DEPARTMENT for ENVIRONMENT, FOOD and RURAL AFFAIRS **CSG 15**

Research and Development

Final Project Report

(Not to be used for LINK projects)

Project title	Estuary Process Research Project
DEFRA project code	**FD1905**
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Executive summary (maximum 2 sides A4)

Overview of the new research on hydrobiosedimentary processes in estuaries

At the end of November 2004 the Estuary Process Research Project (EstProc) was completed successfully after 3 years of innovative research by the EstProc research team. The eleven partners[1] brought a multidisciplinary and complementary blend of estuary process knowledge and skills, analytical and numerical models, and insights into data analysis and interpretation. They brought both applied and academic perspectives, in all of the above.

The results are relevant to those with responsibility for the management of, and engineering works within, UK estuaries and related planning to ameliorate impacts from climate change. A variety of tools are used to evaluate the influence of engineering works on estuary morphology, water quality and ecology, and to make predictions of future changes. Improvements in the related science and technology which underpin our associated forecasting capabilities were identified to be necessary. To address this need the UK Estuaries Research Programme was established in 1997, comprising three phases extending over 10 years. The Phase 1 EMPHASYS project (1998-2000) included a critical analysis of the limitations of existing estuary process models alongside a review of top-down models. Following an appraisal of related progress, a series of prioritised R&D issues were identified in the Estuary Research Plan (project FD2115) for study in Phase 2. EstProc was commissioned to address the key R&D requirements in estuarine processes research.

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EstProc project FD1905, part of the Defra and Environment Agency Joint Flood and Coastal Processes Theme within Phase 2 of the UK Estuaries Research Programme (ERP2), delivered new results to address the research recommendations. Hence the project has delivered:

1. Innovative and fundamental research in estuarine hydrodynamics, sediments, and biological interactions; and,
2. Improved underpinning knowledge and sound scientific results for the estuary research community and end users.

The results of the research are applicable to all estuaries where hydrodynamic, sediment and biological parameters are considered to be present. The detailed work plan for EstProc built on the project Inception Report produced in September 2002 (Report FD1905/TR1).

Progress in the research was achieved through interdisciplinary work between the three main scientific areas listed in point 1 above, through the interaction of experts in computational modelling of estuaries, and other experts in estuary process research. Further advances were made through the interrogation and analysis of existing datasets collected within other research programmes. The EstProc work built on other projects and data sources including:

- Use of data from the EMPHASYS project FD1401 and the uptake project FD2110;
- Humber estuary SMP2;
- EC projects (especially COSINUS);
- UK projects (NERC programmes and research council funded studentships);
- NL projects (RIKZ programmes).

Collaborations in the research team typically spanned the following areas; the development of new theories, synthesis into conceptual and quantitative algorithms, assessments against established data sets captured via a metadata catalogue, and the evaluation of impacts of the new findings in estuary-wide models. The team examined the cross-cutting areas of:

- Estuary wide modelling;
- Tidal flat sedimentation;
- Mudflat-saltmarsh interactions; and,
- Morphological and physiotype (habitat) modelling.

The research results apply to all of the nine JNCC (Joint Nature Conservation Council) estuary morphological classifications to a greater or lesser degree. In some cases, empirical correlations will be relevant to the specific estuary on which the original data was collected, but will relate to other estuaries of that type elsewhere. Work on specific estuaries during EstProc enabled the new results to be implemented within whole estuary process models for the following estuaries:

- Mersey (POL);
- Humber (ABP/Delft);
- Thames (HRW);
- Southampton Water (ABP);
- Blackwater (HRW); and also,
- Tidal flat environments with 2D and 3D tidal flat process models (HRW, POL, PML).

A one-day open meeting to disseminate the research was held in London on 13th October 2004 to present the new results and to receive feedback from the estuary community. The meeting was successful in attracting attendees from Defra and a representative cross-section of the estuary research, engineering and management community. This provided an excellent opportunity for the project team members to share the new findings with the audience, to highlight and discuss the benefits of the research, and to indicate to them how to access the results. The team received feedback on the technical impact of the work, on applications / links to other work, and it also provided a useful forum to discuss and capture ongoing research needs. Key aspects of the discussion in the meeting were fed into the drafting of the final reports.

The research outputs comprise three technical reports describing integrated research results on hydrobiosedimentary processes in estuaries. The reports contain substantial new information and are as follows:

- FD1905/TR2 – Synthesis Report – containing an overview of the project achievements, example applications, a project bibliography and an update on the future research needs in this area.
- FD1905/TR3 – Algorithms and Scientific Information – containing all the algorithms and background information lying behind them. More than 30 algorithms are presented at various levels of development: New

concepts not tested/guidelines; those that build on existing literature and have been implemented and tested in specific cases; and, new algorithms which have been partially tested in EstProc. Many of the algorithms can be implemented directly into computational models.
- FD1905/TR4 – Metadata Report – containing a description of the project website (www.estproc.net) and of the datasets used in the project.

EstProc represents a continuum within the Estuaries Research Programme: It is clear that it has built on previous projects, adds value to existing scientific knowledge, and uses data collected in other programmes. The team has demonstrated that we are starting to see generality in biological aspects – and we have already taken steps jointly to reduce the complexity of the prevailing interactions to manageable descriptions for inclusion in estuary process and morphology models. Results have been presented which can be parameterised for whole estuary models. As a result the physical aspects of prediction to inform estuary management are improved. Also the work underpins and interacts with other ERP2 projects; it feeds new methods into project FD2107 on the hybrid modelling of estuary morphology and into project FD2117 on a new estuary simulator approach.

Scientific report (maximum 20 sides A4)

Integrated research results on hydrobiosedimentary processes in estuaries

The project has improved the basis of understanding of the physical and biological processes existing in estuaries, and the ways of representing them to achieve better modelling. This required the bringing together of the disciplines of hydrodynamics, sedimentation and biology, as a combined approach under one heading of hydro-biosedimentation. This emphasised the cross-coupling and feedback between the separate disciplines that drive processes and that have been defined by previous work to be crucial to making progress in this complex scientific area.

A two-pronged approach was taken to ensure progress over the whole field, and to facilitate the advances in each area at complementary rates:

1. A 'top-down' scientific approach that used general and often empirical results to explore the relationships between average, large-scale characteristics to provide fundamental insights into connections and dependencies, and produce conceptual models of how an estuary, or part of it, might develop in the long term;
2. A 'bottom-up' scientific approach that detailed the processes using rigorous equations, so that magnitudes and rates of change can be assessed; and,
3. Essential to this approach was the development of algorithms and the associated equations that can be used as modules within 'bottom-up' computational modelling approaches or desk-based calculations of estuarine processes.

Objectives

The main driver for EstProc was the need for innovative and fundamental R&D to:

(i) Stimulate scientific advances in prediction of estuary processes;
(ii) Enhance the effectiveness of model simulations; and,
(iii) Underpin the associated requirements of estuarine managers and engineers.

Ten research topics were mapped onto the three disciplines, which form useful categories for arranging the research, as follows:

- **HYDRODYNAMICS** – covering wave modelling, extreme events, sensitivity of inter-tidal zones, and representation of near-bed stresses;
- **SEDIMENTARY PROCESSES** – covering mixed sediments, vertical profiles, and detailed aspects of sediment transport; and,
- **BIOLOGICAL MEDIATION OF PHYSICAL PROCESSES** – covering biological process parameters, effects on erosion, and morphological impacts.

The work undertaken in each category is described in the following sections of this report. Each section presents the key aspects of the new scientific work and summarises the new algorithms that have been produced.

Results

The EstProc team completed work on the ten research topics, each one covering a detailed area of estuary processes which had been identified as requiring new developments in order to take the predictive capability forwards. To achieve this aim, as well as develop new understanding, the team produced more than 30 new algorithms for implementation in estuary models and related analysis. The new algorithms represent improved process knowledge and tools, where tools are both methods and models. The algorithms represent the component parts of physical processes relevant to estuary prediction and include linkages with the biology that is present in estuaries. The algorithms are at various stages of development as befits the level of scientific understanding and ability to formalise and implant that understanding; therefore some of the algorithms are presented as prescriptive step-by-step descriptions for immediate implementation whilst at the other end of the spectrum there are some which are purely at a conceptual stage of development.

The key results produced in each of the three categories are described below:

HYDRODYNAMICS

Wave Modelling

The development, application and assessment of the SWAN, TOMAWAC and parametric (US Shore Protection Manual) models in Liverpool Bay, the Thames, Dengie pensinsula (Thames) and Westerscheldt (NL), indicated their associated capabilities and limitations.

The gridded computational wave models SWAN and TOMAWAC have been developed so that they can be used for waves travelling into shallow water. This allows the relative importance of offshore waves and local estuarine waves to be estimated. This is a particularly important feature for the critical region of the estuary mouth.

The results showed that the simple parametric model is adequate for first-order incorporation of wave stirring in estuaries. This allows the variation in wave impacts, from high to low water and from exposed to lee coasts, to be readily assessed. Advances were made in the SWAN model by developing new approaches to include a quantifiable influence of saltmarsh vegetation on wave dissipation and propagation. The limiting wave height on saltmarshes was quantified from field data. In a coupled development, field measurements and modelling of the waves allowed examination of the effects of intertidal vegetation on waves and wave induced erosion. This led to the proposal of a modified (Collins) drag coefficient to include the effects of variable canopy structure. This enables consideration of the onshore-offshore effects of erosion, as well as the seasonal variations, though the need remains for developing existing methods to deal with patchiness and canopy thickness.

Extreme events

The role of extreme fluvial events associated with high freshwater flow were examined to see how they controlled saline intrusion and the position of the estuarine turbidity maximum for the Tamar and the Humber-Ouse estuaries. To comprehend the sensitivity of estuarine morphology to extreme events, an understanding of how existing morphology relates to prevailing factors such as tides, waves, river flow and sediment supply is necessary. New analytical theories were developed relating the size and shapes of (Coastal Plain) estuaries, to tides and river flow. By linking this theory to simplified descriptions of sediment mechanics, explanations for sorting, trapping and turbidity maxima in estuaries follow. Requisite conditions for estuarine stability indicate fall velocities of approximately 1 mm/s - in good agreement with the values found for settlement of sediment micro-flocs in the project.

Sensitivity of inter-tidal zones

New approaches were developed to allow direct implementation of saltmarsh creek systems in whole estuary models, thereby allowing improved representation of flows and storage on the higher margins of the estuary under extreme tidal levels. Techniques have been examined for coping with sub-grid effects, particularly when dendritic channels are present. One of the new techniques concentrated on schematising sub-gridscale effects, in particular 'dendritic drainage' channels as commonly observed in inter-tidal zones and capable of being picked out with surveillance by LiDAR. Another, a raster-based method, is attractive in that it gives gradual wetting and drying of grid cells, a situation that is both necessary, and difficult to achieve using other techniques.

Likewise the new algorithms for incorporating the impacts of vegetation over saltmarsh developed in the project allow for more realistic incorporation of the effect of vegetation on waves and currents. Indicative thresholds were established between the wave-induced energy density levels at the edge of saltmarsh and the range of transition features, comprising cliffs or slopes with mudmounds. Generic 2-D models were implemented and developed to study the sensitivity over inter-tidal or complete cross-sectional areas. These models utilise both Eularian and Lagrangian (moving particles) approaches. The random walk particle diffusion models have been used to simulate the changing field of suspended sediment concentration with spring-neap currents. This shows many of the features that can be observed in the field, and their dependence can be easily considered through changing such parameters as sediment settling velocity, and sediment erosion threshold and associated rate. The tools are well suited to initial exploration of wide-ranging sensitivity studies of impacts of engineering works and other forms of human intervention as well as Global Climate Change.

Work with simple estuary wide models has explored the dimensional properties of estuaries, and their relationship to tidal range and salt intrusion length. These will act as aids to interpretation of estuary morphological development with changing climate and sea level.

Existing ‘top-down’ approaches to predicting estuary morphology such as the O'Brien relationship, which assumes a simple connection between the estuary tidal prism, and cross-sectional area, have been investigated further for 92 British estuaries. It was found that though larger estuaries exhibited a small scatter about a mean line, small estuaries showed very large scatter. This could not be reduced by inclusion of river discharge into the relationship, but was probably created by the effects of reclamation, construction of jetties and dredging.

Near-bed stresses
A simplified method has been developed for defining the non-linear wave-current interaction, which agrees well with existing measurements, as well as more complex methods. This provides mean and maximum shear stresses over both rough and smooth beds, and will be easier to incorporate into operational models than existing methods. Existing theories limited to 'rough-turbulent' near-bed conditions were extended for application in both 'smooth-turbulent' and 'laminar' conditions appropriate to the resuspension of freshly deposited material. The algorithms were tested against both flume and field measurements and subsequently incorporated into estuary-wide models during the project.

Related studies have provided algorithms for the dynamic representation of sediment ripple formation by random waves. This is useful for estimating time variations in bottom friction and hence sediment transport.

The following summarises the new algorithms and information available for **Hydrodynamics** under each of the specific topics:

1. To improve the ***modelling of waves in estuaries;***
New understanding and a total of six new algorithms have been produced in this topic to deliver improved predictions of: waves in estuaries with parametric and computational model approaches, improved description of the interaction with saltmarsh vegetation, and determination of the limiting wave height on mudflats and saltmarsh.

2. To improve the prediction of the ***impact of extreme events and major anthropogenic influences;***
New understanding and a total of three new algorithms in this topic have been generated; including two approaches to predicting the flow in dendritic channels within the fringing flats and marshes of an estuary, and analytical methods for predicting the impact of changes in mean sea level, magnitude and frequency of storm events (surges, waves, river flow) and supply of sediments on estuary morphology.

3. To investigate the ***interrogation of existing data*** to extract further information, interrelationships and correlations between parameters;
A number of the algorithms in other topics have been driven from interrogation of existing data. Listed here is the new understanding associated with a total of three new algorithms including those derived from; estuary data for salinity, velocity, SPM and mudflat characteristics, effects of suspended sediment on turbulence within an estuarine turbidity maximum, and on the dimensional relationships for estuaries including tidal prism and river flow.

4. To improve the ***representation of near bed stresses;***
New understanding and a total of three new algorithms in this topic have been delivered covering; wave-current stresses generated on smooth and rough beds, the prediction of time varying physical roughness of wave ripples to feed into predictions of total bed shear stress, and on the calculation of bed shear stress in an annular flume for field measurements of bed erosion.

SEDIMENTARY PROCESSES

Mixed Sediments
Fundamental relationships have been established between the composition, i.e. clay:silt:sand ratio and the porosity/density of surficial sediments in estuaries. Approaches have been developed to predict their erosion rate for a given hydrodynamic forcing.

A major step forward has been achieved through consideration of mixed sediments. Previously it was not possible to relate, by simple means, the properties of mixed sandy muds with erosion characteristics, despite the observed constancy in the proportion of sand, silt and clay in different situations. This approach connects mud properties to traditional soil mechanics through simple measurements such as the Atterberg limits. Using these limits, together with the sand content and the dry density, it is possible to estimate the undrained shear stress, and the erosion threshold. The mud:silt ratio appears to remain sensibly constant in European estuaries-enabling a more accurate analysis of erosion rates to be determined from a knowledge of the sand fraction and associated 'liquid' and ' plasticity' indices; commonly determined geotechnical properties of sediment.

Vertical profiles
General-purpose tools for examination of localised processes, including analysis and interpretation of observations, were developed. A generic 1-D model was used to represent vertical variability at a specific point as an aid to interpretation and analysis of data. New analytical expressions for vertical profiles of suspended sediment were developed and these can be readily incorporated in models or used in desk-based analysis of estuary sediment transport.

Detailed aspects of sediment transport
The definition of the complex relationship between settling velocity and mass settling rate of flocculated sediment has been a contentious problem for years. Using a new field instrument in a series of field campaigns has given an accumulation of data on floc size, settling velocity and density. Data for a wide range of estuaries has been amalgamated in this project and algorithms produced. The algorithms quantify the effective settling rates as functions of turbulence intensity levels and suspended concentrations.

The algorithms have been implemented in estuary models and the sensitivity of both suspended concentrations and morphological evolution to these formulations has been explored. Application of the algorithms in conjunction with site observations in a variety of models has shown a vast improvement over use of a constant settling velocity, or one related only to sediment concentration.

For sandy sediments, additional sensitivities of erosion rates to the preceding time-sequences of both deposition and shear stress levels has been indicated. Flume measurements on sand have shown that the threshold of movement is affected by prolonged exposure of the bed to shear stresses slightly below the normally accepted value. This is due to a 'weathering effect', a similar effect has been documented previously for muddy sediments.

Existing 1, 2, and 3D models have been used to examine the relative importance of features commonly missing in operational models. In the Humber estuary it has been shown that predicted sediment transport rates increase from 2D to 3D homogeneous models, but that stratified models show the transport rate can be up to 60 % greater, because of the inclusion of vertical gravitational circulation. Similarly, in the Tamar estuary it has been shown that the secondary circulation produced by bends is important in determining the cross sectional topography. Modelling in the Thames estuary has demonstrated the differences obtained using different representations of sediment settling velocity. An improved comparison with the observed cross-sectional distribution of sediment concentration was found once the new algorithm was implemented.

The following summarises the new algorithms and information available for **Sedimentary Processes** under each of the specific topics:

1. To undertake further investigation into the ***transport of mixed sediments***, where mixed sediments includes sand, mud, gravel or shell mixtures and dredged material with sizes upward of 5 microns;
New understanding and a suite of new algorithms for predicting the transport of mixtures of clay, silt and sand under one heading in this topic, the characteristics of clay, silt, sand mixtures in estuaries with links to geotechnical properties and the erosion behaviour of such mixtures.

2. To expand the ***understanding of the sediment transport profile;***
New understanding and a total of three new algorithms in this topic have been present, including; a new analytical approach to sediment concentration in tidal flows including properties of the mud, an algorithm for the mass settling flux of cohesive sediments derived from data in a number of European and UK estuaries, and generic 1D and 2D sediment profile models based on a Lagrangian description of sediment transport for exploration of sediment transport, and morphology change, in estuaries.

3. To improve the ***understanding of general sedimentary processes*;**
New understanding and a range of seven new algorithms in this topic, including; sediment mixing in the water column and entrainment of fluid mud, on the role and impact of gravitational circulation on net sediment fluxes, on the prediction of density currents at moderate and large sediment concentrations, the role of conditioning of a sand bed by flows below the threshold of motion, a preliminary estimate of the role of day and night conditions on the stability of intertidal sandy

sediments, and on various approaches to bed updating in estuary morphological models, and finally an analytical framework for estuary hydro-sedimentary parameters.

BIOLOGICAL MEDIATION OF PHYSICAL PROCESSES

Relevant process parameters
The bioengineering effects in estuaries include biological mechanisms of enhancing sediment stability and net accretion such as:

- Sediment armouring, biofiltration / biodeposition (e.g. by mussel beds);
- Enhanced cohesion via excretion of extracellular polymeric substances (e.g. by microphytobenthos);
- Filamentous binding (e.g. by *Cladophora*); and,
- Reduction in near-bed flows, induction of skimming flow above vegetation, and wave attenuation (e.g. saltmarsh, seagrass beds, macroalgal mats).

And conversely processes responsible for the destabilisation and net erosion of sediments including:

- Bioturbation by surface deposit feeders (e.g. by clams);
- Increased near-bed turbulence due to increased bed roughness (e.g. by burrowing bivalves such as cockles);
- Grazing on bio-stabilisers (e.g. by *Hydrobia* snails on microphytobenthos);
- Faecal pelletisation of sediment (e.g. by *Hydrobia* snails);
- Enhanced buoyancy of biofilms (e.g. by oxygen bubbles);
- Active bio-resuspension (e.g. by mysid shrimps); and,
- Corrasion by saltating shells carried along by waves and currents.

While limited detailed predictors for incorporating biological mediation have been developed previously these are both species and site-specific. To derive more generic algorithms, the project attempted to identify Functional Group-wide impacts and to focus on observable indices such as: organic fraction, Chlorophyll-a and the interparticle “glue” formed by the extracellular polymeric substances or EPS produced by diatoms living and moving around in the sediment.

Effects on erosion and deposition
The studies have shown vegetation and biota can effect both stabilisation and destabilisation of surficial sediments as listed above through actions such as EPS production, burrowing and bioturbation. The consequent impacts on erosion and deposition rates can yield orders of magnitude reductions or increases over the abiotic case. Algorithms have been developed to make predictions of some of the key effects arising from some of the most common estuarine biota, and these have been presented in a form that can be implemented readily into computational models of estuarine processes. Such implementation has been completed in the project to demonstrate the useability of the algorithms and the nature of the effects produced.

Of great importance is the effect that animals have on the threshold of erosion for sediment. This has been revealed in flume experiments. Most animals are ecosystem engineers that modify their environment by their activities, but they can produce a variety of results, which have up until now confused rather than enlightened approaches. Some enhance erosion because of their disturbance of the near bed flows. Others cause stability as a result of binding the sediment, or protection by trapping the near bed water. Both effects can be seasonal, and are mediated by and are responsive to environmental variables such as temperature and light. The approach developed here depends upon a functional group concept. This means that the inter-species variations can be averaged, with the result that such devices as remote sensing can be used to quantify the biological variables. Spatial patterns in the macro-benthos have been defined, though the role of the multitude of the meiobenthos remains a problem for further investigation. Erosion thresholds and rates have been defined for many of the groups, and the results tested in models to examine dependencies and relationships.

Impacts on morphology
Colonisation by biota involves a wide range of time-scales, ranging from days for deposits of dredged sediments, to inter-annual timescales for climate-sensitive species, and to decades for sub-surface animals. Impacts of vegetation generally involve a strong seasonal cycle with maximum impact in late summer and autumn. Some of the estuary models applied in the project have been used to quantify the impacts of biological mediation on cross-sectional morphologies. The biota has an effect and that effect can now be included in models in a clearer way than was possible before.

The following summarises the new algorithms and information available for the **Interaction between Biological and Sedimentary Processes** under each of the specific topics:

1. To review and prioritise, at an early stage, the relevant ***biological process parameters*** that effect the stability, erodability and deposition of sediments;
New understanding and three algorithms, including; a flow chart methodology for making biological predictions, approaches for the predicting of the biostabilisation and destabilisation of sediments by biota including microphytobenthos/diatoms, the small clam *Macoma*, mussels, and the macroalga *Enteromorpha*, and on the objective definition of a biostabilisation index for field measurements.

2. To undertake investigations into the ***effect of biological processes*** on the stability, erodability and deposition of sediments. Format results for incorporation into existing models for morphological prediction and assess validity through use in different models;
The algorithms listed in 1 are directly relevant to this topic. Outputs here are relevant scientific information and two concepts; one for the relationship between the marsh edge configuration and incident wave energy, and the second assessing a relationship between distance from saltmarsh creeks and the sedimentation rate within vegetated areas.

3. To develop understanding of the ***impact of benthic life*** (primarily macrofauna) on performance of intertidal areas and the effect of the change in flow regime related to tidal stage.
The results in this area were of a review nature rather than new algorithms, but the project has collated and delivered reports on the current understanding of:

- Spatial patterns of estuarine macrobenthos assemblages: relationships with hydrodynamic regime;
- Sediment stability of fine-grained beneficial use schemes: the role of recolonising macrofaunal communities; and,
- The role of meiofauna in estuarine processes.

Application of sediment and biological results in models
As well as the wave modelling referred to earlier for Liverpool Bay, the Thames estuary, Dengie pensinsula (Thames) and the Westerscheldt (NL), during EstProc various of the bio-sedimentary results from the research were implemented within whole estuary process models for the following estuaries:

- Mersey (POL);
- Humber (ABP/Delft);
- Thames (HRW);
- Southampton Water (ABP);
- Blackwater (HRW); and also,
- Tidal flat environments with 2D and 3D tidal flat process models (HRW, POL, PML).

These pieces of work have been documented in the final report and associated reports and papers.

Conclusions
A large range of results have been delivered to satisfy the objectives of EstProc and provide new science and methods for use in assessment of estuary response to engineering activities, or other anthropogenic and natural pressures. At a general level the following specific highlights can be listed as key advances arising from the research:

- The delivery of new science and algorithms;
- The application of physics based biology in estuary models;
- The inclusion of wave-current interaction;
- The improved parameterisation of bed exchange mud/sand erosion, settling, sedimentation; and,
- The dynamical hypothesis for estuarine morphology, especially applicable to coastal plain estuaries.

The overall result of the project has been a step-change in our ability to recognise and simulate the processes we observe and measure in estuaries. There are three reports describing the outcomes of the project published under the title:

Integrated Research Results on Hydrobiosedimentary Processes in Estuaries

These are:

- FD1905/TR2 – Synthesis Report – containing an overview of the project achievements, example applications, a project bibliography and an update on the future research needs in this area.

- FD1905/TR3 – Algorithms and Scientific Information – containing all the algorithms and background information lying behind them. More than 30 algorithms are presented at various levels of development: New concepts not tested/guidelines; those that build on existing literature and have been implemented and tested in specific cases; and, new algorithms which have been partially tested in EstProc. Many of the algorithms can be implemented directly into computational models; and,
- FD1905/TR4 – Metadata Report – containing a description of the project website (www.estproc.net) and of the datasets used in the project.

As well as these three technical reports there is also a wide range of other papers and reports describing outputs from the project. The key ones of these are available along with the technical reports and more information about the project at the project website at www.estproc.net

As well as the October 2004 open science meeting organised by the project and held in London, the project manager presented a paper at the Defra conference in 2003, and project members have given presentations, papers and posters at other workshops and international conferences. The research was described in an extensive article prepared for Issue No 7 of the Flood and Coastal Erosion Risk Management Research News, the Newsletter of the Joint Defra and Environment Agency Flood and Coastal Defence R&D Programme in February 2005.

Our understanding of some crucial variables and their quantification has been dramatically improved, together with the concepts underlying our interpretation of the results of the computational models. Though we use the model results for predictive means in operational engineering and management applications, we need to continually evaluate and build on the sound scientific understanding and good field measurements to be able to have confidence in the predictions from models and their interpretation.

Ways Forward

As well as presenting recommendations for future research requirements to deliver further advances there are a number of other related factors that need to be considered in the way forward, which include further testing of the fully developed algorithms that have been produced as well as research to extend and apply those currently at a lower level of development. In the future we will need long-term field measurements of estuarine bathymetry, suspended sediment concentrations, and more data on the role of extreme events. The long-term measurements are required to identify subtle long-term responses that may be hidden in the errors in our shorter term measurements and in the assumptions and averaging inherent in the modelling.

On-going projects within the ERP, FD2116, FD2117 and FD2107 include elements that have exploited advances made in EstProc. Continuous assessment of the overall value of advances (reported by EstProc and elsewhere) is necessary. This involves incorporation of the new algorithms in a range of models, with applications probably concentrating on those estuaries identified in the ERP as having the most extensive observational data bases (‘recent’ and 'geological'). It is also important that the models are evaluated as they are developed to gauge how the inclusion of improved algorithms modifies their predictive capability.

Related challenges associated with implementation of the EC Water Framework Directive in UK estuaries pose both a challenge and opportunity to construct efficient long-term monitoring networks and predictive capability to support the statutory reporting cycle. These are essential in both this assessment of progress and to enable identification of the larger-scale, longer-term, higher-order, cross-disciplinary relationships that contribute to the evolution of estuarine morphology, and need to be incorporated in bottom-up models to encapsulate geomorphological processes.