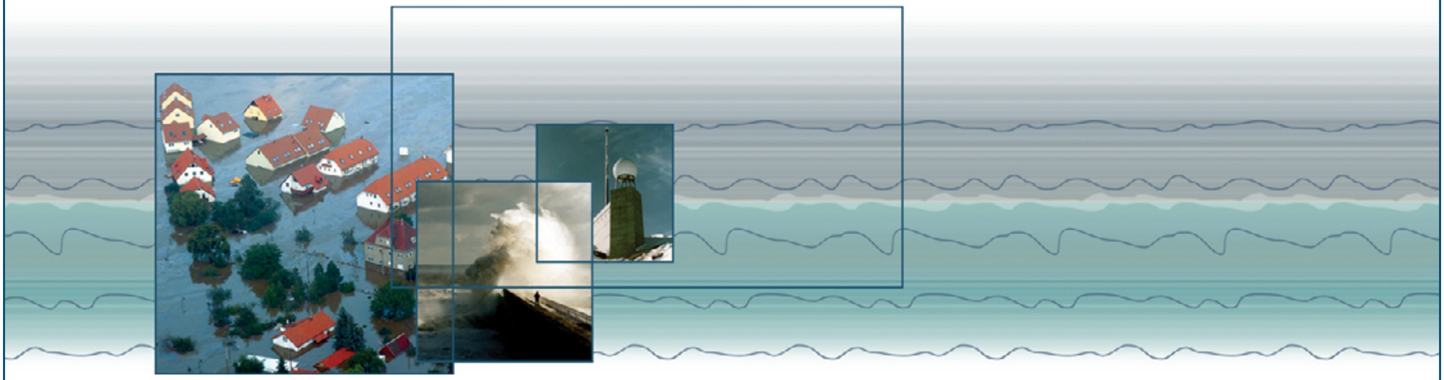
Integrated Flood Risk Analysis
and Management Methodologies



Predicting morphological changes in rivers, estuaries and coasts

EXECUTIVE SUMMARY

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RELATED DOCUMENTS

The full report to which this summary relates is available from the FLOODsite Project Website at http://www.floodsite.net/html/search_results.asp?documentType as Report Number T05-07-02.

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Executive Summary for Task 5

1. Scope of the research in Task 5

1.1 Introduction

Flooding occurs when there is a failure of a defence. This can arise from a functional failure (the conditions exceed those for which the defence was designed) or a structural failure (where some element or components of the defence do not perform as intended under the design conditions). The former arise from society's need to find a compromise between the cost of the defence and the consequences of a flood. Structural failures are generally more dangerous, as they are unexpected, and have been the source of recent notable flooding events. Two major causes of structural failure are: low freeboard leading to excessive wave overtopping of the defence leading to erosion of the back and crest of the defence, or even damage to the armour layers; and toe failure, where erosion of the foreshore at the base of the defence occurs to such an extent that the structure is undermined and collapses.

An example of scour at a seawall in Teignmouth after a severe easterly storm, showing beach lowering near the base of the structure. Beach levels in this photograph are approximately 2m below their 'typical' levels.

Wave overtopping of a seawall at Teignmouth on the main London-Penzance mainline. The overtopping resulted in the temporary closure of the mainline and extensive damage to sea defences along a large portion of the south and Southwest coastline.

Figure 1.1 Examples of beach lowering near the base of a seawall after a storm (left) and wave overtopping a seawall affecting major transport infrastructure (right)
This event was not particularly severe in terms of the wave heights but was estimated by regional authorities to have a return period of over 100 years, due mainly to its unusual surface wind direction, which was strong easterlies. (Photos courtesy of Prof D Reeve).

In **coastal areas** changes in beach morphology that can affect the propagation of waves up to a sea wall, and run-up and overwash of dunes. The assessment and design of sea defences, (including dune systems), often relies on a qualitative review of the morphological variability of the bed levels and slopes in front of the sea defence. During large storms it is not uncommon for beach levels to lower by several metres or more, with beach material being moved tens or hundreds of metres offshore. Such beach lowering will lead to an increase in the still water depth at a structure for a fixed tide level, and thus enable larger waves to reach the structure before breaking. This is a positive feedback mechanism, with beach lowering allowing larger waves to reach the structure. In turn larger waves create more lowering and the process continues. Storm surge is also important in determining water depth and depth-limited wave breaking in front of the structure. Wave set-up serves to amplify the effect. Furthermore, equations used to predict suspended load and bedload sediment transport under breaking waves are only approximate.

Dunes are particularly vulnerable to erosion, and if there are fixed assets (such as sites of special scientific interest) being defended by a dune system, active management may be required. Figure 1.2 shows an example of a dune system which has been subject to recent erosion due to storm waves during a high tide and surge event. A reliable means of predicting the rate of dune erosion under wave attack would be a valuable tool for coastal managers, as would a means of quantifying the amount of overwash to expect should the dunes be breached. Both these questions are addressed in the following sections.

Figure 1.2 Dune system (Dawlish Warren, Devon, UK) subject to erosion at its toe. (Photo courtesy of Prof D Reeve)

Therefore, this research was needed to improve our ability to predict the morphological evolution during the course of a storm through detailed analysis of coastal morphological processes and changes. In parallel with the process models, work was undertaken on two other directions. Firstly, to develop a stochastic description of beach level variations that could be used as part of a reliability assessment in a reliability analysis of the sort undertaken for hard structures (see Task 4). Secondly, to develop a modelling suite that could provide predictions on a ‘system-wide’ scale that is needed for strategic regional assessments.

In **fluvial and estuarine areas** the morphology is expressed in terms of planform, longitudinal profile and cross section and changes in these characteristics are driven by variations in discharge and sediment transport in rivers and, additionally, by tidal currents, density-driven currents, wind induced currents and waves in estuaries. The morphological response to these drivers is dependent on the boundary conditions of discharge, sediment load, valley slope and topography, channel roughness; the bed material, bank material and in-channel and bank vegetation. Rivers are constantly adjusting and evolving in response to the sequences of normal flow, flood flow and drought events which are associated with regional climate, local weather and catchment hydrology (Thorne, 1997). Likewise, estuary morphology adjusts constantly to the fluvial discharge regime, tides and waves.

There are a range of geomorphological classification systems which make qualitative links between channel process, form and stability. Thorne (1997) gives an overview of alternative theories on classifying channel morphology. The approaches for understanding channel morphology aim to relate the cross section, slope and/or planform to characteristics of stability, sediment type and valley landform. The literature also provides some debate about the evolution of morphology and styles of channel change.

In addition to morphological change induced by natural processes, the activities of people on the floodplain and their use and management of rivers and the water environment cause morphological adjustment. Human activities within the catchment and landuse change may influence the nature of the runoff regime and the sediment budget. The construction of embankments and flood defences on the floodplain influence the functioning of the natural river processes. Direct interventions in the channel such as the construction of structures, planform modifications and bed and bank stabilisation measures influence the fluvial geomorphological processes while the capital works are being carried out and following the works. Channel maintenance activities such a dredging and vegetation cutting also influence the natural processes and will result in modifications to the natural channel morphology.

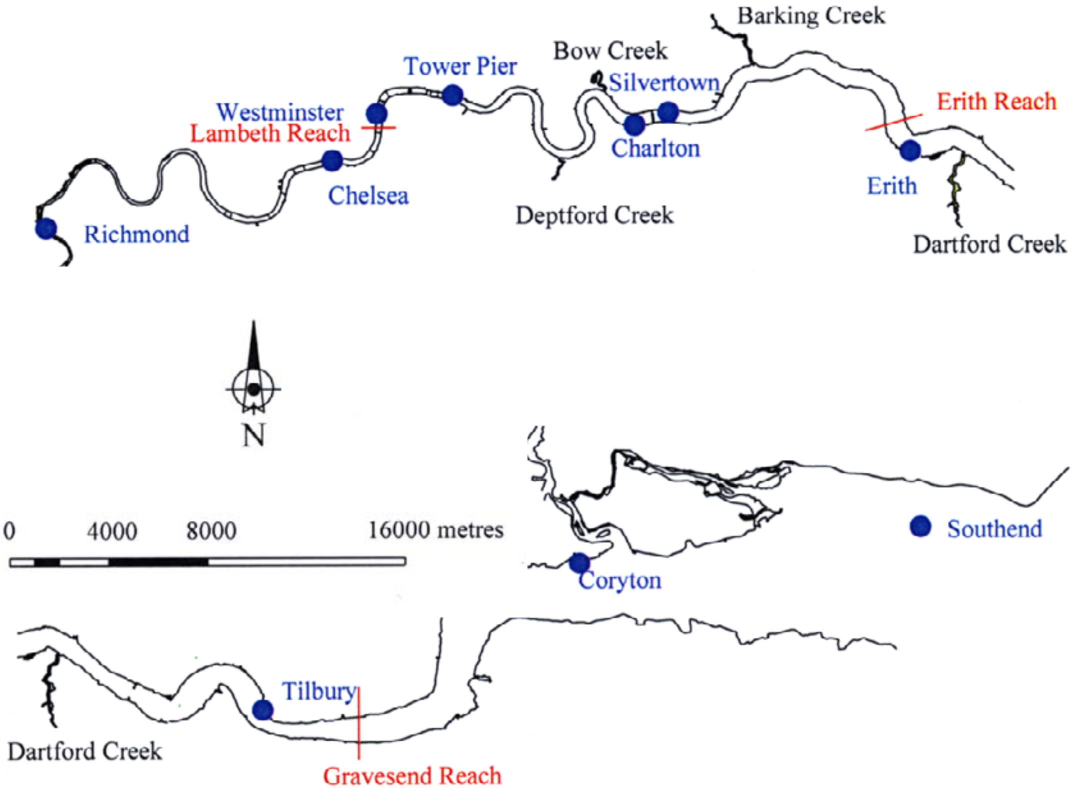


Figure 1.3 Location plan of the Thames Estuary and River, one of the pilot sites.

Morphological changes in river planform are not just a function of hydraulics but can also be influenced by the underlying geology, as can be seen in Figure 1.4 below.

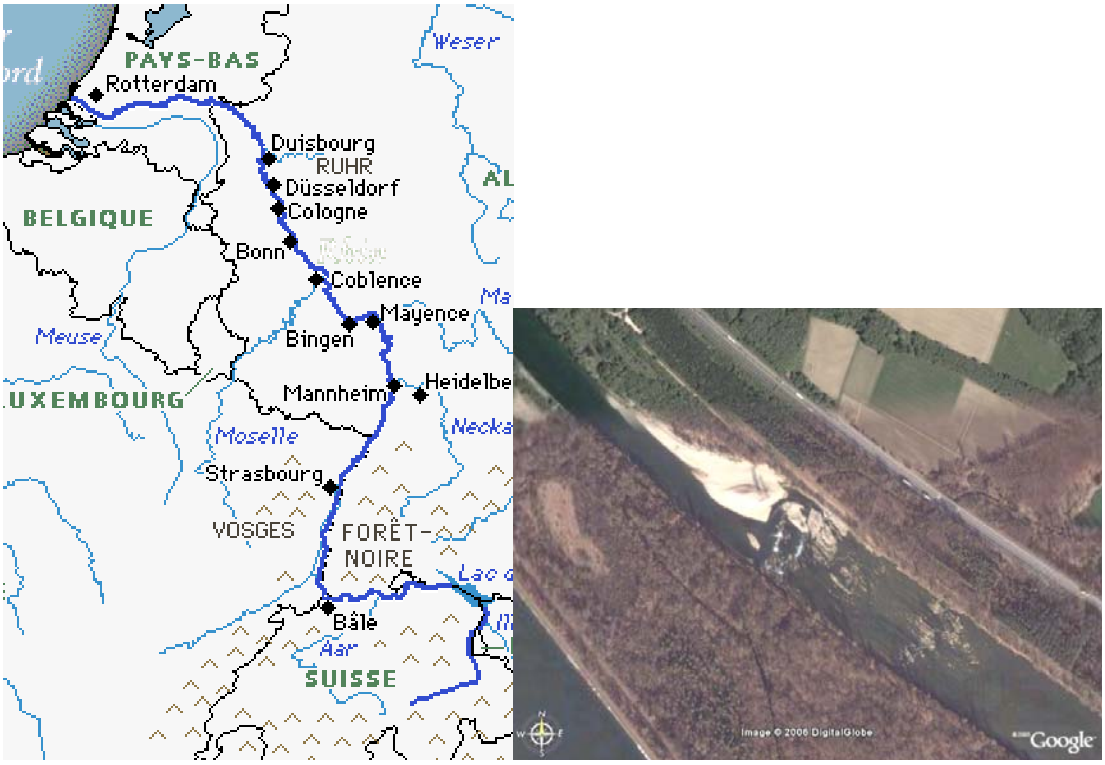


Figure 1.4 a) The full course of the Rhine river; b) Exposed bedrock outcrops at Istein, a few kms downstream of Basle (Google Earth®, 2006)

The use of rivers for transport has led to major engineering schemes to improve navigability and travel time. A startling example of this is shown in Figure 1.5 below.

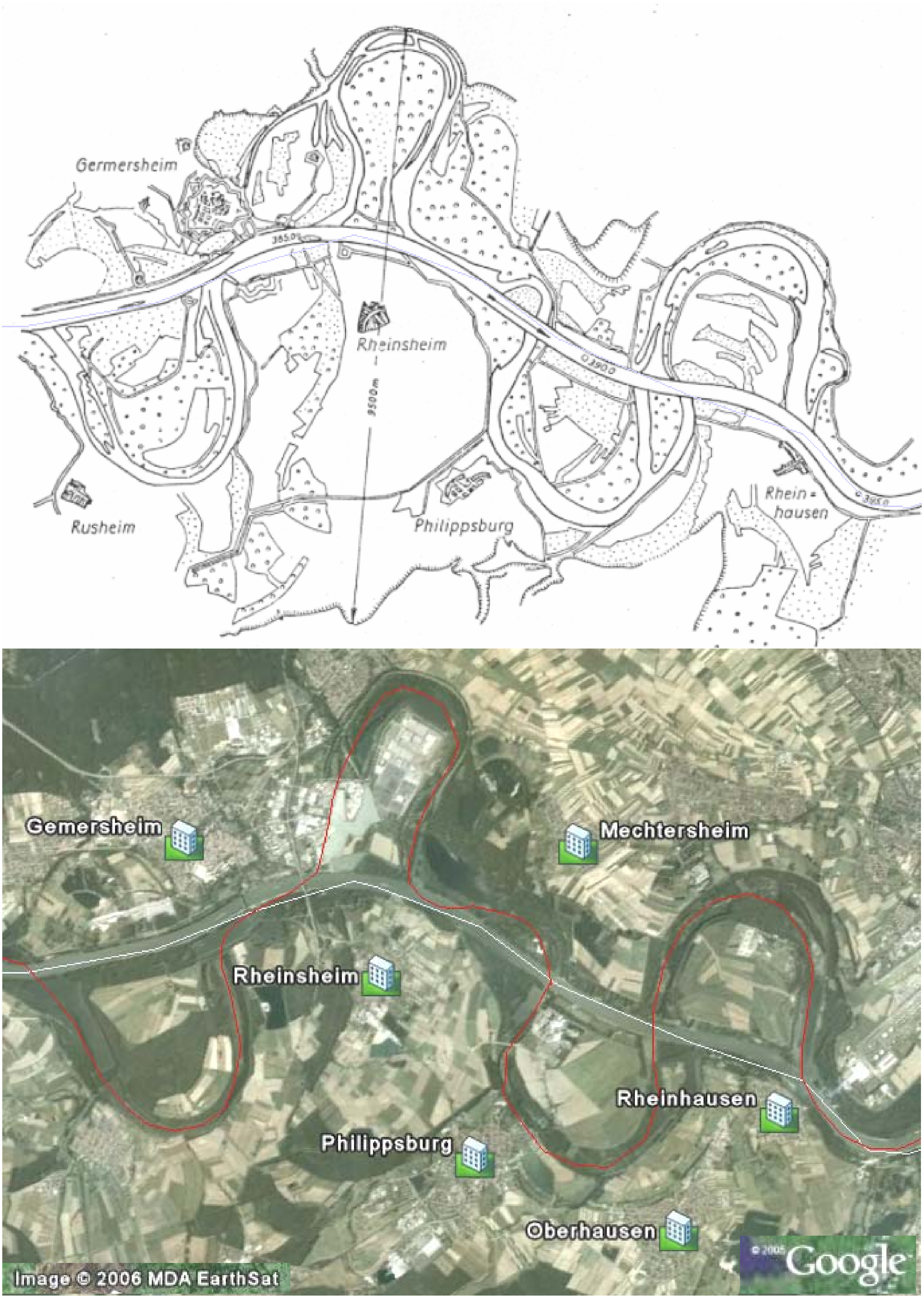


Figure 1.5 Meander shortcuts at Gemersheim (in service since 1833). Above: sketch reproduced from Casper (1959); below: aerial photograph of the present situation (Google Earth®, 2006)

This task has focussed on processes that contribute to flooding due to failure of defences. The task was split into two sections, (a) coasts and (b) rivers and estuaries. Similar considerations apply to rivers and estuaries, except there is minimal wave action and there is usually great engineering of the natural environment to constrain the river movement. Morphological change in rivers and estuaries is influenced by flood hydraulics and so too, is flood hydraulics influenced by morphological change. Although there has been much research into the influence of flooding on morphological evolution, studies to understand how morphological change can influence flood hydraulics and, in turn, flood risk are not widespread. It is arguably this aspect of the relationship that has most impact on the way in which society must learn to live with rivers as flood risk directly influences risk to life, property, infrastructure and the environment. With an increased knowledge of the impact that morphology can have on flood risk, it is possible to implement more appropriate management strategies to deal with morphological change that has an impact on flooding and, therefore, potentially mitigate the likelihood and the consequences of flooding. This rationale has motivated the research reported here which has investigated existing approaches to morphological modelling and develop a method for incorporating the impact of morphological change in an evaluation of flood risk.

1.2 Background

In Task 5, research has been undertaken to improve understanding, models and techniques for the analysis of the performance of the whole flood defence system and its diverse components, including natural and man-made defences (e.g. seawalls, embankments, dunes) and the extent of inundation. In particular, two specific aims were:

(a) to develop an improved understanding of morphological change of beaches over large time and spatial scales and provide a better predictive tool for the response of dunes to storm loading, and
(b) to critically review current knowledge and on-going programmes or river and estuarial morphology, summary existing knowledge and identify a forward programme of detailed and justified research.

This document provides a summary of the research undertaken in Task 5, upon which risk management tools and analyses may be based. It links with a number of other tasks within FLOODsite. Specifically, Task 2 - Estimation of extremes, Task 4 - Understanding and predicting failure modes, Task 7 - Reliability analysis of flood defence structures and systems, and Task 26 – Pilot Study of the Ebro Delta. The linkage between Task 5 and other tasks is illustrated in Figure 1.6.

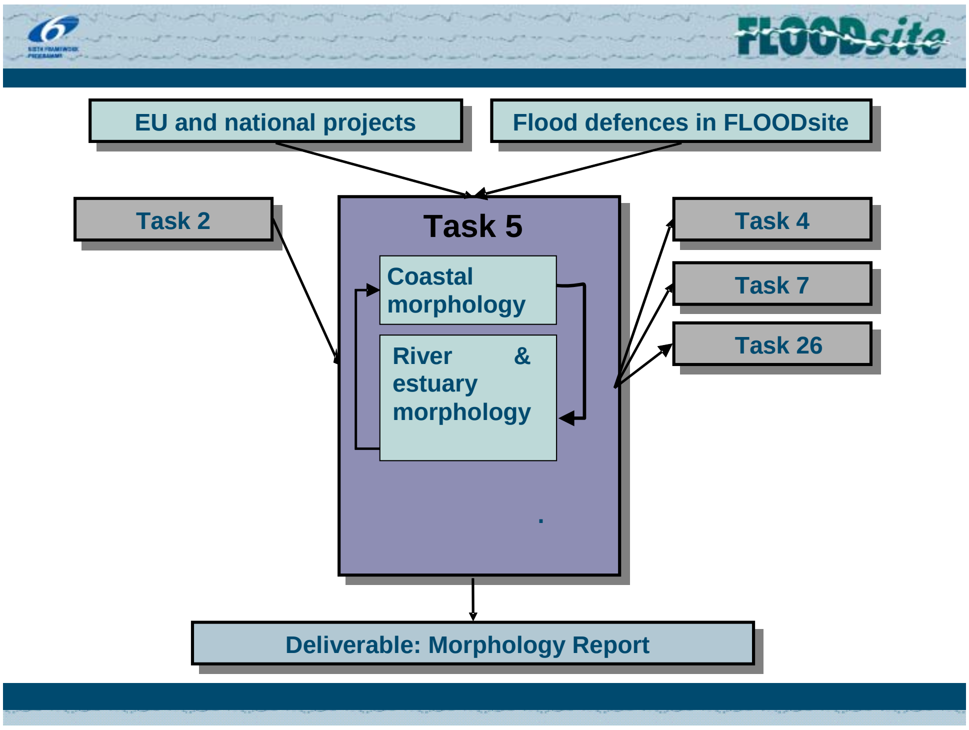


Figure 1.6 Task linkage diagram

The research on coastal morphology has led to a number of new developments. These include:

1. a stochastic model of beach plan shape variability;
2. a regional model for regional scale changes;
3. a rapid coastal evolution model;
4. beach overwash and dune erosion models.

These have all been used on real sites, in order to illustrate their application. The stochastic model has been applied to Christchurch Bay on the south coast of the UK. The regional model methodology for assessing the coastal vulnerability to storm impacts has been applied to the Catalan coast. Storms on the Catalan coast have been classified in terms of their inundation and erosion potential. The methodology has been applied to the longest existing wave record in the Catalan coast for two different coastal types. The rapid coastal evolution model is a fully integrated, dynamically linked coastal management tool, GTI-SEAMaT, which is illustrated through an application to the shoreline of Calabria in Italy. For beach overwash and dune modelling the analytical model proposed by Larson *et al.* (2004a) to simulate dune erosion and dune foot retreat during severe storms was further developed and tested. Four different data sets on dune erosion, originating from the laboratory and the field, were employed to validate the model. An analytical model was formulated to describe the response of a dune to wave impact and overwash. The approach has been applied to sites in the USA and the Ebro delta.

For the estuaries and rivers research different forms of output have been achieved. With an increased knowledge of the impact that fluvial and estuarine morphology can have on flood risk, it is possible to implement more appropriate management strategies to deal with morphological change that has an impact on flooding and, therefore, potentially mitigate the likelihood and the consequences of flooding. This rationale has motivated the investigation of existing approaches to fluvial and estuarine morphological modelling and which has led to the development of a method for incorporating the impact of morphological change in an evaluation of flood risk.

2. Principal results

This Task has produced a diverse set of outputs and results which have been reported in journal papers, conference proceedings, presentations and media interviews. This section provides a brief summary of the key results from Task 5. Work in Task 5 was split into two Activities; one covering coasts and the other rivers and estuaries. Further, within each Activity, each Partner was assigned a particular Action. The organisation of the work within the Task is depicted in the diagram in the Appendix.

The Actions relate to the two Task aims as follows. The first aim was to develop an improved understanding of morphological change of beaches over large time and spatial scales and provide a better predictive tool for the response of dunes to storm loading. This was addressed through four Actions: one developing new techniques describing the statistics of how beaches react to changing wave climate; another developing regional scale evolution models for regional coastal management; a third to develop fast and efficient coastal evolution models to assist in region to country scale coastal management; and finally the development of dune response models. The second aim was to critically review current knowledge and on-going programmes or river and estuarial morphology, summary existing knowledge and identify a forward programme of detailed and justified research. This was addressed through what was essentially a single Actions: investigating suitable modelling approaches that could be used to assess the potential for morphological change in rivers and estuaries.

Two key findings for each action are identified here. Further details may be found in T05-07-03.

2.1 Coasts

1 New techniques describing statistical behaviour

a) Beach levels and alignment vary in response to the variations in prevailing wave conditions. A semi-empirical model, used widely in coastal engineering practice, has been used as the basis of developing a technique to predict the mean and variance of beach position as a function of the probability distribution of incoming wave directions. The model is analytical and, because of its base on a semi-empirical model, has generic applicability. The model provides an efficient means of estimating the mean and variance of beach position which can then be used as input to a reliability analysis.

b) The model has been applied to a site on the south coast of the UK (see Figure 2.1) at which a sequence of beach planform position data are available in order to calculate statistics. Results indicate that the statistics of the beach movement is sensitive to the shape of the probability distribution of the incident waves.

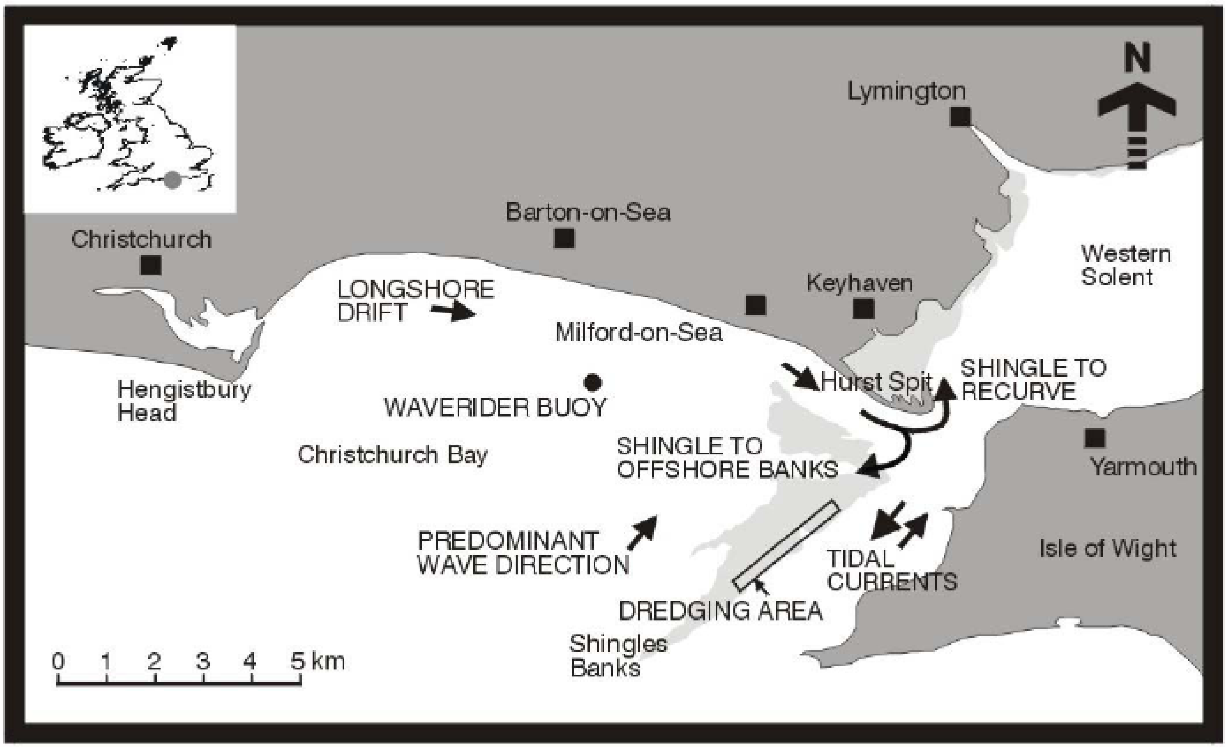
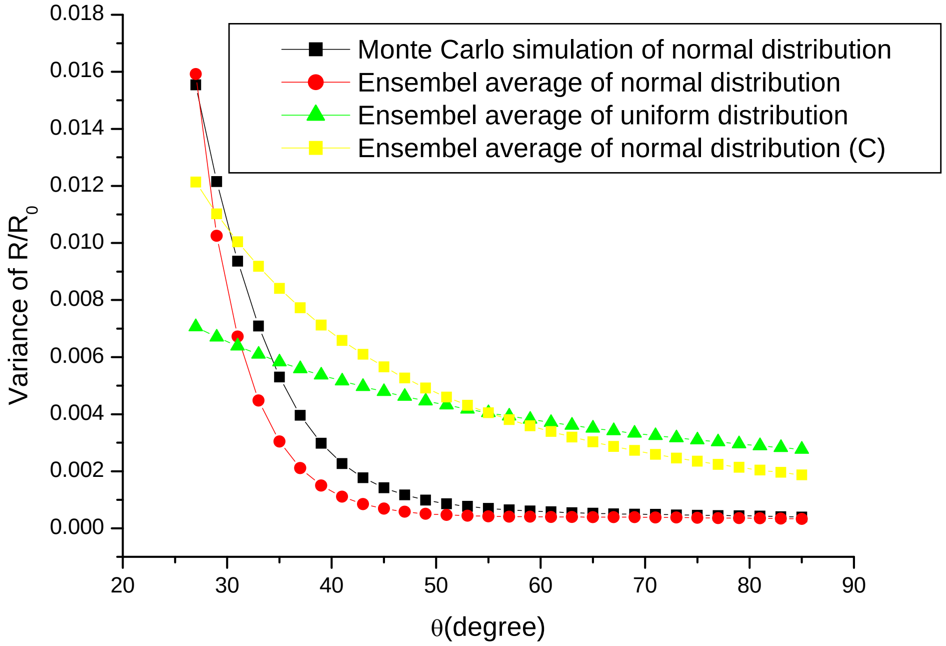


Figure 2.1 Map of Christchurch Bay, UK

A 20-year set of wave measurements were used to compile wave direction statistics. These were fitted to normal and uniform distributions. A three-way comparison was then performed to test the performance of the model, shown in Figure 2.2. This involved using the measured data to generate a sequence of beach positions from which beach position statistics were calculated – giving a ‘baseline’, denoted by Monte Carlo solution in Figure 2.2. Then probability distributions were fitted to the wave direction distribution of the measured waves. Random numbers were then generated with the corresponding distributions and the beach positions simulated accordingly. The position statistics were again calculated directly.

The corresponding variance of the shoreline position, as a function of bearing, is shown in Figure 2.2. This demonstrates that the shape of the distribution of wave direction (not just its mean and variance) is important in defining the beach response. Further, it demonstrates that a reasonably good fit is obtained, in this case, with a Normal approximation. [The curve labelled (Normal C) corresponds to Normal wave direction statistics but a simplified version of the model – which proved not to be a good approximation here.]



These outcomes are important because beaches are now often a crucial component of coastal flood defences. A healthy beach dissipates much of the incoming wave energy before it reaches the coast or defence. However, beaches are mobile, and one with low variance in height will have a lower risk of leading to flooding than one with high variance. Beach alignment is strongly governed by wave direction, but this is the very wave characteristic that is least accurately measured or predicted. The method here provides a means of gauging the uncertainty introduced into coastal flood defence schemes from this important source.

2 Regional evolution models for regional changes

a) A methodology to estimate the coastal vulnerability to storm impacts at the regional scale has been developed. This includes: a classification of regional storms in terms of their characteristics (source), ditto in terms of their induced response (pathways) and a way of spatially integrating storms characteristics and beach characteristics to predict (at the regional level) coastal vulnerability. The method has been applied to the Catalan coast (Figure 2.3) and is fully expected to be of sufficient generality to be applicable to other coasts.

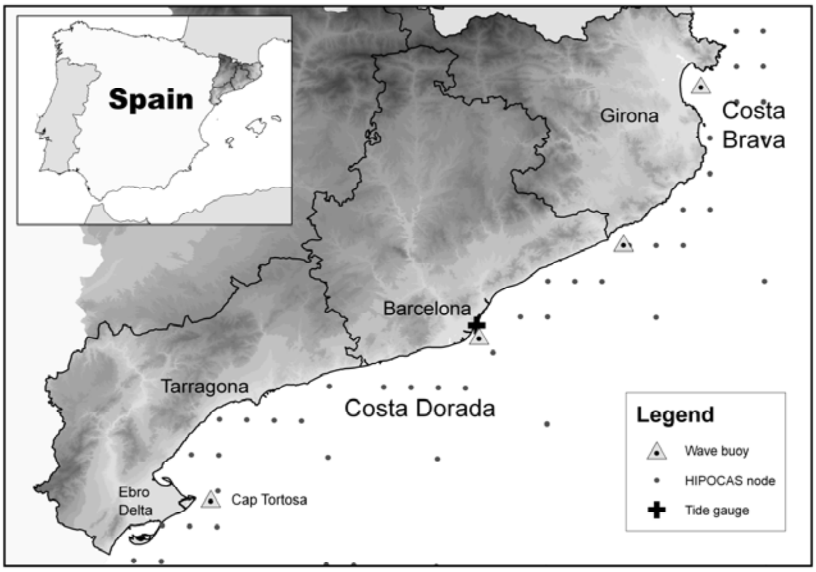


Figure 2.3 Area of study and location of measurement points

b) Flood damage is dependent upon the amount of water that flows over the defence and also the extent to which the defences are damaged and therefore provide less protection. The extent of damage is dependent upon the severity of the conditions (wave height, period and direction) but also the duration over which they act. The extent of overwash has been analysed and characterised by a parameter (cumulative freeboard) that takes into account the time that the barrier/beach is overwashed. An example of the classification is shown in Figure 2.4.

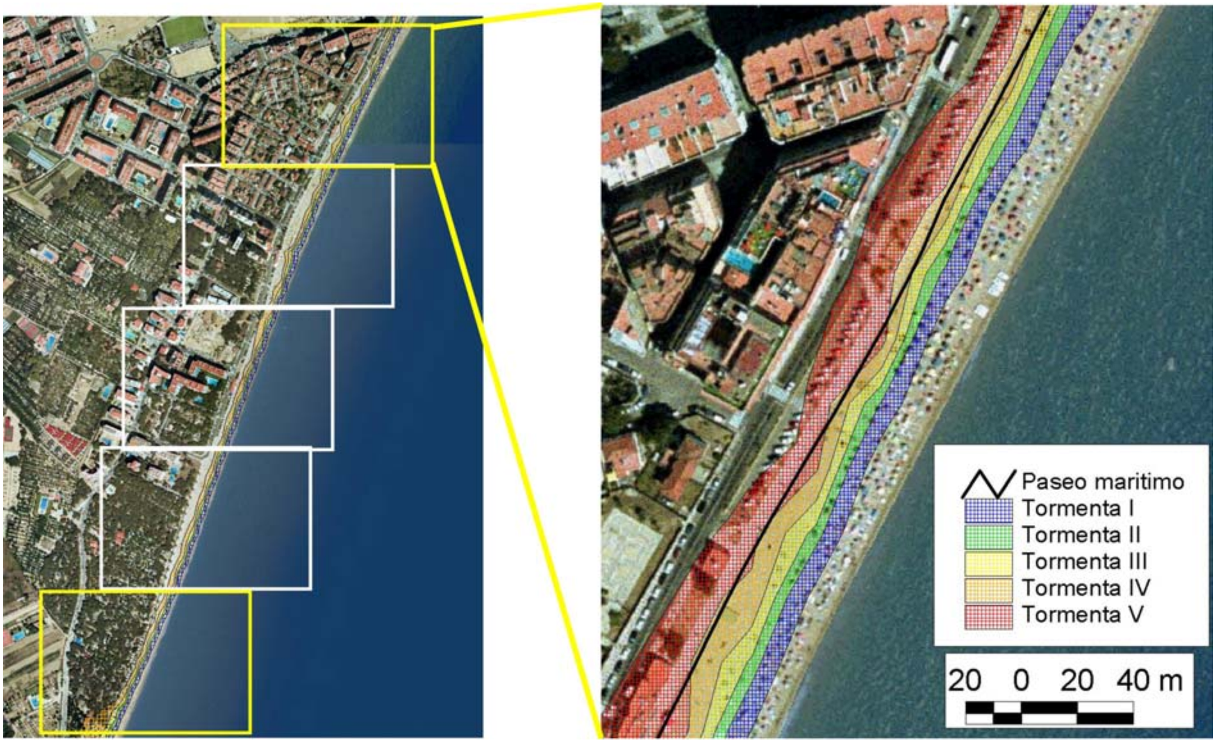


Figure 2.4 Hazard areas to inundation induced by storms of each class in a reflective beach (s'Abanell, Girona)

3 Development of rapid coastal evolution models

a) A regional scale model has been constructed that predicts the morphological evolution of beaches during the course of storms. A diagram showing the component parts of the modelling system is shown in Figure 2.5.

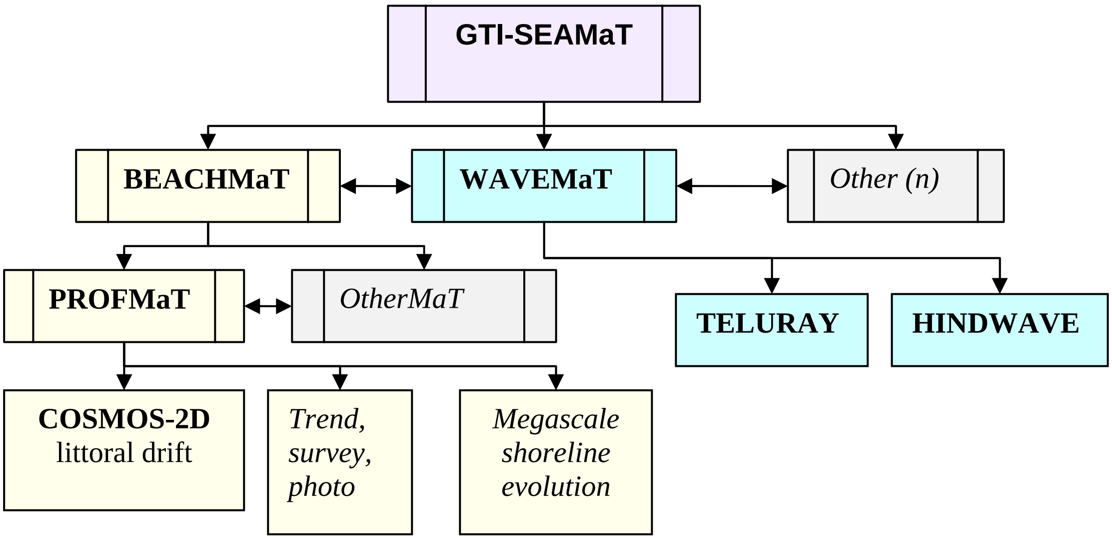


Figure 2.5 Coastal modelling system components

The WAVEMaT module allows both experienced and relatively inexperienced users to derive nearshore wave climates anywhere within the active model domain. The BEACHMaT module is presently configured such that the long-term longshore transport of beach sediment around the coastline can be calculated using the sub-module PROFMaT. The module also allows a macro-scale assessment of the impacts of shoreline intervention upon shoreline trend. The system interfaces with the ArcView GIS software. The system is limited in its applicability only by the limitations of its components. Thus, for wave modelling, the model can cope with refraction and breaking but not reflection or diffraction. Similarly, the beach prediction is based on 2-d profile models and linkage via a simple contour type model. As such, despite its relative simplicity, the system has generic applicability

The system has been applied to a case study in Calabria, Italy, as shown in Figure 2.6.

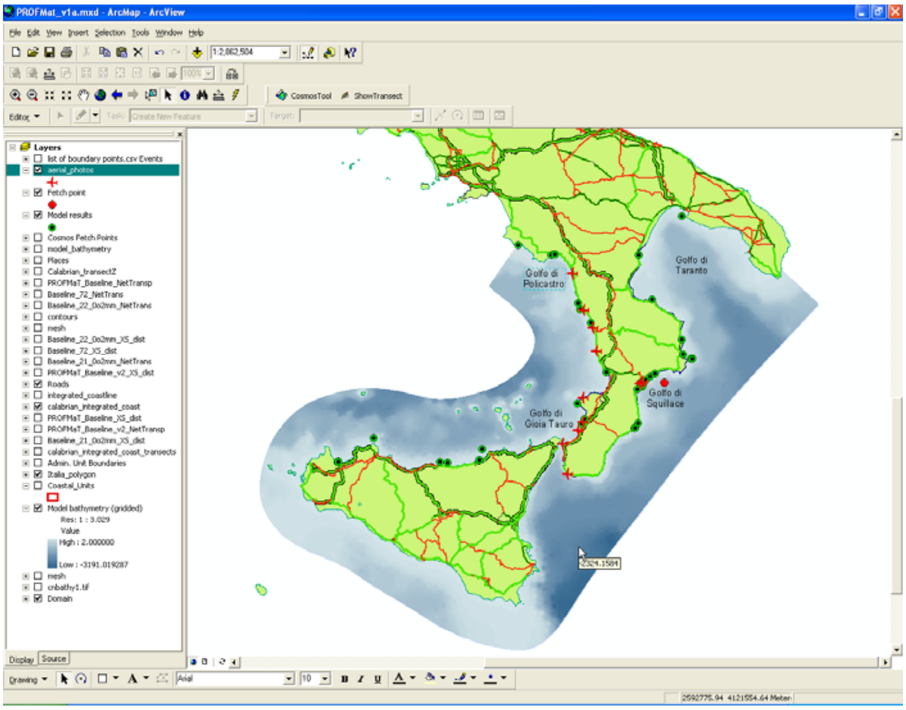


Figure 2.6 Application study area

b) The model has been constructed in a GIS so that much of the spatial tracking required and managed within numerical models through coding is dealt with by the GIS, allowing seamless linking with other databases containing, for example, information on land use. Figure 2.7 shows an example of how the beach profile information can be accessed and linked to wave information.

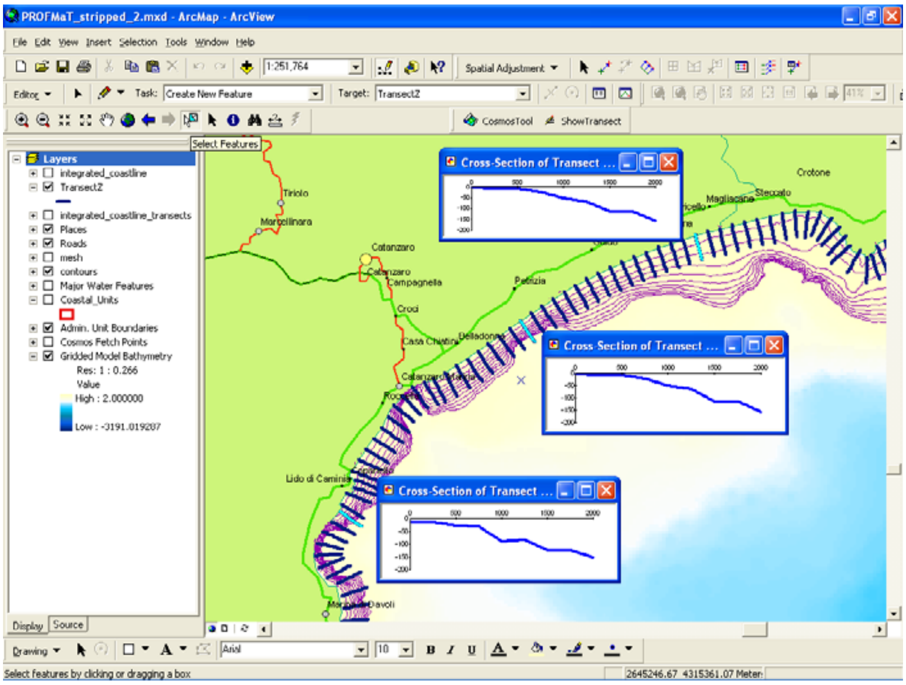


Figure 2.7 Display of transect data within GTI-SEAMaT

4 Dune models

a) Analytical and numerical models have been developed to investigate the sediment transport and morphological response of coastal dunes to extreme waves and water levels, focussing on overwash and erosion of the dune face. An example of the type of process being modelled is shown in Figure 2.8, where a dune has been breached and waves have washed over the top of the dune creating a ‘fan’ of material.

Figure 2.8 Confined washover fan deposited on Ocracoke Island, North Carolina, during Hurricane Isabel, September 2003

Put simply, the model predicts, using physically-based arguments and equations, how the sediment in different parts of the beach profile react to the incoming wave conditions, as shown in Figure 2.9.

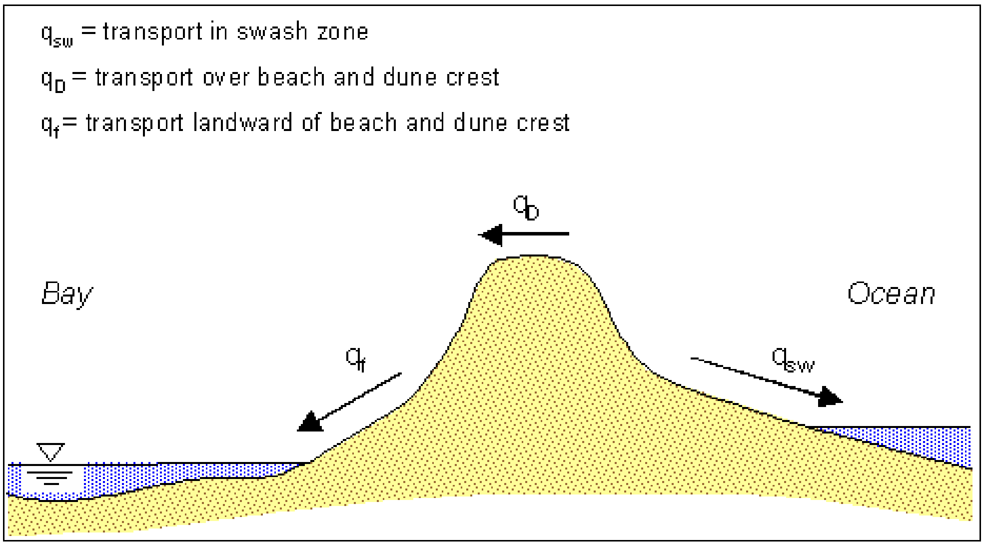


Figure 2.9 Zones of sediment transport during overwash (after Larson et al. 2004b)

b) The models were tested against data and observations for sites on the eastern seaboard of the USA. Overall, a good calibration for a wide range of beach profile types and overwash magnitudes was obtained. The model was able to reproduce dune crest erosion, dune destruction, barrier roll-back, thinning of a washover deposit and overwash over a multiple dune system. The model could be validated if it was applied in regions were the pre-storm morphology and barrier textural surface were similar to the sites of calibration. Model development, calibration, and validation demonstrated the requirement for detailed knowledge of the topography of the modelled region.

2.2 Rivers and Estuaries

Four key findings for Activity 2 (Estuaries and rivers) are identified here. Further details may be found in T05-07-03.

1 Investigating suitable modelling approaches that could be used to assess the potential for morphological change

a) A review of existing research methods and data has been performed. The case studies have provided insight to the approaches that can be used to assess morphological change, evaluate their implications for flood risk and identify management options. These approaches include the use of:

1) physical models
2) one-dimensional, two-dimensional and three-dimensional mobile-bed river models

Figures 2.9 to 2.11 show how modelling has been used in the Thames Estuary to assess the impact of morphological change on flood risk. This information is being used to inform the development of future management options.

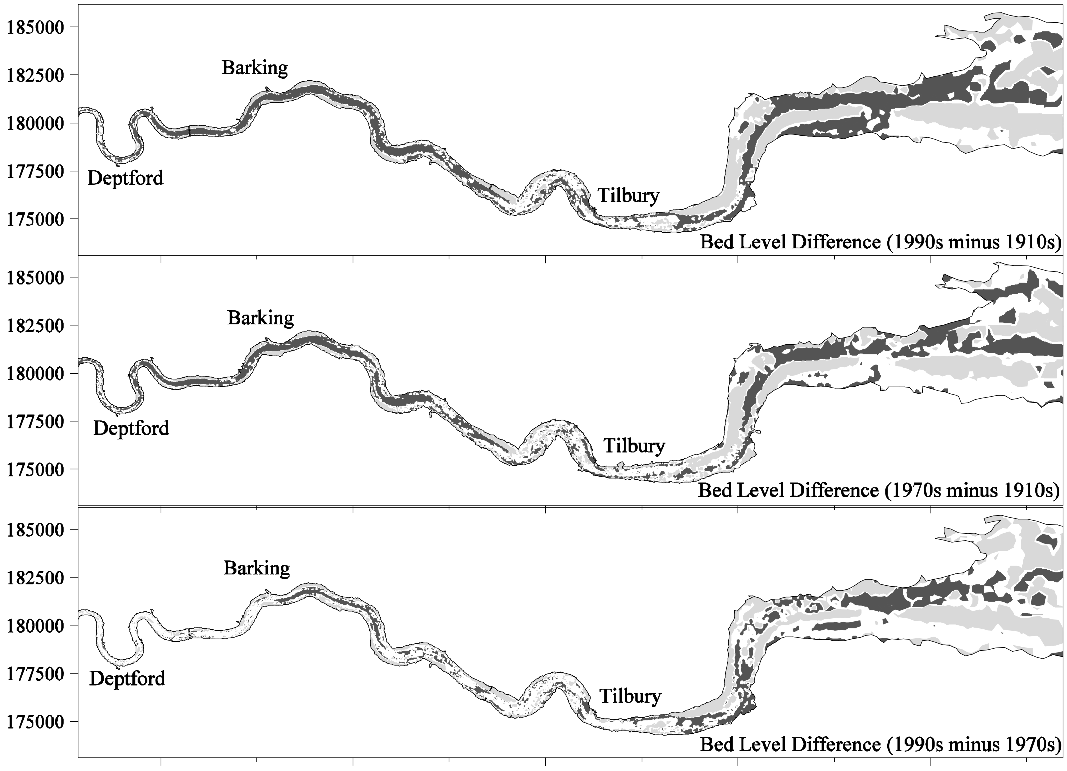


Figure 2.10 Summary of changes to Thames Estuary morphology between the 1910s and 1990s (Light grey indicates depth has reduced, dark grey indicates depth has increased. Changes of less than 0.5 metre are not shown)

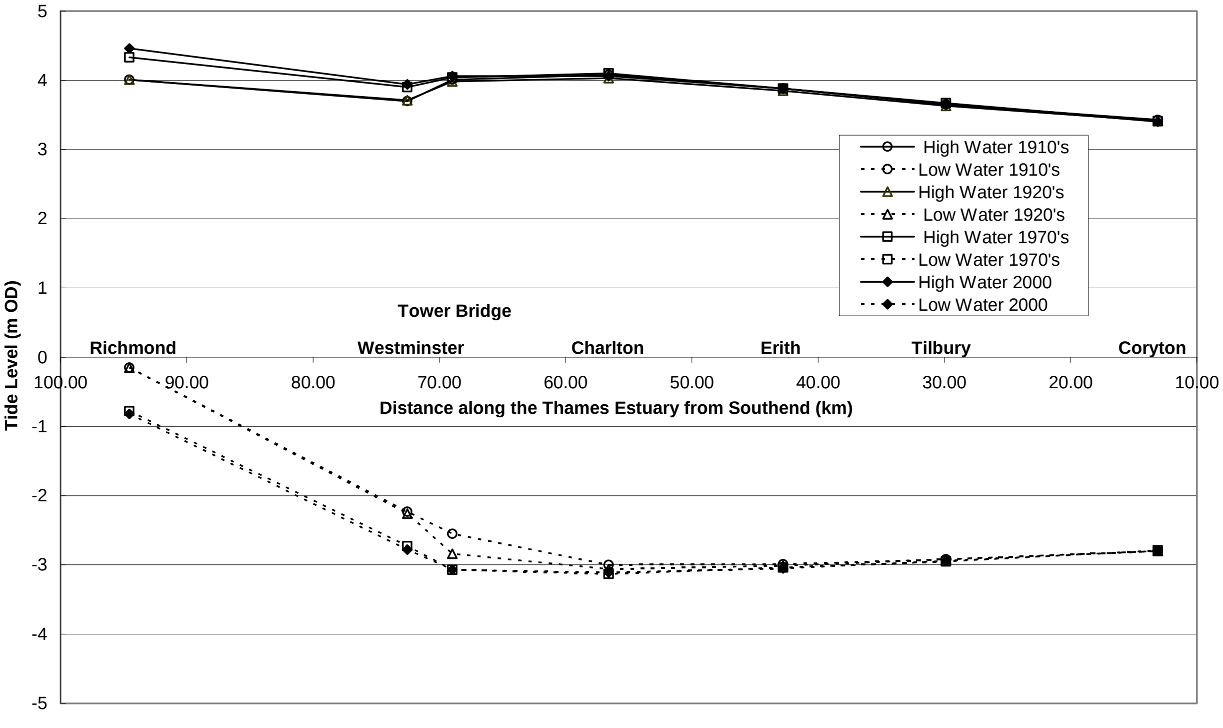


Figure 2.11 Thames Estuary: Modelled changes to spring tide levels in response to changes in morphology

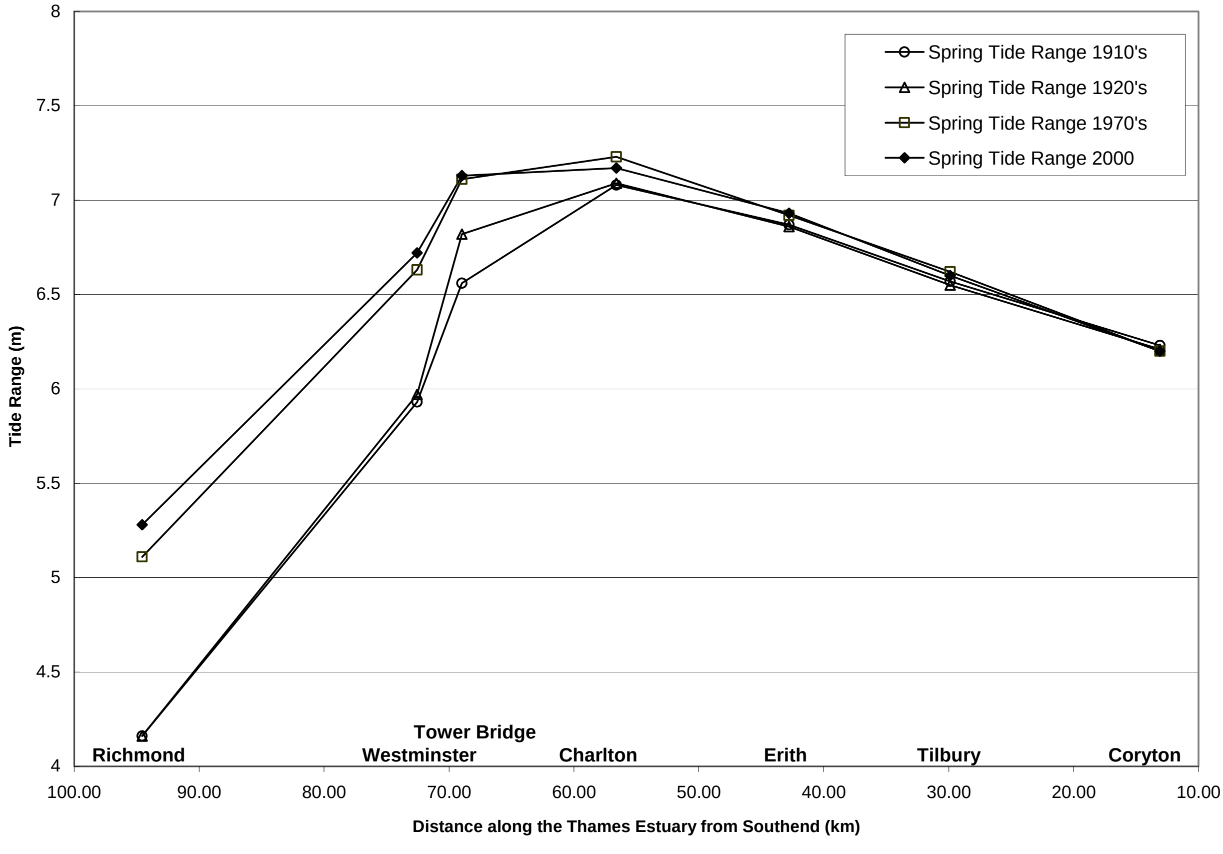


Figure 2.12 Thames Estuary: Modelled changes to spring tide range in response to changes in morphology

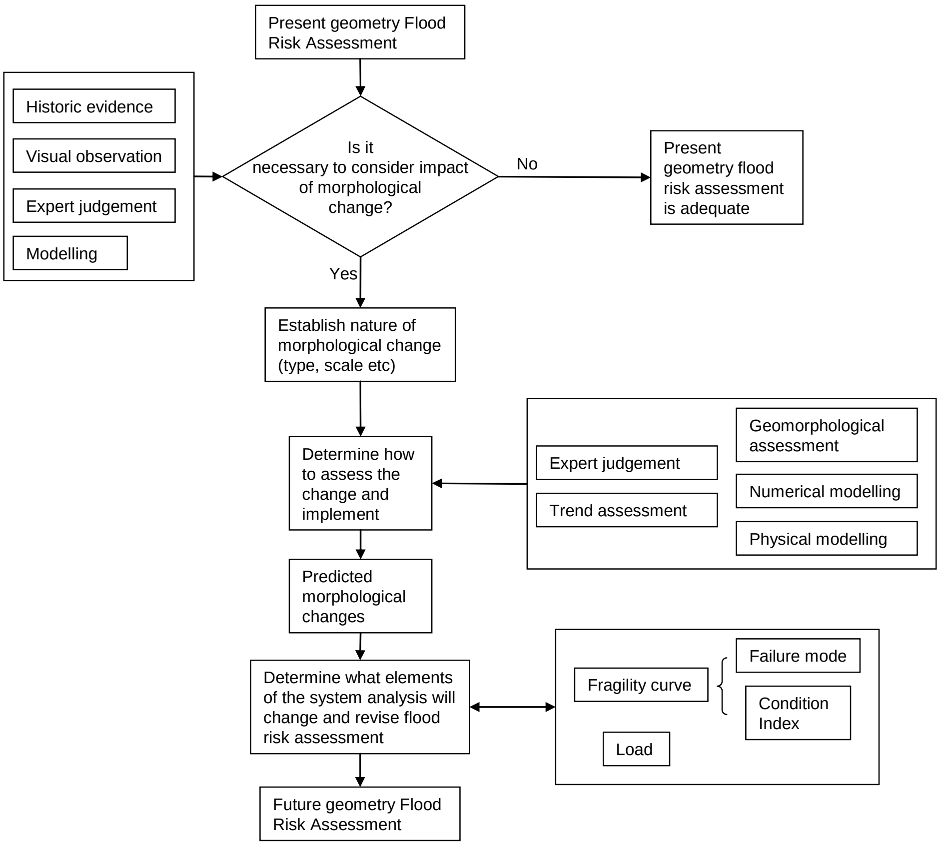
b) Techniques in numerical modelling are discussed and it is highlighted that there are assumptions, limitations and strengths of different types of 1-D, 2-D and 3-D modelling approaches. One-dimensional models do not take into account changes in bank line and so do not model changes in plan form geometry. Two-dimensional models are unable to represent secondary flows at bends and so cannot account for their impact on channel morphology. Three-dimensional models make fewer assumptions but in many cases 3-D codes that are currently used assume hydrostatic pressure distributions which limits their range of applicability to problems in which vertical accelerations can be ignored. The computational speed of models reduces as one goes from one to three dimensions so that one can model extended reaches of river for long time periods using a one-dimensional model while three dimensional models are limited in the spatial and temporal domain. Physical models can represent complex geometries but are limited by their ability to represent fine sediment and scaling limitations on the temporal scales that can be used.

c) The sources of uncertainty in a geomorphological assessment have been identified. These arise from:

1) our incomplete understanding of sediment transport mechanics
2) uncertainty associated with the relationship between hydraulic roughness, bed features and sediment transport
3) uncertainty in the data, particularly characterisation of the sediment within the system
4) uncertainty in the applied boundary conditions. These arise from uncertainty about future flows and water levels and future sediment loads entering the system

These uncertainties can be quantified by the use of sensitivity testing.

d) The proposed approach for assessing morphological impact on flood risk provides a framework for flood risk managers.



The framework requires an evaluation of whether it is necessary to assess morphological impact on flood risk as in some situations where significant changes in morphology are unlikely in the short to medium term; there will be no requirement to assess the impact of morphology on flood risk as there will be no impact.

3. Relevance to practice

The work undertaken in Task 5 provided some of the basic tools that are required to tackle these mounting challenges and adapt accordingly. Effective response to the risks of flooding will require changes in how flood defences are planned, designed and maintained (particularly the inculcation of probabilistic techniques into engineering practice). This is a prerequisite for improved flood risk management. Assessment of present and future flood risk should take account of the probability for morphological change both during a single flood event and as a result of long-term morphological change. The framework that is outlined provides a structure by which this can be achieved.

Matters such as dissemination of flood warnings, clarifications of roles of different organisations involved in flood management and flood warning, effective cooperation between responsible organisations, greater engagement with the public, are beyond the scope of this Task.

4. Remaining gaps in knowledge

Further research is required to apply the methods developed here to a wider range of circumstances so that appropriate modifications can be made to ensure they techniques are robust and reliable for practitioners to use them with confidence. The details for a) coasts and b) rivers and estuaries, are covered in the following sections.

4.1 Coasts

There are a number of areas where there are gaps in our understanding of morphological processes and these influence our ability to understand the morphological evolution of coasts. Sediment transport mechanisms are not precisely understood and the processes by which mixed gravel and sand beaches evolve, armouring and wave interaction with structures affect sediment transport are not fully determined. A thorough understanding of the dominant physical processes that shape the long term, large-scale evolution of shorelines is not available and whilst there has been some research activity to categorise and understand the physics of different mechanisms, these provide only a preliminary steps towards robust models for predicting regional morphodynamics.

The behaviour of waves, tides and surge, together with their impact on sediment transport, in and around estuaries and tidal inlets is another area which is not well-understood. In some cases there are indications that strongly nonlinear processes are important, for instance the amplification of wind waves propagating into an ebb flow. Estuaries and the coast nearby display complex flow and sediment transport properties. Estuaries and tidal inlets generally experience constantly changing morphology and a single storm event may cause a significant morphological change in the pattern of channels and bars. This highly variable morphology means that it is difficult to find surveys of sufficient frequency to describe morphological change at a historical timescale in estuaries. Models of estuary morphology are not well developed and so prediction of morphological change is difficult.

This is linked to a lack of knowledge of the patterns and controls of estuary morphology change. More research is required to look at the development of morphological features and the variations of hydrodynamic conditions.

A further area of difficulty is the understanding of the impact of turbulent structures on sediment processes both in deep water and in the surf zone. This is particularly relevant to local scour and sediment dynamics around structures. The interplay between wave run-up, overwash, crest erosion and beach scour is particularly complex and not well understood.

In relation to regional sediment transport modelling, there are a number of difficulties where an improved knowledge on representing the physical processes is required. Accurate representation of sediment inputs at a regional scale is difficult and modelling the contribution of different sources and the combination of different transport mechanisms needs further refinement. Understanding the interaction between cohesive and non-cohesive transport (particularly in estuaries and tidal inlets, but also on beaches where a sand veneer beach lies on top of boulder clay, could be improved. The representation of beach features, their formation and development, requires more work.

In summary, further work is required on:

- Understanding how the natural variability of waves and tides is reflected in beach level and alignment;
- Improved linkage between different coastal process models to predict with large-scale and long-term coastal morphological changes;
- Developing better understanding of how the errors and uncertainties in data and model output propagate along the chain of analysis and models to the final results;
- Improved numerical algorithms to speed up run times for large scale models.

4.2 Rivers and Estuaries

River and estuary morphology is expressed in terms of planform, long section and cross section and changes in these characteristics are determined by the hydrodynamic and sediment dynamics operating in the system. The science of fluvial geomorphology has built up some understanding about the natural processes of morphological change at various spatial scales and timescales, but it is important to recognise also that human interventions, directly in the channel or estuary and throughout the catchment will influence these natural processes and therefore influence the morphology. It is recognised that morphological change can occur over a range of time and space scales and understanding the interaction of processes and morphology at these different levels is important.

The case studies have provided insight to the approaches that can be used to assess morphological change, evaluate their implications for flood risk and identify management options. The Thames Estuary case study looks at the morphological changes in the estuary over the last 100 years and shows how these changes have influenced flood risk. The results of the assessment show that the greatest amount of change has been recorded in the upper estuary, with a 50% decrease of subtidal sediment volume and a 25% increase of intertidal volume. These changes result in an increase of water levels during MHWS and also during extreme events driven by tidal flooding. The changes in morphology do not result in an increase in water levels during extreme fluvial events. The Severn Estuary case study examines the erosion of the north shore of the Severn Estuary and the erosion of the tributaries that flow into the estuary along the shoreline. The difficulties in identifying the dominant sediment processes are highlighted. It is shown that the morphological change has implications for the condition and performance of flood defences for the area and the discussion addresses potential options for resolving the problems raised.

The review of existing knowledge discusses the main processes involved in sediment dynamics and shows it to be a complex science. The processes of sediment erosion, transport and deposition are discussed. Section 3.5.2 highlights that changes in alluvial resistance have implications for flood management as the hydraulic roughness varies with flow and impacts water levels. The hydraulic regime and its interaction with sediment processes in estuaries is outlined in Section 3.5.3. Approaches for understanding morphological evolution and predicting future channel geometry are discussed in Section 3.5 and emphasis is placed on a good understanding of geomorphological processes. Qualitative and quantitative expert evaluation can provide good insights into the behaviour of a river or estuary system. Techniques in numerical modelling are discussed in Section 3.5.5 and it is highlighted that there are assumptions, limitations and strengths of different types of 1-D, 2-D and 3-D modelling approaches. The key issues relating to the difficulties and benefits of physical modelling are highlighted in Section 3.5.6. Ultimately, any geomorphological assessment relies on the data on which it is based and it is important to recognise that there are a range of types of information that a study of geomorphology requires and that there are different methods of collecting and collating that information.

Further research is required to apply the methods developed here to a wider range of circumstances so that appropriate modifications can be made to ensure they techniques are robust and reliable for practitioners to use them with confidence.

5. References

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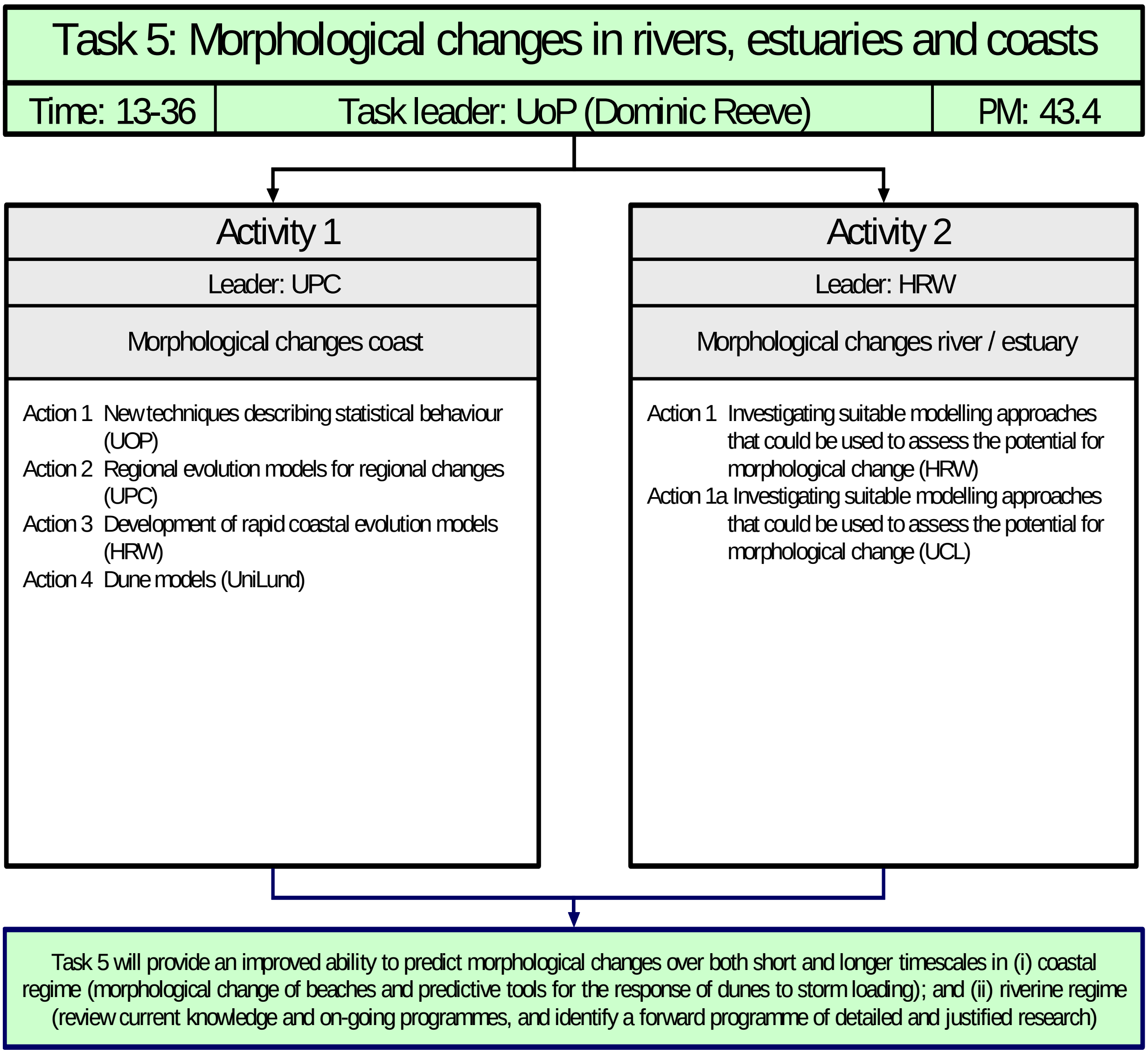
APPENDIX



Task 5: Morphological changes in rivers, estuaries and coasts

Time: 13-36

Task leader: UoP (Dominic Reeve)

PM: 43.4

Activity 1

Leader: UPC

Morphological changes coast

- Action 1 New techniques describing statistical behaviour (UOP)
- Action 2 Regional evolution models for regional changes (UPC)
- Action 3 Development of rapid coastal evolution models (HRW)
- Action 4 Dune models (UniLund)

Activity 2

Leader: HRW

Morphological changes river / estuary

- Action 1 Investigating suitable modelling approaches that could be used to assess the potential for morphological change (HRW)
- Action 1a Investigating suitable modelling approaches that could be used to assess the potential for morphological change (UCL)

Task 5 will provide an improved ability to predict morphological changes over both short and longer timescales in (i) coastal regime (morphological change of beaches and predictive tools for the response of dunes to storm loading); and (ii) riverine regime (review current knowledge and on-going programmes, and identify a forward programme of detailed and justified research)