TR167 - Enhanced UK Estuaries database: explanatory notes and metadata (SiTE P1)

Development of estuary morphological models

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Summary

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Data requirements – Objective 4. for FD2107 were primarily based on expanding the original JNCC/NCC (data for 155 UK estuaries) database and Future-Coast (data for 96 English & Welsh estuaries) database (Burgess et al., 2002). The newly enhanced "*EDB2012*" (Estuary DataBase 2012) comprised:

- Estuary Surface areas, Intertidal areas, Salt Marsh areas, Shoreline perimeter length, Channel length, Spring Tidal range, Estuary Mouth width, and High Water (HW) & Low Water (LW) Volumes.
- More detailed freshwater flows (seasonal statistics) from the Centre for Ecology & Hydrology archives for 65 England and Wales coast estuaries.
- Saline intrusion lengths for most estuaries from literature review and Marine Nature Conservancy Review.
- Neap tide equivalent tidal ranges, based on tidal range information from the Admiralty Tide Tables, were added for all England and Wales estuaries.
- Mean estuary depths (D_{data}), which are equivalent to the mean sea level (MSL), were calculated for most estuaries using: $D_{data} = 0.5 * (D_{HW\_data} + D_{LW\_data})$, where D_{HW_data} and D_{LW_data} are the estimated high and low water derived depths at the mid-tide phase:

  $D_{HW\_data} = 2 * (V_{H\_data} / S_{H\_data}) – (Z_{R\_data} / 2)$

  $D_{LW\_data} = 2 * (V_{L\_data} / S_{L\_data}) + (Z_{R\_data} / 2)$

  (V_{H_data} = volume at High Water; V_{L_data} = volume at Low Water; S_{H_data} = surface area at High Water; and S_{L_data} = surface area at Low Water).
- Mean estuary breadth (B) values were calculated for most estuaries using: $B = (S_H + S_L)/2L$
- The average side-slope (*a*) of most England and Wales coast estuaries were determined using the following relationship: $a = 2D/B$
- The following dimensional parameters were added to the FD2107 data base: D at LW & HW, B at LW & HW, and Surface Area at LW & HW.

Aspects of the original expanded FD2107 *EDB* have been applied to the following case studies during FD2107: a comparison with estuarine morphological theory and the database of UK estuaries (Prandle et al., 2005); an assessment of dynamical controls on UK estuaries (Prandle, 2006); and redefining UK estuary typologies through the combined use of estuary morphology theory and FD2107 data (Prandle et al., 2006).

In addition, the main equations which comprise the Analytical-Emulator (AE), were coded by Manning (2012) and applied to the FD2107 *EDB2012* data. The Analytical Emulator equation derivations are outlined by Prandle (2004). Details of the Analytical Emulator application are reported by Manning (2012), whilst

intercomparisons with other morphological modelling approaches for WP2.7 of FD2107 are reported by both Huthnance et al. (2007) and Norton et al. (2007).

In order to provide a more complete UK estuaries database, JNCC data for the main Scottish estuaries was added. This was followed by data for 110 Scottish sea lochs (*SSLoch2010*). This data was digitised from a report compiled by Edwards and Sharples (1986) for the Scottish Marine Biological Association, in collaboration with the NCC & NERC (PDF version provided by Richard Whitehouse, HR Wallingford). The Scottish sea loch data included: channel length (km), Spring Tide Range (m), maximum depth (m), surface area at high and low water (km^2), high and low water volumes, catchment area, annual rainfall, annual freshwater runoff, mean low water depth, Ratio of supplies of fresh & tidal water, Ratio freshwater to width (i.e. fjordic circulation theory; Long, 1975), flushing time estimates, and tidal prism volume.

The *EDB2012* and *SSLoch2010t* databases, plus some of the Analytical Emulator outputs, are provided in a Microsoft Excel Spreadsheet format file "EDB2012_SSLoch2010-v2-0_text-21Oct2012". The *EDB2012* database is separated into four worksheets: JNCC spring tides, ATT (Admiralty Tide Tables) spring tidal range, ATT mean tidal range and ATT neap tidal range. However it must be noted that only the *JNCC spring tides* datasheet includes all of the Future-Coast (F-C) and JNCC volumes and areas, as these were originally determined for JNCC mean spring tide conditions. The remaining three *EDB2012* datasheets derive their volumes and areas from the calibrated AE equations. This report refers to the current version, 2.0, of the *EDB2012* (as of October 2012). To provide flexibility in use, both the JNCC and F-C estuary reference numbering schemes have been listed. This expanded data-base was originally (2007) archived at the British Oceanographic Data Centre (BODC). We have placed a copy of the updated (2012) version at www.estproc.net.

Some aspects of the original FD2107 expanded data base were also incorporated within the *Simulator* developed by Kevin Morris of Discovery Software Ltd., for FD2117, and aspects of the ERP2 Dissemination project: FD2119.

1. Introduction

The UK's economy is significantly impacted by the effective functioning of its estuaries - for navigation, leisure, property development, flood defence and industry. The Defra has responsibilities for policy and regulations related to the management of proposed estuarine 'interventions' (engineering works, dredging, discharges etc) and long-term planning to accommodate climate change (FD2107 Consortium, 2004). Throughout the next 50 years Global Climate Change (GCC) is expected to significantly affect mean sea levels, storminess, rainfall and river flows, which will impact on future flood risk. Modified flood probabilities can be readily calculated by incorporating the various Global Climate Change scenarios into numerical models (Norton et al., 2007). However, the response for any particular estuary will be further modified by concurrent morphological adjustments arising, naturally (post-Holocene adjustments), as a consequence of GCC and via past and present 'interventions' (Prandle, 2004; Prandle, 2006).

To inform shorter-term management and longer-term strategic policy planning, improvements in the related forecasting capabilities are essential. Usually outcomes depend on hydrodynamics and on sediments, which underlie morphology, and affect both the ecosystem and water quality (Huthnance et al., 2007). However, the sediment regime is extremely challenging to predict.

Methods are needed to predict changes in estuary functioning and so improve ability to manage estuaries sustainably. Management to minimise flood risk and threats to habitats needs to be informed by accurate, reliable tools. However, well-validated tools (models) to predict estuarine behaviour have been lacking, especially for long-term morphological changes (Huthnance et al., 2007).

The UK Defra/EA Estuaries Research Programme (ERP) was formulated to develop techniques to predict large scale, long term morphological changes and the resulting sediment related impacts in estuaries (including water quality aspects) and assess their consequences for estuarine management (HR Wallingford, 1996; Pye, 2000; EMPHASYS consortium, 2000a, b). However, availability of good quality data is usually a major drawback when developing any new numerical estuarine model. A good source of physical data is particularly vital in calibrating and testing a long term predictive morphological model. Whitehouse (2001) noted that "It is rare for there to be adequate data for calibration and validation of morphological prediction methods" -reflecting the paucity and limited accuracy, resolution and coverage of most such data sets. Recognising the limitations of observational technologies, wide use is made of 'proxy' parameters often with complex calibration procedures.

It was therefore decided by the Defra funded FD2107 Project Consortium that in order to increase the availability and scope of UK estuarine physical data; this was part of Objective 4 in the project Inception Report (FD2107 Consortium, 2004). The project did not commission observational campaigns. The aim was to access data from:

(i) any planned observational campaigns concurrent with the project, and

(ii) existing data bases, perhaps requiring additional processing for present purposes.

Therefore to achieve this objective Dr Andy Manning (University of Plymouth & HR Wallingford) was contracted by FD2107 to improve and expand existing data sets, so that they could be applied to newly developed morphological models.

This report provides a detailed outline of a newly enhanced estuary database which comprises a wide array of both qualitative descriptive parameters and "generalised" quantitative physical estuarine parameters. The estuarine data within the database are referred to as "bulk properties." The new database compiled during

Defra project FD2107 by Dr Manning is referred to as the "*EDB2012*" in this report. Additional data for Scottish sea loch is referred to as the "*SSLoch2010*" in this report. In Section 2 of this report, a review of relevant literature and data sources is provided (including brief history of various earlier UK estuary databases), plus how a new estuary database could potentially be applied to a morphological modelling database.

An overview of the newly compiled *EDB2012*, and Scottish sea loch database *SSLoch2010*, is detailed in Section 3. This section includes: the qualitative descriptive parameters, the measured data, derived/calculated parameters, Analytical Emulator computed values, and future access & archiving of the database. The main findings and aspects of the database are summarised in Section 4.

2. Review of relevant literature and data sources

The first phase of the ERP was aimed at producing guidance on the techniques and methods that could be applied to predict changes to estuary functioning. These ERP1 findings were reported by the EMPHASYS consortium (2000b).

With respect to morphological modelling applications, EMPHASYS (2000a) showed that the expert analysis of data relating to morphological change is a key step in developing a credible understanding of the baseline situation. Whilst the analysis of available data may not yield sequential data sets that can be utilised for calibration purposes, the outcome of the analysis will form the basis of any verification of predictive and interpretative techniques that are employed.

Furthermore EMPHASYS (2000a) stated that the availability of good quality data will remain a key issue for the prediction of morphological change in estuary systems for many years to come. EMPHASYS (2000a) concluded that the collation of existing data and new data collection programmes will provide future generations with the valuable information which they will require to manage estuarine systems.

The FD2107 Inception Report (FD2107 Consortium, 2004) referred to "Data Requirements" for 'set-up, forcing, validation and assessment of models' together with sequences of: bathymetries, surficial and suspended sediments. The above data should pertain both to those estuaries selected for intensive studies (Blackwater, Humber, Thames, Tamar, Soton Water, Ribble, Mersey and Dee) and, in a more general sense, to as complete a range of UK estuaries as possible.

This data compilation would utilise information available from: EMPHASYS, Future-Coast, EstProc, JNCC typologies, and other such reliable sources. The FD2107 Inception Report (FD2107 Consortium, 2004) suggested that "Parameters of Interest" could be divided into "bathymetric" and "forcing" parameters. Estuarine bathymetric descriptive parameters of interest included: Depths, breadths, lengths, volume, surface/cross-sectional areas, tidal heights and currents, stratification/intrusion, suspended sediment distributions, geology, saltmarsh/intertidal habitats. Estuarine forcing parameters of interest include: Tidal heights, tidal currents, mean sea level, river flows, wind and waves.

2.1. Joint Nature Conservation Committee (JNCC)

In developing estuary management plans there was a need for baseline information on the natural estuarine environment and how it was being used. Information was needed both in detail for the estuary under consideration and more broadly, so as to set a particular feature or site in its wider national and international context. To provide this British national context as a baseline for the development of sustainable use objectives, the Nature Conservancy Council (NCC) undertook an Estuaries Review which was published as the report of: Nature Conservation and Estuaries in Great Britain. This was a national overview of estuaries, their conservation, wildlife diversity and their anthropogenic uses (Davidson et al., 1991).

The Davidson et al. (1991) overview was followed by the more detailed Joint Nature Conservation Committee (JNCC) reports entitled: An Inventory of UK Estuaries (Buck and Davidson, 1997). The JNCC is a forum through which the three country agencies: the Countryside Council for Wales, Natural England, and Scottish Natural Heritage, deliver their special statutory responsibilities for Great Britain as a whole and internationally.

Much of the information presented in the JNCC inventory was collated between 1988 and 1991 during the work of the Estuaries Review Committee. Thus the inventory provides a “snap-shot” in time for the state of UK estuaries during the late 1980’s. The “Inventory of UK Estuaries” took the form of a series of standardised dossiers, taking each estuary (as defined by the Estuaries Review) in turn.

Each report gives a summary of the key features of interest or significance for estuary management from a nature conservation perspective. Inventories were published in six regional volumes (2-7), with an overview provided in volume 1:

- Volume 1: Introduction & Overview
- Volume 2: South-west Britain
- Volume 3: North-west Britain
- Volume 4: North and east Scotland
- Volume 5: Eastern England
- Volume 6: Southern England
- Volume 7: Northern Ireland

JNCC and NCC used a numbering scheme to identify each estuary. The Hayle Estuary on the north Cornwall coast is estuary number 001, and the estuaries were numbered consecutively working in a clockwise direction around the British coastline, ending at the Helford Estuary on the southern Cornish coast, which was JNCC/NCC number 155. The remaining eight UK Estuaries were located in Northern Ireland and were given JNCC/NCC reference numbers 156-163.

The JNCC & NCC data comprised the following estuarine quantities (units used in brackets); indications of their accuracy are provided:

- Surface Area (ha), Intertidal area (ha) and Salt Marsh area (ha) are rounded to the nearest 1 ha.
- Shoreline perimeter length (km) and Estuary Channel length (km) measurements have been rounded to the nearest 0.1 km.
- Spring Tidal ranges (m) were derived from high and low water Mean Spring Tides (MST) for the site closest to the defined estuary mouth, from Hewitt and Lees-Spalding (1988).
- Geomorphological classification type.
- Estuary Name.
- JNCC/NCC reference number.
- Centre Grid locations.

To illustrate how the JNCC data can be used to qualitatively and partly quantify different physical features of estuaries within a specific region, two examples will be used. The first from Volume 2: South-west Britain, and the second extracted from Volume 3: North-west Britain.

2.1.1. Volume 2: South-West Britain illustrative example

Volume 2 comprises 32 estuaries on the west coast of England and Wales, stretching from Land's End in the south, through to the Great Orme in North Wales. The estuaries on this coastline include: the few on the mainly rocky north Cornish coastline; the estuarine complexes in the Bristol Channel and South-west Approaches; the nine river estuaries flowing into the broad sweep of Cardigan Bay; the inlets and tidal flats fringing the Menai Strait; and the estuaries and embayments on the north and west coasts of Anglesey and North Wales. The sheltered rias and other tidal inlets/estuaries of the south coast of Devon and Cornwall are covered in Volume 6: Southern England, of the inventory series.

Half the estuaries in the Volume 2 region are predominantly bar-built types, with a smaller number of embayments, coastal plain estuaries and rias. All estuaries along this south-west British coast are macrotidal (range is greater than 4m; Davies, 1964). The smaller tidal ranges are found within Cardigan Bay (< 4.5m on MST). Whilst the Volume 2 region includes the 12.3m MST range residing in the Hypertidal (Davies, 1964) Severn Estuary (JNCC No. 007) – the largest tidal range of any estuary in Britain.. Furthermore, demonstrating an area of 55,700 ha, the Severn Estuary is the largest single estuary in the region.

Most of the Volume 2 region estuaries are shallow, reflecting the largely depositional nature of the coast, and this feature is most marked on the Cardigan Bay coastline where there are also large shallow subtidal features stretching several kilometres offshore. The only deep estuaries in the south-west British region are the Severn, Milford Haven (JNCC No. 015) and Loughor Estuary (JNCC No. 013).

2.1.2. Volume 3: North-West Britain illustrative example

Volume 3 covered the 33 estuaries on the north-west coast of Britain between the Great Orme in North Wales and Cape Wrath on the north coast of Scotland. The Volume 3 estuaries fall mainly into two groups. In the southern part of the region are the river estuaries and embayments from the Dee Estuary (JNCC No. 034) to the Solway Firth (JNCC No. 041) and southern shoreline of Dumfries and Galloway (to the north). The coastline comprising Liverpool Bay to Solway Firth includes a succession of large estuaries. In contrast, north and west of Luce Bay (JNCC No. 046) the coastline is formed mostly of older, harder rocks with landforms strongly influenced by glaciation. Here coastlines are strongly indented and large areas of soft sediments are scattered amid the tidal embayments and sea lochs of shores that are predominantly rising relative to sea level (Buck and Davidson, 1997).

Eighteen estuaries in the northern part of the North-west Britain region are of fjord or fjard geomorphological classification. Whereas most of the estuaries in the southern part are coastal plain types, where the tidal ranges tend to be the highest – mostly macrotidal (range is greater than 4m; Davies, 1964); the largest being the Mersey Estuary (JNCC No. 035) which exhibits a MST range of 8.9m at the mouth. There is a general trend for the tidal ranges to decrease northwards, where the estuaries are mainly mesotidal, where the tidal range varies between 2 and 4m (Davies, 1964). The largest estuaries in this north-west region are Morecambe Bay (45,462 ha; JNCC No. 038) and the Inner Solway Firth (42,056 ha). The other large estuaries (over 5,000 ha) are located within Liverpool Bay.

2.2. Marine Nature Conservation Review (MNCR)

The Marine Nature Conservation Review (MNCR) was initiated by the Nature Conservancy Council in 1987 as the third major resource survey, following the Nature Conservation Review. Since 1991 the MNCR was undertaken with the Support Unit of the JNCC.

The MNCR draws together information on marine ecosystems around Great Britain with the objectives of:

- extending the knowledge of benthic marine habitats, communities and species in Great Britain, particularly through description of their characteristics, distribution and extent; and
- identifying sites of nature conversation importance.

The data collected also provides information to support more general measures to minimise adverse effects of development and pollution, particularly on sites and species of nature conversation importance (Moore et al., 1998).

The area included in the MNCR was the coastline of England, Scotland and Wales, extending on the shore from the lower limit of terrestrial flowering plants and within marine inlets from the limit of marine influence out to the limit of British territorial seas. Saline lagoons were also included. The MNCR included a major field survey programme of the shores and near-shore subtidal zone, undertaken to standard methodology. These studies were reported in the: "Coasts and Seas of the United Kingdom – MNCR series" as survey area summaries, each of which provides an account of a discrete stretch of open coast, marine inlet or a lagoon within each area of study.

The MNCR series were published in fifteen regional volumes which corresponded to "sectors" as follows:

Sector 1: Shetland Sector 2: Orkney Sector 3: North Scotland

Sector 4: East Scotland Sector 5: South-east Scotland / north-east England

Sector 6: Eastern England Sector 7: Eastern Channel

Sector 8: Western Channel Sector 9: Bristol Channel and approaches

Sector 10: Cardigan Bay and north Wales

Sector 11: Liverpool Bay and the Solway Sector 12: Clyde Sea

Sector 13: West Scotland Sector 14: Outer Hebrides

Sector 15: North-west Scotland

Each "area" (i.e. estuary, tidal inlet, etc) summary included in the MNCR series contained the following sections: Location, Marine biological surveys, Physical Features, Marine biology, Nature conservation, Human influences, References and further reading, and Sites surveyed.

Of particular interest to project FD2107, the "Physical Features" section comprised:

- the type of physiographic feature as defined in Connor and Hiscock (1996) or, for estuary types, in Davidson et al. (1991);
- the area of the estuary inlet, taken from Buck and Davidson (1997);
- the length of the estuary inlet measured from the relevant 1:50,000 Ordnance Survey map or Admiralty chart, taken from the mouth of the estuary inlet to the limit of tidal influence;
- the bathymetry, summarised from Admiralty charts;
- wave exposure and tidal streams taken from Admiralty charts and field observations, as defined in Connor and Hiscock (1996);
- tidal range figures stated are for the mean spring tidal range, quoted for the nearest secondary port, and taken from Buck and Davidson (1997);

- and the salinity intrusion length/extent/range was either: estimated at the time of the survey, or given as values previously reported in available literature. The descriptive salinity categorisation of Connor and Hiscock (1996) was used to categorise the salinity structure of each estuary/inlet.

2.3. Future-coast

Following the joint MAFF / Welsh Office publication of a flood and coastal defence strategy for England and Wales in 1993, coastal managers and decision makers were encouraged to work together in coastal groups to develop Shoreline Management Plans (SMPs). The first round SMPs represented a significant step forward in long-term strategic planning. However comparative reviews of some of the 49 SMPs indicated considerable inconsistencies in the consideration given to coastal processes, geomorphology and the prediction of future coastal evolution. Furthermore, there was often a lack of appreciation of long-term shoreline evolution and therefore insufficient use of such knowledge as a basis for identifying sustainable shoreline management policies (Future Coast Consortium, 2002).

In order to help guide the second round of SMPs, which started in 2002, the Department for Environment, Food and Rural Affairs (Defra) and the National Assembly for Wales collaborated in the promotion of a coastal process and geomorphological study of the coastline, known as FutureCoast. The Future-Coast - Prediction of Future Coastal Evolution for SMP Review - study was commissioned by Defra and carried out by a team led by consultants Halcrow Group Ltd over a period of 21 months. The study provided predictions of coastal evolutionary tendencies over the next century, which are to be considered in the updating of SMPs and other Strategic Plans targeted at determining broad scale future coastal defence policy throughout the open coast shorelines of England and Wales (Future Coast Consortium, 2002).

The results of the study were distributed to coastal defence operating authorities on a CD in October 2002. The main outputs from this research comprised a ‘toolbox’ of supporting information and data that could be used in future assessments of shoreline behaviour – which included (1) the background thematic studies produced for this project and (2) additional data sets and information generated.

The Future-Coast database (Burgess et al., 2002) comprised the main parameters listed in the six volumes of the JNCC “Inventory of UK Estuaries” (Buck and Davidson (1997) and the NCC “Nature Conservation and Estuaries in Great Britain” (Davidson et al., 1991) for 96 English and Welsh coast estuaries. Future-Coast adopted an alternative reference numbering scheme to the JNCC system, whereby F-C number 001 was the Stour-Pegwell Estuary in Kent. The estuaries/inlets were numbered consecutively working in a clockwise direction around the English and Welsh coastline, ending at the Swale Estuary, which was F-C number 096 (Figure 1). Both JNCC and F-C numbers are used in the EDB2012.

The original Future-Coast data set was further enhanced (by Prof. K.R. Dyer) with the addition of estuary high and low water volume (original units = ha.m) estimates. Also values of Mean River flow (cumecs), and Estuary Mouth widths (m) were included on the Future-Coast CD. Much of the Future-Coast information was also provided as “mapped data” or was linked to maps. Included in these data sets were: cliff behaviour assessments, analysis of historic shoreline movement, uncertainty classification, plus data on nearshore wave conditions and climate change impacts.

2.4. ERP2 Classification

A descriptive estuary classification scheme was then designed by Townend (2005) during ERP2. This scheme was based on aspects of the original JNCC and Future-Coast data.

2.5. Scottish Marine Biological Association (SMBA)

Edwards and Sharples (1986) compiled a report for the Scottish Marine Biological Association, in collaboration with the NCC and NERC, which comprised data for 110 Scottish sea lochs. The SMBA report summarises the morphology of the principal sea lochs in north-west Scotland as an aid to their classification and comparison. The catalogue was primarily concerned with the physical features which influence the physical oceanography of the lochs, together with their marine chemistry and biology.

The Scottish sea loch data included: channel length (km), Spring Tide Range (m), maximum depth (m), surface area at high and low water (km2), high and low water volumes, catchment area, annual rainfall, annual freshwater runoff, mean low water depth, ratio of supplies of fresh and / or tidal water, ratio freshwater to width (i.e. fjordic circulation theory; Long, 1975), flushing time estimates, and tidal prism volume.

2.6. Application to morphological modelling

The Defra/EA funded project FD2107 “Development of Estuary Morphological Models” (Huthnance et al., 2007) addressed the development and application of: top-down, bottom-up, hybrid, inverse and analytical simulation models. These models were used to investigate the effects of long term morphological changes within UK estuaries. In particular the developed models were used to assess impacts of intervention and of global climate change on flood forecasting and associated defences and habitats. A brief outline of the typical range of model types in use is provided (also discussed by Whitehouse, 2001).

“Bottom-Up” (B-U) process-based models are mathematical (probably numerical), spatially-resolving and predictive (probably time-stepping); they use dynamical equations for hydrodynamics, sediment transport and evolution of the bed. Thus B-U models represent our basic understanding of the dynamics underlying morphology. However, their ability and stability for long-term predictions is doubtful. Whilst B-U numerical models can accurately reproduce water levels and currents in estuaries, simulation of sediment transport is more problematic. Moreover, errors accumulate in the evolving morphology; the validity of longer-term (decadal) simulations is uncertain. Net sedimentation depends on subtle and complex interactions, e.g. (i) bed roughness changes within tides, (ii) spring-neap variation in salt wedges, (iii) seasonal sediment supply and river flow, (iv) episodic river / storm surge events and (v) underlying bed structure.

“*Top-Down*” (T-D) approaches are generally 'rule-based' or derived from analyses of geomorphological data. They can derive either (i) from analysing observed long-term morphological evolution or (ii) from some whole-estuary regime concept such as volume, energetics, entropy etc. Examples are trend analysis; form characterisation; regime relationships; translation or “rollover” with rising sea level; accommodation space; sediment budgeting; tidal asymmetry; and equilibrium along-axis profile. Such approaches may be stable for long-term predictions but some are limited to their basis in data; the extent of valid extrapolation may be uncertain; they may lack a time-scale for evolution.

“*Hybrid*” approaches, such as the Regime-SHELL (Wright & Townend, 2006; Norton et al., 2007) aim to fill the spectral-gap and combine complementary T-D and B-U elements. Typically, an equilibrium state (T-D concept) constrains the form of evolution and is approached with rates given by B-U models. An inverse method uses bathymetries to infer “forcing” of bed evolution in a BU-based diffusion-type equation.

Other such morphological model frameworks currently being used include: Inverse approaches, Historic Trend approach, 2.5D approach, ASMITA approach, SANDTRACK approach, Realignment approach (see

Manning, 2012 and Huthnance et al., 2007 for further explanations of each of these morphological modelling types).

All of the previously listed model types require various types and quantities of data for implementation, calibration and verification stages of operation. However it is with the "Analytical" morphological modelling approach, that the newly expanded FD2107 database was aimed at facilitating. It was envisaged that this new database would provide a testing and assessment ground for the newly developed Analytical Emulator (Prandle, 2004; Manning, 2012). The Analytical Emulator (AE) is largely based on one-dimensional equations of axial momentum and continuity, and was originally derived by Prandle (2003). In contrast to the previously listed approaches, the AE operates in a more "generalised" manner and requires far fewer data inputs. A number of general rule-based morphological explicit expressions were derived by Prandle (2004) which included a description of estuarine depth in terms of the river flow and channel side slope.

3. Overview of Enhanced Database

3.1. Introduction

Objective 4 – "Data requirements" for Defra funded project FD2107, as listed in the Inception Report (FD2107 Consortium, 2004) were primarily concerned with expanding the original Future-Coast (F-C) database (Burgess et al., 2002). F-C was largely based on data from JNCC (Buck and Davidson, 1997; see sections 2.1 and 2.2), with the addition of tidal prism volumes. A descriptive estuary classification scheme was then added by Townend (2005) during ERP2.

It was anticipated that the newly enhanced "EDB2012" would provide a quantitative framework within which UK estuary data could be compared in its own right (e.g. Prandle et al., 2005; Prandle, 2006), whilst also providing sufficient data to implement/calibrate/test new analytical morphological models.

3.2. Scope of database & sources used

During FD2107 Data requirements 4, the existing Future-Coast database was augmented in the following ways by Dr Andy Manning:

- More detailed freshwater flows (seasonal statistics) from the Centre for Ecology and Hydrology digital river flow archives for 65 England and Wales coast estuaries.
- Saline intrusion lengths were estimated for most estuaries from literature reviews and Marine Nature Conservancy Review.
- Spring tide data from JNCC were used. Also spring and neap tide equivalent tidal ranges, based on tidal range information from the Admiralty Tide Tables, were added for all England and Wales estuaries.
- In addition, the main equations which comprise the Analytical Emulator model (see section 4.0), were coded by Manning (2012) and applied to the expanded FD2107 database.
- In order to provide a more complete UK estuaries database, JNCC general data for the main Scottish estuaries was added. This was complemented by SMBA data for 110 Scottish sea lochs. The Scottish sea loch database is referred to as *SSLoch2010*.

The new database was compiled during Defra project FD2107 by Dr Andy Manning and is referred to as the "*EDB2012*" in this report. This report refers to the current version, 2.0, of the *EDB2012* (as of October 2012).

3.3. Descriptive / qualitative data parameters

Both the JNCC / NCC and F-C estuary identification reference schemes were used to identify each estuary where possible. The JNCC / NCC scheme starts at estuary 001 which is the Hayle Estuary on the north Cornwall coast, and the estuaries are numbered consecutively working in a clockwise direction around the British coastline, ending at the Helford Estuary on the southern Cornish coast, which is JNCC/NCC number 155. Future-Coast adopted an alternative reference numbering scheme to the JNCC system, whereby F-C number 001 was the Stour-Pegwell Estuary in Kent. The estuaries/inlets were numbered consecutively working in a clockwise direction around the English and Welsh coastline, ending at the Swale Estuary, which was F-C number 096. The F-C estuaries are illustrated in Figure 3.1.

JNCC / NCC estuary names were used to identify each estuary / inlet. The general location of each estuary is described using the central Ordnance Survey grid reference coordinate.

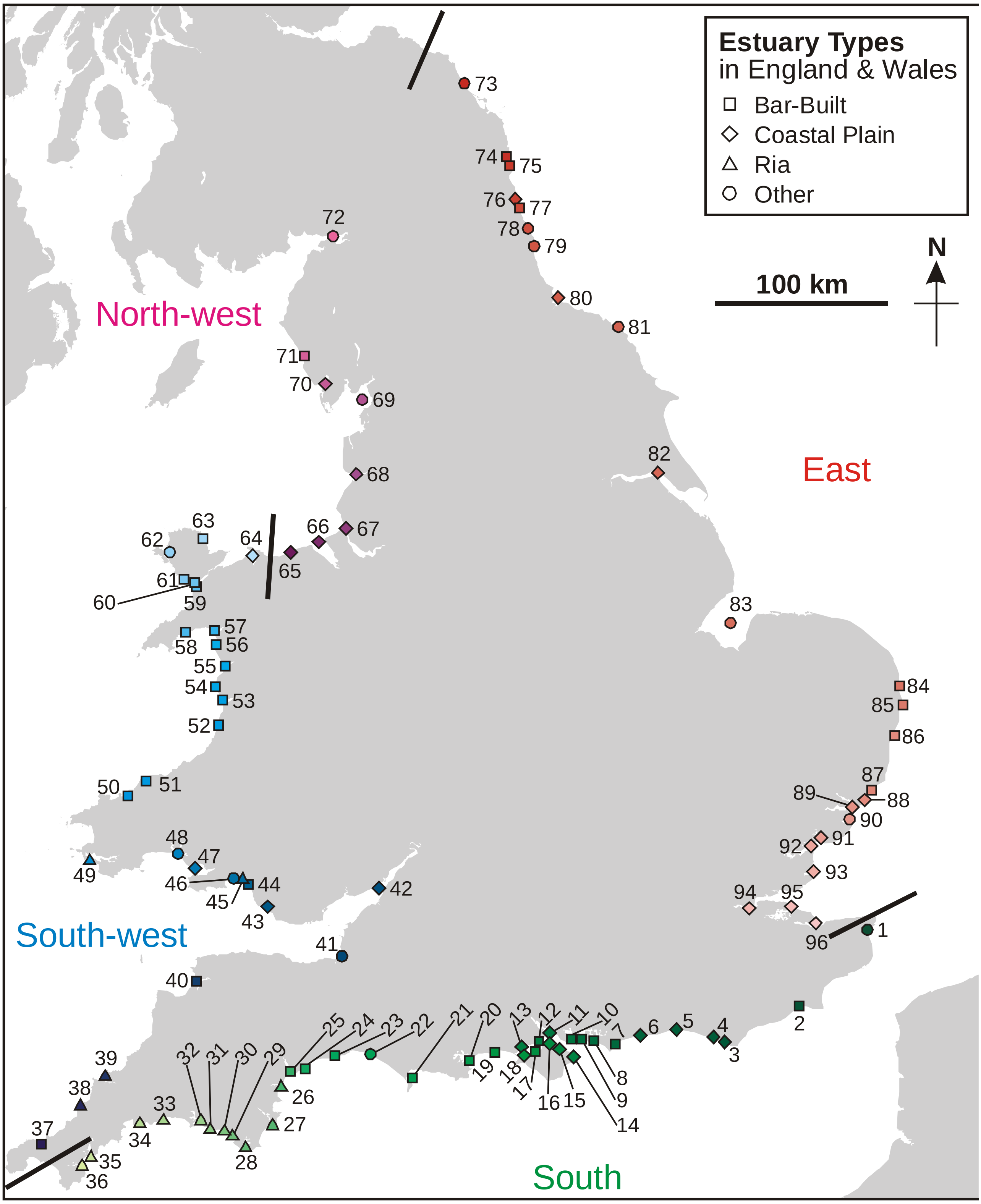
The geomorphological classification of each estuary is based on the scheme originally proposed by NCC (Davidson et al., 1991). The estuary types comprise: Fjords, Fjards, Rias, Coastal plain estuaries, Bar-built estuaries, Complex estuaries, Barrier beaches, Linear shore sites, and Embayments.

Further details on the ERP2 estuary classification scheme are provided by Townend (2005).

3.4. Physical data parameters

This data can be generally sub-classified as: lengths, areas, volumes and flows for the main EstDBFD2107 database, with additional data included for the Scottish sea lochs.

Figure 3.1: Map illustrating the location of the 96 England and Wales Future-Coast estuaries (from Prandle et al., 2006). Numbers refer to F-C estuary reference scheme (Burgess et al., 2002).



3.4.1. "Length" or "Height" type parameters

The various originally measured physical "Length" or "Height" parameters included:

Shoreline perimeter length (SP_{data}), channel length (L_{data}), spring tidal range (Z_{R_data}), and estuary mouth width (W_{mouth_data}). All "Length" or "Height" data are listed in metres, unless otherwise stated.

3.4.2. "Area" type parameters

The various originally measured physical "Area" parameters ("S" denotes plan surface area and "X" indicates cross-section area) included: S_{H_data} surface area at High Water; and S_{L_data} surface area at Low Water; S_{inter_data} surface area of intertidal zone; and $S_{saltmarsh\_data}$ surface area of saltmarsh zone. X_{CSM_data} is the cross-sectional area at the estuary mouth datum; $X_{CSM\text{-}half\_data}$ is the half-tide cross-sectional area at the estuary mouth. All "areas" are listed in m^2.

3.4.3. "Volume" type parameters

The various originally measured physical "Volume" parameters included:

V_{H_data} volume at High Water; V_{L_data} volume at Low Water; S_{H_data} surface area at High Water; S_{L_data} surface area at Low Water; and Z_{R_data} is the tidal range (spring or neap) between HW and LW.

3.4.4. "Flow" type parameters

All flow parameters were reported in m^3s^{-1}.

Q_{data} = Mean River flow; Q_{low_data} = Mean low river flow; Q_{high_data} = Mean high river flow.

Q_{spring_data} = mean river flow averaged over March-May
Q_{summer_data} = mean river flow averaged over June-August
Q_{autumn_data} = mean river flow averaged over September-November
Q_{winter_data} = mean river flow averaged over December-February

$Q_{low\text{-}spring\_data}$ = low river flow averaged over March-May
$Q_{low\text{-}summer\_data}$ = low river flow averaged over June-August
$Q_{low\text{-}autumn\_data}$ = low river flow averaged over September-November
$Q_{low\text{-}winter\_data}$ = low river flow averaged over December-February

$Q_{high\text{-}spring\_data}$ = high river flow averaged over March-May
$Q_{high\text{-}summer\_data}$ = high river flow averaged over June-August
$Q_{high\text{-}autumn\_data}$ = high river flow averaged over September-November
$Q_{high\text{-}winter\_data}$ = high river flow averaged over December-February

3.4.5. Scottish sea loch parameters

The SMBA Scottish sea loch measured data (Edwards and Sharples, 1986; units if different from previously stated in brackets) included: channel length (km), spring tide range, maximum depth below Chart Datum, surface area at high and low water (km^2), high and low water volumes (10^6 x m^3), catchment area (km^2).

3.5. Derived / calculated physical data parameters

This section outlines some of the parameters which were determined from further processing/ computational analysis of combinations of other parameters from the $EstDB_{FD2107}$ database although the calculation of many other parameters is possible.

3.5.1. Estuary depth and width parameters

The mean estuary depth (D_{data}) was calculated from the following parameters available from the F-C database: V_{H_data} volume at High Water (HW); V_{L_data} volume at Low Water (LW); S_{H_data} surface area at High Water; S_{L_data} surface area at Low Water; and Z_{R_data} is the spring tidal range between HW and LW.

D_{data} was calculated as follows:

$$D_{data} = 0.5 * (D_{HW\_data} + D_{LW\_data}) \quad (3.1)$$

where D_{HW_data} and D_{LW_data} are the estimated high and low water derived depths at the mid-tide phase (note: this derivation assumes a triangular estuary cross-section for each estuary):

$$D_{HW\_data} = 2 * (V_{H\_data} / S_{H\_data}) – (Z_{R\_data} / 2) \quad (3.2a)$$

$$D_{LW\_data} = 2 * (V_{L\_data} / S_{L\_data}) + (Z_{R\_data} / 2) \quad (3.2b)$$

Other techniques were used for estimating the average estuary depth (Ddata), representative of Mean Sea Level (MSL) conditions from the database, however Eqn 3.1 proved the most robust approach (Prandle, 2006).

Corresponding values for the average estuary width (Wdata) at Mean Sea Level conditions were calculated using Eqn 3.3, which utilised the same estuary surface area and length values used to estimate the MSL depth

$$W_{data} = (S_{H\_data} + S_{L\_data}) / (2 * L_{data}) \quad (3.3)$$

3.5.2. Tidal amplitude parameter

Z_{data} is the mean tidal amplitude and was estimated for the JNCC data using Eqn 3.4a.

$$Z_{data} = Z_{R\_data} / (2 * 1.55) \quad (3.4a)$$

The ratio 1.55 is representative of the ratio between maximum and average tidal range, reflecting typical values for M_2, S_2 and N_2 tidal constituents around the UK coast (Prandle et al., 2005).

For the Admiralty Tide Tables data (see section 3.5.5), the mean tidal amplitude (Z_{ATT}) was calculated using Eqn 3.4b.

$$Z_{ATT} = Z_{R\_ATT\_data} / 2 \quad (3.4b)$$

3.5.3. Estuary side slope parameter

From the estimates of mean estuary depth and channel width outlined in Section 3.6.1, and by assuming a triangular estuary cross-section for each estuary, it was possible to make estimates of the mean estuary side slope using simple trigonometry as described in Eqn. 3.5:

$$a_{data} = 2 * D_{data} / W_{data} \tag{3.5}$$

3.5.4. Estuary tidal prism parameter

The tidal prism (V_{TP_data}) in an estuary is defined as the volume of water residing between the low water and high water marks. The V_{TP_data} is particularly important for estuary flushing time and residence time determination and was calculated from the database as follows:

$$V_{TP\_data} = V_{H\_data} - V_{L\_data} \tag{3.6}$$

3.5.5. ATT tidal ranges

A corresponding tidal range data subset was produced using values of spring ($Z_{R\text{-}sp\text{-}ATT\_data}$) and neap ($Z_{R\text{-}np\text{-}ATT\_data}$) tidal range, plus the mean tidal range ($Z_{R\text{-}mn\text{-}ATT\_data}$) all derived from the Admiralty Tide Tables. The orbits of the Earth and Moon are periodic with respect to the Sun, which means the observed water level may be calculated as a combination of independent waves, where each wave has its own characteristic frequency, amplitude, and phase. Each wave is considered to be a constituent of the overall observed tide. The tide height is calculated as the sum of all the individual waves at any one time.

The spring ($Z_{R\text{-}sp\text{-}ATT\_data}$) and neap ($Z_{R\text{-}np\text{-}ATT\_data}$) tidal range were calculated using Eqns 3.7a and 3.7b representatively (reproduced here with some minor changes to subscripts from the 2007 version):

$$Z_{R\text{-}sp\text{-}ATT\_data} = (2 * M_2) + (2 * S_2) \tag{3.7a}$$

$$Z_{R\text{-}mn\text{-}ATT\_data} = Z_{R\text{-}ATT\_data} - (2 * S_2) \tag{3.7b}$$

In fact Eqn 3.7b calculates the mean tidal range and in its place the neap range should have been calculated as follows:

$$Z_{R\text{-}np\text{-}ATT\_data} = (2 * M_2) - (2 * S_2) \tag{3.7c}$$

We recommend this is checked by users of the neap tide database.

Values of the lunar and solar harmonics, M_2 and S_2, were obtained from the closest Admiralty tide gauge to the respective estuary. M_2 is the principal lunar semi-diurnal constituent, which represents the rotation of the Earth with respect to the Moon; whilst S_2 is the principal solar semi-diurnal constituent (this represents the rotation of the Earth with respect to the Sun). Corresponding values of Z_O were also included; this is the elevation of mean sea level of the port above Chart Datum (i.e. a local value).

3.5.6. Scottish sea loch parameters

The SMBA Scottish sea loch calculated data (Edwards and Sharples, 1986; units if different from previously stated in brackets) included: annual freshwater runoff (10^6 x m^3 per year), mean low water depth, ratio of supplies of fresh and tidal water, ratio freshwater to width (i.e. fjordic circulation theory; Long, 1975), flushing time estimates (days), and tidal prism volume.

4. Analytical Emulator (AE) derived data parameters

The Analytical Emulator (AE) was originally derived by Prandle (2003). The main equations have been coded by Dr Andy Manning during Defra project FD2107 (Manning, 2012). A number of general rule-based morphological explicit expressions were derived by Prandle (2004) which included a description of estuarine depth in terms of the river flow and channel side slope. Furthermore, the AE can provide estimates of: saline intrusion length, estuary flushing time, in-filling times, and a time and depth averaged SPM concentration. The Analytical Emulator provides an inter-connecting perspective, indicating, in a generalised manner, how changing tides, sea levels, river flows and sediment supplies yield differing 'equilibrium' conditions for different estuaries.

The Emulator is largely based on one-dimensional equations of axial momentum and continuity (Prandle, 2004, 2006). It assumes (as commonly observed) that tidal amplitudes are uniform along the estuary. On this basis, Prandle (2004) found that changes of phase, along-estuary wave-number and current U are functions of the tidal range Z_R and estuary depth D (also friction coefficient and tidal frequency, but these may be considered as uniform between the estuaries considered). In turn, along-estuary change of depth $\partial D/\partial x$ (proportional to change of phase) is a function of the tidal range and estuary depth. Hence estuary length is also a function of the tidal range and estuary depth (by integrating $\partial D/\partial x$ to where D=0). Saline intrusion length is related to depth, bed roughness, current U and river flow Q_f. Its location and confinement within the estuary then lead to a relation (Prandle, 2004):

$$D_{Estuary\ mouth} = 12.8\ (Q_{data}\ a)^{0.4} \qquad (4.1)$$

where a is the side-slope of the estuary (triangular cross-section assumed). Thus the emulator partly explains how estuarine bathymetries have developed in response to tidal and riverine inputs (Prandle et al., 2006).

Using the previously described AE theory, it was possible to use the EDB2012 database to compute AE estimated parameters, which could later be compared directly to the actual data. A few examples of AE computations are given below. A comprehensive outline of the application of the EDB2012 database to the AE during FD2107 is provided by Manning (2012).

4.1. AE estuary bathymetric parameters

The Emulator assumes that the actual estuary length L_{data} (taken from the *EDB2012* database) and mean side slope a_{data} (so calculated) remain constant. The assumed constant single side slope (everywhere in the estuary) involves a compromise between correct volumes or areas at HW, LW or intertidal; in general not all of these can be correct. An average estuary channel depth D_{data} was computed for a specific estuary; the emulator-derived D_{AE} was equated to D_{data} by choice of the calibration coefficient *M,* so providing a good starting position. M typically varies between 0.1-4.7 for *EDB2012*. Therefore the modified version of Eqn 3.9 derived by Manning (2012) is Eqn 4.2 which allows time-averaged river flow Q_f input values to estimate the average estuary depths D_{AE}:

$$D_{AE} = 12.8\ M\ (Q_f * a_{mean})^{0.4} \qquad (4.2)$$

D_{AE} is equivalent to a mean sea level (MSL) datum above the estuary bed. This allowed the emulator equations for the channel width (W_{AE}), D_{AE} and associated channel bathymetry, to be solved reasonably accurately (i.e. at a 95% level of statistical confidence).

The following demonstrate examples of the equations (4.3-4.6) used to compute mean estuary Width, Area, Volume and Depth at low water (denoted with subscript LW), respectively.

$$W_{AE\_LW} = (2 * D_{AE\_LW}) / a_{data} \quad (4.3)$$

$$A_{AE\_LW} = L_{data} * W_{AE\_LW} \quad (4.4)$$

$$V_{AE\_LW} = (A_{AE\_LW} * D_{AE\_LW})/2 \quad (4.5)$$

$$D_{AE\_LW} = D_{AE} + (Z_{R\_data} /2) \quad (4.6)$$

Similar equations are used to determine these dimension at high water (denote with subscript HW). The tidal prism is the difference between V_{AE_HW} and V_{AE_LW}.

4.2. AE SPM concentration parameter

Once the bathymetry is correctly calibrated, the AE theory permits the estimation of the suspended particulate matter (SPM) concentration. This is a temporally and spatially (depth) averaged value C_{AE} (units = gl^{-1}), obtained from Eqn 4.7:

$$C_{AE} = [\gamma * \rho * f (U_{AE}^{2} / 2)] / (D_{AE} * \alpha) \quad (4.7)$$

where γ is a sediment erosion coefficient typically taken as ~0.0001 $m^{-1}s$ (Prandle et al., 2001), ρ is the mean water density (usually a value selected between 1000 and 1025 kgm^{-3}), f is the bed friction coefficient (a typical value is ~0.002). α^{-1} is the half-life of sediment particles in suspension, which Prandle (2004) shows can be related to the time- and depth-averaged particle (floc) settling velocity (Ws; taken as 0.001 ms^{-1} for the FD2107 analysis) and eddy diffusivity (Kz) by:

$$\alpha = (0.7 * Ws^{2}) / Kz \quad (4.8)$$

and

$$Kz = 0.002 * U_{AE} * D_{AE} \quad (4.9)$$

Half-life values typically ranged between 2 hours and 30 hours for the UK estuaries in the enhanced Future-Coast database, whilst Kz values spanned an order of magnitude from 0.002 – 0.02. U_{AE} is the tidal current amplitude and its computation is discussed in the next section.

4.3. AE residual river flow velocity parameter

By assuming a triangular estuary cross-section with a constant side slope a_{data}, Prandle (2004, 2006) showed that the river flow (Q_{data}) into an estuary was a function of both the mean estuary depth (D_{AE}) and the residual freshwater flow speed ($\mathbf{U_{o\_AE}}$):

$$Q_{data} = \mathbf{U_{o\_AE}} * D_{AE}^{2} / a_{data} \quad (4.10)$$

This equation (4.10) can therefore be re-arranged to provide an estimate of $\mathbf{U_{o\_AE}}$ as follows:

$$\mathbf{U_{o\_AE}} = Q_{data} * a_{data} / D_{AE}^{2} \quad (4.11)$$

4.4. AE estuary flushing time parameter

The $\mathbf{FT_{AE}}$ computed by the Analytical Emulator equations define the flushing time as the time to replace half of the salinity content by freshwater over the saline intrusion length (L_{i_AE}). L_{i_AE} is calculated by the AE.

Furthermore Prandle (2004) states that in the Emulator, $\mathbf{FT_{AE}}$ is a function of Tidal Amplitude (Z_{data}) and mean estuary depth (D_{AE}), which means that $\mathbf{FT_{AE}}$ can be written as:

$$\mathbf{FT_{AE}} = [(0.0013 * D_{AE}^{\ 2}) / (f * U_{AE} * U_{o\_AE}^{\ 2})] \qquad (4.12)$$

U_{o_AE} is the residual freshwater flow speed, with units of ms^{-1}. The computation of U_{o_AE} is detailed by Manning (2012). If SI units are used in Eqn 4.12, then dividing the solution by 86400 will convert an $\mathbf{FT_{AE}}$ time in *seconds* into a duration in “days” which is the generally used convention when referring to estuary flushing times.

5. Access and archiving of the database

The newly enhanced estuaries datasets from the FD2107 Estuarine Morphological Modelling project, *EDB2012* and *SSLoch2010* was originally jointly archived with the British Oceanographic Data Centre (BODC), currently based in Liverpool. BODC, as the national data centre for oceanographic data, has an interest in ensuring that the dataset is both advertised and archived safely for the long term.

The data is tabulated in Microsoft Excel format and was available on a self-contained dataset on CD-ROM or DVD. Supporting documentation (e.g. metadata, methods, calibrations, quality control information, publications) was included on the CD so that anybody using the data should have enough information at their fingertips, without needing to contact the project participants. The dataset was prepared by Dr Andy Manning for FD2107. BODC held this CD as a special dataset. This means that the data will not be added to its databases directly; rather it will hold the data in the same format that it is received. The data would, however, be archived (i.e. a backup made and a record that they hold it).

The advantages in lodging a copy with BODC included:

- A complete backup will be made, safeguarding the contents against loss. Our data archiving system follows stringent backup procedures
- We are a permanent point of contact, whereas project participants may be widely dispersed some years down the line
- BODC can advertise the dataset through online data inventories, such as EDMED (the European Directory of Marine Environmental Data), which will briefly describe the dataset and provide the contact points (e.g. BODC and a project contact point)
- BODC will log any requests received for the dataset, so projects can quantify and qualify who is using the data, even many years later
- BODC can send out a copy of the CD, with a licence agreement in place. This is straightforward for use as long as there is no charge involved, i.e. the data are free for research.

In addition to the BODC archiving, aspects of the FD2107 expanded data base were also incorporated within the Simulator developed by Kevin Morris of Discovery Software Ltd., for FD2117. A similar inclusion took place within the Defra “Estuaries Dissemination Project” FD2119 managed by Dr Richard Whitehouse (HR Wallingford); see www.estuary-guide.net.

Due to the size of the enhanced estuary database, the data is not tabulated in this report. We have placed a copy of this report and the current (2012) database at www.estproc.net.

6. Conclusions and Summary

Data requirements – Objective 4. for FD2107 were primarily based on expanding the original JNCC/NCC (data for 155 UK estuaries) database and Future-Coast (data for 96 English & Welsh estuaries) database (Burgess et al., 2002). The newly enhanced "*EDB2012*" database comprised:

- Estuary Surface areas, Intertidal areas, Salt Marsh areas, Shoreline perimeter length, Channel length, Spring Tidal range, Estuary Mouth width, and High Water (HW) & Low Water (LW) Volumes.
- More detailed freshwater flow (seasonal statistics) data was added from the Centre for Ecology & Hydrology archives for 65 England and Wales coast estuaries.
- Saline intrusion lengths for most estuaries from literature review and Marine Nature Conservancy Review.
- Neap tide equivalent tidal ranges (and derived parameters), based on tidal range information from the Admiralty Tide Tables, were added for all England and Wales estuaries. (Note comments related to Eqn 3.7 in this updated report)
- Mean estuary depths (D_{data}), which are equivalent to the mean sea level (MSL), were calculated for most estuaries using: $D_{data} = 0.5 * (D_{HW\_data} + D_{LW\_data})$, where D_{HW_data} and D_{LW_data} are the estimated high and low water derived depths at the mid-tide phase:

  $D_{HW\_data} = 2 * (V_{H\_data} / S_{H\_data}) – (Z_{R\_data} / 2)$

  $D_{LW\_data} = 2 * (V_{L\_data} / S_{L\_data}) + (Z_{R\_data} / 2)$

  (V_{H_data} = volume at High Water; V_{L_data} = volume at Low Water; S_{H_data} = surface area at High Water; and S_{L_data} = surface area at Low Water).
- Mean estuary breadth (B) values were calculated for most estuaries using: B = $(S_H + S_L)/2L$
- The average side-slope (*a*) of most England and Wales coast estuaries were determined using the following relationship: *a* = 2D/B
- The following dimensional parameters were added to the FD2107 data base: D at LW & HW, B at LW & HW, and Surface Area at LW & HW.

It was anticipated that *EDB2012* would provide a quantitative framework within which UK estuary data could be compared in its own right, whilst also providing sufficient data to implement/calibrate/test new analytical morphological models.

To-date aspects of the EDB2012 have been applied to the following case studies during FD2107: a comparison with estuarine morphological theory and the database of UK estuaries (Prandle et al., 2005); an assessment of dynamical controls on UK estuaries (Prandle, 2006); and redefining UK estuary typologies through the combined use of estuary morphology theory and FD2107 data (Prandle et al., 2006).

In addition, the main equations which comprise the Analytical Emulator (Prandle, 2004), were coded by Manning (2012) and applied to the expanded FD2107 EDB2012 database. The Analytical Emulator equation derivations are outlined by Prandle (2004). Details of the Analytical Emulator applications are reported by Manning (2012), whilst intercomparisons with other morphological modelling approaches for WP2.7 of FD2107 are detailed by both Huthnance et al. (2007) and Norton et al., (2007).

In order to provide a more complete UK estuaries database, JNCC data for the main Scottish estuaries was added. This was followed by data for 110 Scottish sea lochs. This data was digitised from a report compiled by Edwards and Sharples (1986) for the Scottish Marine Biological Association, in collaboration with the

NCC & NERC (PDF version provided by Richard Whitehouse, HR Wallingford). The Scottish sea loch data included: channel length (km), Spring Tide Range (m), maximum depth (m), surface area at high and low water (km^2), high and low water volumes, catchment area, annual rainfall, annual freshwater runoff, mean low water depth, Ratio of supplies of fresh & tidal water, Ratio freshwater to width (i.e. fjordic circulation theory; Long, 1975), flushing time estimates, and tidal prism volume. The Scottish sea loch database is referred to as the and *SSLoch2010*.

The *EDB2012* and *SLscot* databases, plus some of the Analytical Emulator outputs, are provided in a Microsoft Excel Spreadsheet format: EDB2012_SSLoch2010-v2-0_text-21Oct2012. The *EDB2012* database is separated into worksheets: JNCC spring tides, ATT spring tidal range, ATT mean tidal range and ATT neap tidal range. However it must be noted that only the *JNCC spring tides* datasheet includes all of the Future-Coast and JNCC volumes and areas, as these were originally determined for JNCC mean spring tide conditions. The remaining three *EDB2010* datasheets derive their volumes and areas from the calibrated AE eqns. This report refers to the current version, 2.0, of the *EDB2012* database (as of 21 October 2012). To provide flexibility in use, both the JNCC and F-C estuary reference numbering schemes have been listed.

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