted by HR Wallingford and ABPmer staff to publicise the existing Estuary Guide website, which was available for demonstration and comment, and completed and ongoing ERP projects. The project made posters available for the following ERP projects:

- FD1905 EstProc
- FD2107 Hybrid modelling (based on a leaflet provided by POL)
- FD2116 Estuary geomorphology
- FD2117 EstSim (based on a leaflet provided by ABPmer)
- FD2119 – current project

As well as

- Saltmarsh management manual (provided by Haskoning), and
- The ERP timeline (poster from 2005 provided by Defra)

Feeback from the conference is presented in Section 6 of Beech and Whitehouse (2007).

3. Enhanced Estuary Impact Assessment System (EIAS)

3.1 Objective and Workplan Summary

The project has delivered an enhanced version of the Estuary Impact Assessment System, issued as a report in Phase 1 (EMPHASYS, 2000a). This enhanced version is in the form of a web-based resource that allows end users to access the results and tools from the research: www.estuary-guide.net .

The existing material from which the present project has been developed includes the Mk1B Estuary Guide – the Estuary Impact Assessment System report (EMPHASYS, 2000a), the guide produced as part of project FD2110 by Brew and Pye (2002) which contained worked examples for two estuaries, and the original web based Estuary Guide developed by Townend (2004).

Consultation with key customers and users was central to the development of the EIAS to ensure that the needs of the estuarine management community were met by the proposed system.

3.2 Delivery of EIAS

WP1 of the project defined and specified the components of an enhanced Estuary Impact Assessment System (EIAS) as the principal means by which results and tools arising from ERP can be made accessible to end-users.

The scoping of the Enhanced Estuary Impact Assessment System (EIAS) informed the project team's understanding regarding the following core areas:

- How the EIAS could be put together in technical terms;
- How the EIAS could be put together in user terms; and
- What the content of the EIAS would consist of.

After the next section outlining the way forward, the above points are covered, firstly by looking at the technical and then the user aspects of the EIAS. At the end there is a brief discussion that also considers maintaining the finalised EIAS after this project is completed.

3.3 The Approach Adopted

At the Flood and Coastal Erosion Risk Management Conference 2007 the project team ran a stand illustrating the Estuaries Research Programme to date. Conference attendees were shown outputs of the ERP and canvassed for opinions through questionnaires to complement the already completed initial consultations exercise (Chapter 2). The general feeling from people when they visited the stand, and from the questionnaires (Beech and Whitehouse, 2007), was that a web-based system similar to the Estuary Guide was a positive step forward. This view confirmed the findings in the report on initial consultations (Beech and Whitehouse, 2007).

On the basis of the above findings, it was confirmed as desirable to move forward with a web based solution. At the same time it was recognised that looking ahead to ERP3, the proposed system was not necessarily the final completed framework that would be required to deliver the Estuary Management System (Whitehouse *et al.*, 2007). However, much of the content in the new web-based system can be extracted, updated and used in a future framework as required. So to keep the outcome flexible and adaptable to new initiatives the system specification was relatively simple with respect to the technical approach adopted.

The approach used the existing branding of 'The Estuary Guide' rather than change to 'The Enhanced Estuaries Impact Assessment System'. From this point forward the EIAS is referred to as Estuary Guide and the associated website www.estuary-guide.net . The reasoning behind this was:

- a) The domain was already established and associated with relevant material (Townend, 2004); and
- b) Site traffic already exists on the existing website created by ABPmer in 2004, with more than 10,000 visitors in 2007.

The re-branding used Defra and Environment Agency logos and a neutral selection of presentation colours as there was no strong requirement to complement existing Defra and Environment Agency websites.

Other discussions with Environment Agency staff about technical aspects of a web-based system highlighted that there were no hard and fast guidelines to adhere to. This is an area that is being addressed currently within the Environment Agency with their conclusions available beyond the completion date of this project (March 2008).

The next sections address the user access and technical aspects considered when creating the new version of the Estuary Guide and offer a basic technical outline of the site and envisaged user functionality.

3.4 User Aspects of the Website

The Estuary Guide contains a wealth of information collated by the project, and this required some careful consideration into both what knowledge base would be available and how users would access information relevant to their own needs. The following section highlights the entry points into the Guide, and then moves onto core content and tools that have been made available to users.

Entry points to the Estuary Guide

When a user goes to the Estuary Guide, there are a number of entry points to find the core content. Figure 3.1 below is a brief overview of the proposed ways into the Guide, with different levels of guidance/steer from the Guide itself.

Access through a 'user profile' ▼ Browse appropriate overview ▼ Steer to relevant part of the Guide	This method is the preferred informed entry point to the Estuary Guide
Access through user tools ▼ Steer to relevant part of the Guide	This is perceived as a semi-informed entry point to the Estuary Guide.
Access through menu/search ▼ Steer to relevant part of the Guide	Fast, direct non-informed access to specific parts of the Estuary Guide.

Figure 3.1 User profile access to the Estuary Guide

User profiles

During the project it was established with the Environment Agency that they support the concept of user profiling to improve the usability of their main corporate site. A similar approach to the Estuary Guide was considered, although full user functionality would have been a large task to implement at all levels of information. However, to improve user access key overview information was tailored to different user groups and at subsequent levels further in all users are referred to the same material. The scope of the user profiling content and level of application could be an area that is developed in the future.

Previous work in FD2119, such as the report on initial consultation (Beech and Whitehouse, 2007), identified a range of interests in estuary management. For the purposes of that collation exercise the groups were divided broadly into four groups of consultee.

- Policy makers – e.g: public sector policy makers; R&D programme managers;
- Operators – e.g: port managers and engineers; public sector regional defence and estuary managers;
- Consultants – e.g: private sector consultants and advisors;
- Regulators – e.g: environmental regulators from both public and private sectors.

In the present site the user definitions are:

- General User – this is the entry point for any categories of user that are not covered by the following two categories
- Consultants/Researchers – this user group essentially comprises those responsible for undertaking technical studies relating to identifying and predicting morphological change in estuaries, either in a research or applied environment.

- Regulators/Operators/Developers/Policy Makers – this user group includes a diverse range of functions within the estuary management process (regulators, operators, developers and policy makers). The role of each of these users is highly varied. However, the benefits they can draw from the Guide are similar.

On the website the users can gain access from the tabs shown in Figure 3.2.

Figure 3.2 User profile access tabs in the Estuary Guide

User content

Much of the existing Estuary Guide material is based on the content of a paper focusing on morphological change in estuaries (Table 3.1 based on Townend, 2004).

Table 3.1 Content of Estuary Guide (Townend, 2004)

- Summary
- Chapter 1 Introduction
- Chapter 2 Estuary management
- Chapter 3 Estuary Setting
- Chapter 4 Study Approach
- Chapter 5 Study Methods
    - Modelling & analysis
        - Analysis & Modelling Guide
            - Data analysis methods
            - Hybrid methods
            - Process based “bottom -up” methods
            - Regime & equilibrium “ top-down” methods
            - Related modelling & analysis topics
- Chapter 6 Presentation of Findings
- Chapter 7 Assessing Impact
- Estuaries research

Each main chapter starts with a short non-technical summary to help the user decide if the information they were seeking is in that section (for example Figure 3.3). Additional interactive image maps and side navigation are available for ease of navigation to other key chapters.

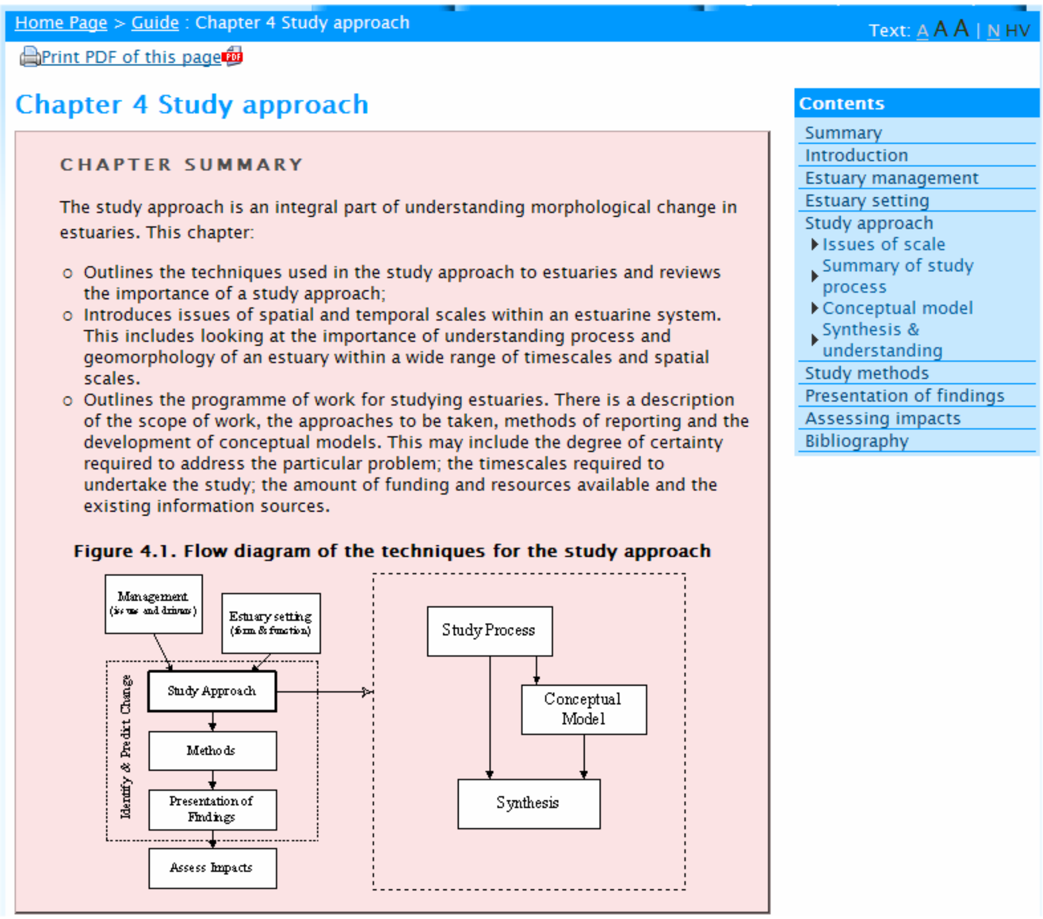
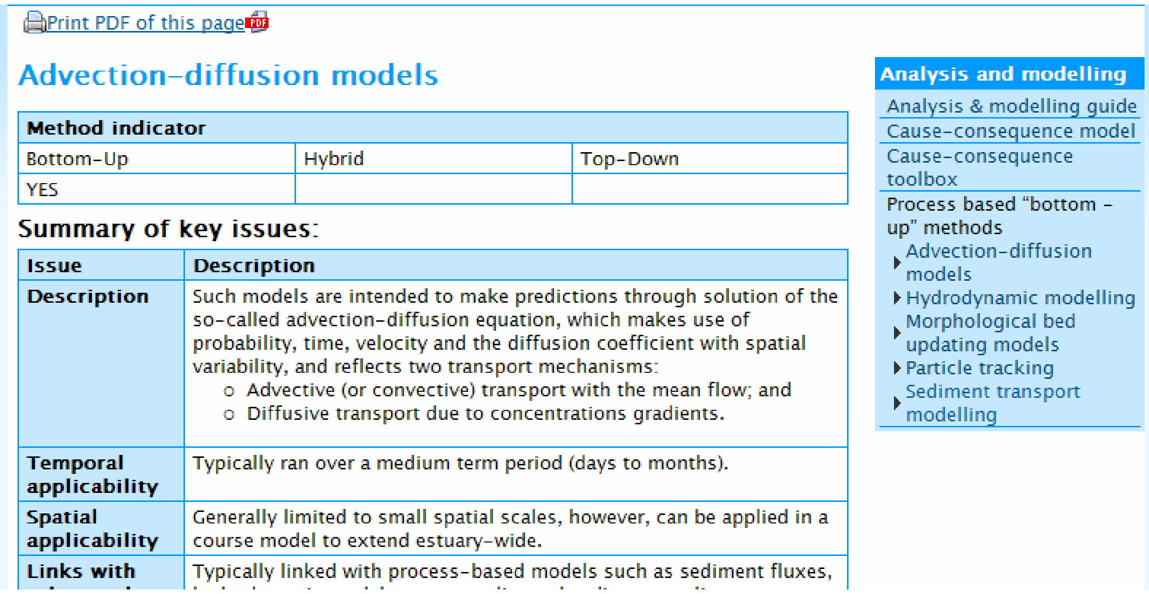


Figure 3.3 Example of an Estuary Guide chapter

The existing knowledge was further supported by a group of documents, which expanded on areas ranging from theoretical concepts to guidance on modelling and analysis. One aspect focussed on reviewing outputs from ERP2 and wider estuaries research. Much of this research has developed new tools and study approaches since the original Estuary Guide was created. The Guide and supporting documents were reviewed and updated to represent a synthesis of the latest research. The types of updates added were in areas like presentation of consistent method/model summary descriptions, formalisation of approaches and typology of UK estuaries.

This has been done by reviewing all content in word format and then taking the final content and providing to users in two formats. One format is as website material (Figure 3.4) and the other as PDF documents (figure 3.5).



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Advection-diffusion models

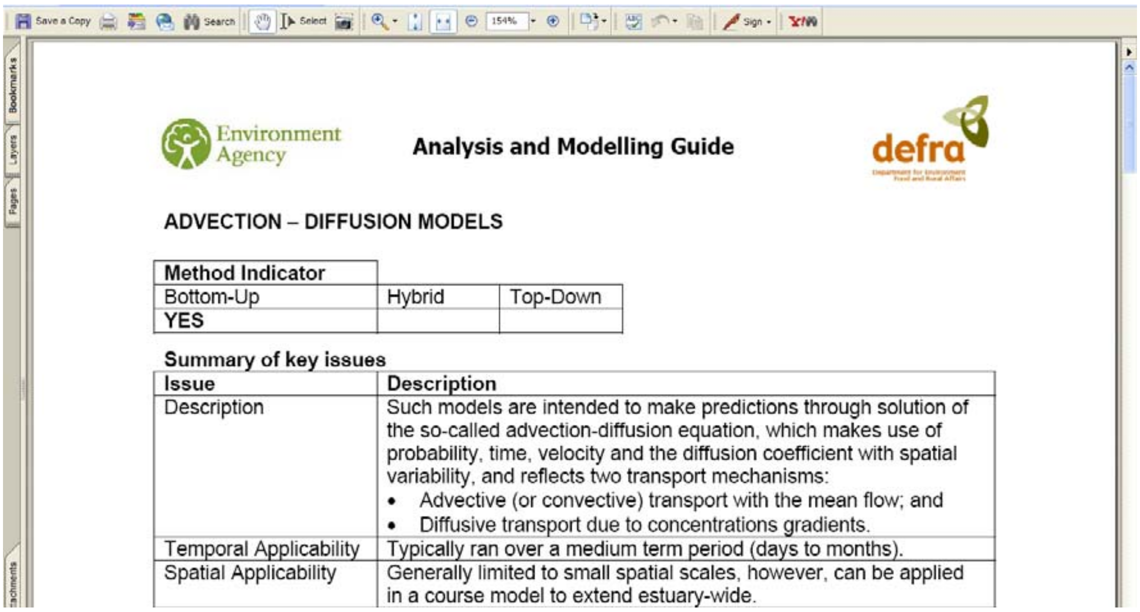
Method indicator		
Bottom-Up	Hybrid	Top-Down
YES		

Summary of key issues:

Issue	Description
Description	Such models are intended to make predictions through solution of the so-called advection-diffusion equation, which makes use of probability, time, velocity and the diffusion coefficient with spatial variability, and reflects two transport mechanisms: o Advective (or convective) transport with the mean flow; and o Diffusive transport due to concentrations gradients.
Temporal applicability	Typically ran over a medium term period (days to months).
Spatial applicability	Generally limited to small spatial scales, however, can be applied in a course model to extend estuary-wide.
Links with	Typically linked with process-based models such as sediment fluxes,

Analysis and modelling
- Analysis & modelling guide
- Cause-consequence model
- Cause-consequence toolbox
- Process based "bottom – up" methods
  - Advection-diffusion models
  - Hydrodynamic modelling
  - Morphological bed updating models
  - Particle tracking
  - Sediment transport modelling

Figure 3.4 Example of content presented in a webpage



Environment Agency | Analysis and Modelling Guide | defra

ADVECTION – DIFFUSION MODELS

Method Indicator		
Bottom-Up	Hybrid	Top-Down
YES		

Summary of key issues

Issue	Description
Description	Such models are intended to make predictions through solution of the so-called advection-diffusion equation, which makes use of probability, time, velocity and the diffusion coefficient with spatial variability, and reflects two transport mechanisms: • Advective (or convective) transport with the mean flow; and • Diffusive transport due to concentrations gradients.
Temporal Applicability	Typically ran over a medium term period (days to months).
Spatial Applicability	Generally limited to small spatial scales, however, can be applied in a course model to extend estuary-wide.

Figure 3.5 Example of content presented in a PDF

The provision of PDFs has the advantages of offering print ready documents and version/date stamped version control. An added bonus is that this information can also be supplied on CD media in the future if required. On top of this core set of documents, where new gaps are identified material has been written and this also included new user-focused overviews. The Estuary Guide content is in addition supported by various user tools, which will allow alternative access to relevant sources of information (e.g. methods, estuary information etc). These are summarised in the following section.

User Tools

To further enhance the functionality of the Estuary Guide, a set of tools has been included. The tools either draw on previous Estuaries Research Programme (ERP) projects (e.g. general ERP outputs and FutureCoast) or existing Estuary Guide information (e.g. Cause-consequence model, content structure flow diagrams). In several instances a database stores the underlying information and web code connects to a database and extracts data based on user inputs. The tools are briefly described below with accompanying screenshots of how they look in the Estuary Guide.

A. Download area with ERP reports/tools available to download.
One aim of this project has been to collate and make available both ERP1 and ERP2 outputs. This has been done by capturing useful ERP outputs in one place, which users can browse, read a summary and either download documents or follow a link to a relevant resource (Table 3.2 and Figure 3.6).

Table 3.2 List of download categories from Estuary Guide

- Estuaries research projects
- Estuaries Research Programme
  - Phase 1 dissemination
  - Phase 2 dissemination
  - Phase 2 training
- Relevant lists of links
  - ERP research project websites
  - Other useful links
  - Useful process modelling software links

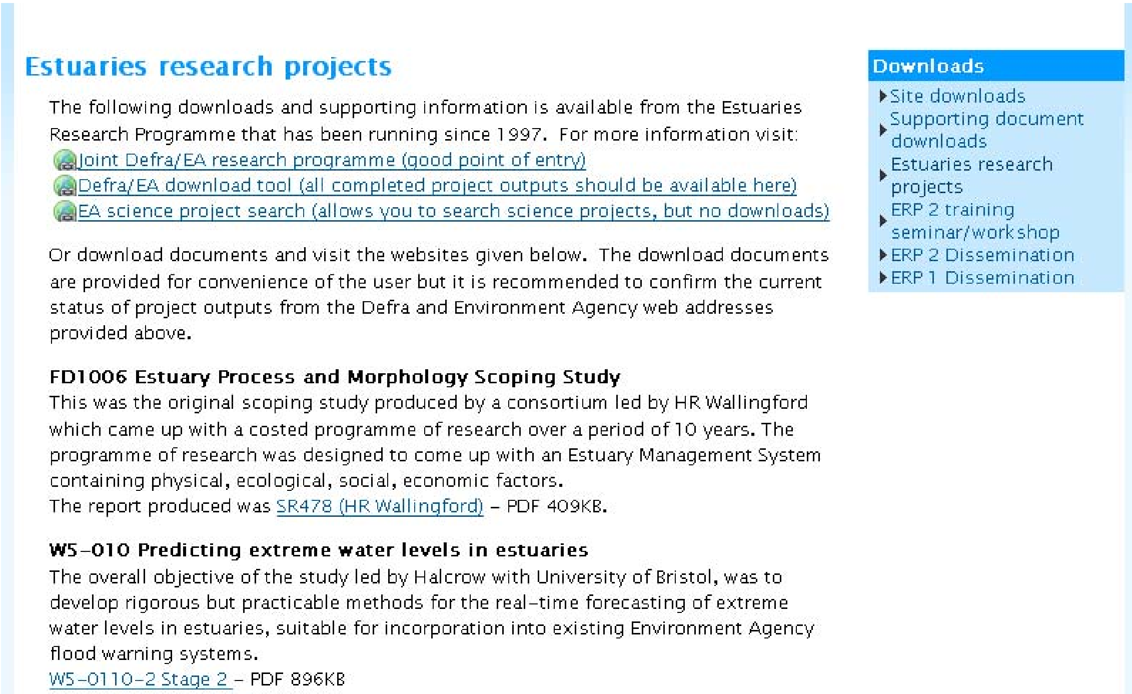


Figure 3.6 Example of a page containing ERP material

B. Cause-consequence Model Toolbox

A challenging aspect for any approach to understanding estuarine morphology is the lack of clear cause-effect hierarchies. The estuary guide provides a toolbox for assessment. The purpose of the cause-consequence model is to map the possible routes from a particular causal action and the resultant changes to the system (primarily in terms of changes in form/morphology). Both actions and induced changes can take place on one or more spatial and temporal scales.

The toolbox provides an online facility based on the cause-consequence model to search for appropriate methods. The causes of change have been grouped into three classes; namely the energy throughputs, the sediment imports/exports and the potential management actions within the estuary. For each cause there will be one or more relevant spatial and temporal scales.

The menu, which can be found on the right of the toolbox web pages, allows the user to move between toolbox stages and make input selections using the drop-down lists presented on each page (Table 3.2 and Figures 3.7 to 3.9).

The methods described in the toolbox comprise a range of options for analysis or prediction of change in estuarine systems. The methods must be applied within a framework (see Estuary Guide chapter on study approach) that leads to a robust conceptual model of the estuary system being studied. At present the user must select the most appropriate method (see Estuary Guide chapter on study methods) for their particular application and no one method is prescribed ahead of any other. Figure 3.10 shows the format of material returned by the website and Figure 3.11 an example of detailed content.

Table 3.2 Cause-consequence hierarchy

1. Select cause of change ▼ (Summary of cause and possible permutations of scale) 2. Select spatial scale – filtered dropdown list ▼ 3. Select temporal scale – filtered dropdown list ▼ 4. Response model – list of methods, brief description & link to detail pages ▼ 5. Detailed method page

Figure 3.7 Cause consequence toolbox interface: Select cause of change

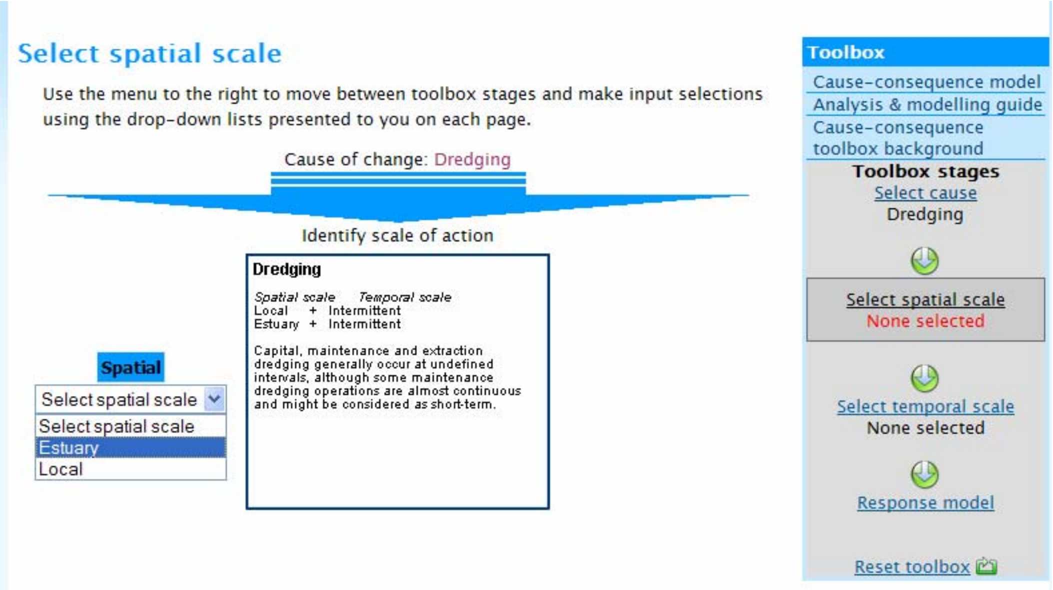


Figure 3.8 Cause consequence toolbox interface: Select spatial scale

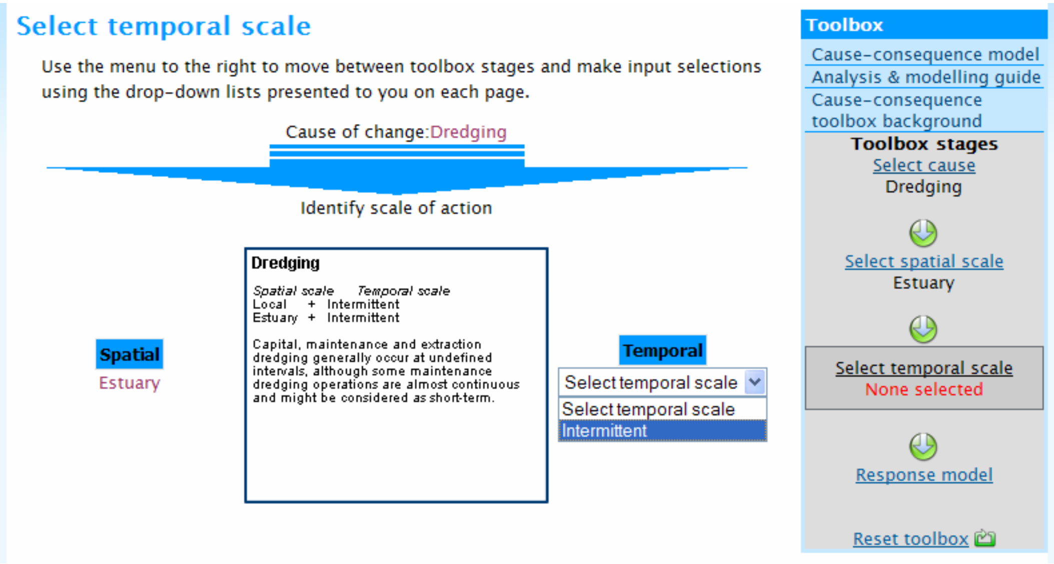


Figure 3.9 Cause consequence toolbox interface: Select temporal scale

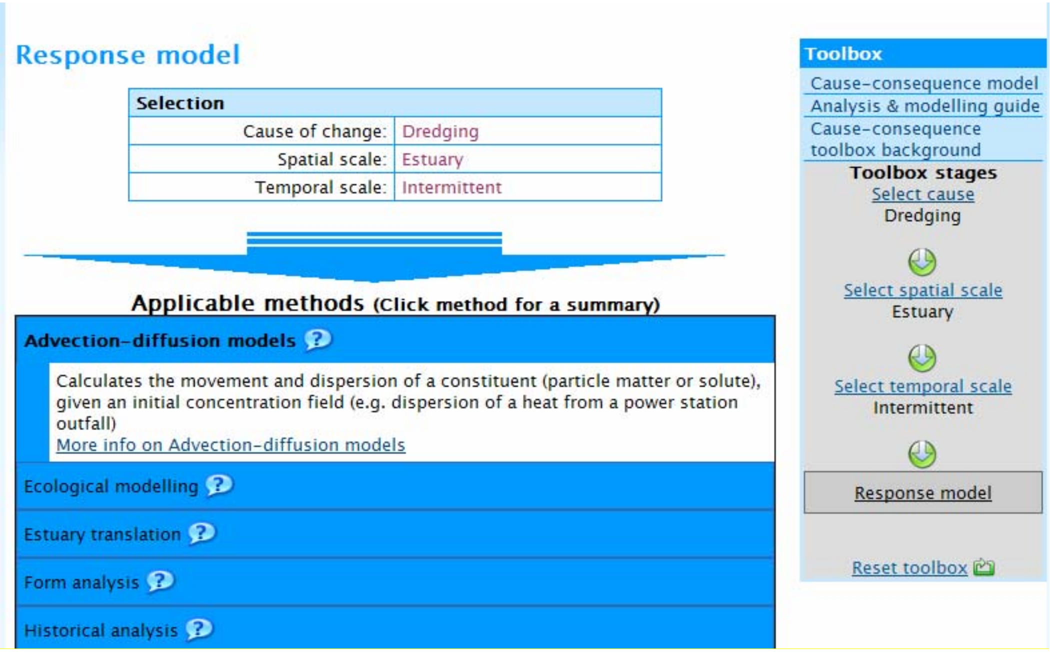
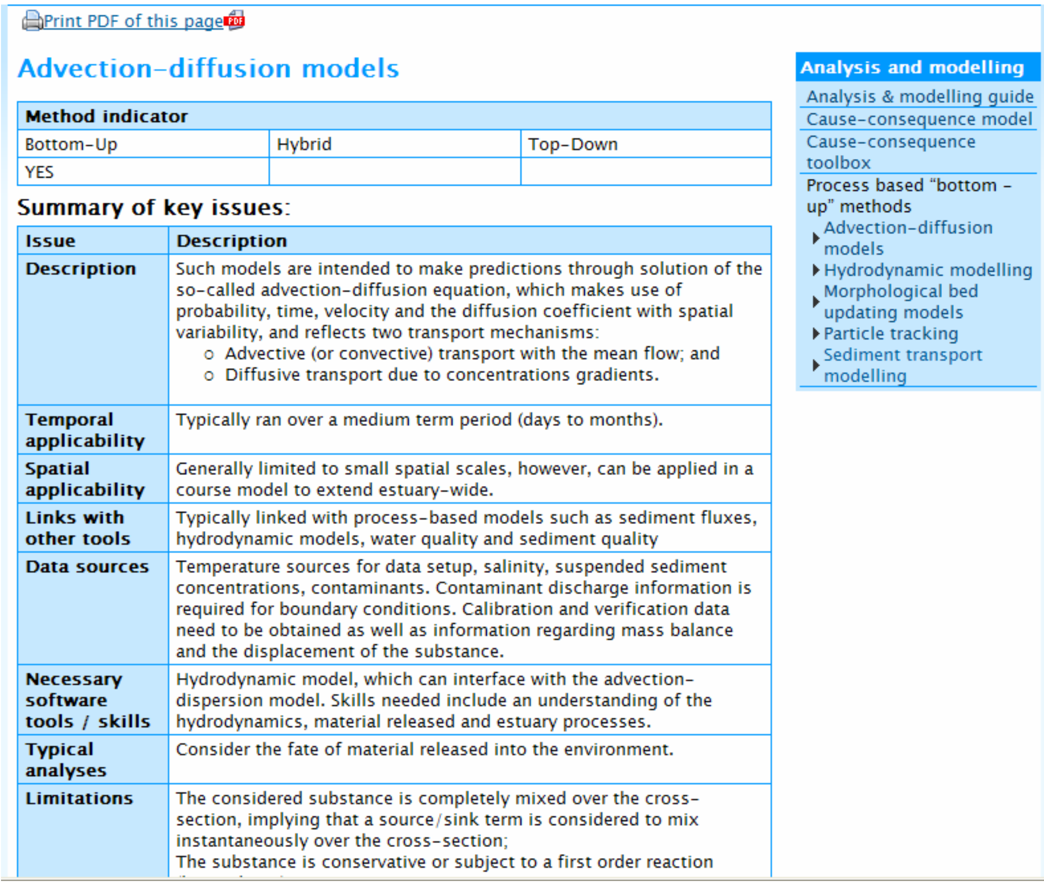


Figure 3.10 Cause consequence toolbox interface: Response model



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Advection-diffusion models

Method indicator		
Bottom-Up	Hybrid	Top-Down
YES		

Summary of key issues:

Issue	Description
Description	Such models are intended to make predictions through solution of the so-called advection-diffusion equation, which makes use of probability, time, velocity and the diffusion coefficient with spatial variability, and reflects two transport mechanisms: o Advective (or convective) transport with the mean flow; and o Diffusive transport due to concentrations gradients.
Temporal applicability	Typically ran over a medium term period (days to months).
Spatial applicability	Generally limited to small spatial scales, however, can be applied in a course model to extend estuary-wide.
Links with other tools	Typically linked with process-based models such as sediment fluxes, hydrodynamic models, water quality and sediment quality
Data sources	Temperature sources for data setup, salinity, suspended sediment concentrations, contaminants. Contaminant discharge information is required for boundary conditions. Calibration and verification data need to be obtained as well as information regarding mass balance and the displacement of the substance.
Necessary software tools / skills	Hydrodynamic model, which can interface with the advection-dispersion model. Skills needed include an understanding of the hydrodynamics, material released and estuary processes.
Typical analyses	Consider the fate of material released into the environment.
Limitations	The considered substance is completely mixed over the cross-section, implying that a source/sink term is considered to mix instantaneously over the cross-section; The substance is conservative or subject to a first order reaction

Analysis and modelling
- Analysis & modelling guide
- Cause-consequence model
- Cause-consequence toolbox
- Process based "bottom - up" methods
  - Advection-diffusion models
  - Hydrodynamic modelling
  - Morphological bed updating models
  - Particle tracking
  - Sediment transport modelling

Figure 3.11 Cause consequence toolbox interface: Detailed method page

C. Searchable online version of the Futurecoast estuaries database

A tool has been created that allows users to search the existing Futurecoast data for UK coast estuaries. The data within the database is derived through various sources – Nature Conservancy Council (Davidson *et al.*, 1991), EMPHASYS (2000b), Dyer (2002) in Futurecoast and Townend (2005).

The user can either select an estuary from a drop-down list (Figure 3.12) or find a list of estuaries by geomorphological type (Figure 3.13).

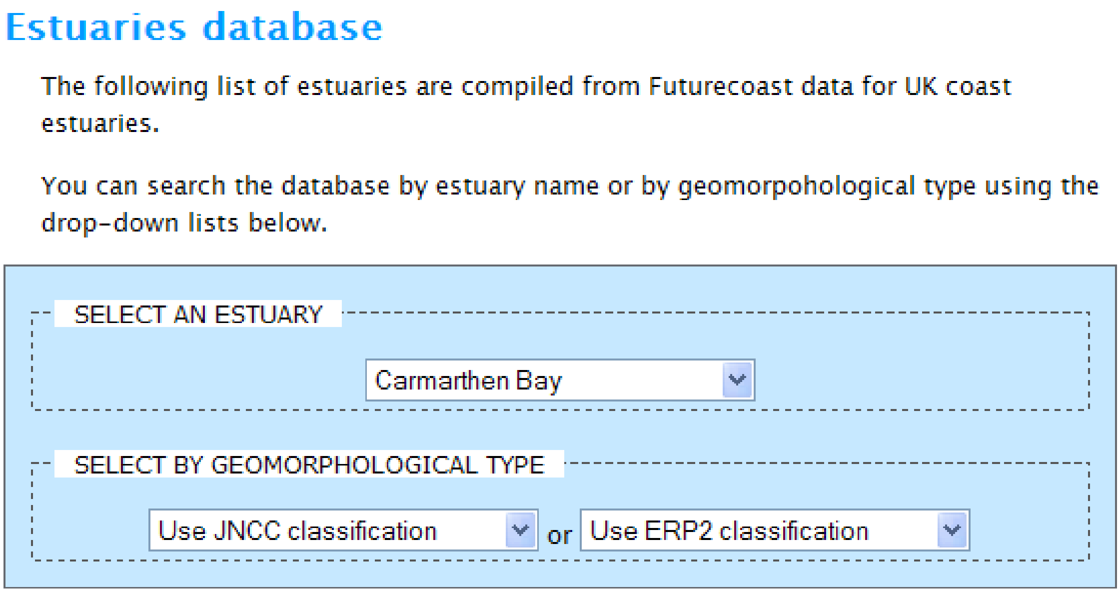
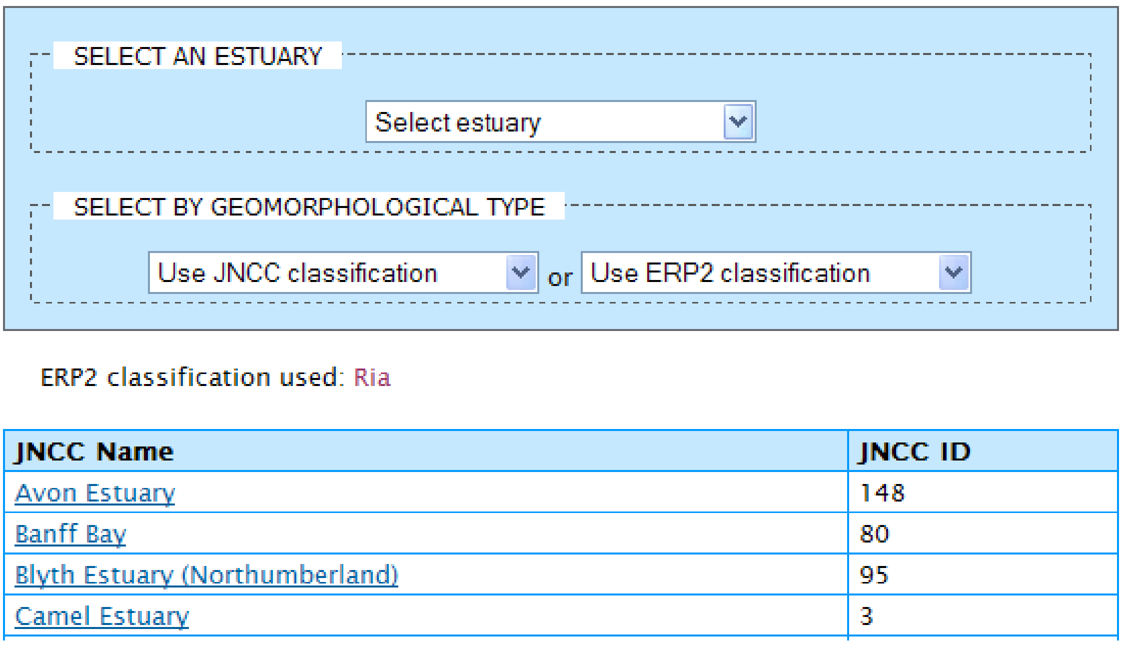


Figure 3.12 Search interface for estuaries information



JNCC Name	JNCC ID
Avon Estuary	148
Banff Bay	80
Blyth Estuary (Northumberland)	95
Camel Estuary	3

Figure 3.13 List of estuaries when selecting by geomorphological type

The details page for a selected estuary contains an interactive Google map and a table of parameters (the user can hover over a parameter name for a brief description) (Figure 3.14). The data displayed is indicative of recently determined bulk properties suitable for broad scale intercomparison of estuaries.

JNCC name	Carmarthen Bay
JNCC ID	14
JNCC grid ref	SN345085
JNCC geomorphological type	Embayment
ERP2 geomorphological type	Embayment read more on estuary classification..
Tidal type	Macrotidal
Shoreline length (km)	115.7
Channel length (km)	30.7
Core area (ha)	8294.8
Intertidal area (ha)	5359.5
Tidal range (m)	7.5

Figure 3.14 Details page of selected estuary

D. Flow diagram floating menu

This allows the user to navigate around the material by clicking on different buttons based on flow diagrams. The flow diagrams were used as a logical navigation system in the existing version of the guide and came from the original report (Townend, 2004) (Figure 3.15).

The system offers a floating menu system anchored left/right of screen that can be minimised when not required.

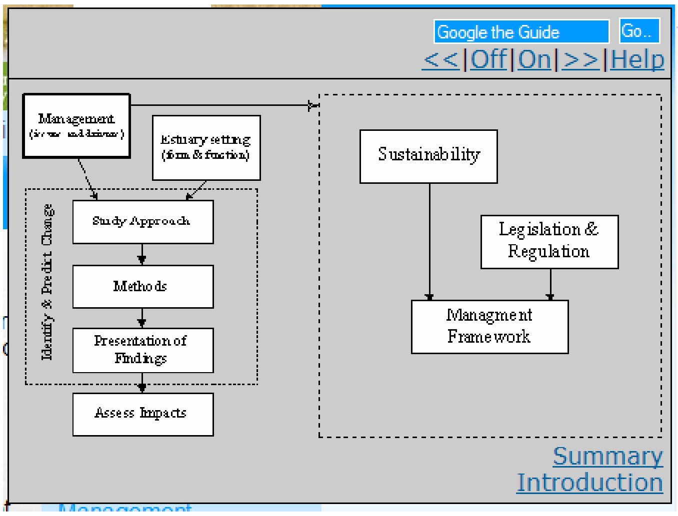


Figure 3.15 Example of a floating menu system

Other items for consideration for the Estuary Guide beyond the project lifetime included the hosting arrangements and maintenance. These items are discussed below.

3.4 Hosting

With respect to taking the system forward into the future, beyond the lifetime of the project, a range of hosting options were considered (Appendix A of Whitehouse *et al*., 2007). An approach was selected which offers housekeeping of the Estuaries Impact Assessment System Mark 2. ABPmer has agreed to cover the hosting costs for the Estuary Guide online for the period March 2008 to March 2013; unless superseded by developments in future ERP projects.

3.5 Technical aspects of the website

Having dealt with the user aspects and hosting of the website the following sections summarise the relevant technical aspects of the Estuary Guide website that relate to its functioning.

Platform

The website hosting platform is a server running MS Windows Server 2003 and IIS 6.0 web server. The core code framework is based on a combination of HyperText Markup Language (HTML), Cascading Style Sheets (CSS), Active Server Pages (ASP) and JavaScript, with the use of Microsoft Access databases for any tools. The underlying site HTML code is based on the HTML 4.01 Strict DTD standard using external Cascading Style Sheets (CSS) to control the look of the site on the screen and when printed. To maximise control over the individual pages common elements like headers, navigation and footers have been stored as separate files and then included using a server based web code language (ASP). This server language has also been used for other tasks like communicating with databases and creating more dynamic interactive pages. JavaScript is both utilised for simple client side enhancements, but also to make use of two Google API modules (Google Maps API and Google Search API). Data used in the toolboxes are stored in flat tables using a MS Access 2000 Database.

Layout Design

After some consideration a centred fixed width layout that both looks clean and still makes the information accessible to small and large screen users was adopted. The following screen-shot presents an overview of the style (Figure 3.16):

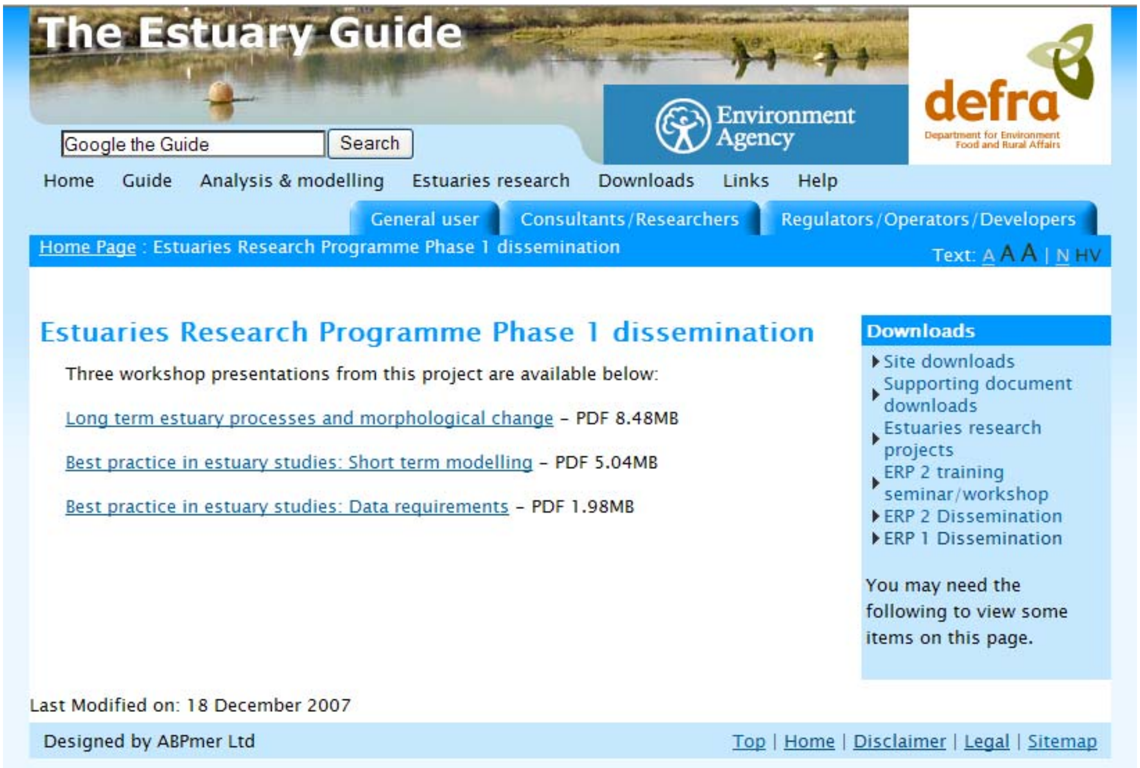


Figure 3.16 Centred fixed width page layout

Navigation

The site was designed with a consistently presented horizontal drop-down menu near the top of every page. There is secondary side navigation available where required, which changes to suit different sections of the site. The included breadcrumb component also allows users to move around more easily and help orientate them with respect to the site architecture. An additional set of user orientated navigation tabs is always available at the top of the page, which take users straight to a tailored level of information.

Accessibility

Web accessibility embraces the concept that all web users irrespective of disabilities have access to information on the web. This requires websites to consider the needs of disabled (and older) users. These requirements can range from accommodating varying degrees of sightedness, colour blindness to blind users using text readers (to name a few examples). The Estuary Guide has attempted to embrace this concept to make it an accessible resource.

Some of these points are illustrated by looking at the top of the web page design where there is:

- A consistent text navigation bar and use of breadcrumb function with text links to orientate the user (Figure 3.17)
- User selection of three text sizes – see left hand side of Figure 3.17, and

- The ability to view a normal or high-visibility version of the site (Figures 3.18 and 3.19)

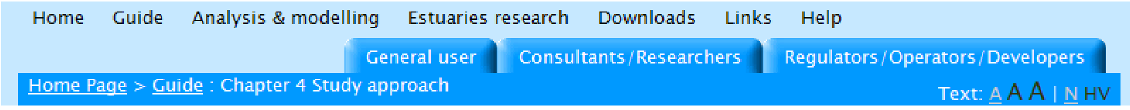


Figure 3.17 Some accessibility features on the website

Below are examples of the normal and high-visibility views of the site:

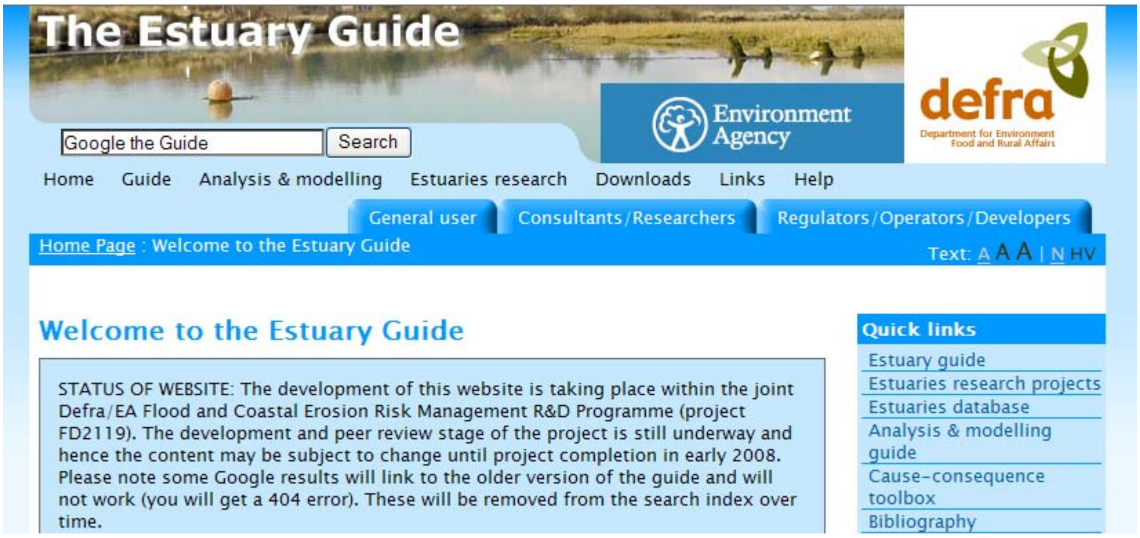


Figure3.18 Normal view

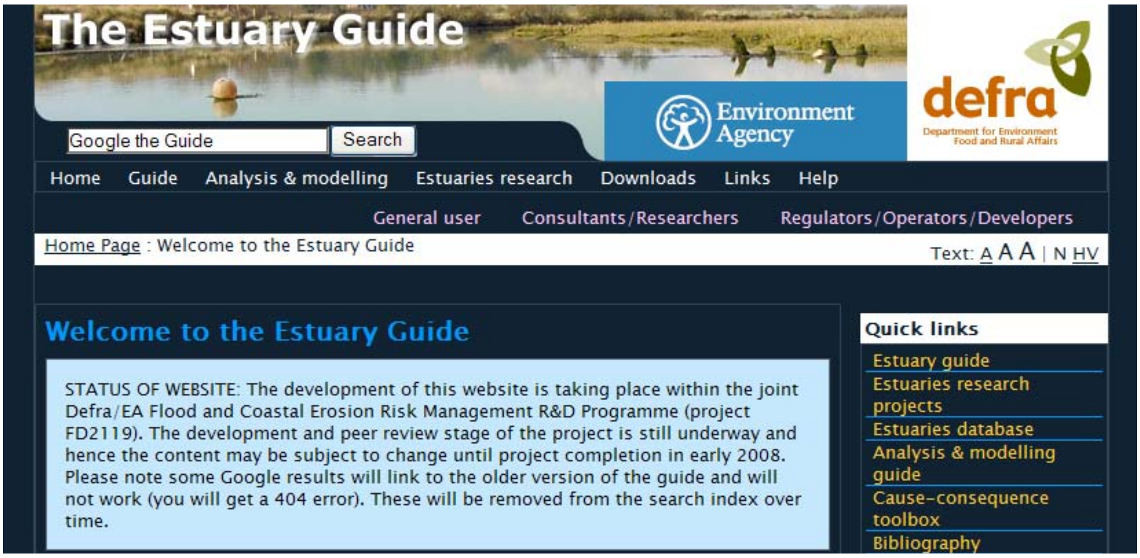


Figure 3.19 High-vis view

There is also a clear page structure with CSS turned off, where text links and a 'Jump to content' link are provided (Figure 3.20).

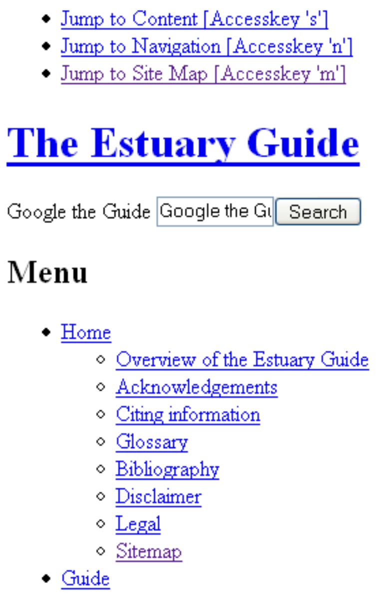


Figure 3.20 Page view with CSS turned off

Site Searches

The Google search engine has been implemented for site searches (Figure 3.21). At the same time advantage has been taken of the more recent Google Search API code to fully embed the search results into the site template.

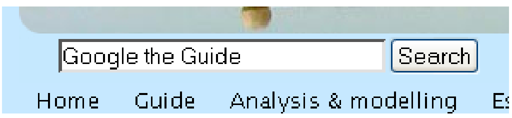


Figure 3.21 Google powered search box

An example of a result from the site search is shown in the following figure (Figure 3.22):

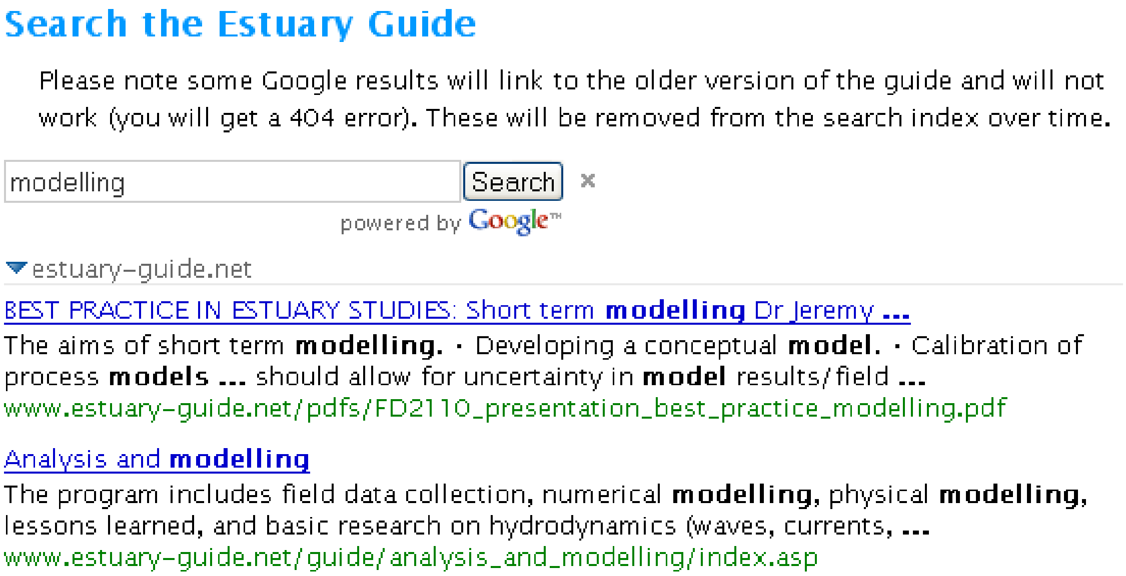


Figure 3.22 Google Search API search results

This has assisted with improving Search Engine Optimisation (SEO) of the website along with other salient pointers, listed below, which have been adopted where possible:

- Encouraging inbound linking from relevant sites
- Using text based navigation with hyperlinks
- Optimising keywords
- Using descriptive text links (i.e. no “click here”)
- Creating compelling targeted content
- Set up and monitoring of site usage using Google Analytics
- Ensuring sitemap is available – allows efficient site crawlability, and
- Using a primary search engine for site searches

3.6 Maintenance

In terms of keeping the system updated to reflect ongoing and new research, and make it the ‘must use’ resource to get the best-informed and accepted knowledge, there is a strong case for putting in place a maintenance programme post project.

This programme would be responsible both for updating the material on the system, but would also follow a route that lends credence to the modifications and maintaining the confidence of users in the system. The programme would sensibly be the responsibility of the existing partners where a large knowledge base already exists, however, there may also be merit in considering an independent group (such as the now extant Estuaries Advisory Group) to add a recognised ’stamp of approval’ to revisions. The regularity of revisions is scalable, but too many would be costly and too few render the system a less desirable resource. As a starting point bi-annual revisions would seem to be a reasonable middle ground, and would allow a controlled approach to the updates. The updates could reflect site use, feedback from users, and the addition of tools, text and case studies. These revisions could be advertised both on the website and by sending an e-mail alert listing modifications made. This is an area that requires more thought as ERP progresses.

To summarise, the project has delivered a web system that took the existing Estuary Guide to the next level by incorporating a synthesis of the latest research from ERP2, and wider estuaries research, and provided a structured and interactive user experience. It was emphasised to users that this work remains as a guide and it is used at their own liability. It will be useful to monitor the uptake of the knowledge, both through observing user statistics and observing over time where other external studies draw upon the information to help bring out links into Phase 3 of the Estuaries Research Programme. A funded maintenance programme will provide a useful bridge past the end of this project, and also demonstrates commitment to the long term goal of an Estuary Management System.

4. Training

The project arranged **two training events** in the form of structured day-long events held in November 2007 in Environment Agency training rooms. These were organised and run by HR Wallingford and ABPmer staff. The two events were:

21 November 2007 Oxford – Osney Depot
Participants: 4 trainers, 9 external attendees, EA project officer

28 November 2007 Peterborough – Kingfisher House
4 trainers, 8 external attendees, EA project officer

These workshop seminars introduced and explored the draft version of the Estuary Guide and the benefits arising from the ERP deliverables through the resources and tools contained within the Estuary Guide. The draft version of the guide had been made available to all participants in a password protected form prior to the training events. Through accessing the online draft version of the guide as part of the preparation for the day take-up and feedback were aided, and questions and discussion were facilitated during the day.

The format of the events was as indicated in Table 4.1 and took on board information from the consultation (Section 2.2). The material made use of presentations and Q&A/discussion sessions as well as interactive sessions using the guide, with all participants having access to the online version of the Estuary Guide.

Table 4.1 Content of training days held in 2007

Timing	Session	Who
09:00-09:30	Registration and coffee	**All**
09:30-09:45	Welcome, intro and purpose of the day – context of the project and where are things going with the estuary guide and Estuary Management System	**Richard Whitehouse and Stefan Laeger**
09:45-10:00	Open forum to raise views on the day	**All - steered by Richard Whitehouse**
10:00-10:45	Estuary processes and geomorphology – general information, estuary types - completed and ongoing research	**Alun Williams**
10:45-11:00	Q&A and discussion	**All - steered by Noel Beech**
11:00-11:30	Coffee break	
11:30-12:00	Introducing the estuary guide as a resource and informed catalogue	**Chris Jackson and Alun Williams**
12:00-12:15	Q&A and discussion	**All - steered by Noel Beech**
12:15-13:00	Improving confidence – estuary study framework and methodology, tools and approaches and prediction horizons	**Richard Whitehouse**

Timing	Session	Who
13:00-13:15	Q&A and discussion; issue of feedback form for completion by the end of the day	**All - steered by Noel Beech**
13:15-14:00	Lunch	
14:00-15:00	Mini-workshop on estuary case study with participants accessing and sharing information from the guide	**All - steered by Noel Beech**
15:00-15:30	Free interaction session on the web using the guide	**All**
15:30-15:45	Review of available tools and future developments with an Estuary Management System	**Richard Whitehouse**
15:45-16:00	Final Q&A/discussion, feedback, thanks and close	**All - steered by Richard Whitehouse**
16:00-16:30	Tea break	
16:30-17:00	Further informal discussions/use of estuary guide as required by participants	

The two training workshops ran to time and generated a lot of discussion and feedback, including a full return of feedback forms. The participants recorded that they had found the event to be informative and that it had raised their awareness of ERP outputs. There were some feedback items of relevance such as:

- Expertise is required to evaluate morphological change, you cannot just turn on the models.
- The estuary guide uses a cause consequence model – this is useful but should be treated with healthy scepticism.
- The guide is a navigation tool for knowledge that is out there.
- Estuaries behave similarly at a basic level, but not all estuaries respond in the same way.
- Methods for evaluating the sensitivity of estuaries are important which can be linked to Water Framework Directive UKTAG work.

The training event materials are available as PDF format files from the estuary guide website. They are also reproduced for convenience in hardcopy format in Appendix 2 to this report.

5. Recommendations for future R&D in estuaries

The research requirements have been brought forward from previous ERP research. The four sections 5.1 to 5.4 are listed in order of completion dates of the projects, and section 5.5 includes a synthesis of the recommendations.

5.1 FD1905 EstProc research recommendations

EstProc produced user-oriented algorithms describing hydrodynamic, sedimentary and biological processes in estuaries and their interactions (EstProc Consortium, 2005a, b). These were presented for stand-alone use in desk study application and for ready inclusion in computational models, as indicated in the present report. EstProc also produced a range of process concepts and less well developed algorithms reflecting a higher level of uncertainty or lack of information in particular areas. One strand of these research recommendations is to take the existing outputs at this level and develop them to working algorithms for implementation in models. The biological influences are now better understood but more integration of the hydrobiosedimentary elements is needed to allow regular implementation of biological effects. There are also some regional studies that need to be tackled which will demonstrate how the hydrobiosedimentary process parameters apply in the estuaries of England and Wales.

Following on from the recommendations of the EMPHASYS Consortium (2000c) the basic headings of data collection, monitoring and research, including model development, is adopted. On the modelling front the process work continues to bolster the capabilities of models predicting processes but also continues to develop the existing links across to ERP2 Broad Scale Modelling projects on hybrid morphological modelling. Phase 2, of which EstProc was a part, comprised the improvement and combination of the best methods, together with new fundamental research. The next levels of development are within a continuation of Phase 2 and also Phase 3, which comprises the development of new, cross-fertilized methods based on the results of the fundamental research from Phase 2.

On the modelling front process work is needed to continue to bolster the capabilities of models predicting processes, but also continues to develop the existing links across to ERP2 Broad Scale Modelling projects on hybrid morphological modelling.

There is also continuing work which needs to be integrated into EstProc and developed forwards to help solve outstanding problems and provide a robust set of procedures for answering awkward practical problems.

The main issues to address are:

- Development of additional process concepts already developed within EstProc (EstProc Consortium, 2005a) up to the level of working

algorithms for feed to Broad scale modelling / Engineering projects (FD2107 and FD2117);
- Wider application of existing (FD1905) and new algorithms within ‘bottom-up’ process models such as the friction factor for wave propagation using a saltmarsh canopy based approach, mass settling flux for flocculated cohesive sediments and biological process parameters that effect sediment stability, erodibility and deposition (details presented in EstProc Consortium, 2005b); and,
- Framework for assessing relevance of algorithms at regional scale and links to existing national databases to ensure maximum interoperability at time of delivering [2]ERP EIAS and EMS.

The outputs will be improved techniques, demonstration of uptake in operational models, generic/regional indicators. It will place the research in the context of existing data initiatives and frameworks and build directly towards the ERP EIAS and EMS to be developed within ERP.

It will support process studies for engineering projects such as the response to ‘managed realignment’ of the coastline, modelling and exploitation of marine data interoperability to support the statutory requirements of the Water Framework Directive, and extended investigation of Global Climate Change scenarios.

The project can only make recommendations – it is up to the funders programmes to be able to take this forward. Thus there is a continuing risk that new research on estuaries will fall into a gulf between research council funding on rivers, coasts and shelf and the end-user focus of the Defra/EA programmes.

Broad approach
The proposed research takes three main strands as outlined above. The first and second strands keep the momentum of the current EstProc project and parallel initiatives to extend the science achievements. To take advantage of the recent advances the ongoing research needs to include the following approaches:

- Mining and analysis of existing datasets to develop algorithms. There will be a need for some new process studies data to develop, extend, calibrate and validate the existing algorithms; and,
- Methodology development and process modelling on contrasting ERP designated estuaries to demonstrate implementation of algorithms extending the range of scenarios that can be modelled and the impact of their inclusion on predictive capability.

Three that might be taken forward are listed above.

There are a number of important areas which can be advanced with the further R&D, these include:

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[2] Estuaries Research Programme Environmental Impact Assessment System and Estuary Management System

1. Incorporation of vegetation and biota into models. Further quantification on the feedback between vegetation and sediments using modelling and data mining of existing datasets;
2. Generalisation of the behaviour of real estuarine sediments building on the geotechnical and hydraulic insights generated within EstProc;
3. Measurements for validation of sediment transport process models including long-term monitoring of tides, waves, river flows, sediment and salinity concentration;
4. Developing sediment budget analysis and framework determining the relative roles of biology, waves, tidal asymmetry, accumulation of sediments and the role of benthos/vegetation [extends the work proposed for FD2116 which is essentially a review of presently available methods within a consistent framework];
5. Improving the understanding of the interaction of tidal flats and channels. A better understanding of the exchange processes, magnitude and timing of sediment exchanges is needed including assessing the role of river discharge and weather and tidal harmonics generated within the estuary. This can be achieved using data analysis and process modelling from contrasting estuaries.
6. Extending the existing estuary sediment floc database to allow prediction in saline conditions throughout the estuary and out to the sea. Determining the role of biology and biochemical properties in floc and bed properties through further laboratory and *in-situ* measurements.
7. Application of process models within contrasting selected estuaries to investigate the applicability of the algorithms. This will need to consider event sequencing and probabilistic approaches, and further development of and implementation of ensemble techniques for process modelling.

The third strand extends the uptake of EstProc into application methods and interpretation. This brings together the improved process understanding with ongoing monitoring initiatives and includes empirical approaches, including a high level screening of the key hydrobiosedimentary parameters expected to be significant.

1. Combination of existing hydrodynamic, sedimentary and biological parameters using GIS based techniques operating at the estuary level, and building on existing databases including EMPHASYS-ERP uptake, Futurecoast, JNCC, EA/Defra, BGS. The relative role of riverine sources, coastal sources, and internal erosion in the estuary to topographic change should become apparent in this.
2. Schematic mapping out of zones of particular 'bioengineer' organisms to establish range of influence around coast of England and Wales. An example of the approach could be development of categories of tidal response building on EC INTRMUD concept of spring low water timing in daylight hours, as well as the budgetary analysis at regional scale done in FUTURECOAST.
3. Generalisation of estuarine suspended sediment concentrations and threshold values leading to relationships between physical effects and biological parameters. Predictions of patterns of biota in estuaries in relation to physical factors will be facilitated by further research on what parameters, or combinations, need to be measured or estimated.

It is expected that demonstrable progress can be made on a substantial portion of the above within a 3-year carefully structured programme of work. The work can be completed by an appropriate consortium building on the significant expertise contained within the EstProc consortium (www.estproc.net) and other research initiatives on process and data initiatives and frameworks. An appropriate consortium or managed network of smaller projects should be drawn together to deliver the research;

Some of the work may link into other work funded under Defra/EA Broadscale Modelling Theme and into Research Council programmes (e.g. building on NERC FREE – Flood Risk in Extreme Events) and other research council grants (e.g. data assimilation project at Reading University, Sarah Dance). The Defra/EA R&D programme needs to facilitate the completion of the necessary process work to ensure that it is not overlooked. It will map out and add value to those marine data initiatives and frameworks being operated within the UK for river, estuarine and coastal areas that are relevant to the screening and application of the EstProc process algorithms.

Supporting initiatives

The above research needs to be supported by implementation of up-to-date and novel technology. This should include:

- Further development of remote sensing approaches, e.g. building on repeat airborne imaging spectrometry, ground-truthed with field spectra, which has been used to establish patterns of suspended sediment dynamics on rising tidal stages at the managed re-alignment site at Tollesbury. Development and generalisation of existing analytical vertical sediment profile algorithms to provide full water depth predictive capability from remotely sensed data;
- Measurement techniques for short term (hours / days) and long term (months / years) changes in intertidal sediment levels. This is essential information for the validation of the next generation of models of estuarine sediment dynamics and morphology. For example, this may be achieved by deploying a new sediment level sensor under development by PML.
- Establishment of a quantitative criterion-based framework for evaluation of model calibration and performance, building on existing approaches, that is appropriate to estuary modellers and end users of the results.

There are a number of initiatives that are appropriate for possible Research Council funding. These would increase the general level of understanding, assist the development of new conceptual approaches, and improve interpretation of models. These include further investigation, quantification and determination of:

- The effects of waves on levels of turbidity within estuaries – their potential influence on the turbidity maximum and on intertidal, mudbank morphology;

- The effect of waves and tidal currents on sediment erosion and deposition in shallow estuaries with the aim of establishing the relative importance of intermittent vs persistent events (i.e. waves vs tidal cycles);
- The importance of the initial flooding and final ebbing over mudflats (i.e. shallow water depth of <10cm) in transporting sediment. Investigations into the importance of drainage from intertidal areas in transporting sediments;
- The impact of a wider range of key biota (than studied in EstProc) on intertidal sediment dynamics and assessing their role as ecosystem engineers on the estuarine mudflats;
- Benthic structure and function along estuarine gradients of declining biodiversity to test hypothesis that there is less replication of ecological function in the low diversity region and therefore more vulnerable to loss of key species;
- The importance of biota in remobilising historically contaminated sediments (bioturbators) or sequestering contaminants (biostabilisation), and the impact of contaminant remobilisation on water quality;
- The influence of a wider range of intertidal biota on flow, erosion and deposition (e.g. *Salicornia*, Mussels), particularly the combination of biostabilisers and destabilisers occurring on intertidal mudflats;
- Incorporation of algorithms for bioengineering of sediments and flow into models of long term changes in estuarine morphology involving feedback between tidal currents and bathymetry. For example to more widely assess the impact of biota on equilibrium shore profiles;
- Detailed measurements of cross-estuary subtidal and intertidal water and sediment properties (e.g. calibrated mini-flumes) to investigate the water-sediment dynamics of mudbank and mudflat morphology;
- Measure turbulence (ADV + other instruments) within freshwater-saltwater interface to examine influence of stability on turbidity maximum and salt intrusion;
- Utilise remote sensing data to examine estuarine turbidity; and,
- Continue to classify turbidity and salinity in contrasting estuaries.

A Short Form A was prepared in July 2005 to take forward these recommendations. A copy of this is included in Appendix 3.

5.2 FD2116 Recommendations for further research

Following delivery of HR Wallingford *et al.* (2006) a range of immediate as well as longer term actions were required to obtain maximum benefit from the completed research:

1. The research needs to inform the update of the Estuary Impact Assessment System developed by EMPHASYS and feed into the future development of an Estuary Management System.
2. The predictive methods need to be applied to practical projects and their performance documented. The approach to achieving this should be discussed as part of the project FD2119 “Development and

dissemination of the Estuary Research Programme". The work on regime theory in muddy and sandy estuaries needs to be taken forward and applied, although some steps have been taken already in the work completed in FD2107 (item 3 below). The analytical work on estuary properties also could be developed further based on the findings in FD2107. Methods for representing the intertidal profiles of estuaries need to be refined and included in whole estuary modelling approaches.

3. The new results on estuary regime need to be implemented in the framework ("shell") for estuary simulation being developed in Defra project FD2107 on development and demonstration of system based estuary simulators.

4. The requirements for data of the predictive methods and the general assessment of data needs will need to be evaluated within Defra project FD2107 on development of estuary morphological model. That project is undertaking a further evaluation and synthesis of the datasets available to support prediction of estuary morphology. The datasets will include information on geological constraints to estuarine development.

5. The formalized methods, including those on regime, can be used in the development and implementation of behavioural models as part of project FD2107. This will build on the ASMITA and ESTMORF type of models using the new research findings of this project leading to an enhanced predictive capability.

6. The framework for Expert Geomorphological Assessment needs formal evaluation and application within a "live" estuary management project, including application of a range of the methods presented.

7. Rework and evaluate the application of the Friedrichs and Aubrey (1988) modelling of tidal asymmetry using a representative cross-section of UK estuaries. This would build on work completed in the Defra Futurecoast project. This work needs to be undertaken for estuaries with higher tidal ranges than considered in the original paper. This makes them more susceptible to hydraulic friction and potential for flood dominance.

5.3 FD2107 Future work

The project output is described in Huthnance *et al*. (2008) and two pieces of software, the Hybrid Model Interface and ASMITA model, are available for download as open source code with user manuals from www.estuary-guide.net. The various other model developments carried out during the project are described in Huthnance *et al*. and can be implemented by following the descriptions provided in the report.

To enable the Analytical Emulator to represent HW and LW (hence intertidal) areas and volumes, the assumption of a triangular cross-section with uniform side-slope could be relaxed to some other uniform shape of cross section. It might be feasible to investigate (e.g.) power-law dependence of breadth and depth on along-estuary distance, implying self-similar rather than congruent cross-sections.

It is desirable and conceivable that the Hybrid Model Interface Regime model be developed to give a rate for the morphological evolution. If sediment transport, flow-dependent erosion and deposition were added to the underlying 1-D hydrodynamic model, a rate of change of area for each cross-section would be predicted. Work in FD2116 has already set out how the Hybrid Regime model could give a rate for morphological evolution and has shown how regime theory is an approximation to sediment transport (HR Wallingford *et al*., 2006).

Other recommendations from FD2107 are as follows:

The possible influence of estuarine circulation could be investigated, adding a (formulaic) supplement to the calculated flow in the Hybrid Regime, “2.5-D” and SandTrack models, as done for the Mersey “2.5-D” model.

The Lagrangian particle-tracking method of the “2.5-D” model is being implemented in the POL Coastal Ocean Modelling System POLCOMS, a fully 3-D model with density effects (e.g. estuarine circulation is naturally modelled, given fresh river inflow).

The “2.5-D” model could be extended to predict morphological evolution using (a modified form of) the development of SandTrack to Morpho-SandTrack in the project. It is desirable and possible to add waves to Morpho-SandTrack; they are already in SandTrack. Morpho-SandTrack could usefully be run alongside more conventional Eulerian morphodynamic models, for comparisons to gain experience of its performance (speed and results).

The project’s extension of ASMITA to predict changes of element areas (as well as volumes) should be fully validated.

There is scope to develop the Realignment model to include effects of biology on bed shear stress, erosion of defences at the entrance to the set back site and erosion of the initial bed.

If the Inverse model is to be used for prediction, there should be some hindcast tests (against some past data not used in the analysis already completed) and trials for other estuaries.

Appropriate components of the FD2107 expanded database should be incorporated within the Estuary Simulator developed in FD2117 (Section 5.4).

5.4 FD2117 Future Work

The research undertaken within EstSim (ABP Marine Environment Research Ltd, *et al*., 2008) revealed the considerable potential of the systems-based approach and its application to develop qualitative or behavioural models to simulate estuary response to change. A web based demonstrator http://www.discoverysoftware.co.uk/estsim/EstSim.html and Matlab research level code are available http://www.geog.ucl.ac.uk/ceru/estsim, the latter was pilot tested in the project and reported on.

A series of recommendations stemming from this work are made below, grouped into appropriate headings:

Complementary Approaches to Mathematical Formalisation
A number of alternative approaches exist to capture defined relationships within a mathematical framework in order to develop a behavioural model. Within EstSim, a review has been carried out of the following three alternative approaches:

- Boolean network approach;
- Network Dynamics (or loop analysis)
- ASMITA (Aggregated Scale Morphological Interaction between Tidal basin and Adjacent coast)

The review concluded that in reality estuary systems are too complex to be fully described by any of the considered approaches alone and the approaches should be considered complementary. It is therefore highlighted that there may be future options to combine the Boolean network approach with more quantitative methods such as ASMITA and loop analysis.

The Systems Based Approach
- EstSim has provided the formal definition of estuary systems in a manner consistent with that developed for the open coast within the Futurecoast study (Defra, 2002). This definition provides the framework for the development of specific estuary behavioural statements, should this be progressed in the future.

Boolean Network Approach
Future research into the Boolean network approach should focus on the following areas:
- The evaluation of more refined variable sets and the development of approaches (and software tools) for the development and testing of complex, yet logically rigorous, Boolean functions.
- Further experimentation with linked sub-systems as a means of minimising the complexity of individual functions, whilst increasing the ability of a Boolean model to resolve the subtleties of estuary system behaviour.
- Investigation of the operator variance associated with each stage of the modelling process (i.e. system mapping, influence diagram construction, formalisation of knowledge into model functions).
- Experimentation with variable decay terms to encompass a broader variety of non-synchronous behaviour.
- A refinement could be made to enhance the function library allowing for selective application of management policies to the different subsystems.
- Many of the estuary variables which are set to “1” or “0” are in reality partially present (i.e. somewhere in between 0 and 1) in estuaries.

- Deciding whether this sort of estuary property has been correctly predicted by the Simulator is a value judgement. A means of making this evaluation process more rigorous would be valuable both for the future development of the Simulator and for its subsequent use.

During peer review it was also noted that without further dissemination activities some of this work may not benefit the ERP or the industry in general, so this is something that will have to be picked up on in ERP3. In the meantime, further dissemination was carried out in the present project (FD2119) through the training (see Section 4) and final seminar meeting on 5 March 2008.

5.5 Synthesis

There are a range of aspects that need to be continued to be developed. On the process modelling front following from EstProc there are additional process algorithms required to be developed to bring a wider applicability of existing capabilities. The work on the links between hydrodynamics-sediments-ecology are probably the most pressing ones that need to be taken forward to assist in evaluating the interaction between habitats and flood management activities and other works in estuaries. Existing process algorithms need to be tested at a regional scale on contrasting estuaries with links made to existing databases. The broad approach relates to the mining of datasets supported by the development of new datasets. The process research is of fundamental importance and a coherent programme of work is required to ensure that aspects are not lost between the funding streams. It is important to bring information on academic and Defra/EA led projects together. One key area that needs to be advanced is on the combination of existing hydrodynamic, sedimentary and biological parameters. The generation of long-term coordinated collection of estuary data directly benefits the effective management and planning of estuary developments. This will also facilitate schematic mapping of zones in which particular bioengineers have significant influence and assist in the development of zoning for estuarine suspended sediment concentration. There is also a requirement for development and application of up-to-date and novel monitoring technologies including remote sensing to provide rapid and regional measurement capabilities.

The research on estuary geomorphology in FD2116 has led to a comprehensive reference report and results have fed through into other projects in ERP2, namely FD2107 and FD2117. The techniques and frameworks need further application and validation within “live” estuary projects to increase confidence and reduce uncertainty. A library of application data should be developed to provide a reference source for practitioners and this information should be disseminated in the form of one or more conferences for estuary users, or by linking into existing conference series, and through the publication of papers in relevant peer review journals. This supports development of the science and evidence base.

Some additional developments on the hybrid modelling of morphology in FD2107 are required to ensure the analytical emulator becomes more generalised and that the rate of morphological evolution can be predicted from hybrid methods based on regime theory. This requires application against historic data for a range of estuaries and a clear evaluation of predictive capability and developments required. The ASMITA model is deserving of further application in the same fashion and developments to include prediction of elements within the estuary including saltmarsh. The role of biological elements in the regime, realignment and ASMITA approaches is required and this can build on research in EstProc. There are components that can also be taken through to the EstSim approach, including use of the expanded estuary parameters database from FD2107.

The FD2117 EstSim work used one approach to mathematical formulation which provided a research level demonstration tool. The tool could be developed further using improvements to the Boolean approach as well as complementary mathematical developments and by linking up to the ASMITA approach. The systems approach has demonstrated benefits in that it has provided a structured approach to definition of morphological elements within estuaries. This can be expanded and the representation of management options needs to be improved.

The improved science and methods are required to inform decision pathways. At present best practice for morphological predictions is to validate against historical change as a precursor to making future predictions. The quality of hindcast should be quantified using appropriate methods. In some cases it will be appropriate to generate an ensemble of predictions and a standard approach to needs to be defined.

In addition, there are also benefits to be gained by bringing together research outputs on coastal morphology and erosion with those on estuary morphology. On the coastal theme the work being carried out in project SC060074 on long-term, large-scale coastal geomorphological behaviour will explore some of the linkages to the estuary morphology. Further work will need to recognise the developments that have taken place on the Tyndall Centre coastal simulator (e.g. Dawson *et al*., 2007), including the interplay of coastal erosion and flood risk, and the project FD2324 on the Risk Assessment of Coastal Erosion.

6. Scope of integrated Estuary Management System

6.1 Objective and Workplan Summary

The project has scoped out the Estuary Management System (EMS) to be developed in Phase 3 of the Estuaries Research Programme (ERP3), both the form this should take and the remaining research required to deliver it. Broadly it is proposed that this should be compatible with the Drivers, Pressures, States, Impacts and Response framework (DPSIR) that has been used in other work and be able to support studies of flood risk, engineering, conservation and water quality. The EMS will support sustainable development in estuaries and encompass the development of adaptive management strategies.

6.2 Pre-2007 requirements

The pre-existing requirements for EMS arise from the ERP Scoping Study, EMPHASYS, the FD2115 ERP2 report, and the FD2119 Inception Report initial scoping.

Sustainable estuaries management depends on an understanding of the system at a variety of spatial and temporal scales. Short-term management decisions may have long-term consequences on the evolution of estuaries and so an integrated approach is required to understand how the system responds to changes in the complex forcing processes present in estuaries, be these natural or as a result of intervention.

To address this need, the ERP was established in 1998 with a 10 year research vision to produce an EMS containing physical, ecological, social and economic factors.

The scoping report (HR Wallingford, 1997) defined the output reproduced in Table 6.1 with respect the EMS in the breakdown of activities into research tasks.

ERP1 (also known as EMPHASYS – Estuarine Morphology and Processes Holistic Assessment System, FD1401) investigated the use of different modelling approaches to predict the morphology of an estuary and how these can be used to evaluate management strategies. Several key reports were produced including a best practice guide for predicting morphological change and a public database including broad scale data for 79 estuaries and more detailed data on the hydrodynamic, bathymetric and sedimentary properties of six estuaries.

Table 6.1 EMS information from scoping report (HR Wallingford, 1997)

Activity/Output	Comments/Benefits
23. OUTPUT: Estuary Management System A completely integrated system combining prediction and modelling methods for morphology, water quality and ecology within the hyper-text setting of a management framework. Includes (inter alia): • Guidelines on existing best practice for planning and design of estuary developments • Identification of techniques for establishing geomorphological, historical and natural variability] • Methods for determining long-term effects of discharges and abstraction • Methods for determining impact of dredging and placement and storage of dredged materials	These items were all identified as user requirements. The information required to address these issues will come through Phases I and II and also capitalise on work underway on the beneficial use and properties of dredged material. Dredged material provides a resource which, it if can be used in an effective and ecological manner, has a large potential benefit to estuary users. By disseminating this information there will be a direct benefit to those involved in providing improved techniques for estuary management and planning.
• An estuary management manual	This is intended to be an incremental manual. In Year 1 introductory text describing estuary processes, morphology and methods for assessing short-term impacts of works will be included. Year 5 will see an additional section on estuary management practice based on the outcome of Phases I and II. Revision in Year 10 based on information from Phase III. This is seen as providing education for practitioners and those who affect estuaries on the history, behaviour and the implications of sea level rise.

ERP2 continued to deliver the original research vision, with several projects taking forward the research produced in Phase 1. Those that have already delivered include the Estuary Processes Research Project (EstProc Consortium, 2005a; FD1905) and the 'Review and formalisation of geomorphological concepts and approaches for estuaries' (HR Wallingford *et al*., 2006; FD2116). EstProc research investigated the interactions of hydrodynamic, biological and sedimentary processes within estuaries to improve understanding, and algorithms were developed as part of the project offering the opportunity for improved predictive modelling. Related work was completed on a Broad scale ecosystem assessment (BSEA) Toolbox – BSEA 1 (Conlan *et al*., 2006; FD2112).

A 'Review and formalisation of geomorphological concepts and approaches for estuaries' (FD2116) built upon the work in Phase 1 by exploring the applicability of the systems approach to methods and tools in EMPHASYS within the framework of an Expert Geomorphological Assessment (EGA). EGA is data driven and seeks to combine data analysis and application with process knowledge and expert tools, guided by experience and this report has produced guidance in the selection and use of these methods in the analysis of estuary prediction.

The most recently completed projects include the ‘Development of hybrid estuary morphological models’ (FD2107) which developed new modelling tools that bring together the current ‘top down’ and ‘bottom up’ process models available to enable 50 year forecasts of morphology to be modelled in the final Estuary Management System. Complementing this was a project developing systems-based estuary simulators (FD2117) which extended the concepts explored in Futurecoast to the estuarine environment. Estuaries were classified into seven types based on behavioural properties and common geomorphological components. A web-based demonstration system enables estuary planners and managers to interactively better understand the morphological behaviour of estuaries.

As a result of the focussed activity under the Estuary Research Programme, a substantial body of information has now been assembled. In addition there are a number of related initiatives within the Defra/EA FCERM[3] programme, the current coastal simulator development at the Tyndall centre and the EPSRC and EC funded programmes, which although primarily focussing on fluvial flooding may generate some relevant outputs.

The EMS will guide both individual estuary management and planning and inform longer-term strategic policy development to ensure sustainable estuaries management is achieved. It will need to be capable of working over a hierarchy of scales from making regional (estuary-wide) evaluations to support strategic decision making to the local scale required to determine the impact of engineering works.

6.3 Original 1997 concept of EMS

The basis of an Estuary Management System was originally set out in the scoping report for the Estuaries Research Programme (SR478, HR Wallingford, 1997). This outlined how in the first two phases of the programme the suitable tools would be developed, documented and combined into a toolbox as part of a broader Estuary Impact Assessment System. This was seen as focussing on hydrodynamics, sediments and morphology in Phase 1 and introducing ecology and water quality in Phase 2. As it transpires, whilst some ecology tools have been developed there has been very little attention given to water quality issues within the programme of work. The scoping study recognised that to predict long-term change in any meaningful way it would also be necessary to integrate the estuary system work with the pressures that derive from the anthropogenic influences. It was envisaged that this would encompass social, economic and legislative aspects. The resultant capability was described as an Estuary

[3] Flood and Coastal Erosion Risk Management

Management System (EMS). A high level description of how the methods, models and tools come together is shown in Table 6.2 and the phasing of the development of the proposed development is as shown in Figure 6.1.

Table 6.2 Types of methods, models and tools (from SR478, HR Wallingford, 1997)

	Estuarine Morphology	Water/sediment Quality	Ecology	Anthropogenic Influences
Bottom-up (Process-based, Short-term) Methods	Physics-based numerical models	Flow-plus-chemistry water quality models	Plant and animal biological understanding	Local socio-economic analysis/methods
Top-Down (Estuary-system, Long-term) Methods	Qualitative, empirical and regime methods	Sediment-pollutant models	Population dynamics models	Institutional framework / macro-economic models
Hybrid (Bottom-up Plus Top-down, Short to Long term) Methods	Long-term, physics - calibrated, morphological models	Long-term water/ sediment quality predictors	Long-term ecological development predictors	Long-term socio-economic predictors
Estuary impact Assessment System	Collection of the above tools			
Estuary Management System	Interlinked combination of all the above tools			

The development of the concept of the EMS was seen as a response to the user requirements identified at the time. This centred on tools to support the decision making process for the future management and planning in and around estuaries.

In general the responses from the users, representing flood defence, water quality, conservation and navigation interests, reflected their responsibility for particular issues and activities within their estuary. The main requirement of users was for tools for the future management and planning of estuaries. The need for these tools was largely driven by legislative requirements such as the EC Habitats Directive. Specific requirements mentioned by users were (text copied from pages 4 and 5 of HR Wallingford, 1997):

- “Improved predictive techniques/models for estuary management with suitable verification and data to assess applicability.
- Improved understanding and prediction of the long-term estuary response to engineering developments.
- Evaluation of beneficial use opportunities for dredged material with respect to flood and coastal defence.

- Improved knowledge of environmental issues with respect to dredging activities.
- Guidelines for good practice in the dredging of contaminated sediments.

Users also requested that dissemination of these tools and their capabilities, and communication between estuary users should be improved. Many of the users acknowledged that the provision of such tools required improved collection and collation of data and identified the following specific points:

- More continuous monitoring of (estuary) inputs and water quality to verify models.
- Continuation of the existing long term field measurements and analysis for the long term picture of estuary behaviour.
- Development of new instrumentation and improvement of existing instrumentation.
- Improved collection, storage, access and dissemination of data, particularly for input to predictive techniques and model verification.
- Optimise and improve use of remotely sensed data.

Users also identified that the following advances in the understanding and prediction of physical processes were required:

- Understanding the long term evolution of estuary hydrodynamics and morphology due to both natural and human induced change.
- Reliable quantitative prediction of the movement of fine sediments.
- Establishing the interaction between fluvial, estuarine and coastal processes in the long-term.
- Understanding estuary processes and parameterising links between hydrodynamics, morphology, water quality and ecology in the long term.
- Understanding saltmarsh and mudflat processes and their interaction with the estuary system. "

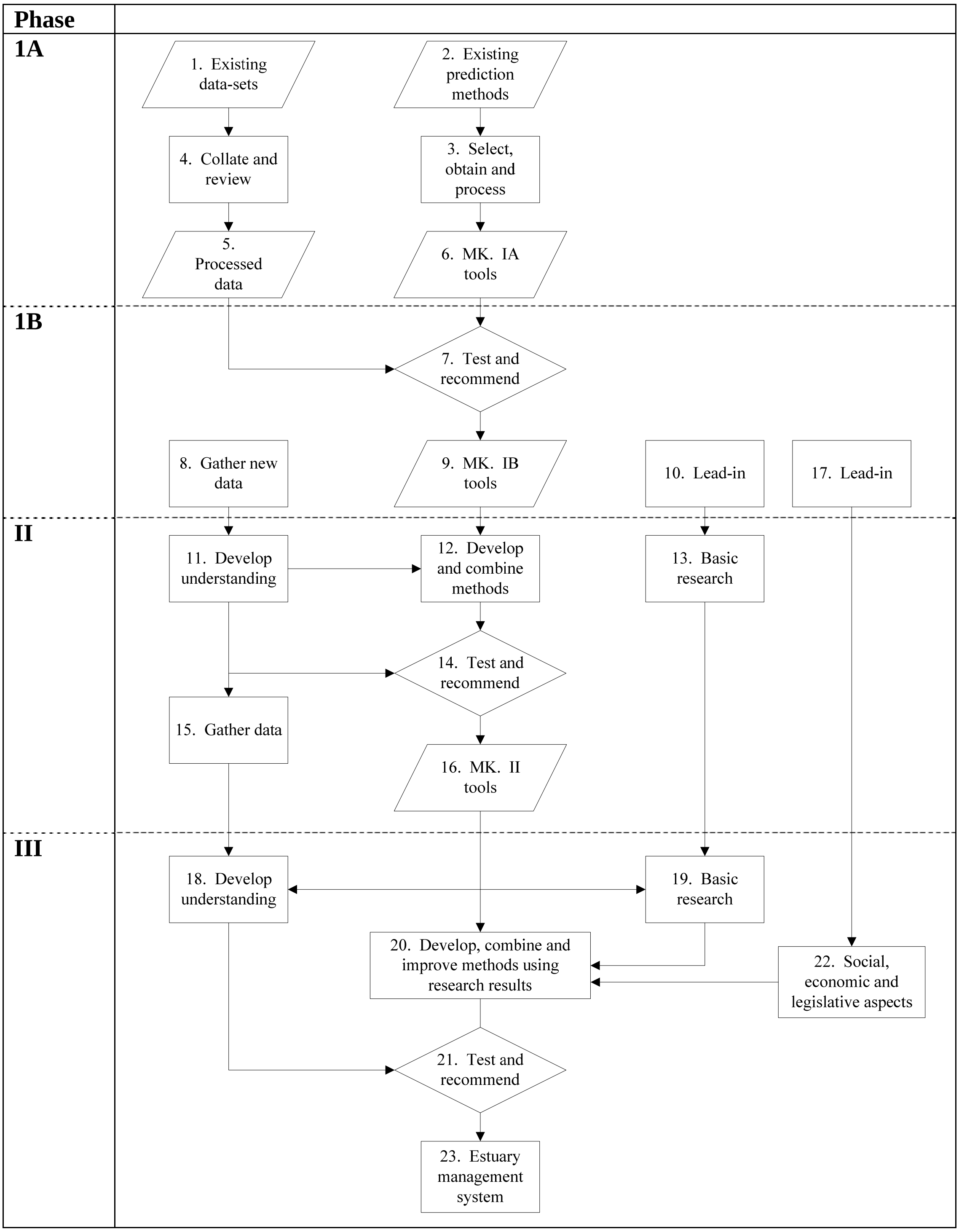

Figure 6.1 Estuaries Research Programme flow chart (from SR478, HR Wallingford, 1997)

Evaluation of progress with respect to ERP plan (Figure 6.1)

Some of these requirements will have been met in part or full by developments since 1997. These requirements have been reviewed in light of the consultation carried out in the present project and based on the work completed in ERP since 1997. Of the work proposed for Phases I and II the majority is completed as anticipated, with notable gaps being on items 8 and 15 relating to the collection of new data and 17 on the lead in work for inclusion of socio-economic aspects. Also there is an ongoing requirement for basic science and understanding in item 13. These items will need to be picked up and carried forward into Phase III.

6.5 Estuary Management System (EMS)

The Estuary Management System shall be a framework for decision making and exploring the consequences of anthropogenic activity in estuaries. It is required to support resource planning in catchments that include estuaries and coasts. The EMS uses the Estuary Guide to provide the links to relevant tools and data. Science and datasets are required to keep the EMS up to date with relevant tools and data. The EMS framework shall be risk-based, system-based and hierarchical to allow national policy planning and strategy planning through to local delivery plans and local operational decision support. The EMS requires morphological prediction as a key component or boundary condition in flood risk assessment (e.g. through RASP based MDSF2: McGahey *et al*., 2007). The links with MDSF2 are discussed in Section 6.8. A modular approach is required to enable different sources of data and methods to be handled in a consistent and traceable fashion to facilitate synthesis of the evidence base.

The EMS software shall be platform independent and able to apply for any scale of planning. A modular approach is required to enable different sources of data and methods to be handled in a consistent and traceable fashion to facilitate synthesis of the evidence base. A core “RASP” (Risk Assessment and System Analysis) engine will be developed by the MDSF2 project and the EMS related modules could be incorporated within this wider risk assessment and decision support tool for planning. The background to MDSF2 is discussed in Section 6.7and proposed links between EMS and MDSF2 are discussed in Section 6.8.

Through consultation and feedback from training on the present project transparency, traceability and clarity were all identified as being key items in delivering an EMS and its associated toolbox of methods and data.

Application of the EMS requires basic data to be available for estuaries – hydrodynamic, morphological, sedimentary and biological data – a consistent long-term national dataset for estuaries is required.

An informed catalogue and framework for methods and how to use them is available from the Estuary Guide. The Estuary Guide provides a consistent resource for use in existing frameworks. The cause-consequence model is an accepted approach to provide direction on model selection for estuary modelling and analysis. It is recognised that this needs to be improved in a continuing fashion with an emphasis on developing a user community based set of case studies and example applications. Accumulation of this experience will lead to reduction in uncertainty about the prediction horizons of the available methods. An ongoing programme of science and accumulation of datasets relevant to estuary management are required to keep the EMS up to date with relevant tools and data.

There are four aspects of EMS development required:

1. Development of tools to be used in flood risk frameworks that calculate flooding damage and hence socio-economic impact
2. Development of tools to be used in water quality and ecological modelling
3. Development of tools to be able to model the natural or anthropogenic constraints on an estuary system; for example using agent based modelling
4. Development of further science and datasets to provide robust evidence based decision making

The third aspect envisages that there is an interaction between management policies that provide constraints on estuary morphological development and the high level targets relating to conservation and water quality. This needs to recognise the behaviour of institutional bodies (government) as well as local bodies (communities and individuals) each with their own aims, strategies and operational behaviours.

To be useful the EMS needs to facilitate:

1. Identification of the environmental changes arising from proposed activities in the estuary and of the features/receptors that could be affected

2. Understanding of the environmental changes in terms of their exposure characteristics, the natural background system, and the sensitivity characteristics of particular features

3. Evaluation of the vulnerability of the features as a basis for assessing the nature of the impact and its significance

4. Management of any impacts which are found to be significant and require implementation of impact reduction measures

The MDSF1 comprised:

- The **Software**, being a customised GIS tool (not a new GIS), developed to work with ArcView Version 3.2a
- A Software **User Guide** giving specific instructions for use of the customised GIS tool
- **Procedures**, explaining the software functions so users have an understanding of the results produced and their provenance, notably the influence of “built in” operations on the results. The Procedures also advise on the appropriate use of the MDSF.

6.6 Proposed Framework for the EMS

For the analysis of future flood risk the Drivers, Pressures, States, Impacts, Response framework (DPSIR) framework was successfully employed within the OST future Flooding project (Evans *et al*, 2004), Figure 6.2. A similar approach is proposed in the research plan to establish the impacts of rural land use and management on flood generation (FD2114: O'Connell *at al*, 2004).

The advantage of the DPSIR approach is that it provides a modelling framework that is consistent with the needs of socio-economic modelling and should therefore minimise some of the issues related to integrating models drawn from different disciplines; notably physical and social sciences (Turner *et al*., 1998). One of the main disadvantages is that it is more difficult to retain an overview of the system (because components may be drawn from disparate sources) and in particular to consider the dynamics and characteristic behaviour of the system as a whole (because idealised reductionism to identify key properties is more difficult to implement). However, as we move to represent ever more complex systems this may be a necessary sacrifice. Again this moves the modelling concept towards networked representations of sub-systems, which may be linked by very simple rules or some complex and highly non-linear relationship. The dynamics has to be considered in terms of states and (through suitable coarse-graining) can be characterised in terms of key properties but not necessarily explicit behavioural attributes.

A DPSIR style presentation of the research and model development needed for coasts and estuaries has many similarities to the FD2114 model, Figure 6.3. This method of approach is appropriate as it provides a basis for linking policy and science/modelling. Some of the components are all ready well advanced (e.g. some aspects of state and impact modelling), whereas others will require some significant effort to establish a comprehensive DPSIR modelling system. Similar developments on the coast such as the Tyndall Centre simulator (Dawson, *et al*., 2007) can also be mapped into this model, Figure 6.4.

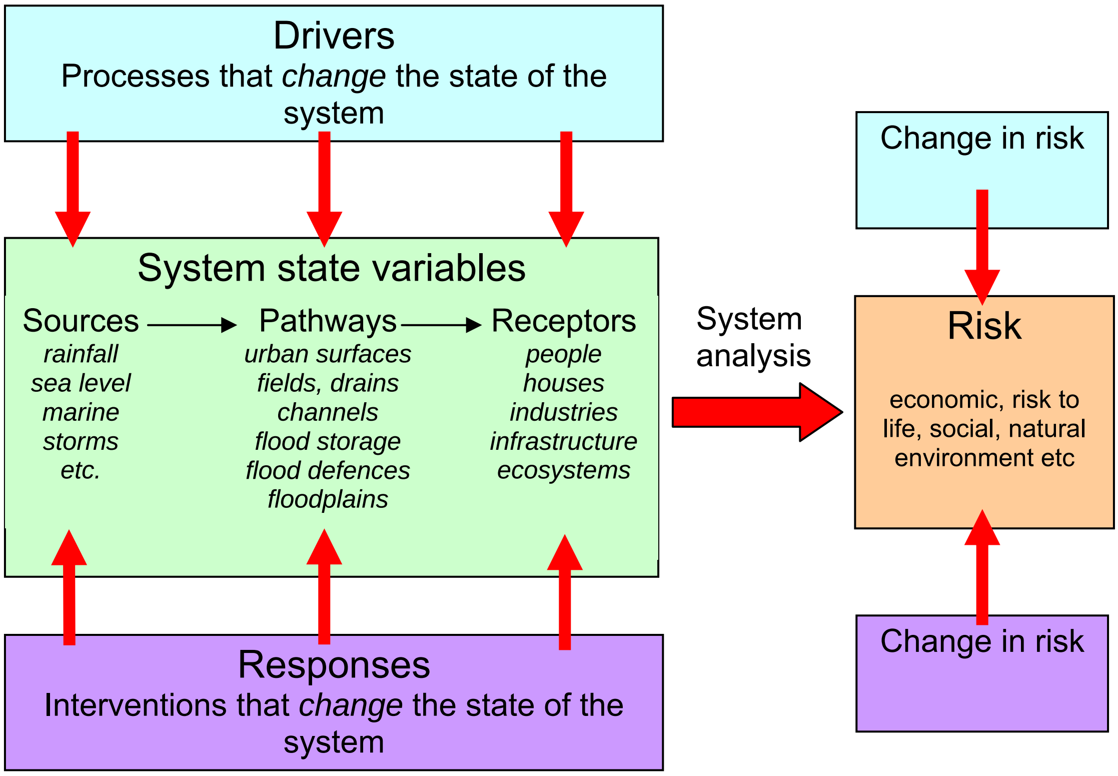

Figure 6.2 DPSIR framework used in OST Future Flooding project (Evans *et al*, 2004)

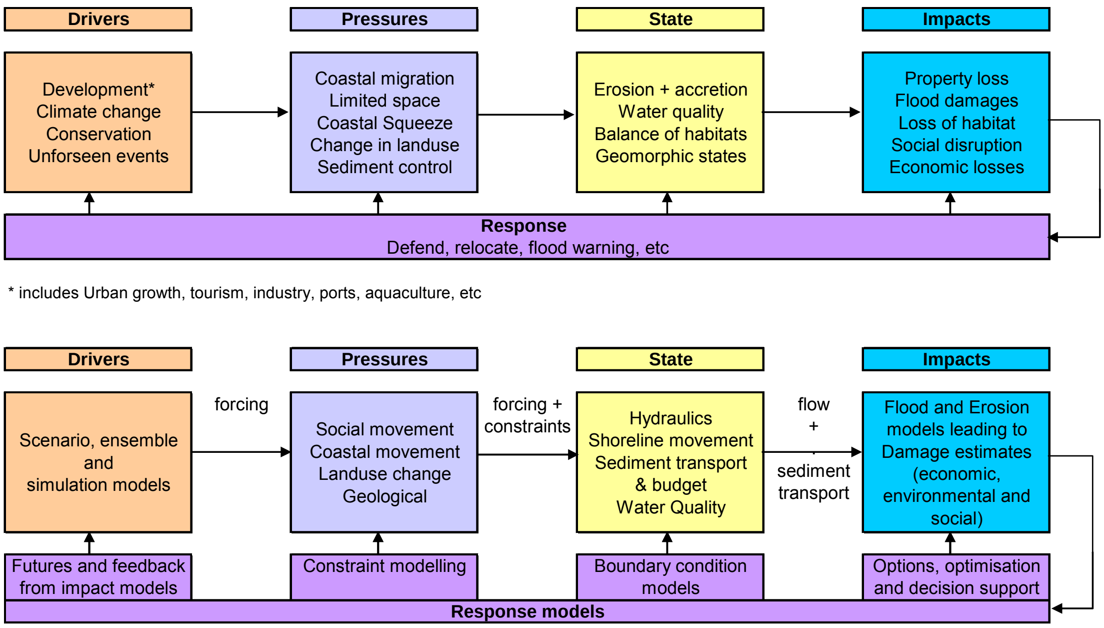

Figure 6.3 DPSIR framework for coasts and estuaries (upper diagram shows the DPSIR representation of the system and the lower diagram shows the modelling representation of the system)

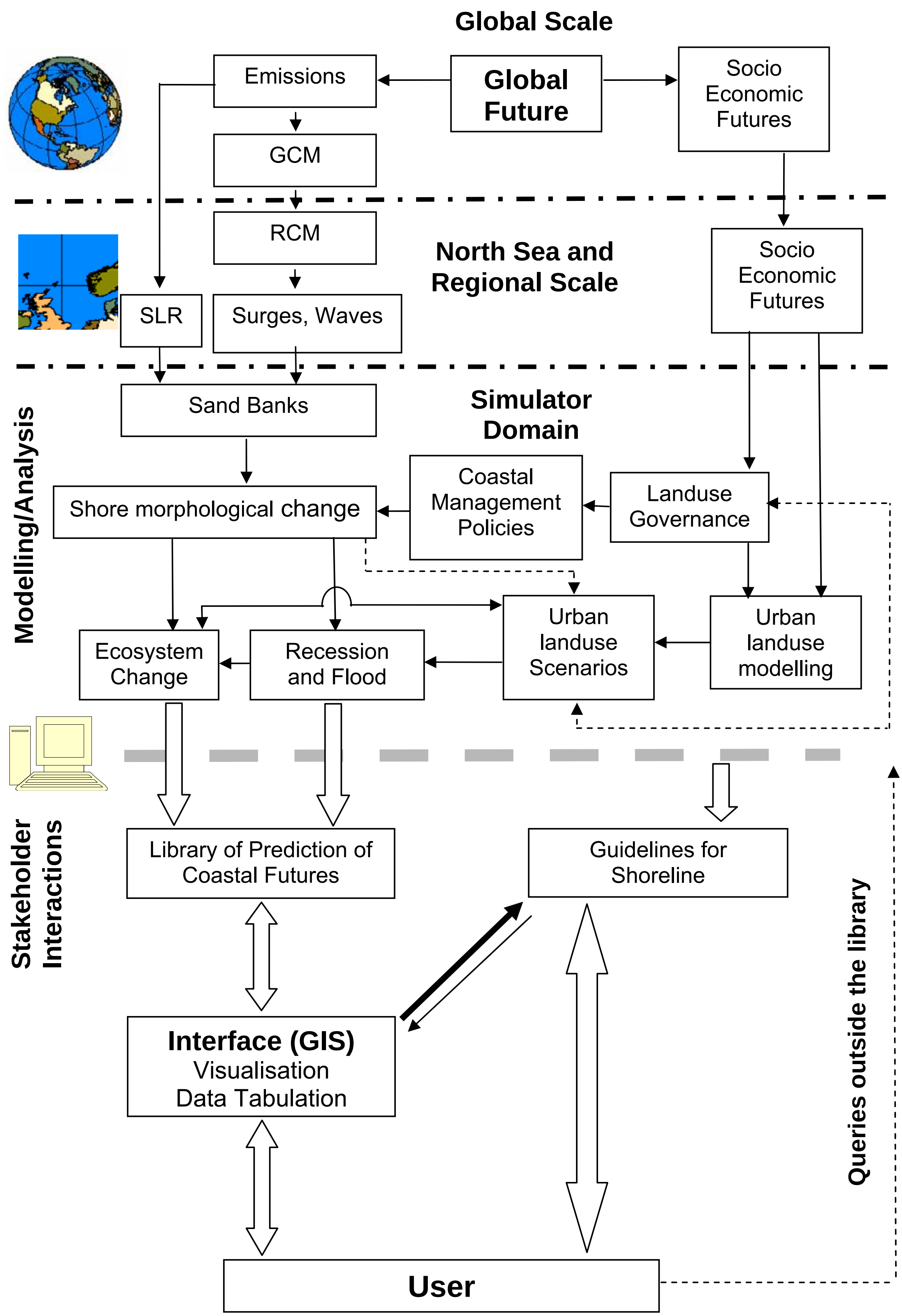

Figure 6.4 Coastal Simulator Framework (from Watkinson, in FD2118 report)

This framework is also being proposed for the future development of Broad Scale Modelling (BSM) and the report from project FD2118 (Wheater, *et al*., 2007) includes Figure 6.5 to illustrate how the DPSIR-BSM framework could be implemented in support of decision-making on future flood and coastal erosion risk management. The report goes on to describe how this framework should be linked to Integrated Assessment of policy options and that in the longer-term (~10 years) stakeholder participation should be enhanced by the use of participatory Virtual Decision Support Theatres. For now it is necessary to be aware of these potential developments, so that the EMS can be mapped into and adapted as part of these future developments.

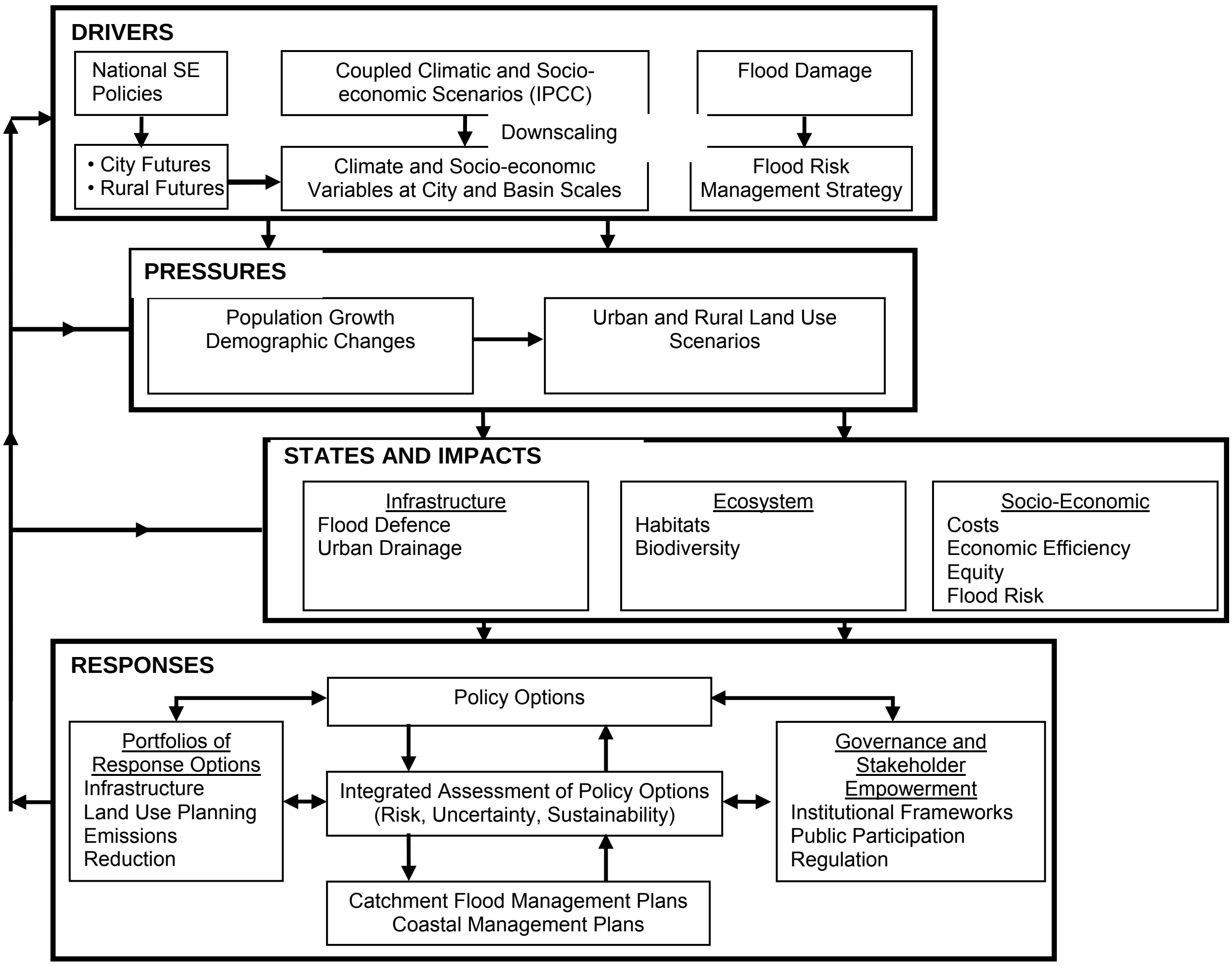

Figure 6.5 DPSIR-BSM framework (in FD2118 report, Wheater *et al*., 2007)

These various research initiatives can potentially all contribute something to the way in which the EMS is formulated. The consultation exercise (Section 2) identified additional material to be considered. The review of what is available and what developments are envisaged (e.g. under the Broad Scale Modelling initiative) have played a major role in the formulation of the EMS.

6.7 Overview of Modelling Decision Support Framework 2 (MDSF2)

There are many challenges in meeting Government and Environment Agency aims of developing a risk-based modelling and decision support system for planning. Over the past 10 years, Defra and the Agency have been challenged with finding holistic solutions to key questions via understanding the '**D**river - **P**ressure - **S**tate – **O**ption - **R**esponse' (DPSOR) cycle (Figure 6.6) and addressed this through the development of risk assessment and decision support tools for FRM planning at different levels (Figure 6.7). However, until recently these methods and tools have often failed to answer the full range of questions and to meet expectations for a variety of reasons (e.g. MDSF1).

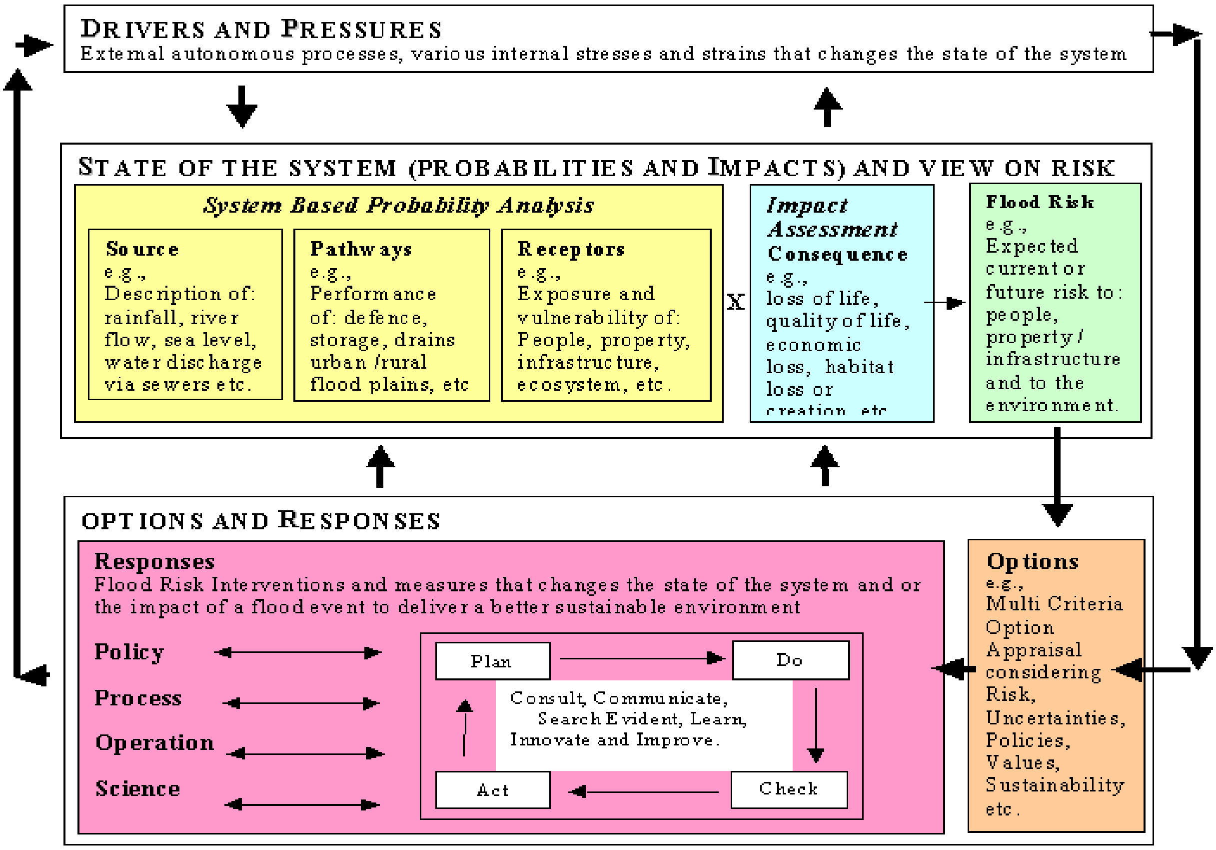

Figure 6.6 'Driver-Pressure - State - Option - Responses' management cycle (Surendran, 2006).

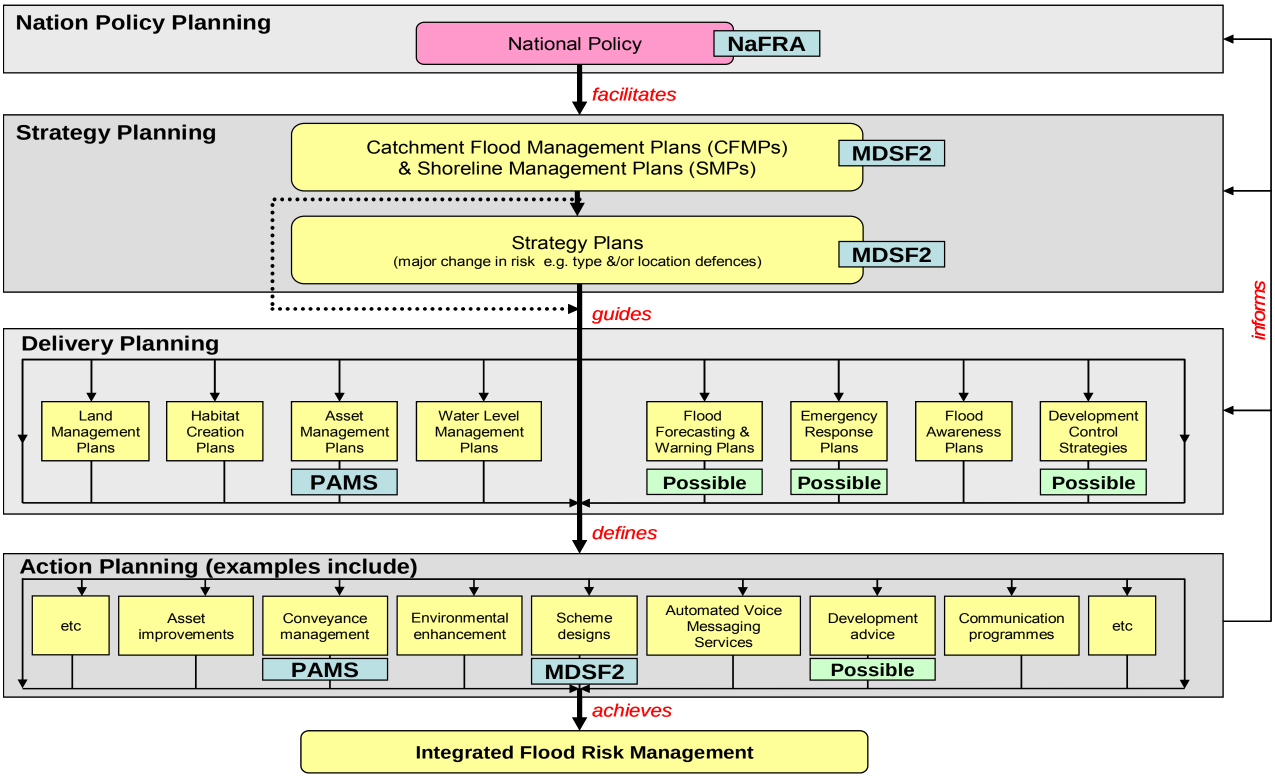

Figure 6.7 An overview of the Flood Risk Management Plans and tools that support FRM (Environment Agency, 2006).

MDSF: The Modelling and Decision Support Framework (MDSF) was developed in 2001 (Evans *et al*., 2002) and has been applied widely for flood/erosion risk assessment in **C**atchment **F**lood **M**anagement **P**lans (CFMP) and **S**horeline **M**anagement **P**lans (SMP) and has also been used on strategy studies and schemes (Figure 6.8). The MDSF1 comprised a GIS based **Software** developed to work with ArcView Version 3.2a, **Procedures**, explaining the software functions and a software **User Guide** giving specific instructions for use of the customised GIS tool.

The MDSF1 Software provides the functionality listed below.

- Assessment of flood extent and depth
- Calculation of economic damages due to flooding
- Calculation of social impacts due to flooding including population in flood risk area and their social vulnerability
- Presentation of results for a range of Cases to assist the user in the selection of the preferred policy. Each Case is a combination of climate scenario, land use scenario and flood risk management option
- Procedure for estimating uncertainty in the results for each Case
- Framework for comparing flood damages and social impacts as an aid to policy evaluation
- Archiving of Cases.

The MDSF, however, uses a simplified representation of the role of defences and does not properly take account of defence performance in the analysis of risks and their management. Its performance and "fitness for purpose" was reviewed in 2004 and the benefits of incorporating better risk modelling of defences and compatibility of the software with Agency systems were identified as keys to the future.

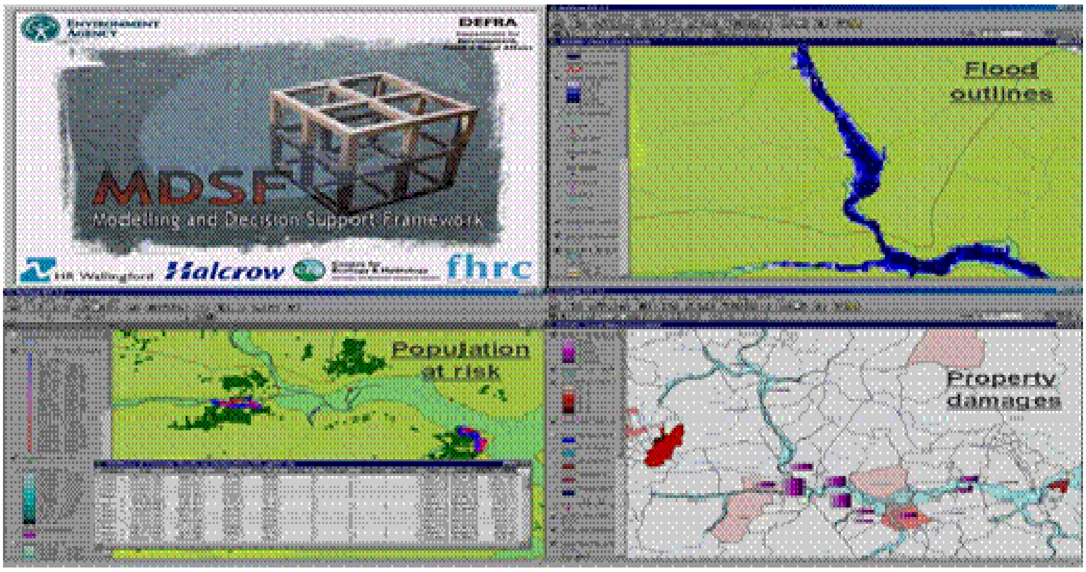

Figure 6.8 Some outputs from the MDSF Tool (Environment Agency, 2005).

RASP: During the period 2000-03, Defra and the Agency were involved in developing concepts and methods for a tiered Risk Assessment for System Planning (RASP) which is fundamentally concerned with the provision of reliable and useful evidence for FRM decisions (DETR *et al*., 2000; Defra and Environment Agency 2002; Sayers *et al.*, 2002; Hall *et al.,* 2003; Environment Agency, 2004). Since the initial development of the original coding of the RASP Tool, the RASP methods, software architecture and codes have been significantly enhanced (Environment Agency, 2006; Defra and Environment Agency, 2007). The continued cyclical process of improvements, testing and usage of RASP model within National Flood Risk Assessment studies (NaFRA, 2002 to 2006); Foresight Future Flooding (Evans *et al.*, 2004); TE2100 studies, FLOODsite (Gouldby *et al.,* 2008) has led to significant advancement of the RASP modelling suite. Originally these practical enactments of RASP methods were developed and used for a specific purpose such as for national Policy Planning –NaFRA, or Strategy Planning –CFMP/SMP, or Delivery Planning – System Asset Management Plans –SAMP, but it could be expanded to other risk based planning at local level and **S**trategic **F**lood **R**isk **A**ssessment (SFRA) to satisfy PPS 25 requirements.

RASP describes the "system state" by the probability analysis of Source-Pathways-Receptors and Consequence or Impacts. RASP supports (Environment Agency, 2006):

- **Systems-based thinking** – that considers all (appropriate) aspects of the flood risk system in a structured manner.
- **A risk-based approach** – that helps problem formation, risk assessment, option appraisal and risk management planning by seeking to target limited

resources (time and money) to achieve maximum benefit (tangible and intangible)
- **A hierarchical process of analysis** – that seeks to provide the assessments proportional to the risk, proposed decisions and special and temporal scale while reuse data and information generated through national policy to project planning activities.

The scoping study for the development and implementation of RASP - SC000065 (Environment Agency, 2006) shows that all system analysis and planning processes are interrelated. A key theme of RASP has therefore been the integration and reuse of common data and software modules. This principle is embedded within MDSF2 through the sharing of a general core "RASP" engine (Figure 6.9) and a common data bank across various levels of decision making. It is envisaged that the proposed RASP Engine and its developments would form the core for all future FRM planning.

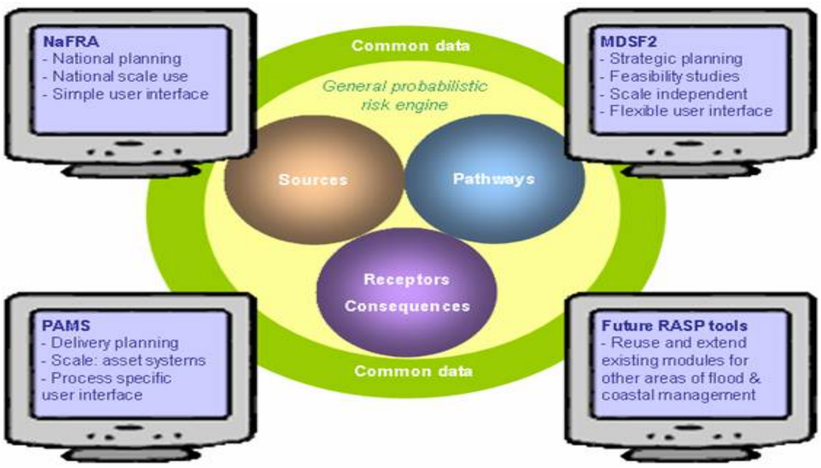

Figure 6.9 General RASP Engine reusing common data and modules (EA 2007b)

Modelling Decision Support Framework 2 (MDSF2)

MDSF2 (Environment Agency, 2005) seeks to improve MDSF1 by: a) bringing in RASP methods, and b) developing a standalone software platform reducing the current dependence on ArcGIS in order to provide a more consistent risk-based modelling and decision support tool on the desk tops of those dealing with FRM planning, inside and outside of the Agency. The tool will allow for the integration of multiple and complex relationships between natural hazards, social and economic vulnerability, the impact of measures and instruments for risk mitigation (infrastructure provision, vulnerability reduction) in support of planning FRM in the medium and long term. It is the intention that MDSF2 provides a better and more consistent decision support tool for Catchment Management Plans, Shoreline Management, Estuary Strategy Plans, **C**oastal **D**efence **S**trategy (CDS) Plans and for scheme appraisal. Therefore providing links between ERP and MDSF2 is vital.

The main drivers for this project are:

- the move to a more risk-based thinking, system-based approach and a hierarchical process of analysis to FRM decision making, and hence the need to incorporate the "RASP" approach, while maintaining/enhancing MDSF1 functionality
- the Agency's desire for a software system which is as scale-less (could be used at different special and temporal scales), platform independent and incorporates uncertainty
- To encourage reuse and integration of data and models and avoid duplication by developing a core "RASP" engine for risk assessment and system analysis for all planning levels;
- an opportunity to address the lessons learnt from use of the Agency's existing tools such as MDSF1 and other RASP family tools

The Phase 1 of this project scoped the development. Phase 2a (scope and system design) was started in 2006 and ended in 2007. Phase 2b – (system development & testing) was started in March 2008. Within Phase 3, the pilot testing on CFMPs and SMPs, dissemination road show & training for Agency staff, production of guidance docs for application will be carried out. The R&D project will end by August 2010. This project includes an initial one-year software support.

The MDSF2 decision support I s based on the RASP **S**ource-**P**athway-**R**eceptor-**C**onsequence (S-P-R-C) approach within the DPSOR based MDSF2 framework. The concept of MDSF2 is illustrated in Figure 6.10. The middle boxes indicate the risk modelling, and the pathway and receptors related risk assessment elements which will fall into the MDSF2 core application. For example, flood spreading behind the defences and the risk-based RASP calculation would be used to determine the spatial risk. The boxes surrounding this indicate the flow of information into and out of the system, including data pre-processing, any external source modelling, the management response and associated costs, all which needed for decision support.

It enables users to readily interact with different elements of the calculation process to create cases or explore 'what ifs' for planning. For example, it shows how changes to the system due to external drivers such as climate change, market forces or urbanisation would alter the Source (e.g. greater loading conditions due to sea level rise), Pathway (e.g. deterioration of defences), Receptor (e.g. altered character) or Consequence (e.g. increased damages/resilience) respectively and the risk ultimately. Similarly the framework indicates how flood risk management (structural and non-structural) responses may reduce the risks. Each option attach to a cost and benefits. The risk and associated costs and benefit would have the influence on selection of the management responses. Therefore within a post-processing module of MDSF2, using multi-criteria analysis the cost, benefit and risk could be weighed and the outputs would provide the relevant decision support.

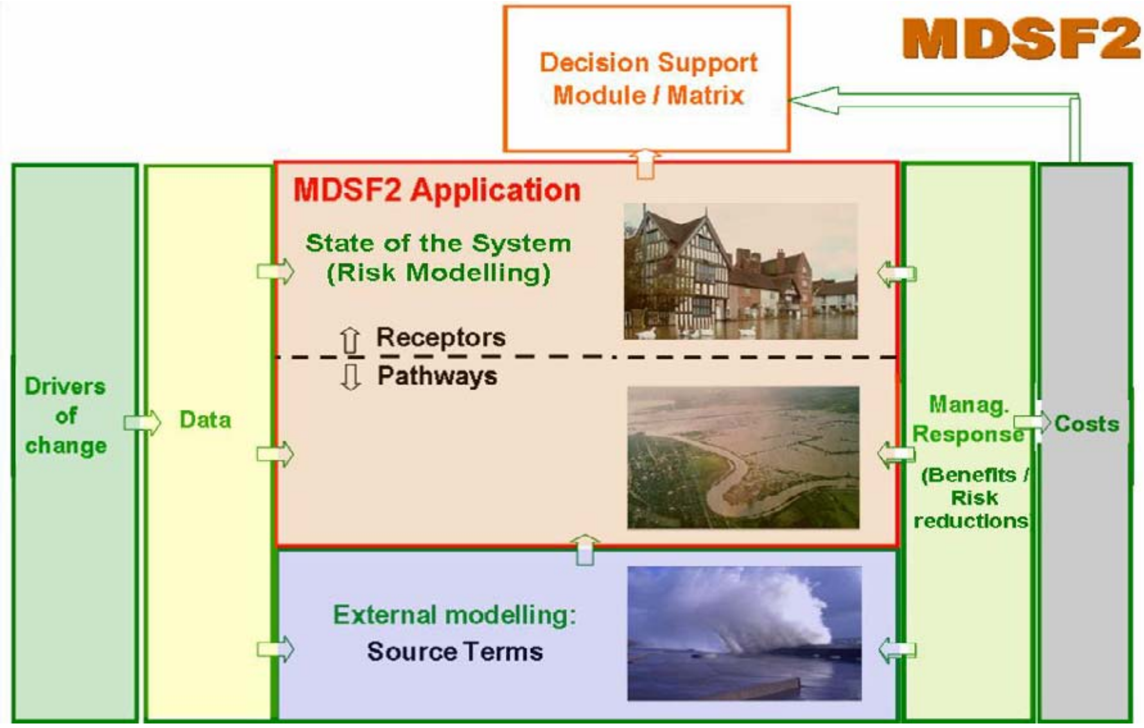

Figure 6.10 Conceptual Diagram to illustrate MDSF2 Methodology (EA 2007a)

6.8 Links between Estuaries Research Programme (ERP) and Modelling Decision Support Framework 2 (MDSF2)

An improved definition of the EMS has been achieved based on FD2119 research, especially feedback from the consultation and training discussions, recognition of links to MDSF2, RASP and PAMS, as well as FD1905, FD2116, 2117, 2118, 2107. Recently the MAR TAG has scoped out opportunities for new investigation (Kevin Horsburgh document, Appendix 4).

MDSF2

MDSF2 seeks to improve MDSF1 by: a) bringing in RASP methods, and b) developing a standalone software platform reducing the current dependence on ArcGIS. MDSF2 essentially provides a means of assessing the risk to assets (receptors) within a defended floodplain. The methodology is probabilistic, requiring as input probabilistic extreme water levels, and including internally for a probabilistic assessment of flood defence failure, flooding due to breaching and overtopping, and hence (through the specification of a particular indicator on the floodplain, be it economic, social or environmental) expected annual flood risk damages. It is the intention that MDSF2 provides a better and more consistent decision support tool for Estuary Strategy Plans.

Links between MDSF2 and ERP

The focus of any links appears to relate primarily to the development and production of Estuary Strategy Plans. MDSF2 is a framework enabling an assessment of the impacts of flooding on receptors, be they property, people, environment or other assets within the floodplain, for different proposed flood risk management options.

Existing links

MDSF2 utilises external models of estuary hydraulic processes to provide the required input source terms (probabilistic extreme water levels in front of Estuary flood defences, both now and in the future) for option assessment within Estuary Strategy Plans. There is therefore an established link to the quality of modelling of estuary hydraulics, including waves.

Future links

It is considered that, under the majority of proposed changes to the widths or depths of an Estuary associated with an Estuary Strategy Plan, the prediction of morphological response will have little bearing on the source terms (extreme water levels in the estuary) for option assessment or appraisal using MDSF2. Morphological prediction in terms of erosion of the estuary banks ("coastal erosion" in lower estuaries and "riverbank" erosion in upper estuaries) does, however, have a direct bearing on the pathway terms in MDSF2.

The main future links between ERP and MDSF2 almost certainly relate to the inclusion, within Estuary Strategy Plans, of habitat creation schemes such as managed realignment areas. Morphological modelling tools are already utilised within such Plans to assist in establishing the feasibility of potential habitat creation schemes, and inform the design development stage of options which may affect morphology. Such schemes typically include the breaching or dismantling of existing flood defences, the construction of new, setback, defences, and the intended creation of habitat (e.g. saltmarsh) in between the old and new lines of defences. Such links are expanded briefly below:

- It is understood that these habitat creation schemes are not included within MDSF2. If environmental indicators are used in MDSF2, then such a scheme would result in reductions in habitat and would not implicitly include an assessment of habitat creation in front of new defences. A useful development within MDSF2 would be the inclusion of an assessment of the benefits of such schemes. More generally, this would include assessments of habitat loss and gain under different climate change scenarios. For example, as a result of a "do nothing" strategy, the result of expected "coastal squeeze" within an estuary, under the current Defra precautionary scenario of 1m relative sea level rise by 2100, might be the loss of significant areas of intertidal habitat in front of defences. As a response, one of the proposed options for appraisal might seek to plan to compensate for this loss, and utilise morphological modelling to support this goal. MDSF2 could be used as a framework for assessing the impacts of both options, in this case specifically including for an assessment and appraisal of environmental benefits associated with different options. It would need to be altered from its current form to do this (primarily because it then moves to including habitats outside of the defended area, i.e.within the Estuary itself).

- Furthermore, an understanding of the evolution of the proposed morphology and saltmarsh could inform the determination of potential benefits in terms of possible reductions in extreme waves and/or water levels at the toe of the new defences (Nottage and Robertson, 2005), informing other inputs to MDSF2. In addition, knowledge of morphological changes at the toe of defences could provide input to the inclusion of improved overtopping formulae or lookup tables within MDSF2 (pathway inputs).

- Finally, where major schemes significantly change the width or depth or nature of part of an Estuary, there will be a more direct link to assessment of morphological changes. An example of this is the Eastern Scheldt Storm Barrier in the Netherlands, where tide range was reduced inland of the barrier. This had the effect of reducing intertidal area by an initial amount corresponding to the reduction in tide range. However, the reduction in tide range may also have led to a focussing of wave energy along a more narrow band of intertidal levels, leading to an unforeseen accelerated loss of such habitats. It is clear that improvements in the ability to predict and assess the impact of such effects before scheme development and appraisal might lead to improved information to support management decisions.

MDSF2 and EMS software architecture links
At present it is unclear how such links might exist, given the status of the MDSF2 developments are not yet so advanced, and given the form of the EMS is also not yet finalised. It is clear that the software platform should assist in the exchange of the sorts of information outlined above and follow the appropriate software architecture guidance prevailing at the time in Environment Agency standards.

Contribution of MDSF2 for calculating flooding damage and hence socio-economic impact
With respect to the above calculation the MDSF 2 and other RASP related projects such as PAMS, NaFRA, FLOODsite, provide frameworks, method to model and evaluate flood risk in rivers, estuaries and coastal systems and databases. They use probabilistic methods to predict future flood risk and impact. PAMS delivers a system for asset management for flood and coastal defences and FLOODSITE is the main EC funded programme on fluvial flooding but considering risk, emergency response and management support systems

6.9 Links between Estuaries Research Programme (ERP) and other projects

There are a variety of other projects of relevance when considering how to implement and develop the research from the Estuaries Research Programme.

Contribution of "TraC-MImAS", "HARBASINS", "Methods to Model and Map the Environmental Consequences of Flood Risk Management - SC060062" for water quality and ecological modelling
The tools such as TraC MImAS (UKTAG, 2007) are used to evaluate relevant metrics for hydromorphology under the requirements of the Water Framework Directive. This is designed with the overall purpose of the hydromorphological assessments in mind, i.e. to be used as a supporting element of the overall

classification that enables differentiation between high and good ecological status for the water body.

TraC-MImAS is underpinned by a series of assumptions:

- A TraC water has some capacity to accommodate morphological change without changes to its ecological status.
- There is a relationship between the extent of morphological alteration and the impact on ecological status.
- The response of a water body's morphology to an engineering activity or other pressure is predictable for that type of water body.
- The response of the ecology to morphological change is predictable and depends on the sensitivity of the ecology of the water body.

"These assumptions will be examined as part of future testing and validation work. As the TraC-MImAS tool is underpinned by professional judgment, it will be operated within an 'adaptive management' framework'. TraC MImAS will be reviewed as new evidence on the relationships between ecology and hydromorphology become available. Where necessary, the tool will be updated. The ultimate aim will be to test/validate the assumptions underpinning the tools and, where necessary, replace professional judgment with empirically tested data…" (UKTAG, 2007, page 6).

Also of relevance is the HARBASINS project (www.harbasins.org). HARBASINS is a European project, which commenced in 2005 and which aims to enhance the compatibility of management strategies for the North Sea's coastal waters, estuaries and river basins. It is due to complete in June 2008. *"The aim of HARBASINS is to enhance the compatibility of the management strategies for the North Sea coastal and transitional waters".*

HARBASINS promotes a functional and ecosystem approach, with basin and system oriented monitoring rather than station oriented monitoring (de Jonge *et al*., 2006). Monitoring should be specified such that cause-consequence can be identified.

The project on Methods to Model and Map the Environmental Consequences of Flood Risk Management is consistent with recommendations in Making Space for Water and the requirements of the Water Framework and Habitats Directives. The overall aim of the project is to develop and test a methodology for assessing and mapping the environmental risk, including harmful and beneficial effects, resulting from flooding. This is needed to ensure that environmental impacts are given proper consideration in flood risk management decision-making.

The project will provide a means of ensuring environmental impacts are given proper consideration in flood risk management decision-making. In developing tools for assessing and quantifying social, environmental and economic benefits in an integrated way, the research will enable robust FCERM decision-making aligned to sustainability metrics. The work wiill derive a graphical method for displaying risk and consequences of flooding and support the development of national vulnerability maps. Due to the complexity and innovative nature of the research, the project has adopted a phased approach whereby an operational tool to assist decision making is ultimately envisaged.

Contribution of "Flood risks to people – Phase 2 – FD2321 and Flood risk assessment guidance for new development – FD2320" for evaluating risks to life and property

The first of these projects has developed and demonstrated a method for assessing and mapping serious injury or fatalities from flooding during, or in the immediate aftermath, of a flood event. The approach is nested within a 'Source-Pathway-Receptor' (S-P-R) model and deals predominantly with a key component of the receptors. The second project developed a consistent understanding in a risk based framework of the key indicators when assessing flood risk for new developments. The study defined what an appropriate assessment of flood risk should be at all scales of development planning and for all types of developments.

Contribution of "Reliability in Flood Incident Management Planning – SC060063" project that models anthropogenic behaviour using agent based modelling

This aspect envisages that there is an interaction between management policies that provide constraints on estuary morphological development and the high level targets relating to conservation and water quality. This needs to recognise the behaviour of institutional bodies (government) as well as local bodies (communities and individuals) each with their own aims, strategies and operational behaviours.

Contribution of "Desk top knowledge management tool for effective use of data and models - SC600032" for development of further science and datasets to provide robust evidence based decision making

With respect to the data, knowledge management aspect, the present project has examined the research to date through delivering an enhanced version of the EIAS (Section 3). This enhanced version is a web-based tool (www.estuary-guide.net) that allows end users to access the results and tools from ERP. Consultation with key customers was completed to focus the development of the EIAS and ensure the needs of the estuarine management community were met.

Coastal and estuary links

The research on coastal morphology and erosion needs to be linked with the research on estuary morphology such that morphology and erosion can be evaluated in a consistent fashion for structural and non-structural assets. On the coastal theme the work being carried out in project SC060074 on long-term, large-scale coastal geomorphological behaviour will explore some of the linkages to the estuary morphology. Ongoing work needs to recognise the developments that have taken place on the Tyndall Centre coastal simulator (e.g. Dawson *et al*., 2007), including the interplay of coastal erosion and flood risk, and the project FD2324 on the Risk Assessment of Coastal Erosion.

Concluding remarks
The EMS can be developed to provide input to existing frameworks, such as MDSF2, for calculating flooding damage and hence socio-economic impact. Developments are also required to fit with assessing the environmental impacts of flood risk management, including ecological and water quality.

Application of the EMS requires basic data to be available for estuaries – hydrodynamic, morphological, sedimentary and biological data – a consistent long-term national dataset for estuaries is required. Where available datasets from existing initiatives should be re-used but there will also be a requirement for new data. Some key areas are outlined in Section 7.3.

An informed catalogue and framework for methods and how to use them is available from the Estuary Guide which provides a consistent resource for use in existing frameworks. The cause-consequence model is an accepted approach to provide direction on model selection for estuary modelling and analysis. It is recognised that this needs to be improved in a continuing fashion with an emphasis on developing a user community based set of case studies and example applications. Accumulation of this experience will lead to reduction in uncertainty about the prediction horizons of the available methods. An ongoing programme of science and accumulation of datasets relevant to estuary management is required to keep the EMS up to date with relevant tools and data.

6.10 Vision for the Estuary Management System

In the next 3 years

1. Implement the systems approach for the Estuary Management system through DPSIR. Adopt a modular and open framework so that a range of appropriate models and techniques can be applied. Determine the best method for presentation and visualisation of results taking note of developments in Broad Scale Modeling.

2. Determine the most appropriate framework for delivery of a Decision Support System. For flood risk it is appropriate to make developments to support the coastal erosion impact module of MDSF2 with the necessary links for environmental factors, including the processes of morphological change and erosion in estuaries, and managed realignment.

3. Consolidate the existing Estuary Impact Assessment System (EIAS) approach for estuary processes and morphology. Make links with existing work on coastal morphology and erosion. Document and benchmark capabilities of predictive models and analysis techniques. Update toolbox as required.

4. Expand the existing EIAS approach to bring in water and sediment quality and ecological analysis.

5. Carry out annual review of progress and dissemination to the estuary user community.

In the next 5 years

1. Continue to upgrade EMS toolbox with links to data and tools.

2. Carry out pilot testing of EMS and revise based on outcome of testing. The final EMS would be greatly strengthened if it is seen to be truly holistic and the investigative methods / tools described are shown to work together a package in at least one ‘case study’ example.

3. Define and implement a minimum set of essential tools for prediction and analysis, with links to the wider set of tools that need to be available.

4. Complete and roll out first version of EMS. Provide training to end users.

5. Carry out annual review of progress and dissemination to the estuary user community.

7. Recommendations for ERP3

This Chapter describes an outline programme of work and an indicative costed timetable. It also refers to complementary and important underpinning work that is required to deliver the full benefits.

As the EMS is a modular system it requires R&D on development and implementation of the system with parallel effort on delivering improved scientific understanding and the necessary tools to capture that understanding within the EMS. A coherent and co-ordinated programme of work is required to capture flood risk science as well as the environmental, ecological and socio-economic aspects required for option appraisal and holistic management of estuary systems. This can be achieved through broadening the scope of R&D to date under ERP and the co-ordination of parallel strands of research, both of which require funding to reduce the risk of the valuable achievements of ERP being dissipated and to ensure work in key areas is captured within the momentum of an effective programme of R&D.

7.1 Programme of work for EMS

The indicative price (2007) and duration of the research required to deliver the EMS is listed in Table 7.1.

Table 7.1 Summary of Recommended Research for EMS (indicative)

Item	Price Estimate	Duration
1. EMS	£600,000 - £1,000,000	1 year – 3 years
2. Estuary Guide	£ 60,000	0.5 year – 1 year
3. Data	£100,000 + Data collection cost	1 year – 2 years + Data programme
4. Capabilities	£200,000	1 year – 2 years
5. Upgrade EMS	£100,000	0.5 year - 1 year
6. Pilot EMS	£100,000	0.75 year – 1.5 years
7. Revise EMS	£ 30,000	0.25 year – 0.5 year
8. Complete EMS	£ 30,000	0.5 year
9. Annual review	£ 20,000 (annual)	0.25 year (annual)
10. Dissemination	£ 10,000 (annual)	0.25 year (annual)
11. Steering group	£ 20,000 (annual)	0.25 year (annual)
Overall	£1.27M – £1.87M + VAT + Data collection	3 years – 5 years (net time) + annual reviews + Data collection programme

It is clear that the development of the EMS requires a combined path of developing the framework and supporting tools but also to deliver the modules to expand the capabilities of existing systems approaches such as MDSF2.

7.2 Supporting initiatives

There is a wide range of supporting science and data initiatives required to ensure the underpinning science and technology does not suffer from degradation, or get missed altogether between the various funding agencies. The EC FLOODSITE, EPSRC FRMRC and NERC FREE programmes are all undertaking relevant research and are supported by the Environment Agency. These science programmes need to be continued and opportunities generated to ensure close linking between EMS development and regular updating of the Estuary Guide. A programme of work and costs need to be identified to accomplish this.

7.3 Development requirements for tools

The development requirements for tools are based on ERP2 research recommendations for FD2115, EstProc FD1905, EstSim FD2117, hybrid models FD2107, FD2119 consultation and training feedback. Specific requirements are listed in Chapter 5 and a synthesis of requirements was given in Section 5.5. The benefits of taking further developments with the science are generated through a wider and credible applicability of methods.

An inclusive process is required to link research and end user R&D. This can be generated through focus on practical management questions (e.g. EMPHASYS Consortium, 2000a; ABP Marine Environment Research, *et al*., 2008) and ongoing consultation, dialogue and dissemination.

As well as the ongoing incremental improvements required there are a number of gaps in the methods identified under five categories:

Methods

1. Apply results of FD2116/FD2107/FD2117 to live estuary projects – gain experience in the application of the methodologies and models developed. In the case of models make use of Hybrid Model Interface, ASMITA (Huthnance, *et al*., 2008) and EstSim (ABP Marine Environment Research Ltd, *et al*., 2008). These models are accessible through www.estuary-guide.net. There is an element of risk but this is essential to the onward uptake, evaluation/adoption and refinement of the methods.
2. Some modifications to existing models will be required to ensure that they can be implemented in a compatible manner with the system approach being developed in MDSF2. The models will provide input data for coastal erosion impact in estuaries.
3. Demonstration of the application of the various tools within the context of one or two specific estuarine problems would be extremely valuable and would help uptake of the outputs of the project among the user community. One potentially suitable area would be the Severn estuary (ongoing flood risk management needs, habitat assessment for designated sites, water quality management, possible tidal barrage power development, potential further port development, possible nuclear power station development).
4. Methods based on topography/tides for predicting mudflat/saltmarsh evolution need to be added to the Estuary Guide.

5. Links to assessment tools for ecological health and functionality (expert ecological assessment) need to be added to the Estuary Guide.
6. A framework for quantitative criterion based analysis of model calibration and performance is required. This will aid assessment of confidence in model predictions and support the evidence base for prediction horizons of models.
7. A toolbox with the level of assessment and quantification of methods is required along with a decision tree for method/model selection. The tools need to take account of the impact of dredging, reclamation, and defences. We need to confirm we have the tools that are required for delivery of SMP scale studies, i.e. over the entire range of space and time scales of relevance.
8. A rules based guidance tool for determining the confidence in morphological prediction needs to be added to the Estuary Guide. This takes information on the nature of the estuary and historic knowledge and gauges how far into the future predictions can be realistically made at the scale and resolution required.
9. The application of Agent Based Modelling approaches to estuary evolution offers some attractions in that it represents the behaviour of the anthropogenic constraints and adaptations.
10. To assist in decision making guidance is required on the threshold points for choice, when would one choice arising be influenced to such a degree that an alternative choice was preferred. Training is needed for decision makers, specialists and operative workers in principles, detailed methods and models. There is a need to link to MSc or similar educational programmes to bring graduates through with the right skills.

Data

11. Key data is required on estuary shape as well as depth (bathymetry) and broad scale morphological parameters used in the estuaries database.
12. Data for long term monitoring of water levels, flows, waves, river discharge, sediment SPM concentration and floc characteristics (cohesive sediments), and salinity are required. Information on temporal and spatial range and variability is important as baseline and indication of sensitivity with respect to WFD delivery and to assess the impact of works in an estuary. Work is required to correlate the effect of waves on Suspended Particulate Matter (turbidity) to see how storminess changes through Global Climate Change will affect contrasting estuaries.
13. Regional characterisation data should be collected and this can build on the network of coastal observatories. There is a framework in place for data banking and management. Also there needs to be a rapid response capability to capture the influence of extreme events in estuaries.

Processes

14. Process based bottom up modelling needs the inclusion of biological effects to produce routine applications for hydrobiosedimentary processes and water quality. Process algorithms are a function of existing data.
15. Sediment properties and behaviour are fundamental to both ecology and water quality (e.g. in terms of suspended sediment concentrations, movement of contaminants etc.). A work module focusing on sediments as a linking factor between physical processes, morphology, water quality and ecology / habitats might therefore serve a useful unifying purpose. This could extend the work on

biological process parameters that effect sediment stability, erodibility and deposition presented in EstProc Consortium (2005b).

16. There is a need to map out expected bioengineer zones and to consider larger scale controls such as the timing of spring low water on the sediment regime (Dyer, 1998).

17. Develop the friction factor description for wave propagation over saltmarshes using a saltmarsh canopy based approach, which will allow species variation and seasonal variation to be captured when modelling the effect of saltmarsh in dissipating the impact of wave energy on flood defences.

18. Take forward the application of muddy and sandy particle tracking models in estuaries, linking sources and sinks of sediment along sediment transport pathways, following the release of material within estuaries (e.g. such as that arising from dredging or deposits at spoil grounds). Enhance these methods to include the effects of waves.

19. Generalise the behaviour of real estuarine sediments building on, for example, the geotechnical and hydraulic basis presented in EstProc (EstProc Consortium, 2005b).

20. Develop understanding and generalise the threshold values between physical effects and biological parameters, related to the ecological carrying capacity of estuaries. Explore the threshold points for geomorphology and ecology.

Morphology

21. The hybrid method ASMITA needs to have elements to assess internal behaviour of estuary, to develop the model to represent areas rather than just volumes and biological responses, e.g. to barrage construction. ASMITA has been used to assess resilience of estuaries to SLR.

22. The estuary 'rollover' concept and method (summarised in HR Wallingford, *et al*., 2006) is used but morphological data is required to provide the evidence that it applies.

23. Geological constraints in estuaries – mapping of geological constraints and anthropogenic constraints in terms of pressures and drivers needs to be taken forward.

24. Undertake meso-scale, medium term morpho-dynamic modelling examining features at a larger scale – e.g. assessing the dynamics of sand banks, mudflats and saltmarsh systems within estuaries, and their relation to changes in medium to long-term water levels, current velocities and wave activity. Analysis of controls on wave activity within estuaries, and their relationship to mudflat – saltmarsh interactions.

25. Make the necessary links between estuary morphology and coastal morphology and erosion to ensure that predictions take account of both environments in a consistent fashion.

26. Investigate the use of sediment records (from cores) and studies of spatial variations in sediment properties has so far been given very little attention in the ERP, yet academic research outside the ERP over the past 20 years has clearly demonstrated the value of the information which can be obtained both in relation to understanding historical change in estuaries and predicting future changes. Sediment properties can provide important early warning indicators of changes in morphology and the driving processes, and

have the advantage compared with short term process studies of reflecting medium-term ‘average‘ conditions.

Technology

27. Develop the application of remote sensing for sediment properties on intertidal areas and for sediment transport in the water column, including the development and application of algorithms to predict the vertical profile of concentration. Ground truthing data will be required to validate the method.

28. Develop robust long term monitoring equipment for hydrodynamic and sediment processes and sediment level monitoring, bringing in water quality parameters.

A more detailed specification for a project taking ERP3 forward and encompassing the key aspects of the EMS and supporting initiatives will be prepared outside of the present project and report.

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Appendix 1 Timeline for ERP (2005) and pen pictures of ERP studies copied from www.estuary-guide.net

Estuaries research projects

The following downloads and supporting information is available from the Estuaries Research Programme that has been running since 1997. For more information visit:
Joint Defra/EA research programme (good point of entry)
Defra/EA download tool (all completed project outputs should be available here)
EA science project search (allows you to search science projects, but no downloads)

Or download documents and visit the websites given below. The download documents are provided for convenience of the user but it is recommended to confirm the current status of project outputs from the Defra and Environment Agency web addresses provided above.

FD1006 Estuary Process and Morphology Scoping Study
This was the original scoping study produced by a consortium led by HR Wallingford which came up with a costed programme of research over a period of 10 years. The programme of research was designed to come up with an Estuary Management System containing physical, ecological, social, economic factors.
The report produced was SR478 (HR Wallingford) - PDF 409KB.

W5-010 Predicting extreme water levels in estuaries
The overall objective of the study led by Halcrow with University of Bristol, was to develop rigorous but practicable methods for the real-time forecasting of extreme water levels in estuaries, suitable for incorporation into existing Environment Agency flood warning systems.
W5-0110-2 Stage 2 - PDF 896KB

FD1401 ERP Phase 1 also known as EMPHASYS
EMPHASYS stood for Estuarine Morphology and Processes Holistic Assessment System. This large multi-partnered project was led by HR Wallingford and delivered three reports and a database. The reports were on a Mark 1 Estuary Impact Assessment System, a comprehensive technical report on modelling and data based assessments of estuaries, recommendations for Phase 2. End project workshop.
EMPHASYS report - PDF 13.8MB (EMPHASYS Consortium, 2000)
EMPHASYS guide - PDF 3.97MB (EMPHASYS Consortium, 2000)
TR113 Recommendations for phase 2 of the ERP - PDF 492KB

Also available from the web at http://www.hrwallingford.co.uk/projects/ERP/

FD2002 Futurecoast
This project was delivered by a team led by Halcrow and produced behavioural statements for coasts and estuaries, a geomorphological manual, assessment of future shoreline behaviour under assumptions of unconstrained (i.e. assuming no defences or management practices) and managed (i.e. assuming present management practices continue indefinitely) future scenarios. A video fly-by around the coastline of England and Wales was also completed in 2001. The report is available as an interactive CD ROM and there is also an accompanying Aerial Photograph CD with the digital video.
FD2002 Futurecoast - PDF 991KB

FD2102 Tidal river bathymetry
This project covered the collection of bathymetry in the River Humber in 2001.

FD2108 BSEIM scoping study
This project was delivered by a team led by Cascade Consulting and scoped the requirements for successful simulation of Broad Scale Ecosystem Impact Modelling. This will require tools that can predict the changes in hydraulic, hydrodynamic, geomorphological and ecological systems and the interactions and feedback loops between each. The simulation of geomorphological change and dynamic ecological consequence require significant levels of investigation and testing, for both freshwater and estuarine/coastal systems.
FD2108 BSEIM scoping report - PDF 1.28MB
FD2112 BSEIM toolbox report - PDF 6.76MB

FD2115 Research Plan
This project was completed by Jon French (UCL), Michael Owen and Dominic Reeve (Plymouth) and delivered a report reviewing Phase 1 of the ERP and presented some detailed ways forward for ERP in Phase 2 including a prioritised 3-5 year programme of estuarine R&D and suggested linkages with other programmes.
FD2115 ERP Phase 2 research plan - PDF 1.15MB

FD2110 ERP1 Uptake and dissemination
This project was led by Royal Haskoning and the project team produced a guidance note for assessing morphological change in estuaries, a public estuaries database, some training materials (PDF 1.98MB) and a report on how to deal with data building on CIRIA project work done by HR Wallingford and LSE. The estuaries database 2003 is now hosted by British Oceanographic Data Centre
http://www.bodc.ac.uk/products/external_products/estuaries/
FD2110 Technical summary - PDF 151KB
FD2110 TR1 Morphological change - PDF 2.11MB
FD2110 TR2 Data best practice - PDF 1.98MB

FD1905 ERP2 EstProc
This was led by HR Wallingford and the consortium delivered three reports – one on algorithms for implementing into your own models for hydrodynamic, sediment and ecological aspects. Also there was a metadata report to allow people to trace the data and there was a synthesis report bringing together the good science under one report cover.
FD1905 TR2 - PDF 3.19MB
FD1905 TR3 - PDF 3.85MB

This is available at www.estproc.net as well as the Defra web.

FD2308 Joint probability – dependence mapping and best practice
This was led by HR Wallingford. This mapped the dependence around Britain for all pairs of variables relevant to flood risk. This filled a gap that delayed the take up of joint probability methods.
FD2308 TR2 - PDF 2.57MB

FD2107 ERP1 Hybrid estuary model development
The consortium led by POL brought together top down and bottom up process models into a hybrid approach. The approach developed allows the time development aspects of bottom up models to be implemented in a longer term fashion using top down derived targets. There are tests on various estuaries including the Thames.

Final report currently out for peer review.
See web at http://www.pol.ac.uk/erp/

WS-0706 Saltmarsh management manual
This was led by Royal Haskoning and has led to an update to the earlier saltmarsh management manual. It is delivered by a website available at:
http://www.saltmarshmanagementmanual.co.uk/

SC030224 MDSF2 RASP Inception
(to complete in 2008)
This project on the Modelling and Decision Support Framework (MDSF) was led by HR Wallingford with Halcrow and University of Middlesex. It dealt with the management of assets within a risk based framework. The MDSF was developed in 2001 to provide a tool for quantifying economic and social impacts of flooding at catchment scale for present day conditions, future scenarios and with flood management options. It has been applied widely for flood/erosion risk assessment as part of the Catchment Flood Management Plan (CFMP) and Shoreline Management Plan (SMP) programmes and has also been used on strategy studies and schemes. MDSF2 is ongoing and due to finish in 2008.
SC030224 MDSF2 main phase initial report - PDF 434KB
For more information see http://www.mdsf.co.uk/

SC040018 Performance Based Asset Management System Phase 2
(ongoing)
This project was led by HR Wallingford and is related to the management of assets within a risk based framework. This builds on Phase 1 which provided a scoping study that included a review of needs, conceptual framework and initial evaluation of the concept. The focus of the present project is to develop methods to support performance-based and risk-based management of the flood defence assets belonging to the Agency and others. The programme supports the provision of improved inspection, maintenance, operation and management of flood defence systems through the identification of appropriate management interventions to provide a desirable reduction in flood risk.
PAMS Phase 1 scoping study report - PDF 1.96MB
For more information see web at
www.pams-project.net

FD2117 ERP2 Estuary Simulators Development (EstSim)
The consortium led by ABPmer worked on the delivery of comprehensive reports on the behavioural properties estuaries based on the classification of estuaries into seven types. Each estuary type has some common geomorphological elements. There are reports and there will be a web based demonstrator for this estuary behaviour.
Final report currently out for peer review.
See web at http://www.pol.ac.uk/erp/

FD2116 ERP2 Review of Geomorphological Concepts
This HR Wallingford led team produced a large text book on estuary geomorphology including information on the steps required in setting up a conceptual model and on the pulling together of data based analysis and modelling approaches to arrive a consensus

through Expert Geomorphological Assessment. This was disseminated at a workshop in London.
FD2116 Technical summary - PDF 47KB
FD2116 TR2 - PDF 6.63MB

FD2119 Uptake and ERP3 Scoping (ongoing)
This project was completed in 2008 and the final report is available below. It delivered an enhanced EIAS building on all the research done to date and recognising the role of EMPHASYS and the estuary guide by ABPmer www.estuary-guide.net. Consultation led the scoping of requirements of the future programme to deliver the Estuary Management System. The report presenting the findings from consultation with end-users of the research in the period February through to July 2007 is available below. The results from the consultation were used to inform the development of the research outputs. Consultation was carried out as a joint activity with project FD2117 during this period, and also as part of the dissemination activities through the Estuaries Research Programme stand at the Flood and Coastal Erosion Risk Management Conference in York (3-5 July 2007). Two training events were held in November 2007 and a final seminar workshop of the project was held in March 2008. The presentations from these events are available by clicking the above links.
FD2119 TR2 Consultation report - PDF 721KB
FD2119 TR3 Final report - To follow shortly

Downloads

- Site downloads
- Supporting document downloads
- Estuaries research projects
- ERP 2 training seminar/workshop
- ERP 2 Dissemination
- ERP 1 Dissemination

Last Modified on: 22 May 2008

ESTUARIES RESEARCH PROGRAMME: Delivering an holistic approach to estuary management

- 3 Phase Programme
- Long-term Programme
- Cross-cutting
- Inter-disciplinary
- Linkages to non-R&D work
- Relevant to wide range of users
- Variety of outputs

- **Phase 1 (Complete)** - tested performance of existing models; collated and scientifically evaluated existing capability; developed prototype Estuary Impact Assessment System (EIAS)

- **Phase 2 (Underway)** – further development of the most promising models; acquisition of new data and their subsequent interpretation; production of interactive software, guidance notes, manuals, reports, and reviews; workshops and open days to disseminate results and outputs; scoping study for future updating of the EIAS

- **Phase 3 (Not started yet)** – may include the development of novel models based on new research and data (including socio-economics and legislation) to deliver an holistic Estuary ManagementSystem (EMS).

- **Funding Organisations:**
  Defra (MAFF)
  Environment Agency
  English Nature
  Natural Environment Research Council
  Engineering and Physical Sciences Research Council

- **Research Organisations Involved:**
  ABP Research and Consultancy
  British Geological Society
  Centre for Environment Fisheries and Aquaculture Science
  Centre for Ecology and Hydrology
  Conlan Consultancy
  Institute of Terrestrial Ecology
  HR Wallingford
  Prof Keith Dyer
  Mouchel Parkman
  Newcastle University
  Plymouth Marine Laboratory
  Posford Haskoning
  Proudman Oceanographic Laboratory
  Sir William Halcrow & Partners Ltd
  University of London
  University of Southampton
  WL/ Delft Hydraulics (The Netherlands)

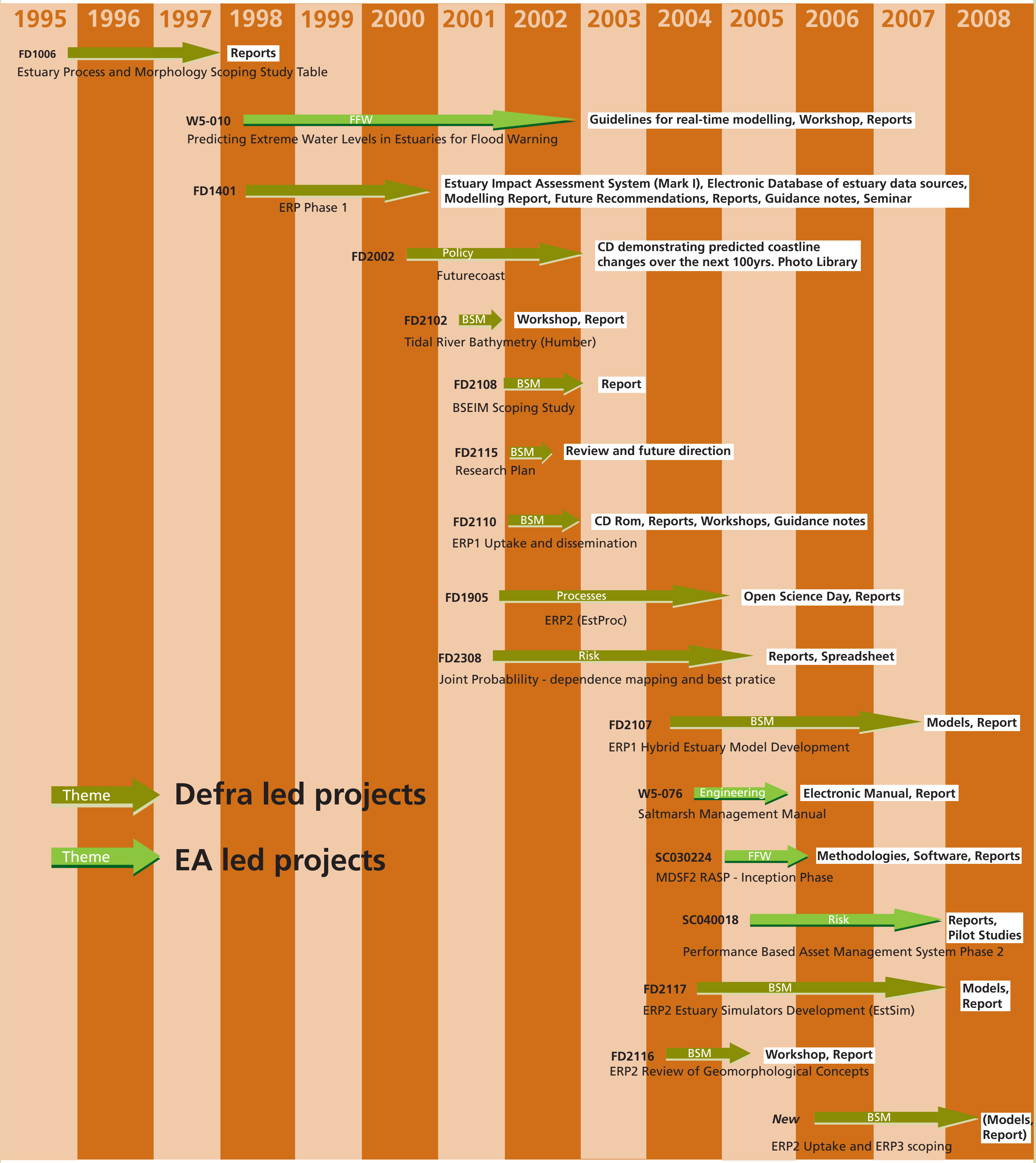
www.defra.gov.uk/environ/fcd/research

www.estproc.net

Environment Agency

defra
Department for Environment Food and Rural Affairs

ESTUARIES RESEARCH PROGRAMME:
Projects and Outputs
(see accompanying literature for more details)



www.defra.gov.uk/environ/fcd/research

Environment Agency

defra
Department for Environment Food and Rural Affairs

Appendix 2 Training seminar/workshop materials

Copies of presentation materials from this project are also available from www.estuary-guide.net

FREE seminar on "Advances in Coastal/Estuarine Geomorphological Research and the new Estuaries Guide" (R&D project FD2119)

Date:
Wednesday 28 November 2007 – Peterborough Environment Agency

Location: [If anyone needs a map please let me know]
Environment Agency
Kingfisher House, Goldhay Way, Orton Goldhay
Peterborough
Cambridgeshire
PE2 5ZR
Tel: 08708 506506

Start time: 09:00 for 09:30hrs.

Overall aim of event:
The Estuary Guide website is being enhanced as part of Phase 2 of the Estuaries Research Programme (ERP). The workshop seminar will introduce and explore the draft version of the Estuary Guide and the benefits arising from the ERP deliverables through the resources and tools contained within the Estuary Guide.

We provide:
Computers, pens and paper, handouts, refreshments and lunch.

Your preparation:
We recommend you view the online draft version of the guide as part of the preparation for the day. This will aid take-up and feedback and provide the opportunity for you to formulate any questions and facilitate discussion during the day. If you have thoughts about how you can integrate the information on the guide into your studies, have any questions or wish to provide any feedback before the day then please email Richard Whitehouse (r.whitehouse@hrwallingford.co.uk).

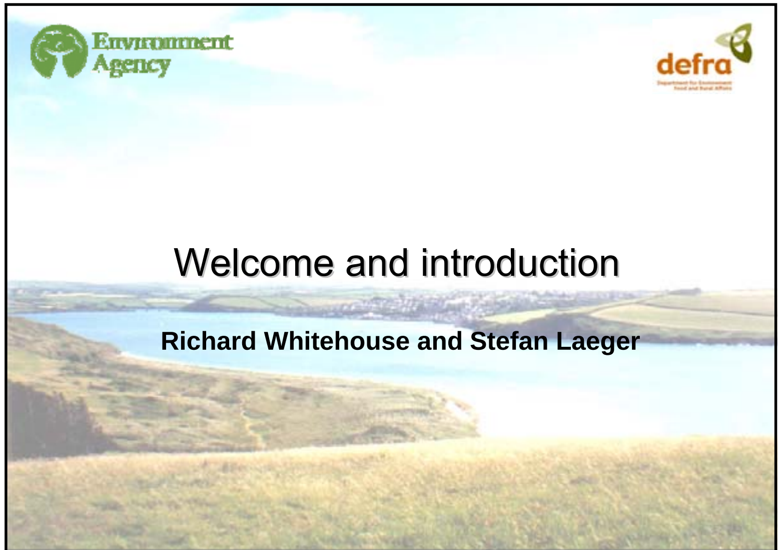
The draft Estuary Guide is currently available at the following password protected web address: http://www.abpmer.net/eias/ **User:** estuary **Password:** Gu1de2

Attendees:
Richard Whitehouse, Noel Beech – HR Wallingford (running the event)
Chris Jackson, Alun Williams – ABPmer (running the event)
Greg Guthrie – Haskoning UK
Mark Lawless - JBA
Bronagh Byrne – Cascade Consulting
Jon Rees, Chris Vivian – CEFAS
Richard Phillips – Atkins
Philip Staley, Niall Phelan, Helen Richardson, Stefan Laeger –Environment Agency

Schedule – see over page.
Richard Whitehouse
22 November 2007

Schedule for Advances in Coastal/Estuarine Geomorphological Research and the new Estuaries Guide 28 November 2007

timing	session	who
09:00-09:30	Registration and coffee	**All**
09:30-09:45	Welcome, intro and purpose of the day – context of the project and where are things going with the estuary guide and Estuary Management System	**Richard Whitehouse and Stefan Laeger**
09:45-10:00	Open forum to raise views on the day	**All - steered by Richard Whitehouse**
10:00-10:45	Estuary processes and geomorphology – general information, estuary types - completed and ongoing research	**Alun Williams**
10:45-11:00	Q&A and discussion	**All - steered by Noel Beech**
11:00-11:30	Coffee break	
11:30-12:00	Introducing the estuary guide as a resource and informed catalogue	**Chris Jackson and Alun Williams**
12:00-12:15	Q&A and discussion	**All - steered by Noel Beech**
12:15-13:00	Improving confidence – estuary study framework and methodology, tools and approaches and prediction horizons	**Richard Whitehouse**
13:00-13:15	Q&A and discussion; issue of feedback form for completion by the end of the day	**All - steered by Noel Beech**
13:15-14:00	Lunch	
14:00-15:00	Mini-workshop on estuary case study with participants accessing and sharing information from the guide	**All - steered by Noel Beech**
15:00-15:30	Free interaction session on the web using the guide	**All**
15:30-15:45	Review of available tools and future developments with an Estuary Management System	**Richard Whitehouse**
15:45-16:00	Final Q&A/discussion, feedback, thanks and close	**All - steered by Richard Whitehouse**
16:00-16:30	Tea break	
16:30-17:00	Further informal discussions/use of estuary guide as required by participants	



Welcome and introduction

Richard Whitehouse and Stefan Laeger

Aim of today

- two way interaction – feedback
- information on estuary geomorphology
- introduce and explore the draft version of the Estuary Guide
- discuss benefits arising from the ERP deliverables through the resources and tools contained within the Estuary Guide
- participate in case study mini workshop

ERP
Estuaries Research Programme

- Supports
  - the policy of developing a capability in sustainable estuary management

Benefits

- **Identify** the environmental changes from proposed activities and the features of interest/receptors that could be affected
- **Understand** the nature of the environmental changes in terms of their exposure characteristics, the natural background system, and establish the sensitivity characteristics of specific features
- **Evaluate** the vulnerability of the features as a basis for assessing the nature of the impact and its significance
- **Manage** any impacts, which are found to be significant and require implementation of impact reduction measures

Background on ERP

- Scoping 1995-1997
- ERP phase 1
  - EMPHASYS 1998-2000
- ERP phase 2
  - uptake 1 in 2002
  - completion 2008
  - uptake of research
- ERP phase 3
  - integrated *EMS

*Estuary Management System

Estuary Impact Assessment System (EIAS)

- Defined in 1997 as follows:

	Estuarine Morphology	Water/sediment Quality	Ecology	Anthropogenic Influences
Bottom-up (Process-based, Short-term) Methods	Physics-based numerical models	Flow-plus-chemistry water quality models	Plant and animal biological understanding	Local socio-economic analysis/methods
Top-Down (Estuary-system, Long-term) Methods	Qualitative, empirical and regime methods	Sediment-pollutant models	Population dynamics models	Institutional framework / macro-economic models
Hybrid (Bottom-up Plus Top-down, Short to Long term) Methods	Long-term, physics - calibrated, morphological models	Long-term water/ sediment quality predictors	Long-term ecological development predictors	Long-term socio-economic predictors
Estuary impact Assessment System	Collection of the above tools			
Estuary Management System	Interlinked combination of all the above tools			

Source: Scoping Study Report, SR478 (HR Wallingford)

FD2119 Project details

- Consultation (completed)
- FCERM conference (completed)
- First draft of enhanced EIAS (completed)
- Training events (now)
- Confirm enhanced EIAS and release
- Scoping report for EMS
- Scoping on tools and benefits
- Dissemination event
- Final reporting hard copy/soft copy/web (Mar 08)

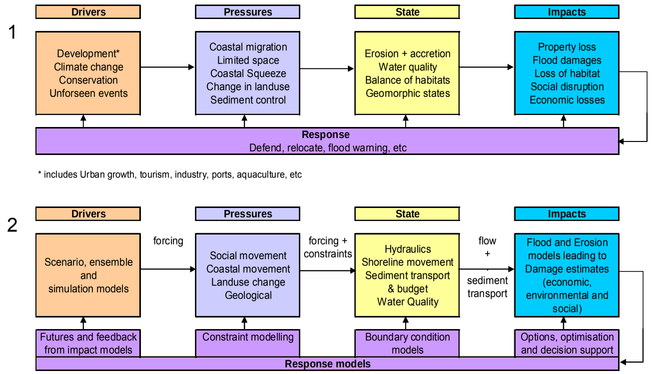
Today

- draft estuary guide
  - EIAS: collection of tools and supporting information

Future

- Estuary Management System
  - framework, data, methods, tools
  - supporting FCERM, Habitats Directive, WFD, [Marine Bill]
- DPSIR approach

DPSIR approach
1. system 2. modelling



Source: as copied from FD2119 inception report

Today's topics

- estuary processes and geomorphology
  - Alun Williams
- estuary guide
  - Chris Jackson
- improving confidence
  - Richard Whitehouse
- mini workshop on estuary case study
  - Noel Beech
- future requirements
  - Richard Whitehouse

Estuary Processes and Geomorphology: Outputs of ERP2

Alun Williams

Overview

- UK Estuary Types
- Estuary Processes
- ERP2 Projects:
  - FD1905 - Estuary Process Research Project (EstProc)
  - FD2107 - Hybrid Estuary Model Development
  - FD2116 - Review of Geomorphological Concepts
  - FD2117 - Estuary Simulators Development (EstSim)

Classification of UK Estuary Types

- ERP2 developed UK database based on:
  - EMPHASYS database
  - Futurecoast database
  - JNCC inventory.
- Futurecoast (Dyer, 2002) classification amended and simplified:
  - Working typology for UK estuaries
- Identify range of UK Estuaries:
  - Behavioural estuary types;
  - Geomorphological elements present within each.

Estuary Typology

Type	Origin	Behavioural Type	Spits[1]	Barrier Beach	Dune	Delta	Linear Banks[2]	Channels[3]	Rock Platform	Sand Flats	Mud Flats	Salt Marsh	Cliff	Flood Plain[4]	Drainage Basin
1	Glacial valley	Fjord	X					X	X	X			X		X
2		Fjard	0/1/2					X	X	X	X	X		X	X
3	Drowned river valley	Ria	0/1/2					X	X		X	X	X		X
4		Spit enclosed	/1/2		X	E/F		X/N		X	X	X	X	X	X
5		Funnel shaped	X		X	E/F		X		X	X	X		X	X
6	Marine/fluvial	Embayment			X		X	X		X	X	X		X	
7	Drowned coastal plain	Tidal inlet	0/1/	X	X	E/F		X		X	X	X		X	

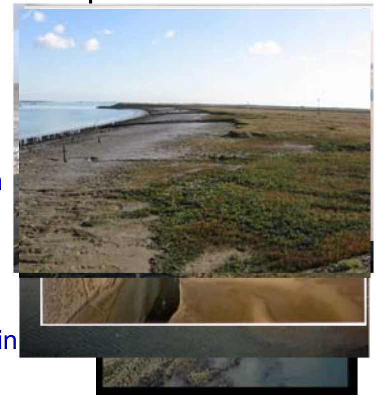
Notes:
1 Spits: 0/1/2 refers to number of spits; E/F refers to ebb/flood deltas; N refers to no low water channel; X indicates a significant presence.
2 Linear Banks: considered as alternative form of delta.
3 Channels: refers to presence of ebb/flood channels associated with deltas or an estuary subtidal channel.
4 Flood Plain: refers to presence of accommodation space on estuary hinterland.

UK Estuary Types

- Fjord
- Fjard
- Ria
- Spit enclosed
- Funnel shaped
- Embayment
- Tidal Inlet

Estuary Geomorphic Elements

- Cliff
- Barrier Beach
- Dunes
- Delta
- Rock Platform
- Channel
- Mudflat
- Sandflat
- Saltmarsh
- Drainage Basin



Characteristic Features of UK Estuaries

- Extensive intertidal areas including saltmarshes, mudflats and sand flats;
- Semi-diurnal tidal regime;
- Wave shelter;
- Water layering and mixing;
- Temperature and salinity gradients;
- Sediment suspension and transport;
- High productivity;
- High levels and rapid exchange of nutrients;
- Presence of plants and animals particularly adapted to these conditions; and
- Presence of migrant and seasonally fluctuating populations of birds.

Estuary Processes

- Area of transition from tidal to fluvial;
- Area of transition from saline to freshwater;
- Mixing can lead to a marked interface and internal waves;
- Salinity gradients can set up density flows along and across estuaries;
- Water movements complicated by surface waves.

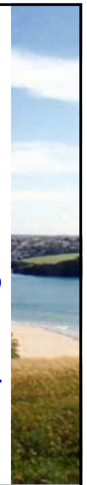
Estuary Processes - 2

- Waves can form within the estuary as well as propagate into the estuary from outside;
- Complexity reflected in sediment transport within the system;
- Sediment supply from marine and freshwater sources;
- Sediment reworking leading to zones of erosion and deposition.

Project FD2119 **Estuaries Research Programme Phase 2** Training Event November 2007

Estuary Processes - 3

- Intertidal areas can appear stable in the medium term but are generally dynamic;
- Sediments can be cycled on different timescales, over a tide or in response to changing sea levels, especially fine sediments.
- Diverse environment – need to consider estuary system as a whole.



Project FD2119 **Estuaries Research Programme Phase 2** Training Event November 2007

ERP2 Research Projects

- FD1905 - Estuary Process Research Project (EstProc)
- FD2107 - Hybrid Estuary Model Development
- FD2116 - Review of Geomorphological Concepts
- FD2117 - Estuary Simulators Development (EstSim)

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FD1905 – Hydrobiosedimentary Processes in Estuaries (EstProc)

- Delivery of new science and algorithms;
- Application of physics-based biology in estuary process models;
- Inclusion of wave-current interaction;
- Improved parameterisation of bed exchanges:
  - – mud/sand erosion, settling, sedimentation;
- Dynamical hypothesis for estuarine morphology – taken forward in FD2107.

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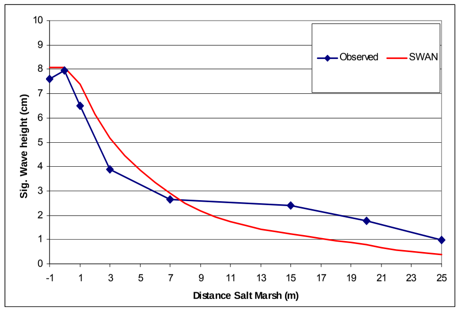
New algorithms

- Improved process knowledge and tools:
  - tools = methods and models;
  - component parts of physical processes;
  - 29 algorithms for specific processes.
- Parameterisation suitable for whole estuary models.
- For example: physical representation of frictional effects of vegetation.
- Calibration:
  - Dengie Peninsula, Essex (floristically diverse saltmarsh)
  - Paulinashor, Western Scheldt estuary (monospecific *Spartina* marsh)

Source: Cambridge Coastal Research Unit and WL|Delft Hydraulics

Western Scheldt, Netherlands

Wave dissipation on saltmarsh



Measured and calculated Hsig for a transect in the Paulinapolder saltmarsh

FD2107 - Hybrid Estuary Model Development

- To improve confidence in model predictions of estuary form;
- Various models (B-U, T-D, Hybrid);
- Eight varied UK estuaries
- Compare model approaches and estuaries.

Models (& *Type*)

- Emulator — *Hybrid*
- Hybrid Model Interface — *Hybrid*
  Down
- "2.5D" — *Bottom Up*
- ASMITA-type — *Top Down*
- Realignment — *Hybrid*
- Particle Tracking — *Hybrid*
- Inverse — *Hybrid*

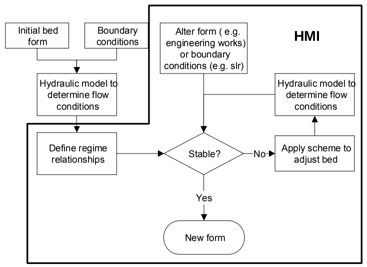
Application of Models to UK Estuaries

- Emulator — All
- HMI — Thames, Blackwater, Humber, Mersey, Southampton Water
- "2.5D" — Mersey, Dee, Ribble
- ASMITA-Type — Thames
- Realignment — Tollesbury
- Particle Tracking — Thames, Mersey
- Inverse — Humber

Hybrid Model Interface (HMI)

- HMI links a 1D hydrodynamic model (bottom up) with Regime morphodynamic top down model.

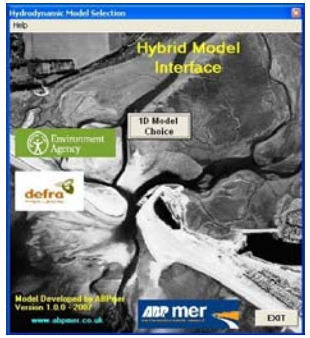
Initial Condition Defined Outside the HMI



Regime Hybrid Simulation

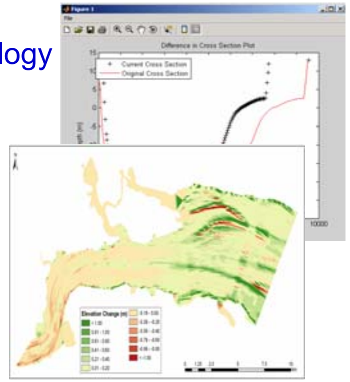
Hybrid Model Interface (HMI)

- Fully windows based tool.
- Open source code.
- Option to include both Mike11 and ISIS (InfoWorks).
- Full documentation (user manual).
- ASMITA (extra).



HMI Results

- New morphology
- Areas
- Volumes
- Water levels
- Velocities
- Discharges
- Habitats

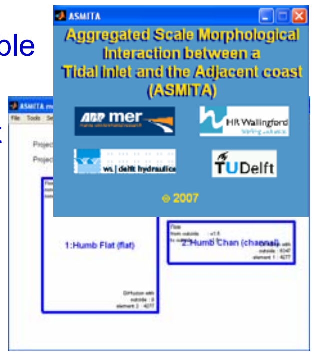


ASMITA-type model

- Developed as a tool to study impacts of sea level rise on Dutch coastline.
- "Aggregated scale" approach: interactions between blocks of channel, flats or delta.
- Hybrid model: simplifies hydrodynamics using semi-empirical relationships.
- Represents changes in the volume of channel/flat/delta elements.

ASMITA

- Code fully available
- Matlab
- GUI environment
- Fully interactive, user-friendly interface
- Documentation



Application of the HMI: Regime and ASMITA

- Model the long-term change in the equilibrium form of the estuary;
- In response to change in forcing factors:
  - Climate change, e.g. increase in sea level;
  - Management of the estuary, e.g. flood defences.

FD2107 - Conclusions

- Best practice:
  - Validate against historic change;
  - Otherwise generate ensemble of possible outcomes.
- Ideally compare model results with alternatives for validation, don't rely on output from one model.
- Predicted trends should be broadly consistent with results of bottom-up models.
- Results show sensitivities of different estuaries to a range of climate change scenarios.
- Not all estuaries respond in the same way.

FD2116 - Review of Geomorphological Concepts

- Rigorous approach to Expert Geomorphological Assessment (EGA):
  - Applies to all methods.
- Detailed review of top down methods:
  - including Historical Trend Analysis
- Potential to lead directly to improvements in the quality and effectiveness of morphological studies associated with flood defence and estuarine impacts.

Methods

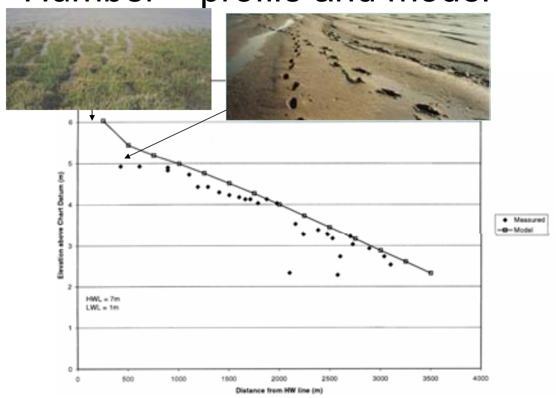
- FD2116 covered the following methods within EGA framework:
  1. Historical Trend Analysis (HTA);
  2. Regime theory and relationships;
  3. Estuary translation or Rollover model;
  4. Entropy-based relationships;
  5. Tidal asymmetry analysis and relationships;
  6. Analytical methods and solutions;
  7. Sediment budget analysis and modelling;
  8. Geological methods for estuarine studies; and,
  9. Intertidal profile form.

Intertidal profile form

- Long-term prediction is possible for tides:
  - Friedrichs, Roberts/Whitehouse, Pethick, Le Hir, Hogg, Wood.
- Predict equilibrium profile shape for prevailing forcing by considering:
  - tides and/or waves;
  - Influence of sediment concentration; or
  - Influence of Sea Level Rise.
- Equilibrium approach:

$$\int_{t^-}^{t^+} deposition\ (x,t)\ dt\ =\ \int_{t^-}^{t^+} erosion\ (x,t)\ dt$$

Humber – profile and model



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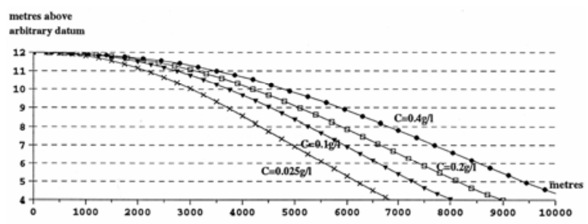
Humber mudflat

Influence of sediment concentration on profile



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FD2117 - Development and Demonstration of Systems-Based Estuary Simulators (EstSim)

- Application of Systems-Based approach to estuary environments;
- Alternative, yet complementary approach to understanding morphological behaviour in estuaries.
- Provides a qualitative framework to assist in understanding:
  - Presence and behaviour of geomorphological features in an estuary;
  - Linkages that exist between them;
  - Their response to change.

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The Systems Approach and Behavioural Models?

- Defining individual components that make up a given environment and characterising how these components interact;
- Mathematically formalising defined components and linkages to develop behavioural model.

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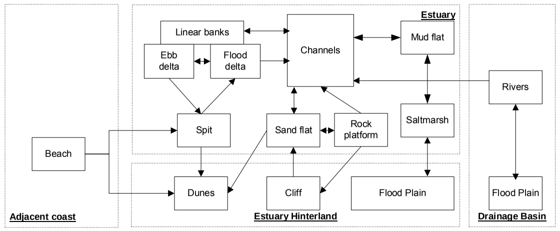
Systems Diagram / Behavioural Statements



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Behavioural or Qualitative Modelling

- Extension of basic systems approach;
- Aims:
  - Capture systems definition within simple model to predict behaviour;
  - Does not need to represent underlying physical processes;
- Systems approach highlights presence of interactions, behavioural approach develops interaction as a relationship (response)
- Mapping estuarine system components first stage in developing behavioural model

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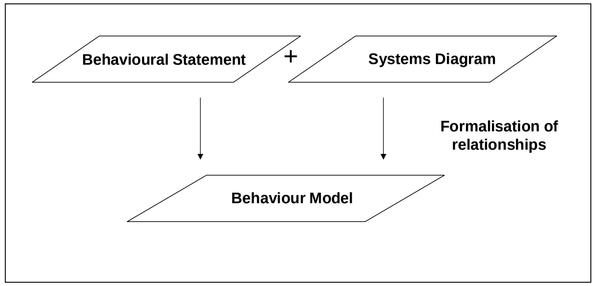
The Systems-Based Approach and Behavioural Models



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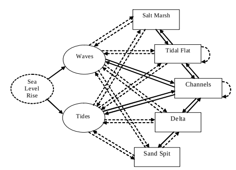
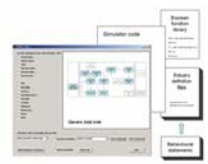
Mathematical Formalisation

- Number of Alternative Approaches
- Boolean network Approach
- *Proof-of concept* prototype simulator





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Manager-System Interface

- Web based graphical user interface
  - Simulation functionality
  - UK Estuary typology

Pilot Testing

- Definition of Key Management Questions
  - Consultation / Review of Legislation
- Pilot Testing of Prototype Simulator
  - Thames and Teign Estuaries

Project Delivery

- Development of UK estuary typology;
- Framework for estuary behavioural statements;
- Means to promote systems based knowledge and understanding;
- Web-based graphical user interface;
- Open source Matlab code for academic community;
- Demonstration of potential of approach.

EstSim Conclusions

- Exciting development of system approach
- Essentially still a research tool
- Requires specialist knowledge to set up tool for a specific estuary
- Should allow formulation of geomorphological knowledge to be represented and tested
- May be options to combine with more quantitative techniques (e.g. ASMITA)

FD2117 EstSim - Outputs

- Web-based graphical user interface;
  - http://www.discoverysoftware.co.uk/estsim/EstSim.html;
- Open source Matlab code for academic community;
  - www.geog.ucl.ac.uk/ceru/estsim;
- Demonstration of potential of approach.

Summary: Methods and Models and System Abstraction

Environment Agency

defra

Introducing the Estuary Guide as a resource and informed catalogue

Chris Jackson and Alun Williams

Overview

- What is the Estuary Guide?
- What information is available?
- Inside the Guide - overview
- Inside the Guide - interactive session

Main aims of the Estuary Guide

- Provide a electronic platform
  - Best practice guidance
  - Knowledge repository
- Collate and electronically capture both ERP1 and ERP2 outputs
- Offer a framework containing synthesis of estuaries research to date

The Guide is…

- An interactive document supported by a series of searchable tools;
- An overview of best practice in the field;
- Based on a collation of industry experience and ongoing research;
- A vehicle for collation and dissemination of the current outputs of the Estuaries Research Programme (funded by Defra and the Environment Agency since 1998) and other ongoing R&D.

The Guide is not…

- A prescriptive set of government advice, rather a summary of best practice;
- A complete and comprehensive guide to estuaries recognising all user perspectives.

Snapshot of the Guide

Sources of knowledge

- Estuaries Research Programme:
  - ERP 1 e.g. FD1401(EMPHASYS)
  - FD2002(Futurecoast)
  - ERP 2 e.g. FD2116, FD2117 (EstSim)
- Other:
  - Estuaries research
  - General scientific research
  - Coastal research

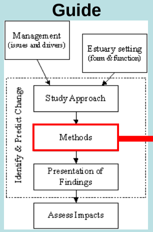
Levels of information in the Guide

- Generic Estuary Guide chapters
- Analysis and modelling guide
- Supporting documents
- Estuaries research
- Links
- Google search results

Levels of information

Estuaries Research (Programme)

Generic Estuary Guide



Analysis & Modelling Guide

- Data analysis methods
- Hybrid methods
- Process based "bottom -up" methods
- Regime & equilibrium " top-down" methods
- Related modelling & analysis topics

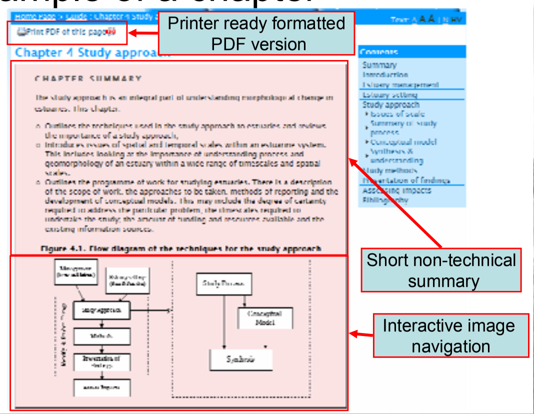
Methods

- Accommodation space
- Analytical solutions
- Expert geomorphological analysis
- Historical trends analysis
- Holocene analysis
- Saltmarsh analysis
- ……

Generic Estuary Guide chapters

- Chapter 1 Introduction
- Chapter 2 Estuary management
- Chapter 3 Estuary setting
- Chapter 4 Study approach
  - Issues of scale
  - Summary of study process
  - Conceptual model
  - Synthesis & understanding
- Chapter 5 Study methods
- Chapter 6 Presentation of findings
- Chapter 7 Assessing impact

Example of a chapter



Analysis and modelling guide

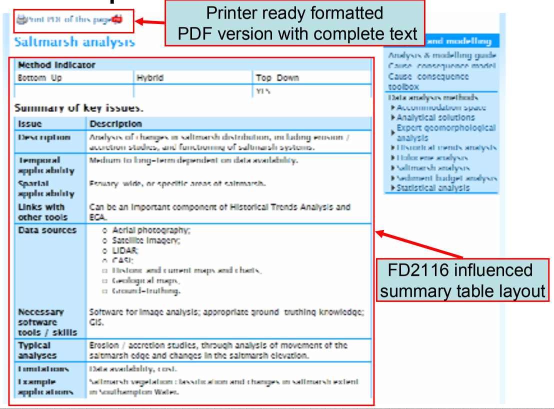
- Data analysis methods
- Regime and equilibrium "Top-Down" methods
- Process based "Bottom-Up" methods
- Hybrid techniques that combine "Top-Down" and "Bottom-Up" methods
- Related modelling and analysis topics

Example of methods list

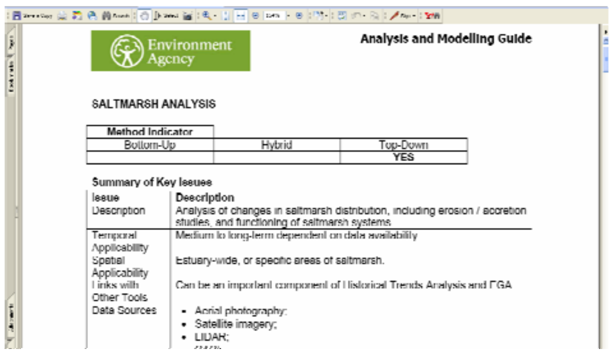
Table 1 Data analysis methods

Method	Brief explanation
Accommodation space	Changes in sediment storage capacity over Holocene time scale (10,000 years)
Analytical Solutions	Characterisation of the estuary system or estuary processes into manageable stand alone mathematical equations.
Expert geomorphological analysis	Using many of the above techniques, together with an understanding of how different types of landform evolve, to assess the expected development of the estuary system
Historical trends analysis	Documents changes to estuary over time from charts, maps and historical archives (e.g. parliamentary records). Identifies any trends. Should include a chronology of human developments (reclamation, dredging, etc)
Holocene analysis	Description of geological development of basin. Usually includes estimates of sea level change and identification of periods of marine regression and transgression
Saltmarsh analysis	Relates properties of exposure and tidal range to the presence and distribution of species
Sediment budget analysis	Reconciliation of sediment inputs, outputs and sources/sinks within the estuary
Statistical, spatial and time series analysis techniques	Uses standard data analysis techniques to identify dominant components, trends, cycles and relationships between variables, to give insights into the dynamics and complexity of the system

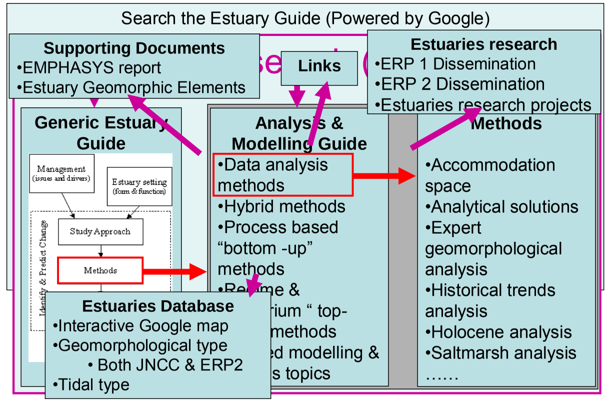
Example of a method



Example of a print ready PDF



Levels of information 2



Supporting documents

- Background papers on management framework
- Background papers on theoretical concepts
- Select Government guidance
- Guidance on impact assessment
- Guidance on habitat creation and restoration
- Worked examples and case studies
- Guidance on modelling and analysis
  - EMPHASYS guide and report
  - EstProc reports
  - Good modelling practice handbook

Estuaries research

- ERP Phase 1 dissemination
- ERP Phase 2 dissemination
- Estuaries database
- Estuaries research projects
  - Timeline of completed and ongoing projects
  - Key documents and websites available
  - Key outputs available (HMI (SHELL), ASMITA, EstSim…)

Links

- ERP research project websites
- Other useful links
- Useful process modelling software links
- Other research project websites
  - FRAME
  - FloodRiskNet
  - Saltmarsh Management Manual

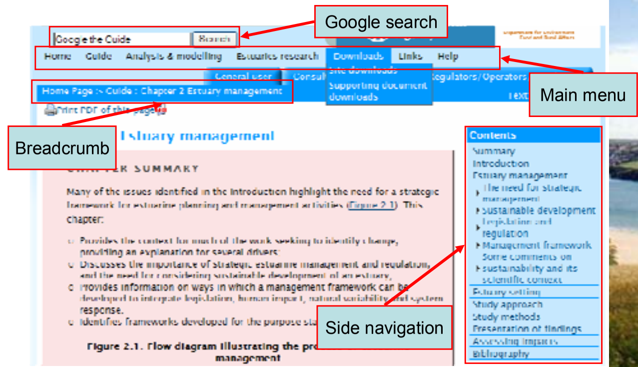
Accessing information

- User profiles
- General navigation
- Main chapter floating menu system
  - Book style contents list
  - Flow system navigation
- Estuaries database
  - Combination of Futurecoast and EstSim data
- Cause-consequence toolbox

User groups

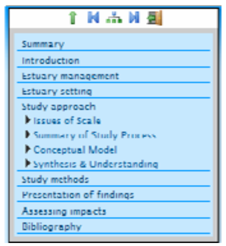
- Consultants and researchers
- Regulators, operators and developers
  - User Group Definition
  - User Group Functions
  - Benefits from the Guide
  - Navigation to Relevant Guide Sections
- General user

General navigation

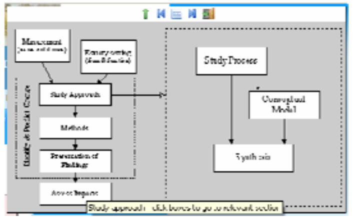


Main chapter floating menu

Book style contents list



Icon	Function
	Top of the page
	Open the menu
	Menu stays on the left of the screen
	Show flow structure
	Show content structure
	Menu stays on the right of the screen
	Close the menu



Flow system navigation

 = Minimal footprint when menu closed!

What is next...

- Finish project team review
- Implement any outstanding key revisions
- Move website to final location at:

http://www.estuary-guide.net

- Propose a maintenance programme to capture ongoing research in the next four years

Inside the Guide – interactive session

Estuary classification 1

Regulators/Operators/Developers

User Group Definition:
This user group includes a diverse range of functions within the estuary management process (regulators, operators and developers). The role of each of these users is highly varied. However, the benefits they can draw from the Guide are similar.

User Group Functions:
In the context of identifying and predicting morphological change in estuaries, the broad functions of this user group are:

- to commission and steer studies;
- to make informed management decisions based on the results and outputs of studies.

Benefits from the Guide:
In line with these functions, the main benefits that can be drawn from the Guide by this user group are:

- An understanding of the estuary management context for such studies;
- An understanding of the physical setting for such studies (such as estuary types, processes and behaviour);
- An overview of the study process including
  - Approach;
  - Brief details of state-of-the-art models and methods;
  - Communication of results; and
  - The EIA process

Navigation to Relevant Guide Sections:
The main element of the Guide that provides benefit to this defined user group is:

- The discussion of best practice in how to identify and predict morphological change in estuaries

This consists of a number of introductory sections that provide context. Specifically these relate to:

- Estuary management; and
- Estuary setting.

Estuary classification 2

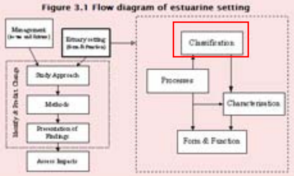
Chapter 3 Estuary setting

CHAPTER SUMMARY

There are many types of estuary determined by their geological setting and dominance of particular processes. This chapter:

- Outlines estuary classification and setting according to topographical and geomorphological classification (Figure 3.1);
- Reviews the ways in which estuaries have been classified in the past;
- Describes estuarine processes, which contribute to the changing geomorphology of an estuary, and assist in the definition of estuary classification;
- Discusses estuarine geomorphological characteristics;
- Summarises estuarine characteristic parameters including estuary length, tidal prism, cross sectional areas and sedimentology;
- Discusses the form and function of an estuary according to controls and constraints of estuary characteristics and process.

Figure 3.1 Flow diagram of estuarine setting



Contents

Estuary classification 3

Table 3.2 Influence of Holocene sedimentary processes on estuary types

Group	Description	Types
A	Limited or no sedimentary influence	12, 14, 16
B	Relatively "young" systems in terms of Holocene evolution	1, 13, 15
B/C	Fall between Groups B and C possibly because of headland control	2
C	Fully developed Holocene environments	3-11

A more recent classification of UK estuaries (Defra, 2002) has developed the first three geomorphological types identified by Pritchard (1967) by including behavioural type to suggest the following seven subdivisions (note: this excludes tectonic/volcanic origins which are found elsewhere in the world) (Table 3.3):

Table 3.3 Defra (2002) estuary classification

Type	Origin	Behavioural type
1	Glacial valley	Fjord
2		Fjard
3	Drowned river valley	Ria
4		Spit enclosed
5		Funnel shaped
6	Marine/fluvial	Embayment
7	Drowned coastal plain	Tidal inlet

This classification has been further developed by the EstSim Project (FD 2117, EstSim Consortium, 2007) to identify specific geomorphological elements of UK estuaries in the form of an estuary typology (Table 3.4). This estuary typology has been applied to UK estuary data and developed into a rule base presented in Table 3.5. The resulting classification for UK estuaries can be found in the Estuaries database and in much more detail at the EstSim website. Each of the estuary types has been mapped in terms of their key morphological components, termed their geomorphic elements (described below), in Systems diagrams for UK estuaries.

Estuary classification 4

The following list of estuaries are compiled from Future-Coast data for UK coast estuaries.

You can search the database by estuary name or by geomorphological type using the drop-down lists below.

SELECT AN ESTUARY
Select estuary

SELECT BY GEOMORPHOLOGICAL TYPE
Use JNCC classification | Use ERP2 classification

ERP2 classification used: Embayment

JNCC Name	JNCC ID
Carmarthen Bay	14
Inner Solway Firth	41
The Wash	101

Estuary classification 5

Estuary detail

Back to search

Below is an interactive Google map and a table of parameters (hover over name for brief description) derived through various sources – Nature Conservancy Council (Davidson et al, 1991), EMPHASYS (2000c), Dyer (2002) in Futurecoast and Townend (2005). The data is indicative of recently determined bulk properties suitable for broadscale intercomparison of estuaries.

Tidal type
Exceptionally large >9m
Macrotidal 4 to 9m
Mesotidal 3 to 4m
Microtidal <3m

JNCC n...	...marthen Bay
JNCC I...	
JNCC q...	...45085
JNCC q...	...bayment
ERP2 geomorphological type	...bayment read more on estuary classification...
Tidal type	Macrotidal
Shoreline length (km)	115.7
Channel length (km)	30.7

Quick links
- Estuary guide
- Estuaries research projects
- Estuaries database
- Analysis & modelling guide
- Cause-consequence toolbox
- Bibliography
- Downloads
  - Site downloads
  - Supporting document downloads

Cause-consequence toolbox 1

Consultants/Researchers

User Group Definition:
This user group essentially comprises those responsible for undertaking technical studies relating to identifying and predicting morphological change in estuaries, either in a research or applied environment.

Navigation to Relevant Guide Sections:
The main element of the Guide that provides benefit to this defined user group is:

- Details regarding methods and models available for analysis and modeling.

This provides access to details of the various methods and models available for examining change within estuaries. Information can be accessed at a number of different levels:

- A brief explanation of each method (as grouped under 5 generic method / model types). Approximately one paragraph
- A tabulated summary of key issues for each methods (such as temporal / spatial applicability, data sources, limitations etc)
- An in-depth description of each method, including reference list.

In addition the following can be accessed:

- Supporting technical documents;
- Software downloads;
- Links to estuaries research; and
- Links to other relevant research

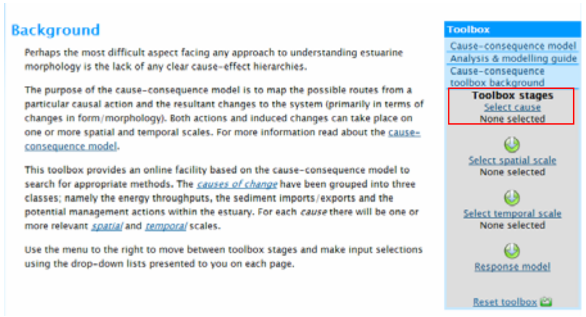
The 'Guide' sections provide a discussion of best practice in how to identify and predict morphological change in estuaries;

Click here to obtain summary details of the type of information found in each of the above sections

Cause-consequence toolbox 2

- Supporting technical documents: These are a series of documents available to download. They provide detailed information to support the the main estuary guide and cover a number of topics. The documents are grouped under the following headings:
  - Background papers on theoretical concepts;
  - Guidance on modelling and analysis;
  - Guidance on impact assessment;
  - Guidance on habitat creation and restoration; and
  - Worked examples and case studies.
- Software downloads: A number of software tools are also avilable for download. These tools have been either fully or partially developed as part of the Estuaries Research Programme. The tools are:
  - ASMITA (Aggregated Scale Morphological Interaction between Tidal inlet and Adjacent coast);
  - SHELL model interface (coupling tool between 1D hydrodynamic models and regime equations).
- Links have been provided to:
  - Other Estuaries Research Programme project websites (i.e. websites developed to host and disseminate details of specific projects within the programme)
  - Other relevant research project websites
- In addition users can access the Cause-consequence model and toolbox a model attempting to map possible routes from a particular causal action to the resultant changes to the system);

Cause-consequence toolbox 3



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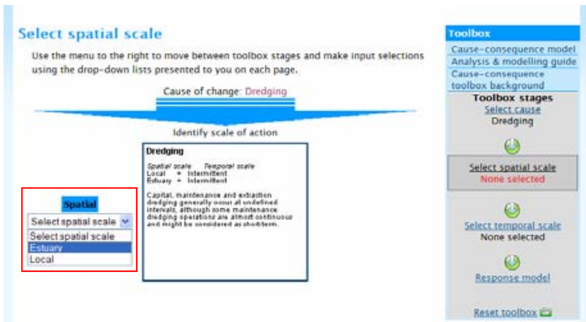
Cause-consequence toolbox 4

Project FD2119 **Estuaries Research Programme Phase 2** Training Event November 2007

Cause-consequence toolbox 5



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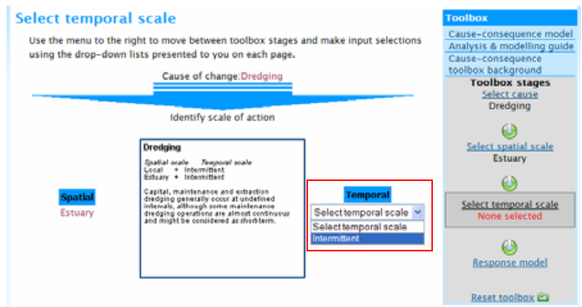
Cause-consequence toolbox 6



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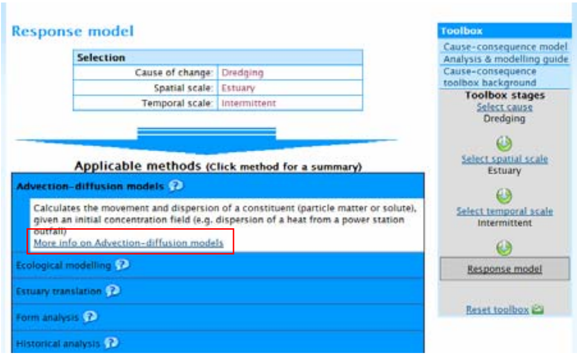
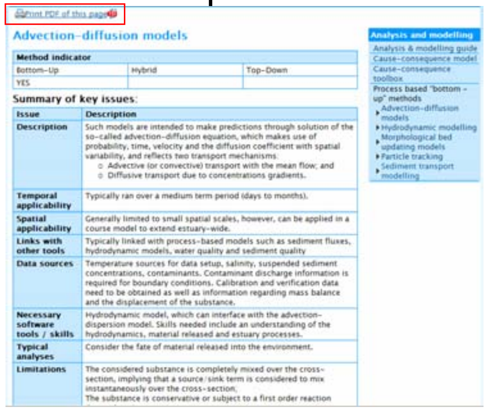
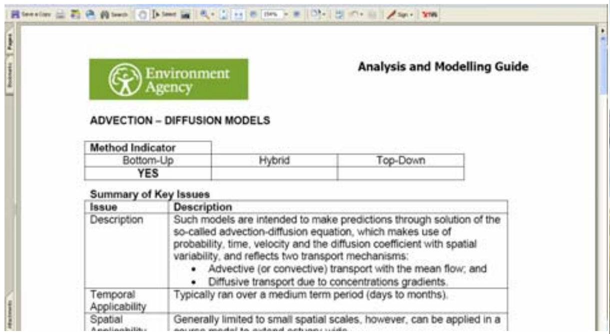
Cause-consequence toolbox 7



Cause-consequence toolbox 8

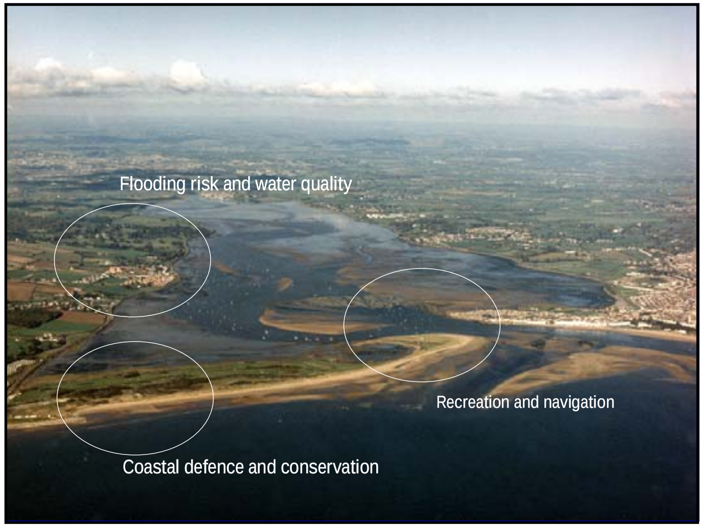


Cause-consequence toolbox 9



Improving confidence in estuary modelling

Richard Whitehouse



Context – EIAS* (EMPHASYS, 2000)

*Estuary Impact Assessment System

- what questions can be answered now
- what information is required to answer these questions
- what tools and techniques are available and what are their limitations
- how can the results be interpreted

Source – report TR114: http://www.hrwallingford.co.uk/projects/ICS0030%20PDS296%20RJSW%200710.pdf

Objective of the guide

- structured guidance as to the most effective choice of approach to prediction of long term morphology for decision making
  - presumption that long term is important
- audience: project promoters or regulators who are not specialists in estuary morphology, as well as specialists
- first published 2000, alternative version 2002
- web based guide 2004, 2007

Review of guidance

- Scoping
- Analysis of existing data
- Collection of new data
- Application of predictive methods
- Synthesis and development of conceptual model
- 'What-if?' testing using appropriate methods
- Presentation of results

- the approach provides a framework to gain confidence in morphological studies

Summary of supporting information

- summary of techniques available for prediction of morphology within estuarine systems
  - Research since 2000 has improved capability
  http://www.abpmer.net/eias/estuaries_research.asp
- summary of techniques for prediction of water quality within estuarine systems
- summary of techniques for prediction of ecology within estuarine systems

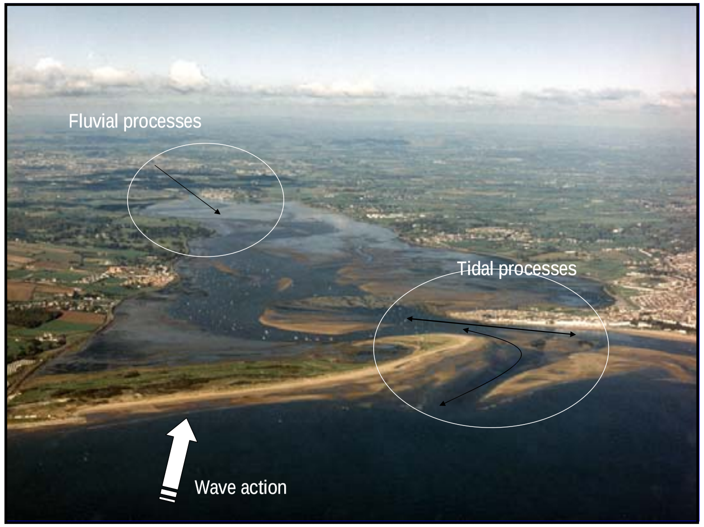
What it does

- it explains the data requirements for a morphological study
- it provides a systematic approach to undertaking a morphological study
- it provides the estuary manager with a variety of prompts as to how to gain confidence in the results of studies undertaken on his/her behalf

Development issues for consideration

Plans and activities: Typical questions

- *what will be the impact of sea level rise and climate change on the habitat resource of an estuary?*
- *will construction of a new bridge affect adjacent flood defences?*
- *will deepening of a riverside berth affect the adjacent inter-tidal mudflats?*
- *will increased freshwater abstraction lead to enhanced siltation in the upper estuary?*



Temporal and spatial scales

- wave period (seconds)
- tidal period (12.4 hours)
- storm event (days)
- annual/Seasonal
- decadal
- historical
- recent geology (Holocene)

- bed ripples
- sand waves
- local areas of change
- saltmarshes/tidal flats
- meandering channels
- human activities
- estuary-wide
- catchment/region

Scoping

- use Expert Geomorphological Assessment (EGA)
- consider the potential effects of a project on estuary morphology
  - cumulative and in combination effects
  - direct and indirect effects
- requires a good knowledge of estuarine processes and an understanding of the system in question
- can specific questions can be turned into more generic issues
  - are there analogues?

Questions relating to morphology

- how did present morphology arise
- influence of tidal processes
- influence of wave action
- influence of fluvial processes
- influence of sediment supply and dynamics
- influence of underlying geology
- influence of associated ecology
- influence of changes in water quality

- impact of sea level rise or climate change
- impact of plan or activity on morphology

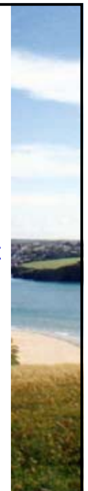
Selection of techniques (1)

- have morphological prediction methods previously been applied in this estuary?
- have morphological prediction methods previously been applied for this type of project?
- what is the main morphological concern for this estuary?
- are there significant design or operational issues associated with project?

Selection of techniques (2)

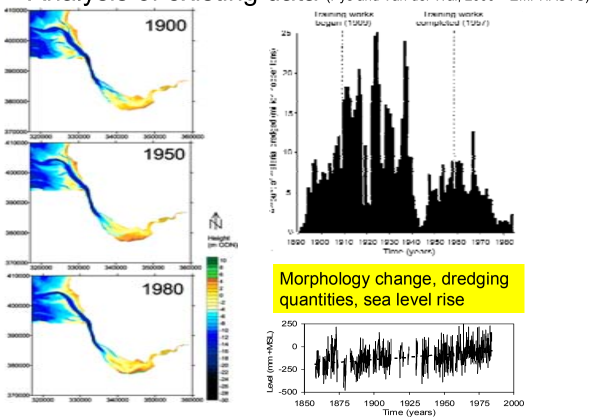
- type of question being asked
- designated status of the site
- scale of works in relation to the estuary system
- available data
- available duration and budget for studies
- degree of certainty required in predictions
- consider water quality and ecology

Analysis of existing morphological data



- consider a wide range of potential data sources
- sources include
  – bathymetric surveys, maps, photographs, LIDAR, CASI, satellite, boreholes/cores, surface sediment samples, archaeological data
- data on historical activities
  – dredging volumes, sea level rise, reclamation, vessel movements, fluvial flows, abstraction, sediment supply
- check quality of data, datums and projections

Analysis of existing data (Pye and Van der Wal, 2000 – EMPHASYS)



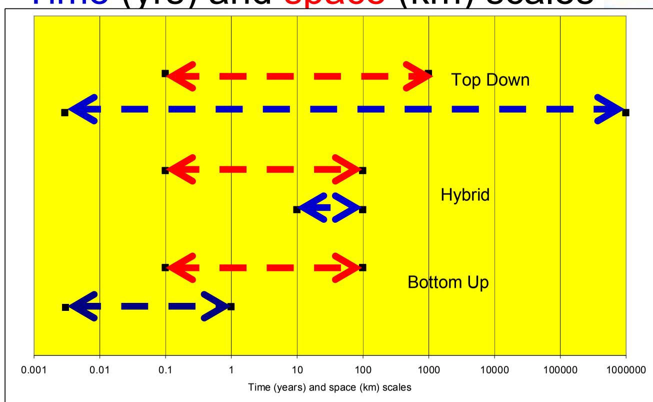
Collection of new data

- to understand process
- if no existing baseline exists
- for calibration and validation of methods
- ensure quality of data is appropriate
- be aware of errors inherent in the method used
- ensure that new data complements existing data

Predictive methods

- data analysis of processes and morphology
  - projections based on analysis
- Top Down
  - semi-empirical/analysis based morphological model
- Bottom Up
  - both: process based computational model
  - and: morphological model
- Hybrid
  - Semi-empirical/computational model
- analysis and modelling guide
  - http://www.abpmer.net/eias/guide/analysis_and_modelling/index.asp

Time (yrs) and space (km) scales



Expressing uncertainty

- qualitative and quantitative (Sayers *et al*., 2003):
  - Deliberate vagueness, 'There is a high chance of breaching';
  - Ranking without quantifying, 'Option A is safer than Option B';
  - Stating possible outcomes without stating likelihoods, 'It is possible the embankment will breach';
  - Probabilities of events or outcomes, 'There is a 10% chance of breaching';
  - Range of variables and parameters, 'The design flow rate is 100 cumecs +/-10 %'
  - Confidence intervals, 'There is a 95% chance that the design flow rate lies between 90 and 110 cumecs';
  - Probability distributions, "precise" probabilities based on multiple realisations.

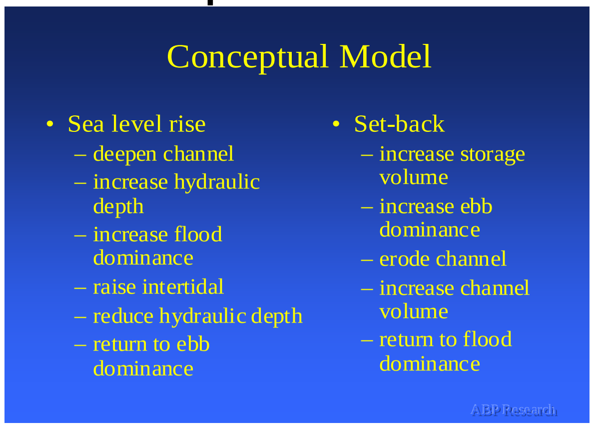
last two widely used at present

http://www.abpmer.net/eias/pdfs/error_and_uncertainty.pdf

Conceptual model of the estuary

- based on available information
- the model:
  - must be coherent and testable (hypothesis)
  - must be self-consistent
  - must contain the components of the sediment budget and how those components interact
  - should utilise all available data and appropriate analysis or predictive tools
  - where differences between data sources/predictions arise, present data to demonstrate the uncertainty
- a necessary and time consuming process

For example

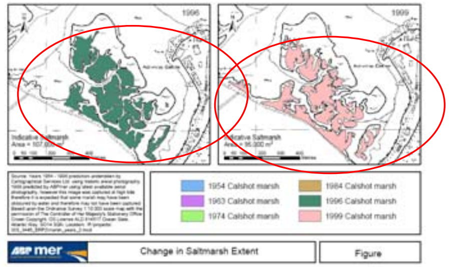


'What-if?' testing

- test conceptual model to examine system response to imposed change
- re-run some of the methods used in establishing the conceptual model
  - relative merits of different options can be investigated
  - absolute quantification of impact can be sought
- further assumptions and recognition of uncertainty
  - in order to provide answers for decision making

FD2116 HTA saltmarsh change

- analysis of trends (and rates of change)
- plan form changes (e.g. Calshot marsh)



Improving confidence - Data

- right type of data
  - right scale and resolution
- adequate quality of data
  - subject to quality assurance
- record steps
  - source – method – processing
- errors in techniques
  - time, space, magnitude

Improving confidence - Top Down

- check generic applicability
  - site specific data may not be available
- plausible physical basis for change
- consistency of results
  - with accepted geomorphological development
  - with other estuaries
- explore scope for error in method
  - uncertainty

Improving confidence - Bottom Up

- expect site specific calibration
- quantify goodness of calibration
- recognise uncertainty in model and data – understand differences
- use direct data to verify sedimentation
- sensitivity and scenario testing

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Improving confidence - Hybrid

- perceived as a generic approach
  - combines Top Down with Bottom Up
- various approaches
- look for same aspects as with Bottom up and Top Down methods

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Evolution assumptions

- check long term outcome
- progressive trend towards equilibrium or series of random steps
- Bottom Up gives rate of change
- use of HTA to evaluate
  - length of record
  - resolution of record

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Level of assessment

- already have
  - conceptual model and process understanding
- assessment with data and judgement
  - is data quantity and quality enough to make the assessment
  - data gaps
- is another predictive method needed?
  - if so which and why
  - a select range of methods can generate confidence
  - calibrated and validated methods

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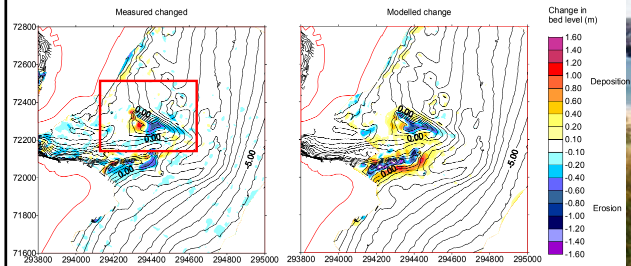
Model validation

a) validity of concepts
b) reliability of equations
c) numerical scheme
d) test predictions against observations
e) adequacy of documentation
f) functional validation
   a) the testing of predictions made by the model against measured values, including question of accuracy of the measurements
   b) use of Brier Skill Score – Sutherland, Haigh, FD2107
g) best practice "hindcasting"
   a) does hindcasting "guarantee" future prediction

Model validation 14 days (Sutherland et al, 2004)

Quantified model performance using Brier Skill Score: Quantified outcome maps onto qualitative assessment of poor – reasonable/fair. Can be improved with better model.



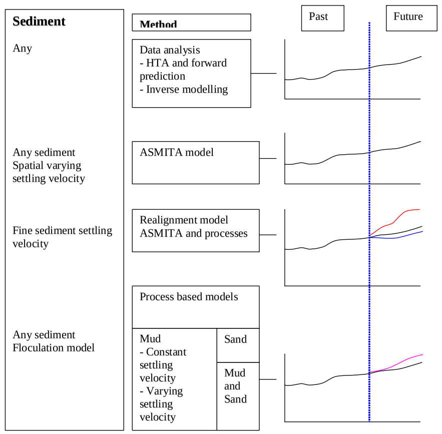
Prediction horizons

- clear horizon
- murky horizon
- forcing – probabilistic
  – e.g. wet winters and dry summers
- response – risk based probabilistic
- guidance on sensitivity testing
  – results in FD2107 report

Sensitivity/scenario tests e.g. 2050

– msl: + 0.30 m realistic, + 1 m extreme
– tidal range: + 2% (Flather et al., 2001)
– wind speed + 10% or direction change suggested by CDV2075*
– (corresponding) changes to 50-year extreme levels
– river flow + 20%
– wave heights + 10%
– wave periods + 5%
– increase the storage area (managed re-alignment)

(*Coastal Defence Vulnerability 2075 project, Defra)

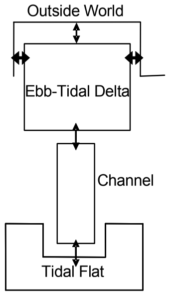


ERP - FD2107 - example

- ASMITA
  - estuary represented as a series of boxes filling/emptying under tidal action
  - flow, equilibrium channel profile, equilibrium sediment concentration
  - single element/multi element
    - along estuary channel or components
  - represent SLR and nodal tide

ERP - FD2107 - ASMITA

- schematisation (Van Goor et al, 2003)

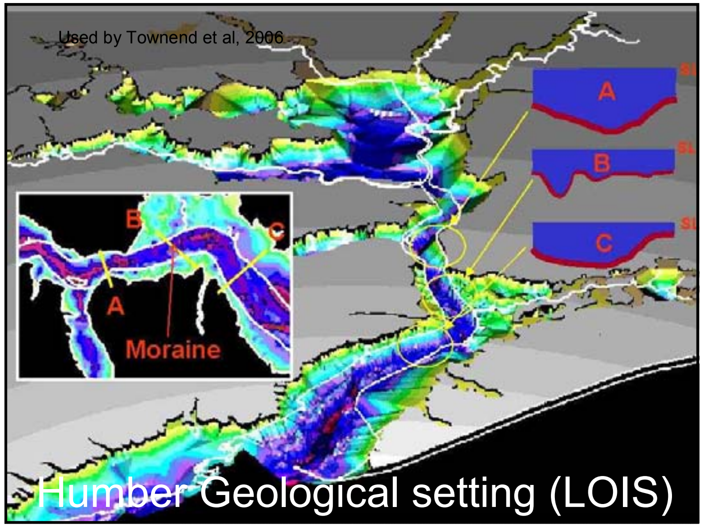


Element definitions:

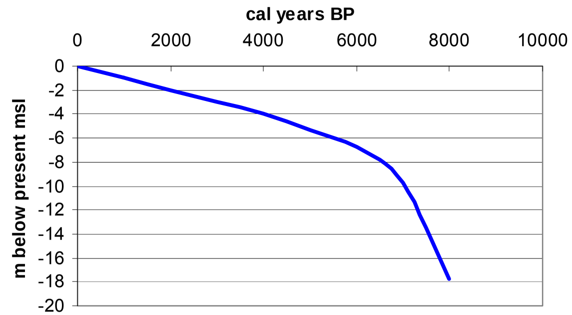
Ebb-tidal Delta: Excess sediment volume above a hypothetical non-inlet shoreface

Channel: Water volume below mean low water

Tidal flat: Sediment volume above mean low water

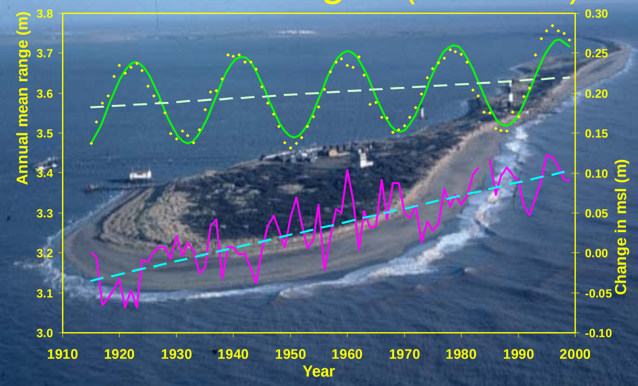


Holocene sea level rise



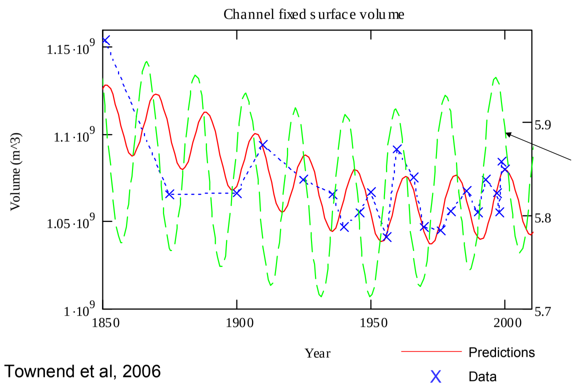
Townend et al, 2006

Historic changes (Humber)



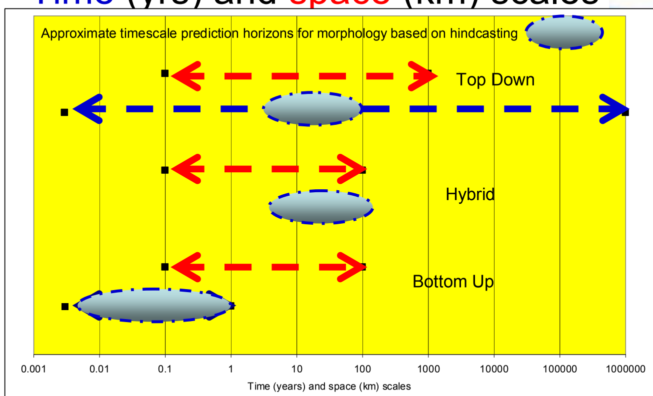
Townend et al, 2006

ASMITA 2-element model (Humber)



Townend et al, 2006

Time (yrs) and space (km) scales



ERP - FD2107 – case studies

- effects of morphological change on flood risk
  - impact of (even extensive) dredging on flood risk is usually small
  - in some cases (near tidal limit) impact may be deleterious or beneficial depending on estuary
    - E.g. Parrett – dredging to remove siltation
  - particular estuarine features may be critical
  - in practice – flood risk and coastal protection issues manifest themselves on the local scale at specific vulnerable locations

FD2107 – simple bottom up model

- sensitivity to 1m increase in depth at mouth in a V-shaped estuary section
- idealised contrasting estuaries
- -ve depths become +ve if shallower

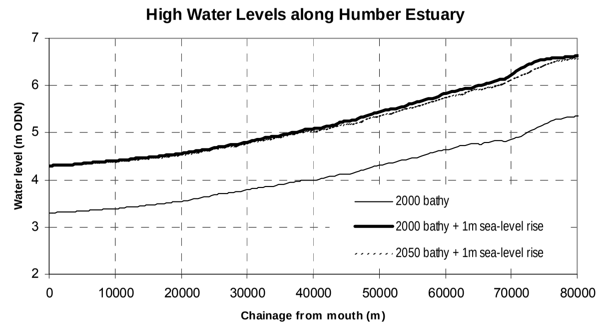
Estuary	Length at still water km	Width at mouth m	Depth at mouth m	Tidal range at mouth m	River discharge m^3/s	Max change in HW level cm	Distance from mouth of max change km
Humber	65	250 - 2500	25	5	280	3	59
Solway	40	100 - 1000	10	6	93	7	32 - 36
Dee	20	60 - 600	6	6	42	2	16 - 18
						-2	4
Lune	10	70 - 700	7	6	35	1	9
						-1	5 - 6
Eden	5	30 - 300	3	3	4	-15	4.5
						-10	2.5

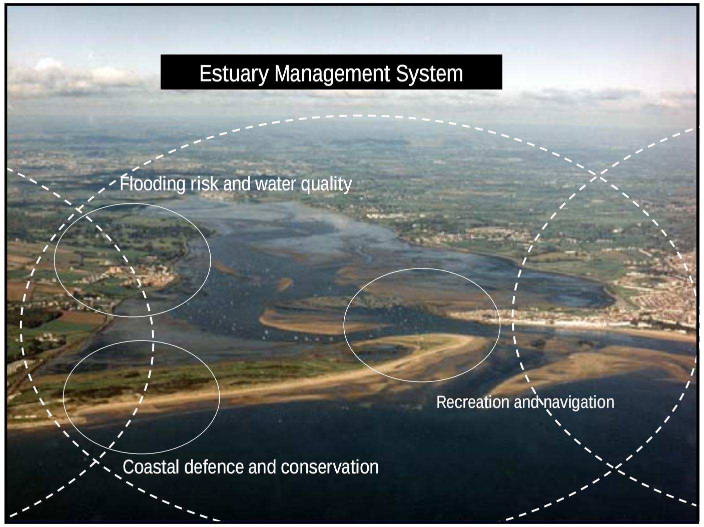
FD2107

- effect of SLR on future water levels
  - e.g. Humber to 2050
- static bathymetry should give conservative estimate
- morphological change provides some reduction
  - similar result seen for Severn

FD2107 (Fig 5.3e, Annex G)

using an existing model to evaluate future levels





FD2107

- estuaries do not all respond in the same manner
  - similar types of estuary behave in a similar manner
- Historical Trend Analysis
  - guide expectations of future change if there are precedents
- use validated models
  - with historic data (hindcasting)
- lack of data
  - either: ensemble predictions with one model
  - or: inter-compare model results

Summary of steps to presentation

- present the conceptual model first
- build on this to develop credibility
- demonstrate calibration/validation of methods
- discuss the level of certainty in the results
- explain differences between models and models and measurements
- confirm that the results are presented in a style suitable for informing the decision makers

Finally

- quality (and quantity) of data

↓

- a robust conceptual model

↓

- confidence in the results (certainty)

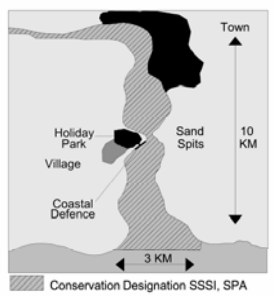
Mini Case Study Exercise

Noel Beech

Roles

- Developer (self)
- Consultant
- Responsible Authority
- Regulator

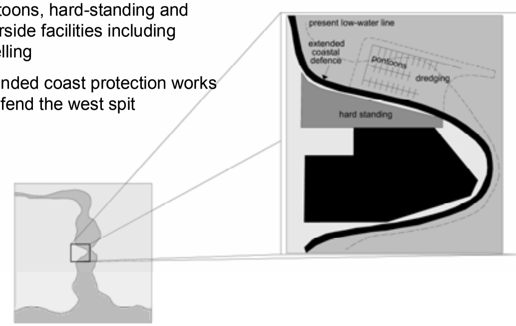
Fictitious estuary!



- •generally sandy
- •constrained by sand spits
- •coastal defence at west spit
- •holiday park and village
- •Town is upstream
- •conservation designations in respect of intertidal features
- •scheme life = 50 years

Fictitious scheme!

- •dredging for all tidal access
- •pontoons, hard-standing and waterside facilities including refuelling
- •extended coast protection works to defend the west spit



The objective of the exercise is to..

…identify essential steps to assess the proposed development

Issues, relating to estuary morphology, to consider at the outset

- What are the principal physical issues to consider in respect of estuary impact? – *Consultants*
- List (some) important statutory obligations to be responded to. - *Responsible Authority*
- What important demands are likely to arise in respect of impacts on ecology? *Regulators*

Before we consider impacts we need to…

- develop a conceptual model of the estuary without the scheme in place
- consider timescales

Timescales

Period	Indicative time (or range)	Need to consider – yes/no
geological		
Holocene		
historical		
decadal		
annual / seasonal		
tidal / storm / waves		

•Put indicative times to the different periods. -*Responsible Authority*

•Identify the most important periods for our case/study purposes. - *Regulators*

•At the outset, which types of approach do you envisage being needed, and why? (i.e. Top Down, Hybrid, Bottom Up). - *Consultants*

Before we engage detailed studies we need to…

- assess scope and availability of existing studies and data
- desk study to facilitate detailed plan of modelling and analysis

Model types and data needs

Available data and studies	data	study
bathymetry	Old Admiralty Chart and 20 year old survey	historic review of historic charts in SMP
currents	direct current metering at the Town Quay (20 years old)	-
waves	UK Met Office, offshore data	SMP broad consideration
tides	POL records for nearby port	SMP plus various
geology and sediments	borehole data (20 years old) from Town Quay	-
benthic	relating to designations	see designations

•Suggest new data needs - *Responsible Authority*

•Suggest bottom up model types (or purpose). - *Consultants*

•Suggest top down /hybrid model types (or purpose). - *Regulators*

Certainty - Uncertainty

- What level of certainty might you be seeking. – *Regulators*
- What level of certainty might you expect to get – *Responsible Authority*
- What steps can you take to reduce uncertainty - *Consultants*

Environment Agency

defra

Available tools and future developments

Richard Whitehouse

Available tools

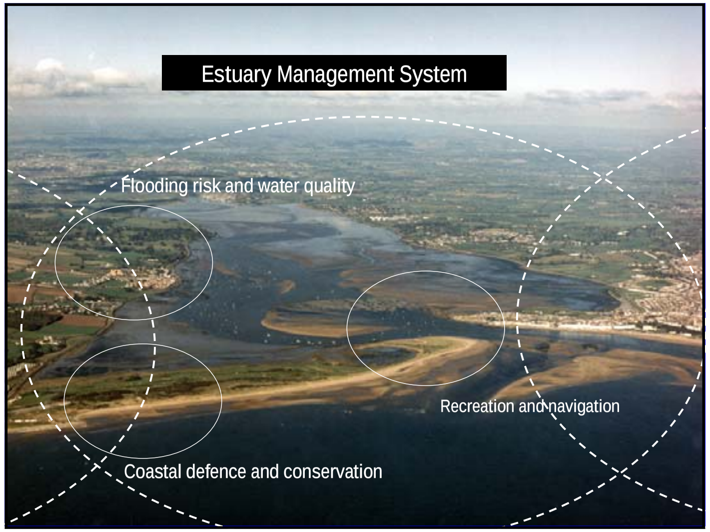
- overview of current status
- benchmarking required
- uptake of tools and methods

beyond FD2119

- collate experience with estuary guide
- document application of methods

Future

- complete FD2119
  - finalise estuary guide
  - final scope EMS
  - gap analysis on tools



Future (1) – 3 to 5 year programme

- implement systems approach through DPSIR
  - how far towards a DSS?
  - expert System using rules base?
- update/reissue the EIAS guide
- review and collate the metadata (and) datasets needed
  - links to PAMS etc
- document and benchmark capabilities of predictive models
  - update toolbox

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Future (2)

- upgrade EMS with links to data and tools
- pilot testing of EMS
- revisions of EMS based on pilot testing
  - minimum toolbox
- complete and roll out EMS
- annual review, dissemination, steering group

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Appendix 3 Short Form A (2005) for Biosedimentary Processes

DEFRA / EA Short Form A for R&D Outline Project Proposals for 2006/07

TITLE: Biosedimentary Processes in Estuaries

Purpose (Key Customer) - Why is the R&D needed?

The Estuary Processes (EstProc) Project FD1905 completed and presented its scientific work in November 2004, drafts of the three final reports have been reviewed, and the final versions are expected to be delivered in August 2005. A costed list of areas that can be productively advanced with further R&D has been compiled by the EstProc team.

One particular area of interest and uncertainty revealed by the EstProc project is the complex relationships between biology and sedimentology in estuary environments. Biological activity affects sediment erosion and availability, and sediment activity affects biological processes and estuary ecology. A proper, quantifiable and working understanding of these interactions is becoming more important as issues of estuary habitat and stability are raised in the context of interventions such as setback of flood defences and engineering of flood protection structures.

The key users are all those who are endeavouring to manage estuaries in the context of flood risk management, through model simulation and prediction of estuary responses. The direct users are the modellers, but the ultimate beneficiaries are the estuary managers, conservators and developers who have to balance development and protection against sedimentary and ecological change in extremely complex tidal systems.

Summarise the **Issue(s)** that the research addresses?

Summary (Overall) Objectives

The proposed research will address the following issues and areas identified in the EstProc study.

- Further quantification on the feedback between vegetation and sediments using modelling and data mining of existing datasets. (£40k)
- Generalisation of the behaviour of real estuarine sediments building on the geotechnical and hydraulic insights generated within EstProc. (£40k)
- Extending the existing estuary sediment floc database to allow prediction in saline conditions throughout the estuary and out to the sea, including exploration of the links and feedbacks with benthic ecological structure.(£40k)
- Determining the role of biology and biochemical properties through integrated studies using floc measuring equipment and newly implemented technology to examine the nature of floc erosion from different estuarine sediment beds. (£60k)
- Developing sediment budget analysis and framework determining the relative roles of biology, waves, tidal asymmetry, accumulation of sediments and the role of benthos/vegetation. (£60k)
- Development from EstProc of the generalisable functional roles of organisms, both positive and negative, biomass distribution coverage and significance. Estimation of the period and magnitude of biological modulations relevant to hydro-sedimentary

response. (£40k)

- Combination of existing hydrodynamic, sedimentary and biological (or proxy parameters) within the general framework using GIS based techniques operating at the estuary level, and building on existing databases including EMPHASYS-ERP uptake, Futurecoast, JNCC, EA/Defra, BGS [this approach is expected to be successful but the level of generalisation will depend on the content and coverage of the relevant datafields]. (£60k)

Technical / scientific objectives – timebound and measurable

Context (Background)

The EstProc project has produced user-oriented algorithms describing hydrodynamic, sedimentary and biological processes, presented for stand-alone use in desk study application and for inclusion in computational models. It has also produced a range of process concepts and less well-developed algorithms reflecting the higher uncertainty or lack of information in particular areas.

One particularly notable and innovative advance from the project has been the investigation of the interactions between estuary biota and sediment dynamics. This is an area of cross-disciplinary science where the interactions have been suspected or qualitatively known about for many years, but have been considered 'too difficult' to research and quantify. Sedimentology has generally been described and characterised in terms of physics. But the EstProc results have revealed just how important the biological dimensions are, and has made informed recommendations as to where further research effort would be productive and bring knowledge and practice nearer to the truth.

How the R&D fits into and will advance current state of knowledge

Main Outputs / User / Benefits

The outputs will be further improved algorithms describing the relationships between sedimentology and biology that can be translated and implemented into estuary models and predictions. The project will also bring together existing dispersed data sets as a data resource and foundation for this, and any future, research.

The project will substantially benefit all who are trying to understand, manage and predict estuary environments, and the impacts of flood risk management strategies in estuaries.

State what the output(s) will be; how and by whom would it be used; what benefits will this bring?

Timescale / Costs / Costs by year

3 years / £375k,
including an internal project consortium management and dissemination budget of £35k.

Give duration and total cost, plus breakdown over each year of the project

Other Funders (internal or external)?

Through a project consortium arrangement, the project will draw on and benefit from the academic research being funded through Research Council and EU research programmes.

Are there prospects of other funders – Agency or DEFRA (internal); Departments or Research Councils (external)

PREPARED BY: Mike Thorn, MouchelParkman (Theme Leader), based on recommendations from the EstProc consortium headed by Richard Whitehouse, HR Wallingford.

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Which one of the following types of R&D would this project come under:		
Operational **X**	Policy	Strategy
Which would be the main EA Theme that this project would come under:		
Adapting to Climate change	Reducing Flood Risks **X**	Ensuring the Air is Clean
Using Natural Resources Wisely	Improving Inland/Coastal Waters **X**	Protecting / Restoring the Land
Greening the Business World	Quality of Life	Enhancing Wildlife
Principal DEFRA / EA Theme: Fluvial, Estuarine and Coastal Processes		

mfct 29/07/05

Appendix 4 MAR TAG scoping document prepared by Kevin Horsburgh

A brief summary of estuarine research: opportunities for new investigation

Context

At its meeting on 12 June 2006, the Defra/TAG Theme Advisory Group (TAG) on Modelling and Risk identified the need for a review of current estuarine research, with an emphasis on "gap analysis" and the identification of useful future projects that fall within the TAG's remit. This short review addresses that request: logically, a full scoping report could follow (although some resource would be demanded) that would lay down the framework for a strategic program of estuarine and coastal research over the medium term (4-5 years), including short form A's.

Historical overview

There has been a strategic and developmental period of estuarine research (funded by Defra/EA and previously by MAFF) over the past decade in the shape of the UK Estuaries Research Program (ERP). The main focus of this work has been techniques to predict large-scale, long-term morphological changes and resulting sediment related impacts in estuaries (including water quality aspects). An approximate timeline of the major contributory projects is given in the table below.

Defra/EA ID	Project name	Comments
FD1006	Estuary Process and Morphology Scoping Study	Original scoping study led by HR Wallingford
FD1401	ERP Phase 1 (EMPHASYS)	Phase 1 study of modelling estuary morphology and processes
FD2002	Futurecoast	Produced a geomorphological manual and predictions of shoreline behaviour in (a) unconstrained and (b) managed scenarios
FD2108	Broad Scale Ecosystem Impact Modelling scoping study	Scoped necessary tools for capturing the feedbacks between hydrodynamic, morphological and ecological systems
FD2115	ERP Phase 1 review	Reviewed Phase 1. Outlined Phase 2 with a prioritised 3-5 year program
FD1905	ERP2 EstProc	Three reports: algorithms, metadata and synthesis
FD2107	ERP1 Hybrid estuary model development	Hybrid models for (50 year) morphological prediction
FD2116	ERP2 Review of Geomorphological Concepts	Text book. Instructions on how to combine data and modelling to achieve an Expert Geomorphological Assessment
FD2117	ERP2 Estuary Simulators	Geomorphological classification

	Development (EstSim)	and web-based demonstrator
FD2119	Uptake and ERP3 Scoping	Scoping the future program to deliver an Estuarine Management System

To summarise the staged nature of the program, ERP Phase 1 (1998-2000) included a critical analysis of process-based "bottom-up" model limitations alongside a review of "top-down" models. ERP Phase 2 (2000-2007) recognised the need to use both approaches and gave priority to developing hybrid models combining both elements. The purpose of such models is in the management of estuarine catchments and ecosystems. Morphological models such as these can be used for flood/erosion risk assessment alongside tools such as the Modelling and Decision Support Framework (MDSF).

Recommendations from the previous work

The foregoing represents a substantial body of interconnected work. It is natural to await the final conclusions of FD2119 on the formulation of an Estuarine Management System. This, in essence, leads to an anticipated third phase of the original program (i.e. ERP3). Certain key recommendations for future work have already been put forward. Some of the recommendations that could be addressed in significant new studies are highlighted below:

- The algorithms developed in FD1905 (EstProc) could be further developed in the light of improved process understanding, in particular:
    - Biosedimentary processes and biological influence
    - Quantification of the feedback between vegetation and sediments
    - The role of intertidal mudflats and channels
- The various process algorithms deduced for specific sites need to be assessed at a regional scale (this ought to form part of EMS under ERP3)
- The type of models developed in FD2107 could be linked to the formalised regime methods set out in FD2116
- The conclusions of FD2107 suggested a range of further developments that would enhance the model performance:
    - The 1D model underlying the hybrid model could be improved to account for sediment transport, flow-dependent erosion and deposition
    - The 2.5D model could be extended
    - The validation of the ASMITA model (which predicts Thames evolution relatively well) could be extended to include element area

Opportunities for new aspects of estuarine research

Despite the success of ERP in its various phases there are clear opportunities for other aspects of estuarine research. Arguably the most important (certainly the most timely) is to spin-up research that investigates the effect of barrage systems on estuarine dynamics, morphology and ecosystems. Government energy strategy at this time implies that barrage schemes may by implemented over the next 5-10 years, and we now have the necessary modelling tools (e.g. for accurate inundation modelling) to properly calculate their impacts on systems and flood risk management.

A second topic that warrants study at this time is the effect of extreme erosional events on the geochemical sediment store. This would take into consideration how extreme events (water levels and wave fields) may disturb chemical laden sediment stores, and the subsequent impact on water quality.

FRMRC and FREE

Any ongoing strategy for estuarine research must ensure that it does not overlap with parallel projects funded under Research Council auspices. Instead, any TAG program should seek synergy with these programs. The two main examples currently are the Flood Risk Management Research Consortium (FRMRC) and Flood Risk from Extreme Events (FREE). The first phase of FRMRC is organised into nine Research Priority Areas (RPAs) as below:

RPA1 - Project Management and Integration
RPA2 - Land Use Management
RPA3 - Real Time Flood Forecasting
RPA4 - Infrastructure Management
RPA5 - Towards Whole System Modelling
RPA6 - Urban Flood Management
RPA7 - Stakeholder and Policy
RPA8 - Geomorphology, Sediments and Habitat
RPA9 - Risk and Uncertainty

Although none of these has a unique focus on estuaries, there are strong elements of research relevant to estuaries in RPAs 3, 4, 5 and 8. FRMRC2 is at the outline proposal stage, and it contains an explicit Coastal Flood Management theme. The science projects within this will concentrate on broad-scale coastal flood and erosion risk models (and will draw upon existing datasets for future marine conditions, e.g. those being generated as part of the UK Climate Impacts Program UKCIP08). The work packages within the Coastal Flood Management theme are:

WPC1 – Model level assessment for offshore-inshore storm wave propagation
WPC2 – Long term, large scale hydro-morphological coastal modelling
WPC3 - Coastal management: broad scale integrated flood and erosion risk models
WPC4 – Robust planning of portfolios of structural and non-structural measures under uncertainty
WPC5 – Breaching: the development of theoretical and practical tools
WPC6 – Advanced adaptive modelling for overtopping and breaching
WPC7 – Defining a robust ensemble uncertainty estimation within coastal flood risk management

There are distinct opportunities to develop complementary estuarine research that exploits the activities within this theme of FRMRC2.

Conclusions

- A number of research avenues arise naturally as a result of the UK Estuaries Research Programme (ERP). Specifically, recommendations from FD1905 and FD2107 should be fully evaluated and – if appropriate – distilled into new short form A's. The outcome of FD2119 (when all consultation is complete) will scope out the nature of an integrated Estuary Management System (EMS); the development of the tools making up this system should also be the subject of a new proposal.

- New research is recommended to investigate the effect of barrage systems on estuarine dynamics, morphology, ecosystems and flood risk. The impact of extreme erosional events on geochemical sedimentary environments is another candidate. Both areas of research should take into consideration the effects of future sea levels, and wind/wave climates.

- To maximise the interaction of TAG funded work with existing, Research Council led programs, efforts should be focused on defining synergistic lines of research with the Coastal Flood Management theme of FRMRC2.

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12 November 2007

Appendix 5 Summary of feedback obtained from FD2119 training events and final meeting

The following feedback has been taken into account during the completion of the project and the preparation of a programme of future work to develop the EIAS and associated tools and the EMS.

A. The FD2119 training events led to the following requirements being identified (not presented in any particular order):

- It was suggested that there might be a tool box of methods that have a level of assessment and qualification; there is an equivalent approach taken by the River Restoration Centre http://www.therrc.co.uk/
- There is a need for a decision tree for users to help decide which model approach should be taken and to document (audit) the process
- There is a cause-consequence model, it would be useful to have the converse of this – a consequence-cause model; this might be effectively Historical Trend Analysis feeding into a rules based approach
- The range of tools available needs to be categorised more clearly and a toolbox with key tools needs to be made available; this might usefully reduce the number of tools to a key set as it was considered not always an advantage to have so much choice in methods
- Links to tools, recommendation on tools with respect to dredging, defences, reclamation
- Develop a successor to the TraC MImAS tool
- Recommend use of case studies – two case studies are included in FD2110 report
- Provide worked examples of using models, tools or methods
- Develop sensitivity maps for estuaries as screening tools
- Cross-reference UKTAG TraC water body typologies and JNCC/Futurecoast/EstSim classification of coasts and estuaries
- There is a view amongst regulators and competent authorities that they need to adopt a precautionary principle and seek compensation sites for (major) engineering works in estuaries. This may also arise in some cases because of uncertainty in the predictions or evaluation methods used. It may not have been necessary to adopt that route in the first place
- There is a need to make links with a strategic overview including Making Space For Water and adopting and promoting clear dissemination pathways

B. The March 2008 final seminar meeting produced feedback as follows (not presented in any particular order):

Future areas of R&D under the Estuary Research Programme

- Tools underlining SMP policies (are process based models sufficient due to their constraints and scale and prediction horizon?) 100 year

predictions (of morphology) are needed for SMPs. State purpose and limitations of methods. Consider use of whole systems approaches.
- RASP approach does not include estuaries – only rivers and coasts – and hence need to be extended.
- Improved knowledge of limitations of modelling techniques/approaches
- Improved knowledge of links between morphology/sediments/habitats/water quality
- Pilot testing of how models can be integrated/used in real schemes/projects
- Maintenance of Estuary Guide
- Integrating of models/tools/techniques for estuaries, coasts and their interactions
- Management of estuaries needs information on water quality and habitats. Metadata is needed and link up to WFD tools would be beneficial. Support training uptake and keep website going.
- Pilot testing (*of methods*) needs to be done.
- Approaches of how results of different models (morphology, WQ, sediments, habitats) can be interpreted together (e.g. through GIS mapping)
- Links to existing EA Hazard Maps
- Exploratory data analysis/techniques to bring together results from estuarine, coastal and fluvial models
- Links to Tyndall Centre Coastal Simulator Tyndall Simulator – in Phase 3 extending to estuaries from coasts.
- Integrate plans and knowledge management and visualisation.
- More exploratory data analysis is needed to bring together information from coasts and estuaries. Think of estuaries and coasts together, for example the Thames Estuary goes half way up the east coast.
- Application of existing tools to real estuary projects/schemes/strategies
- Research into whether the equilibrium concept does actual apply to managed estuaries in the UK under e.g. sea level rise and other forcing conditions – what does that mean for model applications? Many modelling approaches seem to rely on idealised conditions which do not always hold true Use of equilibrium concepts – estuaries are often considered to be metastable (e.g. *things remain in a similar state until a change in forcing (or resistance) pushes a system across a threshold from one stable equilibrium to a new stable equilibrium*). There are long time lags in estuarine systems so it is not good to rely on equilibrium or regime methods by themselves. They may be a useful aid to understanding.

Involvement of Stakeholders and uptake

- Revival of the now defunct Estuary Advisory Group
- Agencies need to be informed about the available tools.
- Better dissemination of FCERM/ERP project outputs within the EA and outside
- Build requirement to use ERP into briefs for strategy studies. Trialling of ERP products needs to be included in the relevant project briefs during

the tendering processes (for that EA NCPMS/area level buy in is necessary) ERP output needs to be built in at National Policy Level.

- Project Area Steering Groups are being set up by EA. Potential participants should contact Stefan Laeger if interested.
- Factory testing only done if CEFAS/EA/NE requires it (*and pays for it*).

Comments on ERP, science, R&D needs

- Mixed sediment dynamics (mud:sand mixtures).
- Sediment-chemical-biological interaction.
- Quantifying estuary shape and bathymetry.
- Linking of ecology and water quality with (hydro)morphology.
- Integration of estuarine environments within coastal environments.
- Development of science in order to improve model performance and process knowledge.
- Long term monitoring of (other) estuaries (tides, waves, SPM etc).
- Long term detailed monitoring of morphology at selected locations.
- Proper recognition of stochastic uncertainty of predictions. Needs multiple runs, sensitivity analysis, statistical bounds of predictions.
- Process studies, especially related to water quality, mixing and dispersion.
- Impacts of managed realignment on tidal prism in estuaries.
- Use of remote sensing for measuring sediment concentration and flow (*speed and*) direction.
- Sediment supply to new areas of managed realignment –is there enough sediment to infill shrunken marshes?
- Development of models for constrained estuaries.
- Research on estuary-coast interaction.
- Work on linking models, especially at broad scale, within systems, framework.
- Important to increase availability of data, especially to researchers. EA Lidar data, for example, are hard to get hold of for university based research. We could do a lot with existing data!
- Extending conceptual models beyond equilibrium assumptions.
- Monitoring of coast, remote sensing of sediment and bathymetry.
- I heard of the project only recently and came to find out what it can offer me. I'm interested in sediment movement in estuaries and particularly the links between sediment, hydrodynamics and water quality. I think the estuary guide could give me some useful pointers and today has been a good introduction.
- Carefully consider the research that is required before commissioning.
- Test the existing model framework, possibly in the context of a coastal observatory (*which one really applies to estuaries?- apparently long term monitoring of tides, waves, river flows is done! Not SPM and sed floc characteristics – is it possible?)*, where all useful variables are measured.
- Excellent program of research. This is a good time to take stock and assess how well it work as a management tool. Connect up with next phase of Tyndall centre.
- Impacts of climate change on estuarine processes, both short (floods) and long term (sea level rise).

- Integrated modelling approach – from catchment to coastal basins level.
- Reduce inter and intra model uncertainty.
- Very useful, well organised event. Venue and catering excellent.
- Sharing of knowledge – specific project work undertaken and shared.
- Develop broader links with understanding of coasts and estuaries, rather than piecemeal approaches to interactions.
- Development of tools to support marine assessments with respect to morphology under WFD.
- Improve understanding of relationships between morphology and habitats. Include coastal areas and on going projects in that area.
- Making the outputs (*of the research*) available.
- Embeding the ideas and concepts into FRM policy as best practice.
- Extending the data observations within estuaries.
- FD1401 EMPHASYS, FD1905 EstProc and FD2116 Estuary Geomorphology are the most important to extend.
- Biological and physical interactions, ecosystem models; validation of models.
- Linking physical processes to biological and ecological response.
- Morphodynamic modelling at meso spatial and temporal scales.
- Sediments as recorders and predictors of estuarine change. Integrated model development and practical applications in relation to morphodynamic modelling and sediment as recorders and predictors for specific areas (Severn Estuary, Wash,?).
- Sediment records of environmental and morphological change need to be considered.
    1. A great deal of progress has been made in ERP1 and ERP2 and every effort should be made to continue the programme with a follow-on Phase 3 if the full benefits of the investment so far are to be realised.
    2. While considerable progress has been made in achieving a better understanding of and prediction of short-term estuary processes, geomorphological concepts related to broad scale, long-term changes and in the development of the Estuary Guide as a user-oriented tool, there remain significant gaps which need to be addressed in Phase 3, not all of which were fully identified in the original Scoping Study. These include:

       (a) More attention needs to be given to meso-scale, medium term morpho-dynamic modelling. The basic processes of sediment entrainment, transport and deposition are understood well enough for most purposes, and further detailed work might be considered as ‘fine tuning’ in relation to the broad scale objectives being considered here. However, there is a need to examine features at a larger scale – e.g. the dynamics of sand banks, mudflats and saltmarsh systems within estuaries, and their relation to changes in medium to long-term water levels, current velocities and wave activity. Controls on wave activity within estuaries, and their relationship to mudflat – saltmarsh interactions, have not yet been considered in any detail.

       (b) The use of sediment records (from cores) and studies of spatial variations in sediment properties has so far been given very little attention in the ERP, yet academic research outside the ERP over the past 20 years has clearly demonstrated the value of the information which can be obtained both in relation to understanding historical change in estuaries and predicting future changes. Sediment properties can provide important early warning indicators of changes in morphology and the driving processes, and have the advantage compared with short term process studies of reflecting medium-term ‘average conditions. There is a need to incorporate these methods into the ERP.

(c) To date very little attention has also been given to water quality and ecology issues of estuarine management, compared with the physical processes and morphology. These aspects need to be addressed individually but more specifically in terms of the relationships to morphology, physical processes and sediments. Sediment properties and behaviour are fundamental to both ecology and water quality (e.g. in terms of suspended sediment concentrations, movement of contaminants etc.). A work module focusing on sediments as a linking factor between physical processes, morphology, water quality and ecology / habitats might therefore serve a useful unifying purpose.

(d) There is a requirement to tie any future ERP work in more closely with practical management questions. Demonstration of the application of the various tools within the context of one or two specific estuarine problems would be extremely valuable and would help uptake of the outputs of the project among the user community. One potentially suitable area would be the Severn estuary (possible tidal power development, further port development, possible nuclear power station development).

(e) The final EMS would be greatly strengthened if it is seen to be truly holistic and the investigative methods / tools described are shown to work together a package in at least one ‘case study’ example.

- Over the years the following issues have been encountered where a greater understanding of estuarine sediment dynamics would help. Most of them boil down to the behaviour of fine silts in the estuary, since these tend to carry the contaminants. Four issues spring to mind:
  1. growth of algal mats. Sediment-bound nutrients may play a part but I think the bigger constraints are the physical ones of elevation and bed stress, which will be affected by changes to estuary morphology.
  2. sediment oxygen demand in the Tyne estuary is a significant contributor to oxygen depletion which, in dry summers, leads to salmon deaths in the upper estuary. It's caused by anaerobic degradation of sediment organic carbon, generally associated with fine sediments.
  3. movement of TBT-contaminated sediments, which are a problem in the Tyne estuary particularly (because of its history

of ship-building and repair) and elsewhere to a lesser extent (because controls on disposal constrain dredging)
4. we also have issues with disposal of dredgings contaminated with other substances, notably heavy metals, some of which come from historic local sources and some from further up the catchment.

It would be good to be able to quantify and predict sorting of sediments in estuaries and transport and fate of silts and their contaminants.

- Over the course of work in FD2119, a few key points have emerged (as highlighted in the FD2119 report). Among these: there are outstanding issues regarding consistency / availability of data within estuaries at a national level. Also, WFD is a significant driver for the need to understand morphological behaviour in estuaries and associated ecological status (i.e. the need to provide consistent morphological data / knowledge to link with areas such as ecology).

  With this in mind, the potential need is identified for a 'futurecoast for estuaries' to provide consistent baseline of morphological knowledge and data for estuaries in England and Wales. This could build on some of the concepts applied in FD2117 and also on the development of datasets within estuaries in various phases of ERP. ERP(3) would seem the logical location for such a study, although there would potentially be important benefits across various aspects of the Agency's work, for example: WFD would be a particular beneficiary, in terms of providing the underpinning morphological knowledge to inform work on ecological status. The Estuary Guide would seem to provide an ideal platform for such a development.

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